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Developing an Electrical/Electronic Component Qualification Process for the Case Company

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My profession encompasses working in areas related to electronics engineering. Process development and Supply Chain Management have been my core areas of interests. This inspired me to do a Master's program in Industrial Management which helped me to connect my interest and do this thesis in process development to apply my learnings to a real time business challenge at the case company, my employer.

I am thankful to my employer for authorizing me to utilize a real business case in this thesis, which gave me an opportunity to do research in my area of interest and an opportunity to develop myself professionally. I would also like to thank all the informants - product engineers, principal engineers, managers and head of departments who took part in this study. Special thanks to Stelvio and Janne! Thank you for your immersive thesis guidance despite your busy schedules.

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Thanks to my dad, my true inspirational hero behind my Master's studies and I dedicate this to him, but he is no more. I thank my mom and my brother who have been very caring. Finally, my special thanks to my loving wife Garland, who supported me in every moment and to my loving three-year-old son Shaunn who was cooperative. Love you all.

A long-awaited dream to pursue a degree of my choice in a foreign land came true after seventeen years, in the form of this Master's degree. Also, it still surprises me that it was in 'the land of a thousand lakes' and where 'Nokia' was born, that I could always cherish. Year 2018-2019 - The reality is, it was more challenging and extremely rewarding. Kiitos!

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This thesis focuses on developing an Electrical/electronic component qualification process for the case company, a large-scale original equipment manufacturer (OEM). Electrical and Electronic component are the key elements in the products manufactured by the company. Demand of components has surpassed the supply, which has led to component scarcity. Moreover, rapid change in component technology and component portfolio consolidation has made the situation worse. Hence, the existing component qualification process could not live up to the task, and hence, there was a need to develop a component qualification process that would enable efficiency and address the business needs for broadening the supply base in the company and mitigate the risk of component scarcity.

This study utilized Design research and qualitative data analysis, as the outcome of the thesis is a working solution ready for implementation. The research design of this thesis consists of four phases that include three data collection rounds. Data came from the company internal documents, workshop, interviews and telephonic discussions.

The study started by conducting the current state analysis to identify the strengths and weaknesses of the current component qualification practices. It was followed by literature study to address the identified weakness in order to build a proposal for a new component qualification process. The proposal for the new process blended together (a) the strengths from the existing practices, (b) the ideas from literature that were merged into the conceptual framework, and (c) the input from the stakeholder's suggestions and feedbacks. Based on them, the study proposed a component qualification as a process, coupled with an established responsibility assignment matrix in the form of RACI chart connecting all the participant who are involved in the process. The proposed component qualification process was simulated using a custom-developed application software for validation.

When implemented, the proposed component qualification process will benefit all the product groups in the company and help to standardize their processes and practices. Most importantly, the process will facilitate the broadening of the supply base, improve the process efficiency, and enable better traceability. This will help to address availability issues and meet on-time delivery of the products. The proposed process was approved for implementation in case company.

Keywords	Component Qualification Approaches, Designing and Defining Business Process, Role, Responsibilities, Information flows, Stage-Gate Model, Process Development, RACI

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Acronyms

ATE	Automated Test Equipment
BPMM	Business Process Maturity Model
BU	Business Unit
CE	Component Engineer
CM	Contract Manufacturer / Contract Manufacturing
CMMI	Capability Maturity Model Integration
CSA	Current State Analysis
EMS	Electronic Manufacturing Services
EOL	End of Life
ESD	Electrostatic Discharge
FAT	Functional Application Testing
FCT	Functional Testing
FFF	Form, Fit and Function
FMMEA	Failure Mode Mechanism and Effect Analysis
HALT	High Accelerated Life Test
IC	Integrated Circuits
ICT	In-Circuit Testing
IOT	Internet of Things
MNC	Multinational Corporation
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Board
PCBA	Printed Circuit Board Assembly
PE	Product Engineer
PEMM	Process and Enterprise Maturity Model
R&D	Research and Development
RACI	Responsible Accountable Consult and Inform
RAM	Responsibility Assignment Matrix
RASCI	Responsible Accountable Support Consult Inform
REACH	Registration, Evaluation, Authorization and Restriction of Chemical Substances
RoHS	Restriction of Hazardous Substances
SCM	Supply Chain Management
SW-CMM	Software Capability Maturity Model

1 Introduction

Processes are vital for every organization. A process is a sequence of interdependent and linked procedures which, at every stage, consume one or more resources which can be in the form of time, energy, machines and money to convert inputs into outputs. These outputs then serve as inputs for the next stage until a desired goal or end-result is achieved. (Business Dictionary 2019). Focusing on a suitable process that could perform in the right way can pave path to success. Good processes and procedures establish an approach to standards, practices and communicate within the business. However, not every process creates value, but the processes that are performed repeatedly and provide cost benefit (or) obtain customer satisfaction (or) guide business growth (or) the combination of all these, are the important ones.

This study explores the qualification process for an electrical/electronic components in an industrial equipment manufacturing industry whose products serve various industrial customer's needs. The qualification process for electrical/electronic component plays a major role in hardware product design right from the product Research and Development (R&D), then through the maintenance phase and in-service phase in a product's lifecycle. The electrical and electronics manufacturing industry segment has been experiencing a mix of challenges and opportunities, while there prevails a continuous change in business environment and technology in organizations.

1.1 Business Context

The case organization is a multinational corporation (MNC) consisting of various subdivisions in terms of Business Units (BU). The case company of this Thesis is one among the business units and is a large-scale original equipment manufacturer (OEM) whose business is in design and manufacturing of industrial equipment to serve various needs of industrial customers with global footprints addressing various market segments. Various variants of electrical equipment (products) that meet the need of different industry segments and market demands are catered to the customers and end users. The case company offers a wide product portfolio to address the customer needs and is positioned as market leader in business and technology. All products manufactured in the case company tend to have a very long lifecycle, and the case company's assurance to its customers include quality, reliability, on-time-delivery and long-term availability.

Product development is an integral part of the business in the case company consisting of electrical design, mechanical design and software development teams across Research and Development (R&D), Product Engineering and Product service departments. Supply chain management (SCM) is integrated with all the functions in product development to ensure the desired goal is obtained. Every department and team are constantly looking for possibilities to optimize processes, continuous improvement and waste reduction to create value and obtain better cost savings.

To succeed and sustain in today's competitive business environment, the case company is constantly seeking opportunities for optimizing and improve the processes to do things better that in turn enables to keep the assurance furnished to its customer.

1.2 Business Challenge, Objective and Outcome

The case company has a well-defined product development process and it has been in practice for several years. The Electrical design team and Mechanical design team collaborate with the supply chain to ensure long-term availability of the components, manufacturability of the products and smooth flow of goods to manufacturing sites throughout their lifecycle. Electrical and electronics components are one among the key elements for all the products (in other words, heart of the product) to function which are designed and manufactured. Most of the electrical/electronic components are used multiple times in various products across the case company's product portfolio. Non-availability of any single electrical or electronic component at a given time for any products in the production line will halt the manufacturing process which leads to missing the customer delivery and will incur financial loss as well in other forms.

However, there is a persistent challenge in delivering the case company's products on-time due to a serious shortage in electronic components supply observed in recent years. The same phenomenon is also reported and acknowledged globally (Jabil 2018; EPS New 2018; TTI 2018; Arrow 2018). The surge in global innovation boom have resulted in rapid change in components technology, component miniaturization, changes in form fit and function (FFF), and shortening component lifecycle. Also, mergers and acquisitions of companies have led to component portfolio consolidation which further makes the component availability situation worse.

The primary cause of this increasing challenge in electronic component supply shortage is because of the high demand from various markets and hence, the lead times to obtain the electronic components are growing from several months even to a year. The key factors for the cause of demand in electronic component market are rapid and stable growth in automotive industry, continuous growth in smartphone industry and germinating of Internet of Things (IOT). Several suppliers have placed the electronic components on allocation to the current booming industries (automotive, smartphone and IOT). Henceforth, suppliers are not ready to support the needs of industrial electronics equipment manufacturers, to which the case company's core business belongs. Also, counterfeit components have evolved in markets due to global shortage that possess business risk.

To overcome the component shortage situation that affects the case company's product build and production lines, the case company needs to broaden its supply base by introducing multiple sources for every electrical/electronic component as those components will be used on various variants of the products across the product portfolio. There are various types of electrical and electronic components available and used in the products where most of the components are commodity parts and few components are custom made parts. Unfortunately, electrical and electronic components do not work as a plug and play device on any given circuit. Henceforth, any new component which meets the fit, form and function (FFF) criteria must be tested and validated thoroughly to ensure its quality and reliability before the component is qualified or approved to be used in any product and in production.

The problem with existing component qualification process does not allow to live up to the task due to inadequate process and procedures. Most importantly, there is no common component qualification process adapted in practice that could encompass all the key stakeholders in R&D, Product Engineering and Product Service departments. In addition, the existing practices are not documented well, nor used efficiently.

In light of the above, the objective of this thesis is *to develop a common electrical/electronic component qualification process for the case company*, which could be leveraged to use across the R&D, Product engineering and Product service departments.

The outcome of this study is a component qualification process which would be compatible with the case company and support value creation and fit with the engineering approach-based IT platform to enable global replication within the case company.

1.3 Structure of the Thesis

To converge precise and transparent information, key internal stakeholders from four departments functioning under the same business unit in the case company were interviewed, followed with a workshop to analyze the current electrical/electronic component qualification process. During the interview phase and workshop the pain areas of the process, opinions and possible wishes were collected that are in common interest of the business goals. The concepts of process improvement and development were explored through existing literature.

This thesis is written in seven sections. Section 1, Introduction, describes the business background information and overviews the present thesis. Section 2, Method and material, explains how the study is conducted. Section 3, Current state analysis, scrutinizes the current practices followed for the electrical/electronic component qualification process in the case company. Section 4, Best Practice, overviews best practice on the topics of component qualification processes/approaches, defining/designing business processes and defining roles, responsibilities and information flows. Based on the insights obtained on best practices, the section suggests a conceptual framework. Section 5 covers developing a component qualification process for the case company based on the conceptual framework and proposes a qualification process. Section 6, Testing/Simulating the proposal, provides a summary of the test results of the proposed process. Section 7, Discussion and Conclusions, summarizes the thesis and recommendations for the next steps towards the implementation.

2 Method and Material

This section describes the research approach, data collection and analysis methods used in this Thesis.

2.1 Research Approach

Research approach, according to Kananen (2013: 13-27) broadly defines an approach to a problem that encompasses gathering data, analyzing and examining the methods prevailing to the approach. The choice of research approach is influenced based on the issue being studied, researcher's experience and the audience (Creswell 2014:21). Thus, choosing an appropriate research strategy approach is essential for successfully reaching the research objective. Research strategy is different from a research method, and accordingly the choice of methods is associated with strategies. In practice, the most widely used and commonly known are quantitative and qualitative research strategies. Based on the nature of the research and project considered every strategy possesses its strengths and weaknesses. (Denscombe 2010).

Qualitative analysis tends to use words or visual images as the unit of analysis, combine researcher involvement, relate with small-scale studies, with holistic perspective and associate with data analysis during data collection. Qualitative data are irreplaceable and in general qualitative data analysis is likely to be considered as iterative, inductive and researcher-centered. Qualitative data analysis produces richness and details to the data, and a tolerance of vagueness and variance with alternate explanations and the data and the analysis are grounded. (Denscombe 2010). Both qualitative and quantitative research strategies can be used for a variety of research approaches. For the field of business studies, the most widely known and frequently used are the Case studies, Action and a newer one, Design research approaches.

According to Kananen (2013), Design Research leads to inducing a practical working solution, while it does not limit to be narrative. It presents the characteristics and process of action and development research with a goal for change or development. The notion of Design research is such as products, services, processes and action. The goal of Design research is not to generalize research, rather the objective of the research is to achieve a better change relevant to the situation on hand and improvement in business

context. Design research and Action research are related, where the goal of both researches is to realize change or improvement. In Design research, the researcher participates as an external participant, whereas in Action research the researcher is an active participant of the development of product, process or activity. Design research has the similar objective as development work carried out in organization like, improve process, activities, products, or service. (Kananen 2013).

According to Kananen (2013), “Design research is not a research approach of its own as it deals with a combination of several or many methods or a research strategy that is used to develop an object or to eliminate a problem”. Design research helps development work that benefits the situation at hand and the interested participants involved in the phenomenon while this kind of development work happens in business and organizations. To benefit the external participants, the development work needs documentation. The goal of Design research is uncovering a better option for the circumstances that must be tested to manifest its functionality. (Kananen 2013).

Based on the nature of this study and the expected outcome in this thesis, which is a working solution in practice, a Design Research approach strategy is selected for this study combined with Qualitative data analysis. This study is a real-life situation in a business environment with an objective to develop a process framework for electrical/electronic component qualification, which should be a solution that works in practice. The study collects data within an organization and methods used to collect data in this study include interviews, workshops, observation and documents that provide details required for the analysis. Henceforth, Design research approach with Qualitative data analysis are considered as the appropriate methods for this study.

2.2 Research Design

This section describes the research design in this study with an aim to develop a common electrical/electronic component qualification process framework. The research design for this study is illustrated in Figure 1 below, with an intention to progress gradually from one phase to the next.

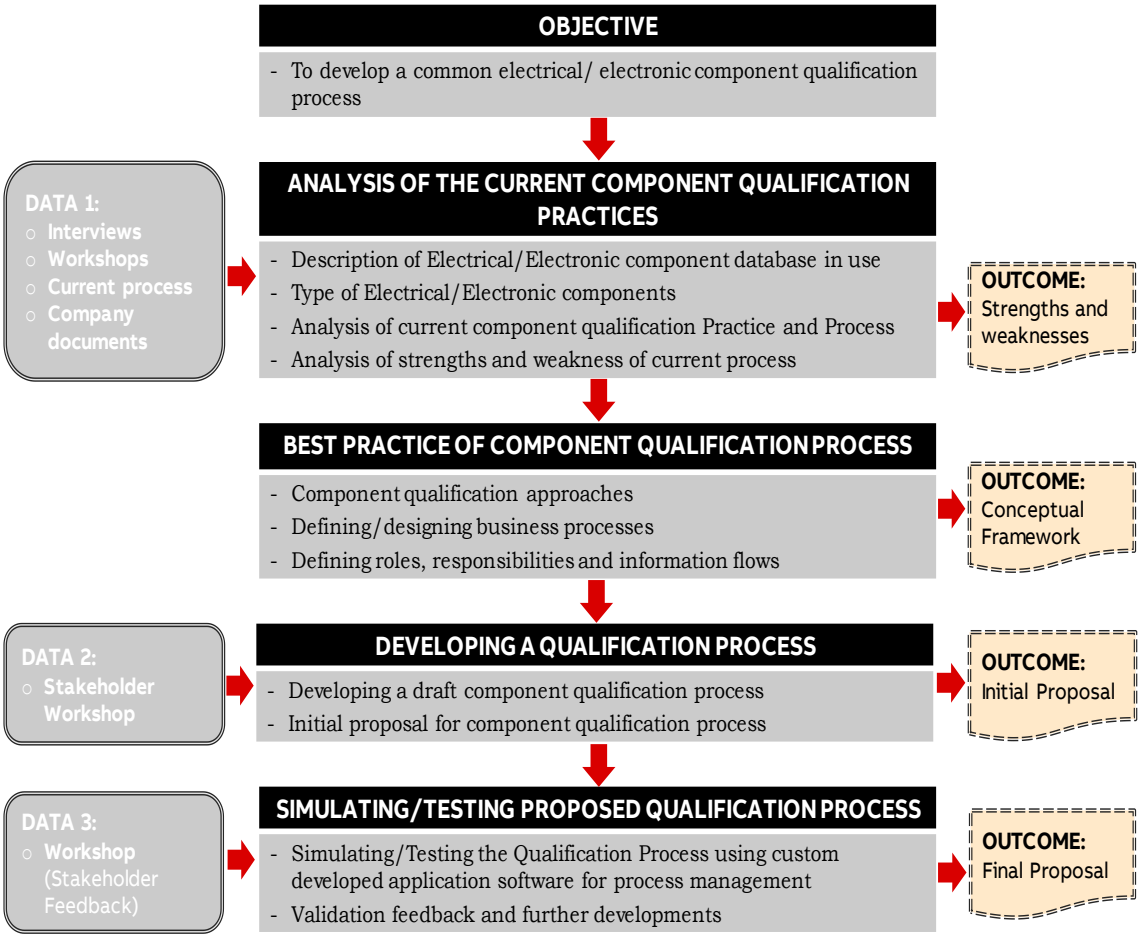


Figure 1. Research Design of the study.

As shown in Figure 1, the research design is built accordingly to achieve the goal to develop a common electrical/electronic component qualification framework for the case company.

The research design comprises of five phases, along with the data collection and expected outcome on the respective phase. Initially, based on a business challenge possessed in the case company the objective is identified in the first phase. In the second phase, a current state analysis is performed to obtain an understanding of existing practice from various sources (Data 1), with an aim to identify the strengths and weaknesses of the existing process and practices in the case company. In the third phase, the study focuses on best practices in industries and from literature to address the targeted weaknesses to build a conceptual framework. In the fourth phase, the existing business process is tackled through the conceptual framework and a draft proposal for electrical/electronic component qualification process is developed, and then it is reviewed with the key

stakeholder in a workshop which forms Data 2 and further feedback obtained is integrated into the draft proposal to develop an initial proposal. In the fifth phase, the initial proposal is simulated and tested in a custom-made software application and based on the feedback obtained, a final proposal for common electrical and electronic component qualification process for the case company is derived.

2.3 Data Collection and Analysis

This study acquired data from various sources comprise of various rounds and the data was collected in three rounds on respective phases. Data is collected by means of interview, workshops, discussion and from case company specific documents. Table 1 below briefly overviews the details of data collection round for Data 1, Data 2 and Data 3. The collected data was utilized in the thesis in accordance with the research design presented in Figure 1.

Table 1. Data collection rounds, Data 1-3.

Data	Data Source	Purpose	Utilized thesis section
Data 1	1) Internal Documents 2) Interview and workshop 3) Telephonic discussion	Obtain feedback about the existing process - How efficient is the existing process - Strengths and weaknesses of existing process	Section 3 (Current state Analysis)
	3) Workshop	To evaluate the fishbone diagram	
Data 2	1) Workshop	Suggestion and feedback for building the initial proposal ¤ Review of draft proposal, which consist of > Draft proposal - end-to-end business process > Draft proposal - Detailed workflow diagram > Draft proposal - RACI Matrix (Responsibility Assignment) > Draft proposal - process framework	Section 5 (Building the initial proposal)
Data 3	1) Workshop	Testing/Simulating and Validating the initial proposal	Section 6 (Building Final Proposal)

The Table 2 below exhibits the details about the participants who represented during the interviews, workshops and telephonic discussion occurred during data collection round for Data 1, Data 2 and Data 3, along with the specifics when the data collection took place and how the data collection has been documented.

Table 2. Details of interviews, workshops and discussions in Data1-3.

	Participants / role	Data type	Topic, description	Date, length	Documented as
	Data 1, for the Current state analysis (Section 3)				
1	Respondent Group 1: - Product Engineers (4) - Principal Engineer (MD) - PE Manager (MD)	Workshop	- Current Component Qualification process in MD - Strengths and Weakness of the current process	02/2019, 60 mins	Field notes
2	Respondent Group 2: - Principal Engineer (ID)	Face to face Interview	- Current Component Qualification process in ID - Strengths and Weakness of the current process	02/2019, 30 mins	Field notes
3	Respondent Group 3: - Principal Engineer (SD)	Face-to-face Interview	- Current Component Qualification process in SD - Strengths and Weakness of the current process	02/2019, 30 mins	Field notes
4	Respondent Group 4: - Principal Engineer (DS)	Face-to-face Interview	- Current Component Qualification process in DS - Strengths and Weakness of the current process	02/2019, 30 mins	Field notes
5	Respondent Group 5: - R&D Manager	Face-to-face Interview	- Current Component Qualification process in R&D	02/2019, 30 mins	Field notes
6	Respondent Group 6: - SCM Manager	Telephone discussion and email	- Current Component Qualification process effects in SCM - Strengths and Weakness of the current process	02/2019, 15 mins	Field notes
7	Respondent Group 7: - Product Engineers (4) - Principal Engineer (MD) - PE Manager (MD) - Principal Engineer (ID) - Principal Engineer (SD) - Principal Engineer (DS)	Workshop	- Review of fishbone diagram (cause and effect validation)	02/2019, 60 mins	Field notes
8	Respondent Group 8: - SCM Global Manager - SCM Manager	Workshop	- Review of fishbone diagram (cause and effect validation)	02/2019, 45 mins	Field notes
	Data 2, for Proposal building (Section 5)				
9	Respondent Group 1: - Product Engineers (2) - Principal Engineer (MD) - PE Manager (MD)	Workshop	Initial Proposal building	04/2019, 75 mins	Field notes

	- Principal Engineer (SD) - Principal Engineer (DS) - Manager SCM (2)				
	Data 3, from Validation (Section 6)				
10	Respondent Group 1: - Product Engineers (4) - MD Principal Engineer - SD Principal Engineer - DS Principal Engineer - Manager SCM	Workshop	Validation of initial Proposal	04/2019, 75 mins	Field notes
11	Respondent Group 2: - PE Manager (MD) - Global PE Manager	Workshop	Validation of initial Proposal	04/2019, 60 mins	Field notes
12	Respondent Group 3: - SCM Global Manager - SCM Manager	Workshop	Validation of initial Proposal	04/2019, 50 mins	Field notes

As seen from Table 2, data for this project was collected in three rounds. In the first collection round, Data 1 was collected for the current state analysis (CSA). The collection of data for the current state analysis happened in seven sessions. The data collection method includes workshop, face to face interview and telephonic discussion. The respondents were select from various product groups and based on their active involvement in the case companies existing electrical/electronic component qualification process. Data 1 field note is displayed in Appendix 1.

The second round was to collect Data 2, and it was conducted for building the initial proposal. The Data 2 was gathered from the suggestions and feedbacks obtained from key stakeholders, while the draft proposal was showcased during the workshops. Data 2 field notes is displayed in Appendix 3.

The third round was to collect Data 3, and it was to validate the initial proposal. The validation of initial proposal with the identified key stakeholders occurred in three sessions. The feedback and suggestion were consolidated to form the Data 3, and the same is displayed in Table 7.

Primary methods used for data collection in this study are interview and workshop, and the details was recorded in the form of field notes. The interviews were formal, semi structured and held in case company premises with the framed questions. The workshop

was conducted to presented data, for discussions and to obtain feedbacks, suggestions and inputs. The details were recorded in the form of field notes.

In addition to the current state analysis for Data 1, it also utilized the below internal documents listed show in Table 3 below.

Table 3. Internal documents used in current state analysis (Data 1).

	Name of the document	**No of pages**	**Description**
1	Process for approving alternative sources	01	Document describes the purpose, objectives and activities of the PCBA alternative source approval process.
2	Alternate PCBA component approval	01	Workflow diagram
3	IT platform of existing process management	N/A	Intranet of case company

As seen in Table 2, the biggest part of the data was collected for current state analysis of the existing component qualification process in the case company. The study continues further to Section 3, where the finding and analysis of data 1 is discussed.

3 Analysis of the Current Component Qualification Practices in the Case Company

This section presents the findings and observations from the current state analysis (CSA) of electrical/electronic component qualification practices followed in one of the business unit in the case company.

3.1 Overview of the Current State Analysis Stage

The current state analysis aims to analyze the case company's existing electrical/electronic component qualification practices. The analysis was accomplished in four steps.

First, the CSA classifies the type of component that needs to be qualified. Second, it describes the current component qualification practices and process in the case company. Third, the analysis identifies the key findings obtained from the CSA. Finally, it summarizes the strengths and weaknesses of the existing practices and select the focus for improvements.

The data for the current state was collected in three steps: First, the existing component qualification process and the available documentation was reviewed. Second, key stakeholders were identified for each product group who are actively involved in the existing component qualification process in the case company. Third, a workshop and interviews were organized with the key stakeholders of various product groups by means of workshop, face to face and telephonic conversation. Finally, the data gathered from various key stakeholders was consolidated to construct a process map of the existing component qualification process and a fishbone diagram to perform cause and effect analysis.

The investigation was performed by conducting interviews and workshop where the process was mapped and analyzed together with various parties involved in the process. The first part presents an overview of the current state analysis stage. The second part provides a broad view of electrical/electronic component database usage and practices in the case company. The third part briefly describes the type of electrical/electronic component used typically in the industry and in the case company, and those are the type of components that undergoes component qualification in the case company. The fourth part focuses on the current component qualification practices and process. The fifth part discusses the key findings from the analysis of current qualification practices and process. The sixth part summarizes the strengths and weaknesses of existing practices.

It is also important to notice that, according to industry practice, electrical components or electronic components are referred to as “components” in hardware design and also typically, electronics design or electrical design is referred as ‘hardware design’. Henceforth, for the ease of use and understanding further, the thesis will refer to an electrical and electronic component as ‘component’ or ‘electrical/electronic component’ accordingly based on the context for better understanding.

3.2 Description of Electrical/Electronic Component Database in Use

Electrical and Electronic components are used in almost every industry segment, right from modern toys to military equipment. The case company is an original equipment manufacturer (OEM) dedicated to design and manufacture of products that serve all industries and all applications with a wide range of product portfolio, where electrical and electronic components are the heart of the products designed and manufactured.

The case company possesses a well-equipped IT infrastructure with a centralized component database, which is accessible across the globe used dedicatedly for the management of components and printed circuit board assemblies (PCBA). Each product group in the case company has product owners who have the responsibility to design and maintain products belonging to their group and under their responsibility. In addition, each product group has various variants of products and the internal teams need to maintain the design and manufacturability of the product. As mentioned earlier, the electrical and electronic component database in the case company is centralized, and the components are categorized based on their nature according to international standards. The lifespan status of the electronic components is also managed for each component and flagged as active, last time buy, obsolete, end of life or disqualified accordingly.

Figure 2 below illustrates a simplified overview of the component database configuration and its usage across various product groups globally in the case company. The approved components are in a centralized database, which is used in various products across different product groups in the case company.

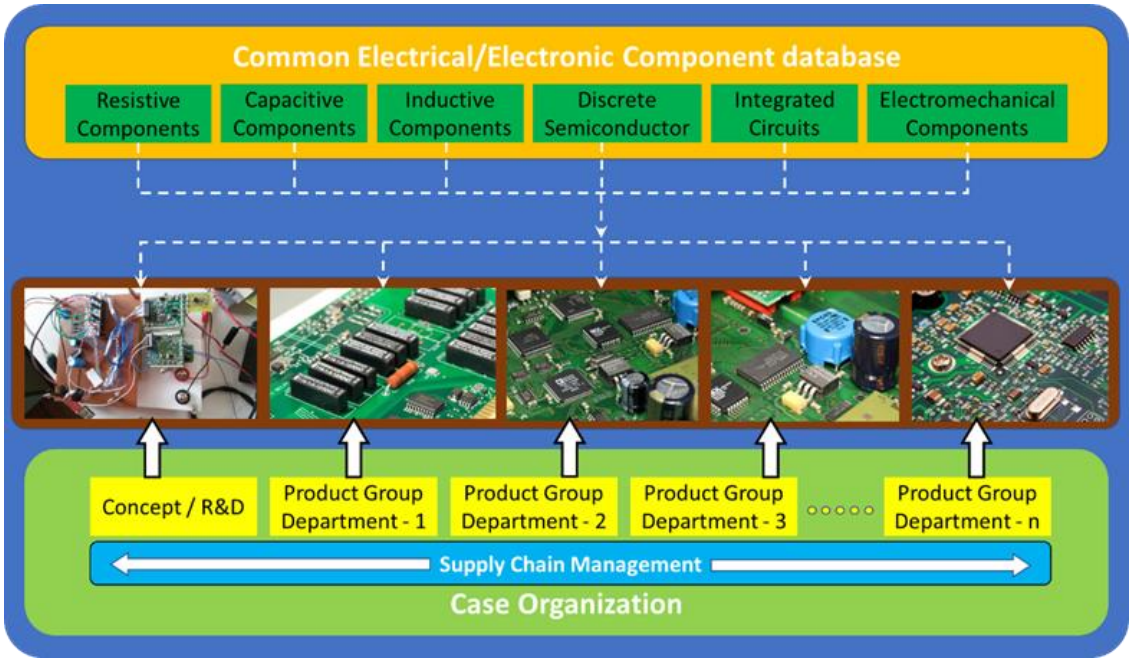


Figure 2. Overview of electrical/electronic component database in case company.

As seen in Figure 2, a simple configuration of database and usage of different components in various products illustrated to give a brief understanding. Based on each component's nature and its electrical specification, the testing and validation of the component usually take from weeks to months to complete the qualification process. The qualification status of the component is updated based on the qualification results. To be noted, 'qualification' refers to testing, verifying and validation of component and 'qualified' refers to approved component. Supplier information management, components' electrical specification validation and component footprint geometries are followed according to internal standards. Simply said, the qualified component or set of qualified components are used or reused in various products in the case company. Since the components are managed in a centralized database, if one component has a problem in quality or non-availability (shortage) or end-of-life, it affects all the products which use this specific component which further leads to complications in production and manufacturability. And, vice versa, if a new component is qualified and approved to be listed on the centralized database, based on an internal company process it is mandatory to obtain an approval from all the product owners who own the respective product across the product groups. Moreover, if an alternate component needs to be qualified, it must fulfill the existing requirement of form, fit and function (FFF) and should be able to be used in all the existing products which are currently active and manufactured.

Thus, the electrical/electronic component database and its usage in the case company has a significant role in the products manufactured. The following sub-section describes the type of electrical/electronic components at a general level.

3.3 Type of Electrical and Electronic Components

Product design in general consists of electrical design and mechanical design, and both teams collaborate with the supply chain to ensure the manufacturability. The scope in this study is limited to focus on electrical and electronic components and their qualification. Electrical design in the case company's OEM products consists of various types of electrical and electronic components which are used at various phases of the products' life cycle starting from R&D until the product reaches End of Life (EOL).

Electrical and electronic components are used in hardware design, in various products and its variants across different product groups across the case company. The specific component identified to be used in a product typically starts from R&D, and then further continues to be used during the product's maintenance phase and product service phase.

Electrical products or equipment are built using various electrical and electronic components which are usually found in circuits as per the functional logic of the component. Combination of various components, the functional logic plays a vital role in building devices or products (equipment) and henceforth components are the fundamental building blocks for the circuits. These components typically have one or more electrical terminals that are connected or soldered on to a printed circuit board (PCB) that allows to pass signals across the circuit board to serve different functions based on the logic design.

A component can be classified into its broadest division of categories as active components, passive components and electromechanical components, because there persist abundant types of specific component and packages/sizes. In a general level, active components typically rely upon a source of dc voltage to produce power gains, while mostly passive components are independent of any applied voltage. Electromechanical components typically perform electrical operations by moving parts within the device or using connectors. But however, for the ease of use to find the components from a huge database in the case company, the classification of the components is further narrowed

down and categorized as Resistive component, Capacitive component, Inductive component, Optical component, Discrete semiconductor, Integrated circuits and Electromechanical components. Table 4 below presents the classification of electrical/electronic components.

Table 4. Electrical/electronic component classification.

Component Type	Component Category
Resistive Component	– Fixed resistors – Variable resistors (Potentiometers, Trimmers) – Varistors – Thermistors
Capacitive Components	– Ceramic capacitors – Aluminum electrolytic capacitors – Polymer aluminum electrolytic capacitors – Film capacitors – Tantalum capacitors – Glass capacitors – Mica and PTFE capacitors – Niobium (oxide) capacitors – Thin film capacitors
Inductive Components	– Chokes – Common mode chokes – Transformers – Current transducers
Optical Components	– LEDs – Opto isolators – Fiber optic modules – Optical fibers
Discrete Semiconductors	– Diodes (PN and Schottky) – Zener diodes – Transient voltage suppressors – Bipolar transistors – MOSFETs – Power MOSFETs
Integrated Circuits	– Linear regulators – Switching regulators – FPGAs and processors – A/D and D/A converters – Line drivers, receivers, transceivers – Memory circuits

Electromechanical Components	– Connectors – Crystals – Relays – Fuses – Switches – Wires

The list of components presented in Table 4 are only a few among the key electrical and electronic components used on various designs and products across the case company. These components have further classifications, which is not showcased here, as it is not essential for this study.

The following sub-section describes the current component qualification process and practices in the case company.

3.4 Analysis of the Current Component Qualification Practices

The main problem with the current component qualification process is that it is not well defined, documented and controlled. This absence of a functional process, procedure, and a common approach in the case company needs solving. The component qualification process in the case company is functional currently but does not deliver efficiency and performance and value that could be realized swiftly. Further, since the existing qualification process is followed without any uniformity across the various product groups in the case company, this leads to redundant approval from all the product owners across the case organization as the components are managed by a centralized database and used in various products. Component usage in the case company has been briefed in Section 3.2 and portrayed in Figure 2.

The description of the current practices and process are the present integral part of the functional environment in the case company. The current process has strengths and weaknesses which will be further explored in the following section 3.5. The current component qualification process and practices are overviewed and discussed further in the sub-section below.

3.4.1 Outline of the Current Component Qualification Process

As mentioned earlier, the current component qualification process is functional, but cannot live up to the task. Figure 3 below depicts an overview of the current component qualification process followed for all type of PCBA components in the case company.

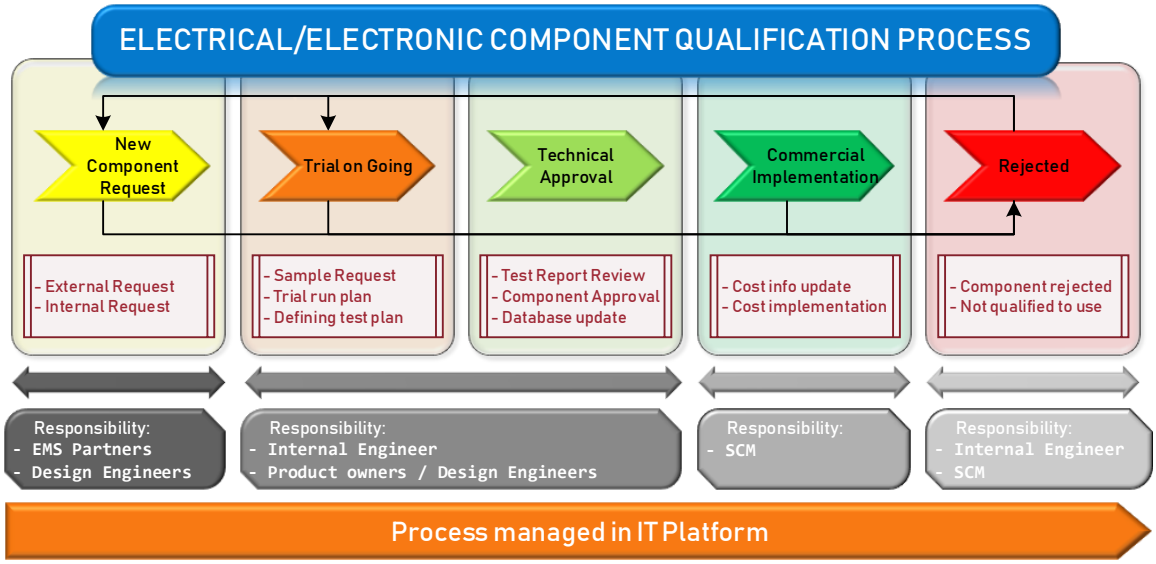


Figure 3. Current electrical/electronic component qualification process in case company.

As illustrated in Figure 3, the component qualification starts with a New request, then subsequently moves to Trial on Going, Technical Approval and Commercial Implementation, and this is the workflow in practice currently. If the component does not pass the criteria to be used, then it is rejected. Each phase in the workflow consists of various subprocesses/activities that need to be performed. However, the sub-process is not defined or documented, and it does not have a workflow or process defined currently. The practice followed currently is not defined and documented. Moreover, the practice varies based on the individual handling the case. Subsequently, each stage of the component qualification process is explained below.

New Component Request originates when there is a need for a component to be used in the design or to replace an existing component that does not exist in the component database and that is the starting point in the process. The need for the new component to be qualified can be for various reasons such as better quality (or) better cost saving (or) better availability (or) for alternative component, but in some cases, they can be a combination of everything, as well. The request for new component qualification could originate from internal engineers or from external electronics manufacturing services

(EMS) or contract manufacturing partners. If the new requested components do not meet the form, fit and function, the request is rejected. There is no structured process defined to execute this task and in most cases the request is not complete as there is always some key data missing that halts the process.

Trial on going is a stage when the component is taken forward for further review and testing. During this phase, component samples are ordered, and a test plan is drafted by the internal engineer in the case organization based on his needs for that particular product the engineer handles. The trial plan consists of; who builds the unit, where to mount the new sample component, what parameters to test and how to perform the testing. After the completion of testing and validation, the engineer decides whether the component is qualified or not qualified according to the results. Based on the qualification results, the requested component moves forward or is rejected in the process. There is no structured process defined to execute this task. The information is scattered across and the documentation is not shared with the right stakeholders. In short, there is no traceability and no well-defined ownership.

Technical Approval is provided when the new component has passed all the defined qualification test requirements as per the trial run plan as described in the previous stage. Once the component is approved by the engineer, it is added into the centralized database for further use in design and production as applicable. If not approved, the component is rejected. There is no structured process defined to execute this task.

Commercial implementation is handled by the supply chain management (SCM) team. The latest cost information of the new component is obtained in coordination with the EMS partners to ensure the newly added part is taken into use and the cost information is aligned between the case company and the partners. The supply chain also updates the cost into the internal system that is used to calculate the Bill of Material (BOM) cost. In a few cases, if the qualified components are not suitable to be used due to any commercial reasons, the component is rejected.

Rejected state of a component means that the component does not qualify to be used in a design or in a product. Hence, no more action is taken further.

Overall, the existing practice is functional with constrained elements. In the following subsection, insights from the existing process are briefed to understand the challenges faced during the process.

3.4.2 Findings from the Current Component Qualification Process

The component qualification process in the case company is currently functional but does not exhibit efficiency and value as the process is feeble. The case company has all the necessary equipment and engineering tools to perform the qualification process of the component. This section provides insights from each stage of the process involved in the component qualification process, which includes discussion and response from various respondents, the author's work experience in the same domain at the case company and observation from the functioning of the process in real time.

During the *new request* stage, the most common problem is lack of key input data in the request, which is mandatory to act on the request. As described in Section 3.2, there are various owners from each product across the product group responsible for each product line and design and henceforth, the new component request is not assigned to the right owner who should hold the responsibility as there is no properly defined existing process. Hence, this needs some manual intervention to channel the new request towards the right direction. This continuous act of new requests is repeated by the requestor and over a period of time it continues to pile up without any action and without producing any value to the business. This was well summarized by two respondents as follows:

> *Missing key input data (such as datasheet, cost, correct vendor part number, correct internal part number) and incorrect where used information lead to piled up request. (Respondent Group 1, Respondent Group 2)*

A stable flow of new requests gets accumulated at *trial on going* stage. Internal engineers in the case company strive their best to act upon it but are not sure which component and request needs priority. Judging by the response from the respondent group and from observation of the process in real time, it is clear that the lack of priority mapping was the route cause and addressing it in the process could help to focus that brings value and enhances efficiency. Typically, a trial run plan should be given, and the plan should be traceable. Emails are exchanged between the parties and the information is not documented and thus no traceability of details making it very hard to find traces of the past

history. Most of the components, which come in new requests, are alternate components, which typically are used in multiple products across various product groups in the case company as exhibited in section 3.2. Hence, there is a need for technical approval from various owners, but it is challenging to obtain the approval from all the stakeholders, as it is either time consuming or hard to get hold of all the stakeholders, or there is a resistance for approval from some design owner/product owner. In a few cases, after all the testing and validation is completed by an engineer and the component is qualified to be used, there may be resistance in approval as another design owner or product owner insists on performing some extra test to approve. With such chaos in the process, it is evident there was no clear priority mapping, no common process approach, no common requirements and lack of common basic test criteria. Also, a persisting challenge in managing resources for testing and validation needs consideration. This was commented on by multiple respondents as follows:

> *Lack of priority mapping, and redundant approval from various owners are key pain areas. Common approach and basic test criteria requirement across the case company is not in place. (Multiple Respondents)*

Technical approval is provided after successful completion of Trial on going. In this stage the responsible internal engineer in respective product group(s) reviews the qualification results and all the required technical details that enable approving the component. However, it is worth noting that all the reviewed data is not shared/saved in the repository. Lack of placing all the test and validation data as a package into the repository while approving the component, tends to lose all trace of test results and hence cannot be shared with the other product group approvers or retrieved in future. Not all approved components are added to the component database in the process. The problem was explained in the following way in the interviews:

> *No testing details and validation data is updated in the request or stored. It's good to have when seeking others' approval. (Respondent Group 1, Respondent Group 2)*

Commercial implementation is handled by the SCM. The approved components' latest price info is obtained from the respective suppliers and is updated into the enterprise resource planning (ERP) system. The cost info is exchanged between the SCM and EMS partners to ensure the manufacturing BOM reflects the right cost information.

> *The faster the component qualification process, the better the potential cost saving, value realization and tackling the availability issue. (Respondent Group 6)*

Disqualified components are flagged as *rejected*. However, in the current process flow, a place holder is lacking to move a part to be reviewed later. Hence, those new component requests, which possess a wrong perception, are flagged as rejected. Indeed, over a period this component request loses its trace and is not revoked back to proceed with the qualification process. Maybe it is a critical component or maybe not; it depends on that point of time based on global market conditions.

The process workflow is managed in an IT system that could be accessed globally. The system in place is not sophisticated to handle the entire process, but it possesses some strengths and weaknesses. The process workflow management is loosely controlled, not structured and not defined. Across the flow of process there are various inputs, data and responsible stakeholders who perform actions at each stage needs to be traced and are vital for the component qualification, but nevertheless there is pure lack of traceability. It was also found that various practices are in place, which are also not documented, and the practice is not the same across various product groups.

The report continues further to the analysis of strengths and weaknesses of the existing electrical/electronic component qualification process.

3.5 Analysis of Strengths and Weaknesses of the Current Practices

Assessing the strengths and weaknesses of the current process is important for improving the process. Continuous improvement of a process yields better results through constant review, measurement and action gradually. Looking at the strengths and weaknesses together in the current process helps to understand the situation and gain a better overview of the process and its improvement areas.

During Data 1 collection stage, the strengths and weaknesses of the current component qualification process in the case company were identified and chalked down in the form of a fishbone diagram, which identifies the cause and effect relationship in the existing process. Source of data and informants are as per Data 1 list are shown in Table 2.

Figure 4. Fishbone diagram - Cause and Effect analysis of existing process.

Metropolia

Figure 4 shows a fishbone diagram that was used to perform cause and effect analysis and is structured according to the association with the existing process. Findings are illustrated in Figure 4 which characterizes the strengths (in green) and weaknesses (in red) of the current component qualification process. The findings are consolidated and grouped in eight categories which depict the potential cause and its effects.

Figure 4 above clearly visualizes the findings, which comprise a considerable amount of weaknesses and a few strengths. The diagram is characterized by eight main causes (methods, tools, data, input, management, environment, communication and people) and thirty secondary causes.

Eight causes are grouped as component qualification practices (methods, tools, data, input) and process development practices (management, environment, communication and people). The component development practices causes are essential to qualify the component and process development cause are essential for efficient operation of the process. However, all the causes are associated with each other and affect the performance of the component qualification process.

The following sub-section provides a detailed description of the strengths and weaknesses which were identified.

3.5.1 Strengths

The strengths of the existing component qualification process within the case company are highlighted in green in Figure 4. The advantages in the current process are clearly in the *Environment*, but however the current process also exhibits a few strengths in *Tools, Data, Inputs and Management*.

The case company has a well-equipped environment to perform component qualification in terms of infrastructure and physical resources. As exhibited in Table 4, there are various types of electrical and electronic components that are used in multiple products and are designed by various designers. Based on the internal need arises within the case company to obtain guidance to perform qualification testing, in house experts are available globally to aid assistance. Also, in order to obtain knowledge about some special case component, there is a possibility to involve the right stakeholder from R&D or Product engineering or Product service departments as and when the business demands,

which varies based on the case handled. The environment to drive the process is healthy, and established process is adaptable for global use and collaboration in terms of IT infrastructure and test equipment to perform the component qualification.

The electrical and electronic component market is highly volatile globally and it is always good to have multiple sources of components that helps to mitigate business risk. Therefore, it is good to obtain a new component qualification request from different sources to maintain a repository with their cost info. The requests for new components come from internal engineers and from contract manufacturing (CM) partners as described in Section 3.4.1. The requests and their data can be managed in the process flow and metrics can be tracked and monitored on the progress of the request in the qualification process.

To manage the component qualification request, the case company has good infrastructure and IT platforms that are scalable to manage the process flow and data. In addition, the company has all the required engineering tools and equipment to measure and test the component within the company without any external dependency and it is available globally. As the case company has various cross functional teams covering the needs of across the world, and there is a decent collaboration established within the project teams.

3.5.2 Weaknesses

Weaknesses are the areas that have the potential opportunities to improve. Addressing the weaknesses could bring better efficiency, cost benefits and meeting the business needs/demands.

The results of the Current state analysis presented in a fishbone diagram in Figure 4, disclose the weaknesses that are highlighted in red. The major causes of weaknesses in the existing electrical/electronic component qualification process are *Methods, Communication and People*. A few more weaknesses are also present in *Tools, Data, Input and Management*. The findings are discussed based on their causes.

As exhibited in the fishbone diagram Figure 4, *Methods* is one among the key causes that need focus, because it exhibits more weakness. It is very evident that the existing process has no clear process defined and a description of the process is not available. Moreover, there is no clear documentation, or it is uncertain where it is maintained. The

process which is currently working or followed in the case company has lack of a common approach towards component qualification which is a key pain area, because as described in Section 3.2, there are many possibilities that the same components can be used in various products across different product groups. As component logic and working environment varies based on the products' design, it is important to have a common qualification approach which is currently deficient. It is also important to have a common requirement for test criteria (inadequate currently) that could meet the needs for various product groups utilizing the same components. Based on the current practices in the case company, it is mandatory, if a component is approved to be used that all the product owners or the design owners of various product groups must provide approval for that component before it is updated to the centralized component database by the component team due to process gap. With the standardized process to maintain a centralized component repository in place, there is always a redundant approval required from various product owners which is time consuming and there are cases that the tested component which is approved by one product owner is not approved by another. Moreover, there is no defined workflow and activities for each phase, as practice varies. This gap in methodology followed in the component qualification process needs consideration for improvement.

People is one among the other causes that displays several weaknesses. This discloses the inadequacy of mutual effort in the existing process. As there are various product owners across the product groups there are no clearly defined roles and responsibilities. In addition, there is a scarcity in resources for testing and validation to accomplish the qualification process. Additionally, other priorities override the resources availability and hence it is difficult to estimate the availability of resources. As a result, there is a delay in the component qualification process that sustains.

Communication plays a vital part in the process that helps to exchange information between the stakeholders and manage the information flows. Due to the vague definition of roles and responsibilities there is a gap in communication between the stakeholders. In a few cases a challenge in finding the right stakeholder causes delays in the process. Due to lack of proper process in place, a frequent manual follow-up and reminder for each component request is needed. This is time consuming and naturally when there is a huge number of requests in a queue it becomes quite hectic to handle the cases in the present process flow.

Input and *Data* exhibits few weaknesses which is exhibited. The requests for component to be qualified get accumulated due to various reasons which are associated with various causes, such as missing key input data to validate the request, lack of resources to perform the task, no clearly defined roles and responsibilities and lack of priority mapping. As there is no clear requirement of data defined, the required data is not stored or collected at each phase of the process. All data are retained in individuals' email inbox and those data are not harmonized to provide better traceability.

Tools plays a key role in a process that helps to plan, execute and control the process flow. Engineering tools are required to perform the component qualification process while the request management tools are needed to control the process flow. While all the required engineering tools are available there persists a weakness in the request management tool that controls the process flow where the workflows are loosely controlled and not structured well.

Process *management* is essential to align and streamline the process based on business needs and its functions, and it helps to improve the process. Currently for the component qualification process there is no process committee or no established process improvement gathering or meetings to discuss about component qualification process improvement plan, and it is a weakness.

3.6 Summary of the Strengths and Weaknesses of the Current Practices

The component qualification process that is currently in use at the case company possesses strengths and weaknesses which were analyzed and illustrated in Figure 4. The strengths and weaknesses recognized are summarized and classified for ease of reference. The summary of strengths is exhibited in Figure 5 and summary of weaknesses is exhibited in Figure 6 accordingly.

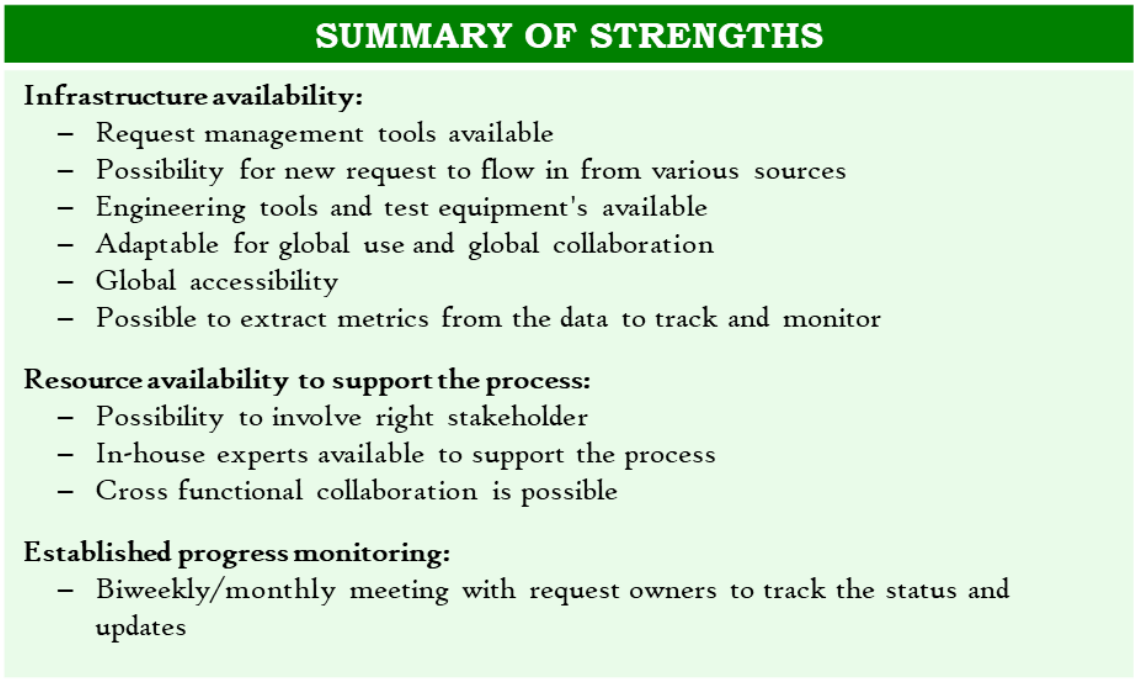


Figure 5. Summary of strengths.

As rendered in Figure 5 above, there are three key strengths summarized in the existing component qualification process in the case company. The first strength is classified as Infrastructure availability, where the case company manifests all the required infrastructure facilities to execute the component qualification process. Request management to facilitate various requests from different stakeholders and monitor the progress, engineering tools, test equipment and facility to perform component qualification and the infrastructure are available for global use and global collaboration. The second strength is classified as Resource availability to support the process, where the case company has inhouse experts to support the process and the right stakeholder can be involved on a case by case basis. As the team in the case company is global, cross functional collaboration is possible with the means of infrastructure in place. The third strength is classified as Established progress monitoring, as there is a dedicated practice to follow up the progress with stakeholders on a biweekly or monthly basis. According to the respondents, the existing process is functional, but it is not very effective and possesses weaknesses.

Figure 6. Summary of weaknesses.

As rendered in Figure 6 above, there are six weaknesses summarized in the existing component qualification process in the case company. The weaknesses are summarized as *Inefficient process workflow, Lack of imperative data, Lack of uniform process and methodology, Feeble distribution of role and responsibility, Inefficient collaboration and communication and No process improvement or development gathering*.

Lack of imperative data is one among the weaknesses identified in the current component qualification process. When a new request for component qualification is submitted there is lack of key mandatory input data that is required for component qualification process further. In addition, while there is a constant flow in request for new components there must be priority mapping that helps to keep focus, and it is currently lacking. All these factors lead the new component qualification requests to accrue. Moreover, the data requirement for the component qualification is not clearly defined and harmonized.

Inefficient process workflow is a weakness found in the current component qualification process, which is mainly due to the lack of unestablished structured workflow process or

activities and the workflow is loosely controlled. As the workflow proceeds forwards in the current process there is a great amount of data that follows or is required at each phase to perform during the process, but those data are not traceable over a period, as they are not harmonized or collected at each phase of the process. The process workflow, sub-process and activities are not defined and documented.

Lack of uniform process and methodology is a weakness noticed across the process flow which is currently practiced. Components are used in various products across the product groups. Hence, there is a need for common approach/methods and common requirement criteria for testing and validation which are lacking in the current process. There is no clear process definition and description in place. Due to the lack of common needs to perform component qualification, there comes a need for redundant approval from various product owners or designers across the product groups in the case company. Moreover, the current practice in place varies across the product groups within the case company.

Feeble distribution of role and responsibilities is another weakness that was spotted. The component qualification process in the case company involves various stakeholders which varies based on product groups at various phases. It was significant to notice that no clear role and responsibilities had been defined/identified for taking ownership to perform the qualification process. Due to the lack of defined roles and ownership, there is always a need for frequent reminder or follow up needed for the component request, which is time consuming. Moreover, there is also lack of internal resources to perform testing and validation, because other project priorities overtake the resources availability.

Inefficient collaboration and communication between the stakeholders pose a challenge. Gaps in communication and information flows between the stakeholders persist and moreover the right stakeholders are not involved in communication to communicate at the right time as the component qualification process progresses.

No process improvement/development gathering is in place because there is no process development committee for the component qualification process to steer the process improvement or development activity. Hence, there is no well-defined process for component qualification in place, nor it is documented. Hence it is not practiced in the routine project environment.

Based on the key findings, the *Environment* features the main strength in the process. However, due to the weaknesses found in *Methods, People and Communication,* the existing component qualification process cannot live up to the task and is not efficient. Considering the existence of various types of components and their usage in the various products in the case company and analyzing the strengths and weaknesses of the existing process, there is a need to develop a component qualification process that could be prevalent across the case company. Figure 7 below, exhibits the weaknesses identified for further focus in this study.

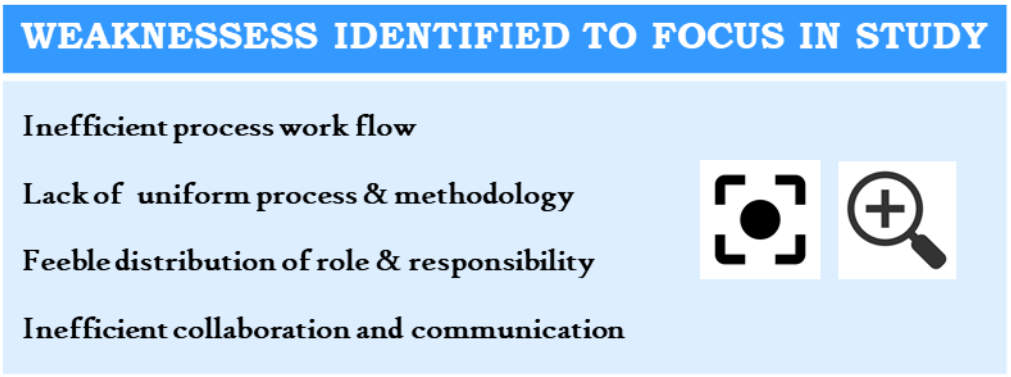


Figure 7. Weaknesses targeted for further focus.

As indicated in Figure 7, the weaknesses identified to be addressed in this study are inefficient process workflow, lack of uniform process and methodology, feeble distribution or role and responsibility as well as inefficient collaboration and communication.

To develop a common component qualification process for the case company, the thesis advances further to garner knowledge from literature review to find best practices, concepts, ideas or solutions that will be used to build a conceptual framework in Section 4.

4 Best Practice and Insights from Literature on Building the Component Qualification Process

This section provides insights and is focused on theoretical background obtained from the literature study on component qualification approaches, process development, business process, process workflow, and roles and responsibilities. These focused areas selected in this study is based on the identified weakness from the current state analysis presented in Section 3.5.

The first part discusses about the component qualification approaches. The second part discusses about designing/defining business process. The third part discusses about roles, responsibilities and information flows. And the forth part, utilizes the best practices from the literature study to develop a conceptual framework for this study.

4.1 Component Qualification Approaches

Electrical engineering is everywhere in the present era and it has transformed our lives extensively in diversified areas. The transformation in electrical engineering has resulted in creating technology and products to make our daily life easy. Product design is an integral part and vital to a manufacturing enterprise to survive and prosper (Stoll 1999). Design has various disciplines, including electrical engineering design, mechanical engineer design, architectural design etc. (Otto and Wood 2003). In-depth knowledge in electrical and electronics theory is used to design, develop, test and manufacture any electrical or electronic equipment/product, which utilizes the electrical and electronic components associated with the product.

Components are the basic element in electronics, which are mounted on a circuit board and are essential for electronic system design and manufacturing. Quality and robustness of the components determines the quality of the product and its reliability during its product life cycle. Electronic components undergo rapid technology advancements in performance and size. A mistake in qualifying and selecting a component could possess a potential risk to disqualify the entire design and the product. (Eeherald 2017). Thus, selecting the right functional component and its supplier in the design is essential to

product manufacturability, quality and reliability (Hnatek 2003:180). Henceforth, component qualification is vital in product design and development throughout the product's life cycle.

A qualification process is a set of associated or collaborating activities that transforms input into output to demonstrate the ability to fulfill the specific requirements of a product or process (ISO 9000:2005). Therefore, it can be said that a qualification is a process consisting of testing, verification and validation.

Electronics components are the building block of the electronic products or systems development and these parts are critical for reliability. Selecting, specifying and controlling a part (or component) is a major engineering process in building a complex electronic system (referred to electronic product). (Fuqua 1987).

Hnatek (2003) highlights that Component Selection and its qualification is a critical process for products high performance and reliability, and component selection begins from component engineering by discussing along with design engineering to assess the technology and functionality. Birolini (2006:81) highlights that component selection and qualification should be based on the intended application. Component selection criteria should be based on where the component will be used, technology of the component, quality, long term behavior of the component based on the relevant electrical and environmental parameters. Components reliability is more important aspect when selecting the component. Also, cost and availability in the market to support the industry needs is also a key parameter that needs consideration in component selection. Birolini (2006:81).

According to Hnatek (2003), selected component should meet the required performance characteristics (electrical and mechanical characteristics) requirement of the design and it is important for quality, reliability and product manufacturability. The selection process must ensure to opt the right technology and functional components from the right suppliers. OEM's need to evaluate their supplier's facility and processes to ensure the supplier's financial health and stability and its long-term business plans which is important or could say mandatory for critical component suppliers. The role of Component Engineer (CE) in OEM's is associated with proactive involvement in product development and strategic planning right from the conceptual phase. The role of CE also includes continuously improving the OEM's component qualification process, in order to be pro-

ductive and to support fast time-to-market and shorten product development and life cycle. Improving the component qualification process, ultimately improves the product quality by evaluating test data provided by supplier, conducting component specific analysis, generating functional technology road maps and performing technology audits. (Hnatek 2003). There is a huge concern and increase in interest in the industry towards environmental sustainability to reduce the usage of hazardous Substances that impacts human and environment globally. Henceforth, different nations have regulatory bodies and regulatory requirements that place restrictions on the component selection choices (For example, RoHS, Restriction on the use of certain Hazardous Substances). Therefore, important criteria for selecting a component should comply with meeting the regulatory requirements, RoHS directives and support a lead free (pb-free) soldering process. (Sadanand 2017).

As highlighted by Birolini (2006:81), components, materials and assemblies influence the quality and reliability of the equipment and system. Hence, component selection criteria, component qualification testing or testing of components along with total assembly of the product and component failure modes (its mechanisms and analysis) must be considered as part of the qualification process. According to Hnatek (2003), Component Qualification tests are performed to foresee the reliability of the product and to ensure the product functions as per its intended application. Therefore, the component qualification performed must answer the following questions:

- Will the component, function in the application as designed? and
- Will the component, function as intended for the life of the product?

To answer the questions, according to Hnatek (2003), selecting a component with a low failure rate favors to achieve high reliability of the product. (Hnatek 2003).

According to Birolini (2006), recommendations and key selection criteria of a component are based on environment, performance parameters, technology, manufacturing quality and long-term behavior of performance parameters and reliability. *Environment* tests are tests performed based on the environment condition that consists of dry heat test, damp heat cycle test, thermal test, vibration test, mechanical test and free fall test. *Performance parameter* for each component is to be defined based on the intended use in the design or product. *Technology* of the component needs to be defined in terms of package form, package type, operating temperature resistance etc., as electronic components undergoing a rapid change in technology. *Manufacturing quality* at the supplier site also

plays a significant role in the component's reliability and any reliability problems or change in defective level need to be reported back to supplier for corrective actions. Long-term behavior of performance parameters can be verified by performing accelerated reliability tests. The reliability of the component is determined based on its failure rate and depends on the stress factor which is a key selection criterion in component selection. (Birolini 2006:81-86).

The qualification test process must be according to the actual technology and business needs. Even though manufacturers perform their part of the reliability testing, the OEM performed application-based testing (functional application testing or FAT) is more critical for successful component qualification. Due to technology improvements and market conditions the qualification technique and processes for component qualification must be continuously reviewed, evaluated, refined and updated by both suppliers and OEM's. Component qualification is a constantly evolving process. Application-based qualification, also called as Functional application testing, defines the component qualification process and component selection. (Hnatek 2003). An example of application-based qualification and entangled items are listed below in Figure 8 as a fishbone diagram.

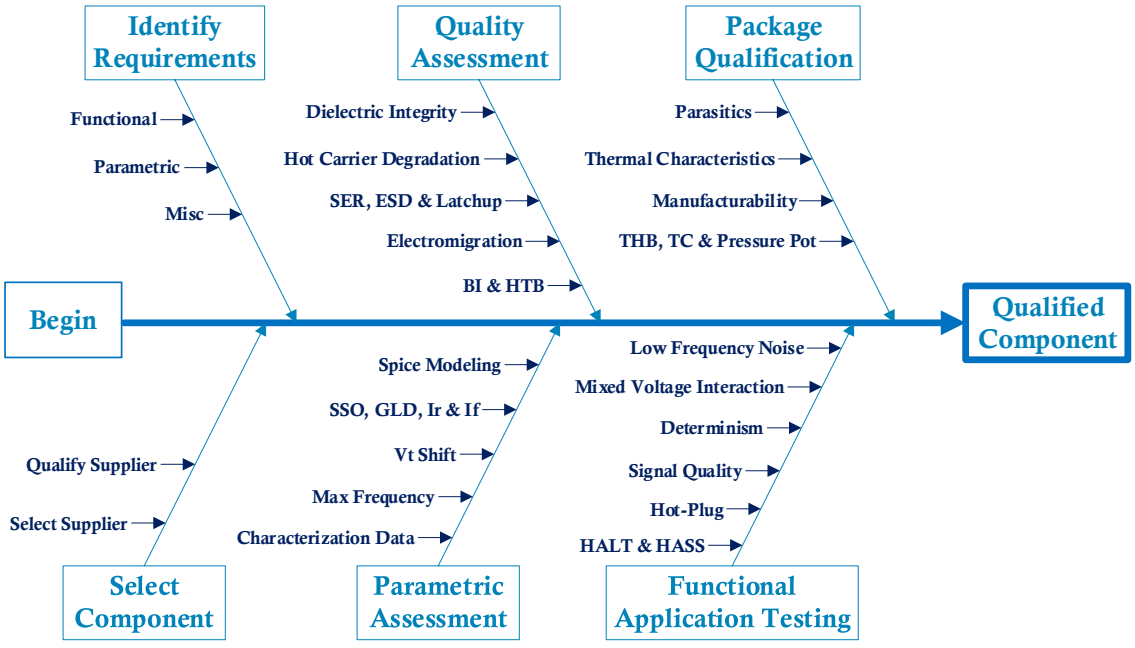


Figure 8. Example of application-based qualification process flow (Source: Hnatek 2003).

As imparted by Birolini (2006), the objective of the component qualification test is to verify and ensure the selected component is suitable for the intended application. A component qualification test deals with (i) *investigating the electrical performance* as per parameters, (ii) *analyzing technology limits* based on an environmental test and other special tests (based on application), (iii) *Reliability testing* to obtain failure rate information, (iv) *Failure analysis* to find out the failure cause and failure mechanism, (v) *Supply conditions* from the supplier to meet the business needs to define the cost, schedule and to find out second/alternate sources, and (vi) *Final report* to communicate the quality issues or reliability issue to supplier to take corrective actions. For special complex components (like Integrated Circuits, IC) more severe stress tests are performed to verify and validate the technology limits and failure mechanism that include Internal visual inspection, passivation test, solderability, electrostatic discharge (ESD), technological characterization, high-temperature storage, thermal cycles and humidity or damp heat test (85/85). The goal of a reliability test is to find out the failure rate and long-term behavior of the electrical parameter of the component, which typically consists of a dynamic burn-in test and failure analysis (Birolini 2006:87-101).

Electronic hardware reliability is influenced by various factors that include circuit design and system design reliability, manufacturing process reliability, and product reliability. However, the individual components used in the product design are the decisive factor for reliability. (Hnatek 2003). Also, Tekcan and Kirisken (2010) state that a reliability test is a balance of electrical, mechanical and environmental testing and further Hu (1994) remarks that evaluation of product reliability is essential to satisfy the expectation of customer to ensure long-term reliability of components and products.

Manufacturing enterprise (here refer to OEM) must develop a component qualification strategy that is needed for the product and based on the real-time field conditions. An engineering decision making process is needed to develop a component qualification test strategy with a logical step-by-step situation analysis, and the strategy should address application specific understanding between the component's performance, reliability, risk, product performance and cost. (Hnatek 2003).

According to Wang et al. (2008), qualification of a product aims to verify if a product satisfies or surpasses the intended application's reliability and quality requirements and henceforth, qualification needs to be an application specific process. Wang et al. (2008) state that Design level qualification can be performed by virtual qualification practice

which is based on validated failure models (application of physics of failure) with a physical testing which is less expensive and less time consuming. Product qualification is typically physical testing on manufactured prototypes products (can be referred to as assemblies) to verify the functionality of the product and performance of the product for reliability assessment, and the tests performed are High Accelerated Life Test (HALT), Strength limit test and Failure mode mechanism and effect analysis (FMMEA). Further, quality assurance testing in mass production is performed to screen the products before the product is delivered to the customer. (Wang et al. 2008). Also, Tekcan and Kirisken (2010) point out various other tests based on international standards that could be used to ensure the products' reliability in the consumer electronic and the details of different type of test performed is provided in Appendix 2. According to Birolini (2006:107-111), the components selected have to be mounted on the electronic assemblies (referred to as a printed circuit board, PCB) to perform an electronic assembly component qualification test. Typically, *component qualification test* includes performance testing, to analyze the electrical properties and behavior of its electrical parameters on the assembly at different temperature, and *environmental test* to find out the technology limits and failure mechanisms of the assembly such as cracks, component mounting problems, solder joints, deformation etc. (Birolini 2006:107-111).

According to O'connor and Kleyner (2012), the definition of Reliability according to engineering is stated as "the probability that an item will perform a required function without failure under stated conditions for a stated period of time". Design for Reliability process varies based on the type of industry, type of product, product development cycle and product specific factors. Figure 9 depicts the generic form of engineering activity flow that is needed to achieve a failure free design, and it suits well with the general product development process of Concept-Design-Development-Manufacturing-Operation/Support. (O'connor and Kleyner 2012). The reliability of electronic equipment or product's functions are linked with the reliability of each component used on the equipment or on product to function. A proper qualification of a component mandates to understand a component failure under long term operational condition. (Hu 1994).

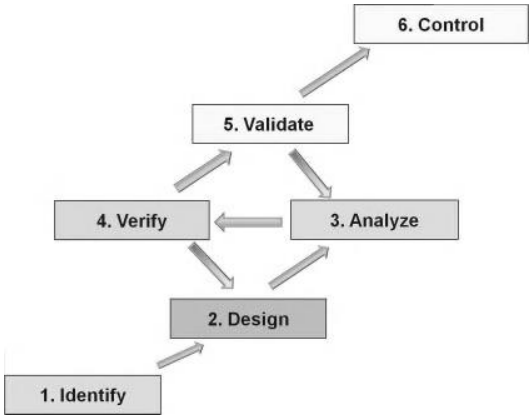


Figure 9. Design for Reliability activities flow (Source: O'connor and Kleyner 2012).

Hu (1994) states that knowledge of physics-of-failure is important to perform a reliability qualification of electronic components and must be categorized by failure site, failure mode, and failure mechanism. Component reliability qualification must be guided by failure mechanism analysis. Continuous improvement in component qualification process is necessary in order to address the demand of new materials, technologies, and manufacturing processes. For critical components used on the product, it is important to find the critical failure mechanism and it must be verified in design and manufacturing process. During the qualification process, the focus should not be only on the failed component, but investigation must be also performed on the interconnection failures that are influenced by material, geometries and the usage of the components. (Hu 1994).

According to O'connor and Kleyner (2012), for qualifying a component to be used in mass production it has to be tested, verified and validated. Accordingly, testing is an integral part of the product development in the design for reliability process, which begins early at the design phase. A complete system (product) validation test comprises of reliability specifications, field environments, possible failure mechanisms, acceleration models, and other considerations. Figure 10 below depicts an example of parallel test flow for an electronic product or system. (O'connor and Kleyner 2012)

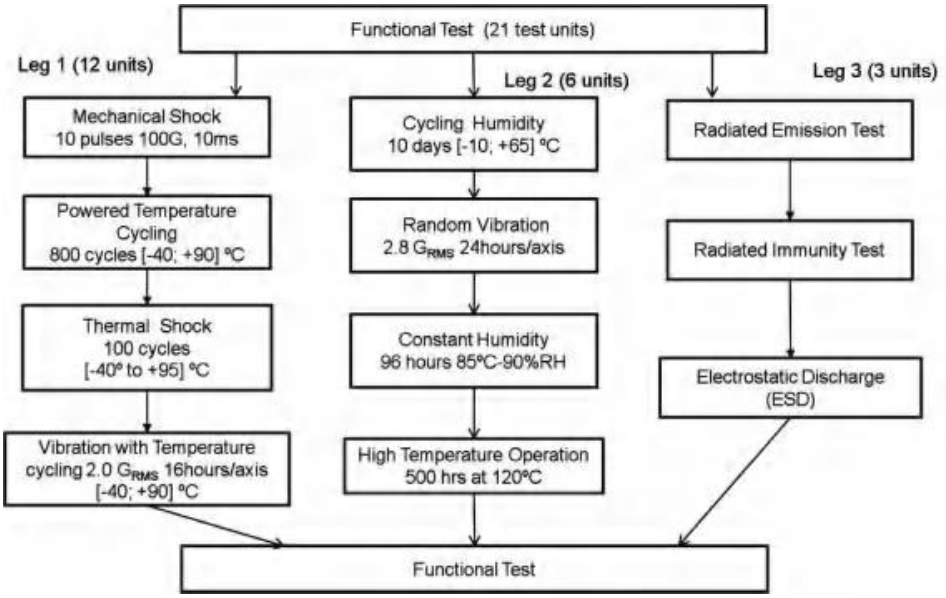


Figure 10. Example of a parallel test flow for an electronic device. (Source: O'connor and Kleyner 2012).

As mentioned by O'connor and Kleyner (2012), it is also very important in electronic production to have test methods to ensure quality, cost and reliability. Automatic test equipment (ATE) is used to perform assembly testing on manufactured circuits in electronics production. The main types of testing consist of Vision Systems or Automatic optical inspection, In-Circuit testing (ICT) and Functional Testing (FCT). Figure 11 below, illustrates the electronic equipment test strategy. (O'connor and Kleyner 2012).

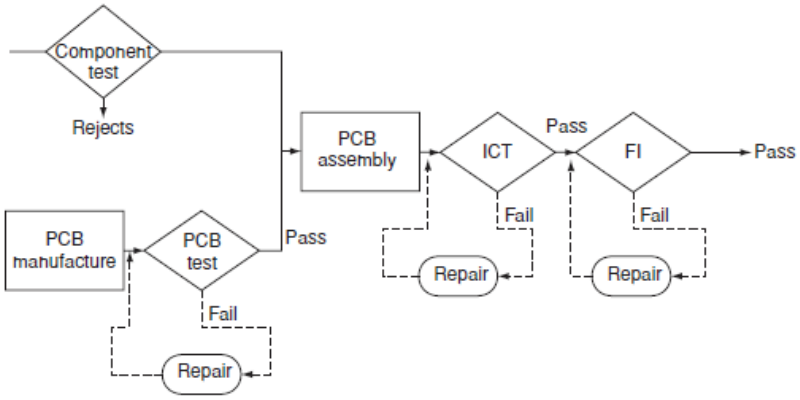


Figure 11. Electronic equipment test strategy. (Source: O'connor and Kleyner 2012).

According to Black (2009), project context and specifically the life cycle of the testing are important factors in the overall process followed in software or systems project (product design). Understanding the project context helps to fit testing in the overall system's life cycle and there are many life cycle models available. Testing phases tend to vary based

on various contexts, but it is necessary to include a component test phase, unit test phase and system test phase. Realistic test execution must be planned by the project team based on the application. Drabick (2004) highlights testing has a life cycle and the process is not simple. A model selected should locus in the right direction to develop a testing process or to improve an existing process. However, all models need to be modified and tailored to perform according to the business needs. Tailoring the process yields a usable and valuable test process. Black (2009) states further that a matured process needs to be reproducible and measurable, and for continual improvement of the process plan-do-check-act (PDCA) cycle must be repeated which is also called the Deming cycle. Figure 12 below portrays a testing process framework recommended by Black (2009) that could manage testing of hardware and software systems. However, the testing process framework in Figure 12 below proposed by black (2009) can be modified and tailored to meet the business needs.

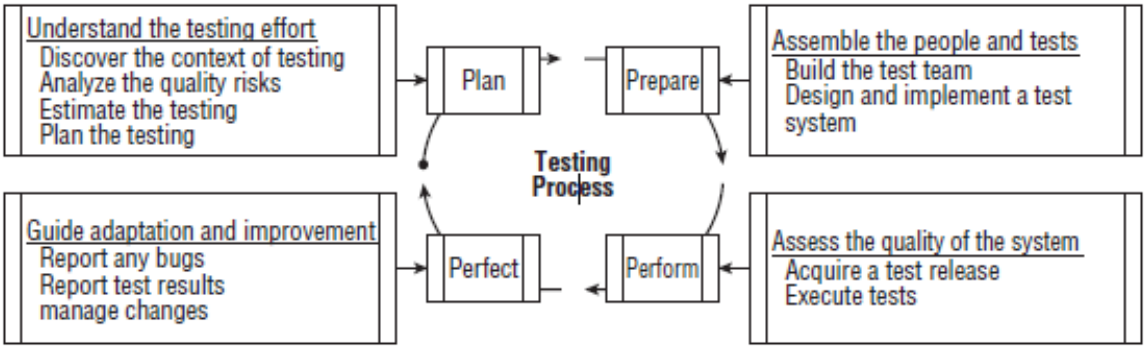


Figure 12. The testing process framework. (Source: Black 2009).

National Research Council (2001) points out that decision making comprises various ways in an engineering context, but the process of decision making is influenced by a bunch of conditions or contexts as presented below in Figure 13. Decision making is vital and not all decisions are easy, and they may possess compromises, entail risks and cost of failure (Harvard business essential 2005).

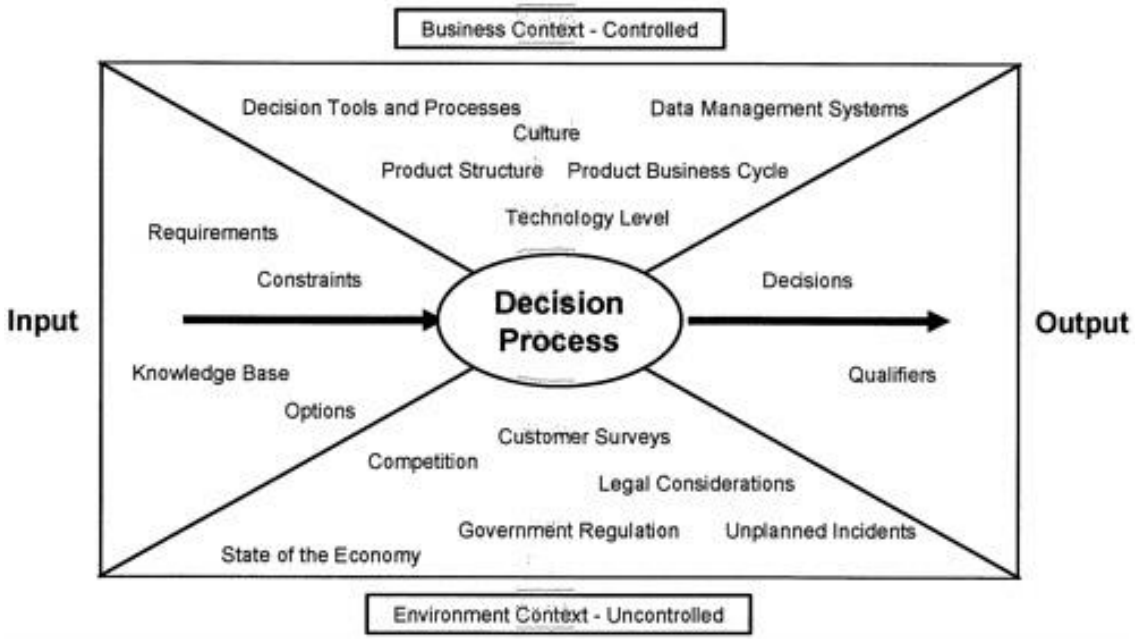


Figure 13. Decision process - Business and Environment context (Source: National Research Council 2001).

Figure 13 above illustrates the business context elements and environment context elements that influence the decision process. Business context decisions are in the control of the company representing the long-term view and Environment context decisions are not in the control of the company but must be considered during decision making in component selection and component qualification.

To abridge, this section provided insights from the literature study addressing an overview of the components' importance in an electronic product or system and the context of component qualification was defined. Moreover, the importance of component selection, component qualification testing, qualification strategy, reliability qualification, testing methodologies and decision making were explored in context with component qualification approaches. The following section explores the practices to define and design the business process and workflows.

4.2 Defining /Designing Business Processes

Remarkably, almost every organization has developed processes based on their needs (Davenport 2005), and organization sees everything as a process under the lens of business process (Bititci et al. 2011). Structured business processes have enabled to sense the value delivered to its customers, partners and internally to the organization. It applies

to organizations of all sizes and types. Also, organizations focus of attention is on 'process'. (Sharp and McDermott 2009).

Various definitions for process and business process prevail in general. According to Becker et al. (2003), "A process is a completely closed, timely and logical sequence of activities which are required to work on a process-oriented business object" and "A business process is a special process that is directed by the business objectives of a company and by the business environment". Likewise, Anand et al. (2013) describe a process as containing "a set of attributes and principled flow of steps in order to achieve a task" and business process as "a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer" or "a specific ordering of activities across time and place, with a beginning and an end with clearly defined inputs and outputs". Further, Sharp and McDermott (2009) have adapted the terms process and business process and define business process "as the chain of activities that establish a 1:1 relationship from the earliest triggering event through to the final result". Henceforth, from various definitions the ultimate goal from a process or business process is to achieve a desired output or result that creates value to the customers (internal or external), based on the input obtained and processed in a systematic approach and activities in a sequenced workflow.

Hammer and Stanton (1999) state that many organizations have transformed from process redesign to process management and also their focus of measurement system is process performance which has changed from measuring unit goals to process goals. With these changes in organizations they have emerged as real process organizations and have harvested more benefits as a result. (Hammer and Stanton 1999: 109). Organizations are getting transformed to process-based approach and it is practiced in their business. By focusing on redesigning their processes (internal and external) and measuring their process, organizations from every industry sector and of all sizes have accomplished cost improvements, quality, speed, profitability. (Hammer 2007:111).

Process is an integral part of any business, and according to Martinsuo and Blomqvist (2010), "Processes are customer value adding chains of activities that utilize resources". Here 'customer' refers to internal of external, known or unknown and 'value adding' refers to the value realized by the process as part of output results, and 'chain of activities' refers to a simple or complex value adding operations with interrelated activities. The

objectives of the process and resources utilized in the process are linked with the organization's structure, while the role of processes can vary per the methods used in the organizations. Feedback is an essential element of process management which is depicted as a simplified view of the process in Figure 14 below. (Martinsuo and Blomqvist 2010).

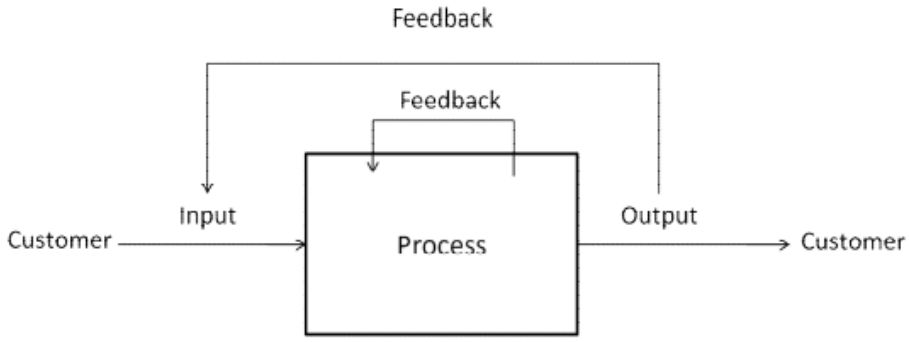


Figure 14. Simplified view of process with feedback. (Source: Martinsuo and Blomqvist 2010:8).

According to Bititci et al. (2011), an organization may look at everything as a process, and process has attracted wide interest in organizations that has deep impact on business growth and survival. It is also argued that the key driver for organizational flexibility, agility and sustainability is based on how the organizations set up and manage their business process, to maintain or improve their performance over time. Organizations with experienced mature business processes enables continuous improvement, scanning, monitoring, control and evolution capability. A series of cross-functional tasks that are inter linked with workflows to obtain or achieve a purpose/outcome is called a business process, which is classified as operational process, support process and managerial process.

Basic steps for any kind of process development is illustrated in Figure 15 below, which begins with identifying and defining or specifying the scope of the project for development for process, and then to analyze the existing process to collect all the available and reliable data using appropriated data collection techniques. The current process must be evaluated to understand whether it could achieve the desired output. Further, after current state analysis, the next step is to identify the process development areas, model the process, perform pilot test, obtain feedback and improve the process. Once finalized, the following step is to replace the old process and launch the developed process and then implement the process and monitor. It is important to ensure the objective of the process

development is achieved and it is still valid. Necessary training must be provided to the stakeholders who are influenced with this change. (Martinsuo and Blomqvist 2010:8).

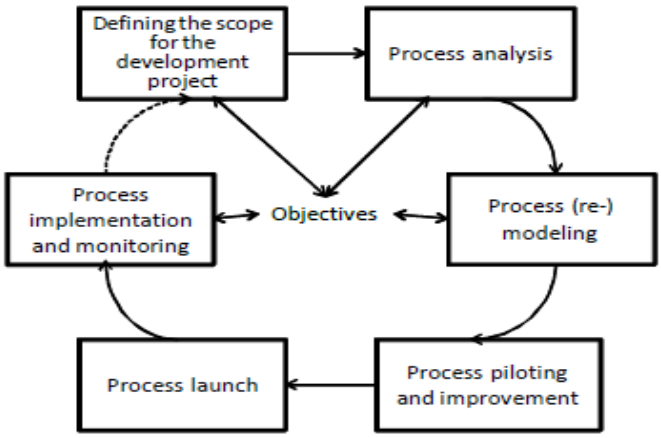


Figure 15. Basic steps in process development. (Source: Martinsuo and Blomqvist 2010:8).

Andersen (2007) explains that business process classification has numerous ways, but most leading companies which are process oriented classifies their processes while other organizations classify them at a general level. At a generic level, the business process can be divided as primary process and secondary process, where primary processes are the core process that creates value and secondary processes are activities needed to support the main process that does not create value directly. (Andersen 2007:35). As adopted by Sharp and McDermott (2009), a set of steps is called a process, where 'enablers' are the determinant who influences the process performance. Enablers obstruct the process (can be termed as change resistance) and it is important to find them, so that they can be adjusted suitably. Figure 16 shows the process enabler framework provided by Sharp and McDermott (2009), is supported by six enablers.

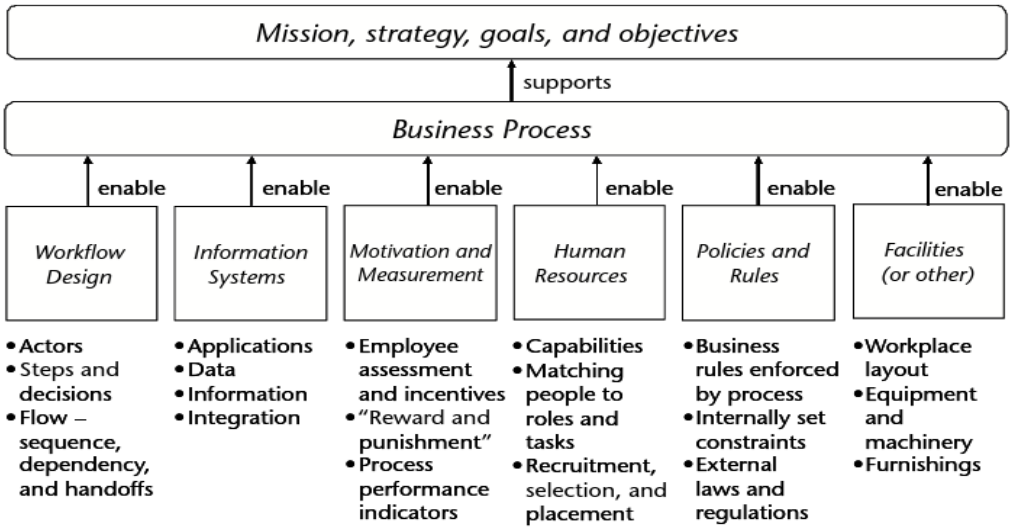


Figure 16. Process enabler framework – supported by six enablers. (Source: Sharp and McDermott 2009: 69).

In process redesign, accordance with Figure 16 above, enablers influence the process, and enablers determine how the process works. Process performance can be adjusted by enablers. As seen in Figure 16, enablers (workflow design, information systems, motivation and measurement, human resources, policies and rules and facilities) in a business process can be adjusted to deliver the desired outcome from the process, which indeed supports the performance targets (mission, strategy, goals and objectives). To redesign a process successfully, all the enablers must be adjusted and mapped accordingly to support one another to achieve the goal of the project. (Sharp and McDermott 2009: 69-70).

Hammer (2007) anticipates organizations must guarantee the processes they are following eventually to be more mature by having process enablers related to individual processes and enterprise capabilities implemented to entire organizations. Process enablers consist of Design (how to execute a process), Performers (who execute the process), Owner (senior executive who holds responsibility for process and results), Infrastructure (IT systems to support the process), and Metrics (to measure and tract the process performance). Enterprise capabilities consist of Leadership (senior executive to support the creation of processes), Culture (customer focus, teamwork, personal responsibility, desire to change), Expertise (skills and methodology for process redesign), and Governance (procedures for managing intricate projects and change initiatives/management). (Hammer 2007: 113).

As indicated by Liu and Wen (2013), there are various maturity models such as Business process maturity model (BPMM), Capability maturity model integration (CMMI), Software capability maturity model (SW-CMM) addressing various needs. In order to assess the maturity of the process and the enterprise, Michael Hammer developed Process and Enterprise Maturity Model called as 'PEMM' which has two dimensions, displayed in Figure 17 below.

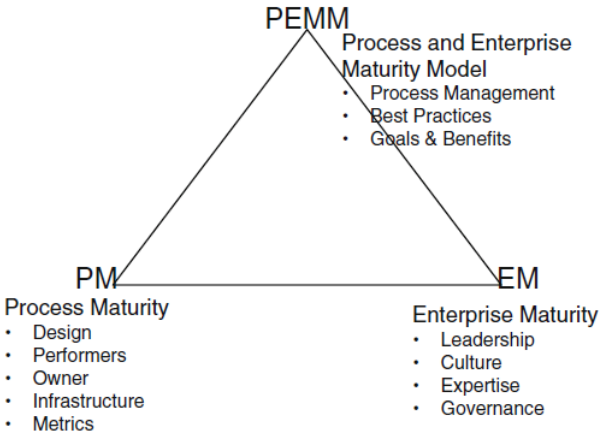


Figure 17. Michael Hammer's PEMM. (Source: Liu and Wen 2013).

As indicated by Power (2007), Michael Hammer's PEMM is simple and straightforward while comparing it with other maturity models. According to Power (2007) PEMM has several weaknesses. The framework lacks connection between the maturity levels and business outcomes, strategic alignment is not included in enterprise model, IT as an enterprise capability is not included in enterprise model and the level architecture in PEMM suggests a stage-gate approach. (Power 2007: 3). It is not important which tool is important but placing the tool in action is important. However, PEMM has some potential weaknesses which are relatively easy to overcome by customizing to meet the unique needs. (Power 2007).

O'Connor (1994) indicates that to improve the development of new products, organizations have devised phased-review workflow processes that cut across the organizations function termed as 'Stage-Gate', which can reduce development cycle time, cost reduction, produce successful products and encourages horizontal and vertical communication in the organization. (O'Connor 1994). According to Edgett (2015), the stage-gate model is a proven process approach that creates value and transforms ideas to successful new products, and when put in use it creates a culture of product innovation excellence and realizes product leadership, high performance teams, customer and market

focus, robust solutions, accountability, alignment, discipline speed and quality. A stage-gate process model is exhibited in Figure 18 below.

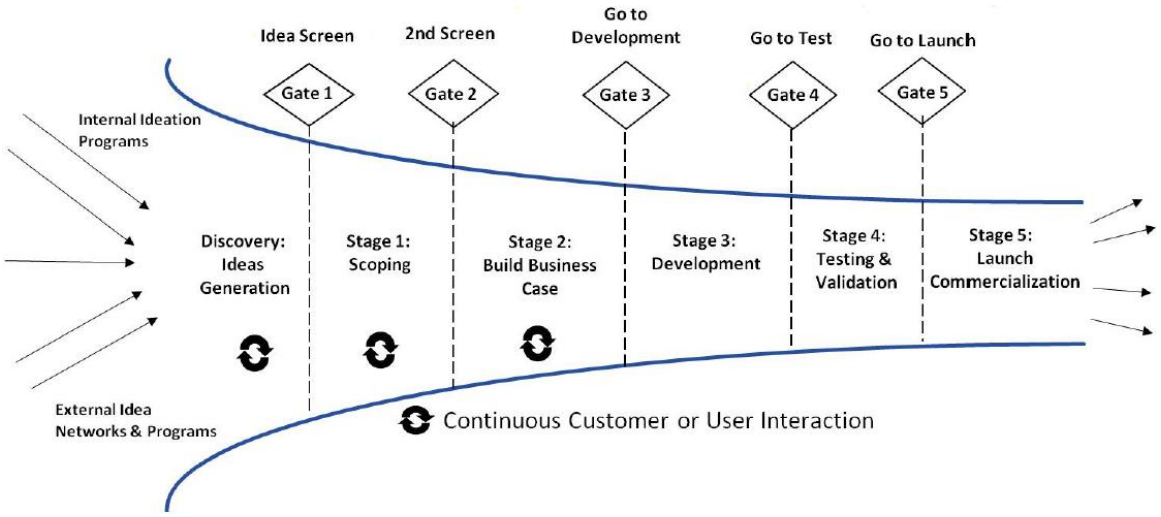
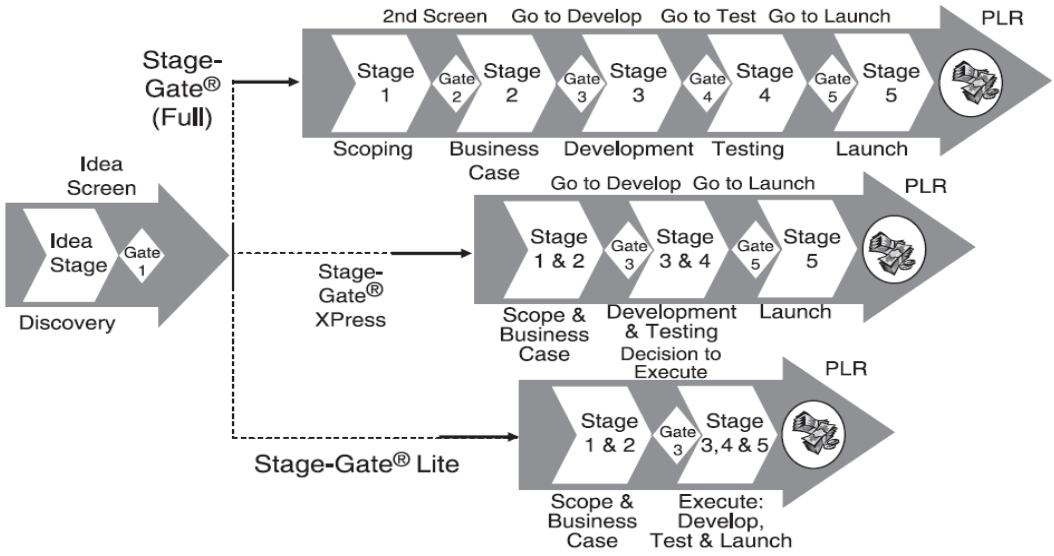


Figure 18. A Typical Stage-Gate Process. (Source: Edgett 2015).

Figure 18 above exhibits a generic stage-gate process which consist of five stages and five gates, a gate in beginning of each stage where it starts from ideas or a need and ends with a product launch successfully. The project starts with an idea termed as Discovery and the subsequent sequential stages are Scoping, build Business case, Development, Testing and Validation and Launch/Commercialization. Activities in each stage are defined and the project leader drives the project through each stage, where information required for the next stage or decision point is collected. The activities defined within the stage can be parallel and cross-functional. The project passes thorough each gate where a decision is made by Gatekeeper and the decision is termed as Go/Kill decision and these gates serve as checkpoints. Each gate has a specified function and gate 3 is the toughest decision that makes a choice whether to continue with the development further. Decision makers are called gatekeepers. Deliverables are measured at the gate as defined and it is the basis for decision criteria, and accordingly the gatekeeper takes the decision, and typically it is the project leader. (Edgett 2015: 4). The positive feature of the stage-gate process is its lean gates and the benefits of using this stage-gate model are because it is well documented (Copper 2008).

Conforto and Amaral (2016) acknowledges the implementation of the stage-gate model in a technology driven projects combining with agile project management was positive and successful. Over the past few years the stage-gate model has been enhanced to

become a scalable process that can be scaled to fit different types of projects and also can handle very risky level of projects. In order to handle various sizes of projects the process has transformed into multiple versions to accommodate business needs and accelerate projects. Figure 19 below, exhibits the next generation of the stage-gate model. The Stage-Gate Xpress is for moderate risk projects (such as improvement, modification and extensions) and Stage-Gate Lite for very small projects. This next generation Stage-Gate system has flexible, adaptable and scalable, efficient, lean and rapid system, with more effective governance, portfolio management integration, incorporated accountability and continuous improvement. (Copper 2008: 213-232).



Major new product projects go through the full five-stage process (top)
Moderate risk projects, including extensions, modification & improvements, use the XPress version (middle)
Sales-force & Marketing requests (very minor changes) use the Lite process (bottom)

Figure 19. Next Generation Stage-Gate is Scalable to Suit Different Projects. (Source: Copper 2008: 223).

Smart et al. (2008) state that all organizations consider process as a generic factor and also as a strategic asset and the need to adapt a business process orientation. A process strategy establishes a connection between strategic intent and the management's action to set up the process infrastructure. To run and control business process management is essential to improve individual processes. (Smart et al. 2008: 494-495). According to Davenport (2005), organizations are looking to standardizing process that enables to ease the communication of business operations, enables smooth exchange between the teams across the process boundaries to achieve relative performance measurement. Set of standards is needed for organizations to, establishing process activity and flow

standards, process performance standards and process management standards, that could transform the business performance. (Davenport 2005).

According to Maddern et al. (2014), researchers have urged to manage a process in a horizontal aspect preferably, rather than vertical perspective with a customer focused view. It is meaningful and challenging to manage a process from end to end, as processes are hierarchical in nature and interdependent. An industry practitioner community has reported that an end-to-end process is focused widely, where the output of one process is input to the another. Each business process may have subprocesses, activities and tasks. Organizations explore to opt for end-to-end process management as a channel for improving performance. (Maddern et al. 2014).

Grover and Malhotra (1997) state that a process will comprise a customer representing either an internal or external organization. Having an efficient process with the help of process owners by providing authority to focusing on customer needs brings efficiency, customer satisfaction, reduces waste, optimizes chaos and upsurges responsibilities, and performance of the whole process. Figure 20 below exhibits that reengineering a process flow horizontally in a vertical organization is achievable by giving priority to process, process owners, cross-functional teams and place less emphasis to a vertical organization. (Grover and Malhotra 1997: 200).

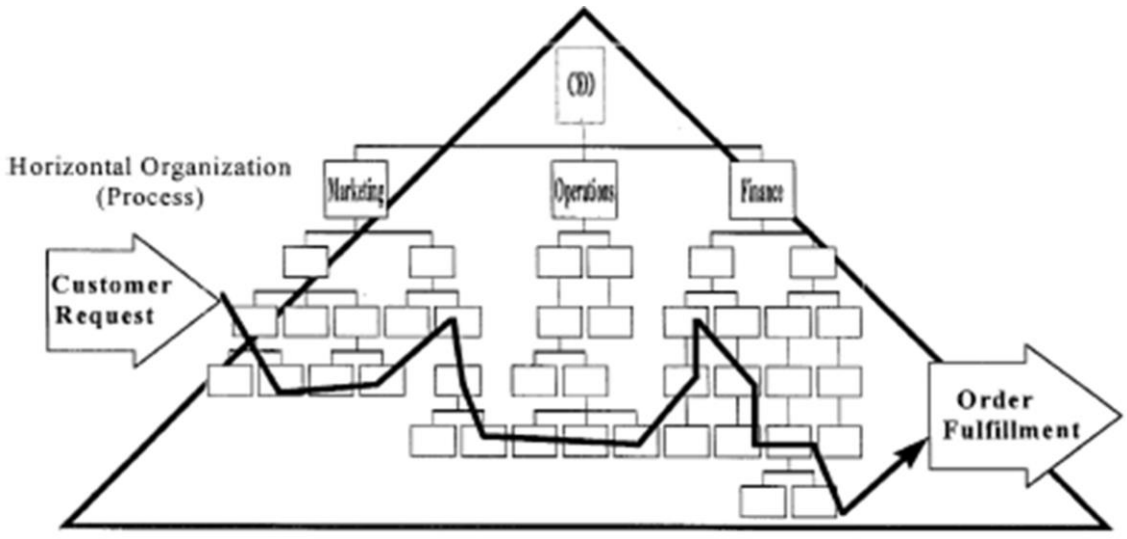


Figure 20. Process flow in an organization. (Source: Grover and Malhotra 1997: 200).

According to Hammer and Stanton (1999), the presence of a process owner in an organization establishes a difference between a process enterprise and conventional organization. It is highlighted that process owners demonstrate the active representation of the organization's commitment to its processes. An essential need for process owners and to have process ownership is to design a process and guide progress as the business environment changes. To accomplish a good outcome, the process owner should have real responsibility and authority for process designing, performance measurement and training employees, while they still follow the organization defined reporting structure. The vital skill needed for a process owner is to influence and closely collaborate with one another because processes tends to overlap, and the same employees are involved within the organization. (Hammer and Stanton 1999: 113). Organizations have ascended from process redesign to process management by appointing process owners with targets and authority. Process performance is measured and has changed the way it functions among the employees to give priority as a whole process. A true process enterprise has realized its benefits as a result of well-integrated management structures with their core processes. (Hammer and Stanton 1999: 109).

As imparted by Rohleder and Silver (1997), process improvement and process innovation are prevalent in organizations and are vital constituents of business which contributes significant financial benefits. Figure 21 below furnishes a process improvement framework suggested by Rohleder and Silver (1997) that could be used as a guideline and must be tailored to meet the needs of the process, whereas creativity is a vital element of process improvement. Process improvement and reengineering are extensively driven across business globally and are the key components for business strategy while it progressively desires a structured approach which involves process measurement and modelling. (Rohleder and Silver 1997: 140-142).

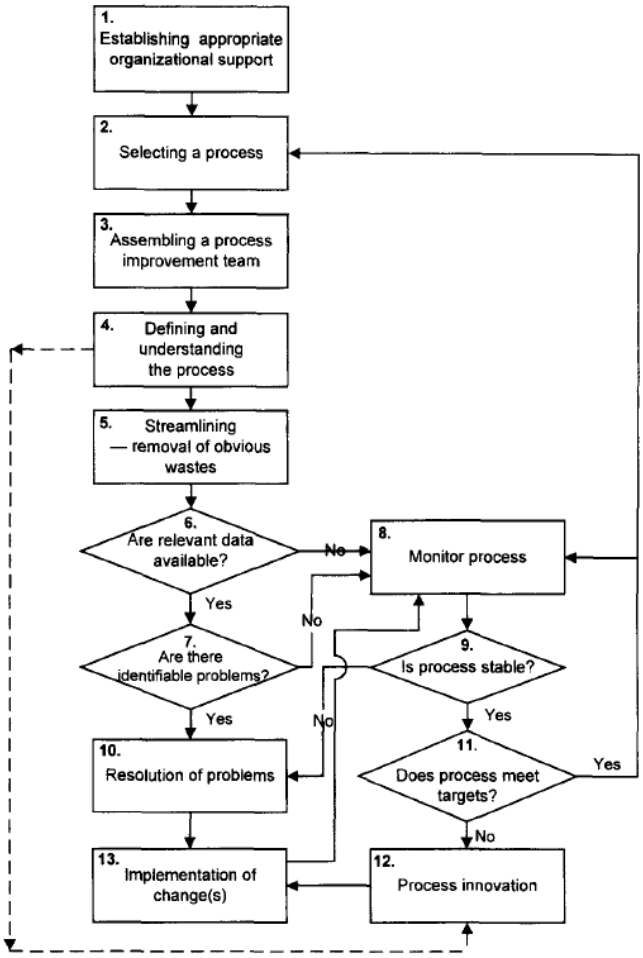


Figure 21. The process improvement framework. (Source: Rohleder and Silver 1997: 141).

As mentioned by Jacka and Keller (2009), Process Mapping is not just making a map, rather it is representing the whole flow of process and activities (whole system) that results in a successful project or achieving the actual task. Martinsuo and Blomqvist (2010) highlight that it is essential to identify processes from the core business practices and its operation environment, by determining the key stakeholder on the value chain and defining the value adding activities for the process. Mapping the process involves linking the information and material flows for the value adding activities from start to end and with a detailed level information of resources and their assigned task. For a process to be followed uniformly across, a detailed description of each activity in the process is required for all parties to be consistent. While there are various ways to have a detailed process description and the most common methods are flow chart, process flow diagram, task matrix and textual instruction. Martinsuo and Blomqvist (2010). Process maps is a simple graphical representation of the processes depicting the information flow and the interdependencies between the processes and activities which clarifies the scope of the

project or process and its expected outcome in the form of a workflow. Typically, business process architecture depicts the business process and its flow across the cross-functional units in the organization to achieve the goal. Process workflow models is to sequence, show or tag the actors and depict the flow of work and information while it flows along the process. There are several ways to draw a business process and one among them is the swim lane diagram format. (Sharp and McDermott 2009: 94-96,201-203). Good practices suggested by Martinsuo and Blomqvist (2010) for process modeling are many. According to them, the process must be clear and logical, describing the process should be consistent and done in a straightforward manner, upon completing the process detailing everyone adheres the process and process should be managed to accomplish its objective. A process can be continuously improved by monitoring, measuring and obtaining feedback. (Martinsuo and Blomqvist 2010:19-20).

According to Sharp and McDermott (2009), showing the flow of work is the main purpose of workflow modeling, where every responsible actor (here refers to participants) is mapped throughout the process flow. The basic components are actors, steps and flow. Swimlane diagram in workflow modeling shows what is done, who does it and in what sequence. Sharp and McDermott (2009) highlight and point out that swimlane diagrams are very popular, simple and easy to understand and can be utilized to show the entire end-to-end process. It is also highlighted that not everyone understands the complete business process easily, but a well-designed swimlane diagram ensures easy understanding of the business process and it depicts what really happens. (Sharp and McDermott 2009: 210-203).

Process improvement or development is a substantial management concept for organizations to succeed, but it depends on how it is put in action, acknowledged and standardized. Process management helps to channel information, redesign process, which includes planning, structuring and evaluating the process. (Grover and Malhotra 1997). Continually improving products and processes and developing new ones to increase the productivity of a firm is the objective of the innovation archetype externally. In manufacturing strategy, a strategic choice must be consistent between all the choices both internally and externally boils downs to the choice of process, equipment, product design, organization or management. (Kuula et al. 2012: 108). Process standardization provides abundant benefits such as reducing overhead cost, common process and practices across reduces business dealing/transaction cost, increases organizational flexibility. It

is important for organizations to standardize their processes to the possible extent without meddling to meet the customer's needs. (Hammer and Stanton 1999: 113-114).

To abridge, this section provided insights from the literature study on process definition, key process and sub processes, process development, process workflow and maturity model, process management and process strategy, process standardization and process improvement. The following section explores the practices to define roles, responsibilities and information flows.

4.3 Defining Role, Responsibilities and Information flows

Defining clear roles and responsibilities is essential and it has a positive impact on improved process management, operational performance and business growth. Lack of clarity on roles, responsibilities and information flow is an integral issue that disrupts the process. Typically, in organizations enablers or actors involved in a process tend to have various hats in their job description outside the process environment, that may lead to confusion and delay in progress and expected result or outcome.

According to Sharp et al. (1999) stakeholder has a broader definition adapted by various researchers based on their intended context. However, Sharp et al. (1999) cites and define stakeholders as "a group or individual who can affect or is affected by the achievement of the organization's objective". Identifying a stakeholder is not so clearly defined and can be vague, while charting a stakeholder and individual or groups varies based on the context and is not one to one. Stakeholders are connected to each other and they interact with each other to exchange information, products, instruction or by providing support tasks. (Sharp et al. 1999). Collectively from various authors cited by Sharp et al. (1999), stakeholder includes engineers responsible for development and maintenance, end-users, managers, others involved in a process who influence the system, customers, domain experts etc., and they can be internal to project team, external to project team, internal to company, external to project team and company. (Sharp et al. 1999). Henceforth, this could also be correlated within a project's business process environment.

Kofman et al. (2009) put forth that expectations clutched by individuals and by others guide human behavior according to role theory. In general, a functional role or functionalist approach is correlated with a set of skills and behaviors expected from an individual

accomplishing the role and in interactionist approach is developed and discussed based on the person fulfilling the role and interaction with others. Also, Kofman et al. (2009) point out that in organizations there is often a discrepancy in role understanding and role expectation as they are influenced by assumptions that are wrong and information that is inaccurate. Henceforth, individuals in a business process and in an organization are confused or if the roles are not specified clearly with the requirement he/she is likely not to meet the expectations which affects team performance, decisions, communication and morale. (Kofman et al. 2009: 10).

Business process established in accord within an organization obligate to manage the responsibilities of the process participants for all the activities they are involved. The activities may include frequent collaboration with various stakeholder who holds multiple responsibilities, accountability and consultation in process-oriented organizations (Cabanillas et al. 2018). Role holder's rights and responsibilities can be depicted in various ways that help to make decisions and one among them is the RACI matrix (Kofman et al. 2009:10). To set an expectation with stakeholders, successful completion of project and to realize the business objective, a simple RACI matrix can be used as a tool in projects (Khan and Quraishi 2014). McGrath and Whitty (2017) argue that accountability and responsibility concepts are generally confused, and it impacts projects and general management. Henceforth, when defining roles and responsibilities across organization and within a project, it is important to have clarity about accountability and responsibility. (McGrath and Whitty 2017).

Responsibility assignment matrix (RAM) is a responsibility modeling mechanism that contributes to plan, organize and coordinate work and activities. RAM can be also called as RACI or RASCI matrix that helps in distribution of work in business process management to organizations to model their business process. (Cabanillas et al. 2018). RACI or RASCI matrices are used to furnish information detailing, who must do what for each activity, who must be informed when activity is done, and which helps organizations to manage the responsibility assignment of role holders with respect to activities carried out. Execution flow of the activities is called as business process and, activities are the meeting point between the RACI matrices and business process. (Cabanillas et al. 2011). According to Jacka and Keller (2009: 256), segregating and eliminating misunderstanding of responsibility issues within a process or a department can be achieved by RACI Matrix which visualizes individual's role within the process by identifying who is

Responsible, Accountable, Consulted and Informed. Table 5 below, describes the definition and description of RACI and RASCI methods where R denotes 'Responsible', A denotes 'Accountable', S denotes 'Support', C denotes 'Consult' and I denotes 'Inform'.

Table 5. Role and Responsibility Charting Definitions (adapted from Smith et al. 2005; Jacka and Keller 2009; Cabanillas et al. 2018).

Method	ROLES AND RESPONSIBILITIES CHARTING DEFINITIONS	Method
R (Responsible)	The "doer" is the individual(s) who actually complete the task or works on the activity. The "doer" Is responsible for action/implementation. There is typically only one person responsible for an activity and also Responsibility can be shared	**R** (Responsible)
A (Accountable)	The accountable person is the individual who is ultimately answerable for the activity or decision. There should be only one Accountable for each activity. (or) person who must approve the work performed by the person responsible for an activity	**A** (Accountable)
	Person who may assist in completing an activity by actively contributing in its execution. there may be several people assigned to this responsibility for an activity instance.	**S** (Support)
C (Consult)	The consult role is individual(s) (typically subject matter experts) to be consulted prior to a final decision or action or moving forward with the process. More than one person can be consulted. (or) Person whose opinion is sought while performing the work, and with whom there is two-way communication	**C** (Consult)
I (Inform)	This is individual (s) who needs to be informed after a decision or action is taken and is part of the process. (or) Person who is kept up-to-date about the progress of an activity and/or the results of the work, and with whom there is just one-way communication	**I** (Inform)

Responsibility charting is a systematic approach to formulate relationships related to functional roles, actions, decisions, participation and communication which leads to RACI Matrix (RASCI Matrix) that depicts a clear individual responsibility in relation to the process identified. (Smith et al. 2005; Jacka and Keller 2009). Responsibility charting is

generally used in work process or within department or in a project to improve or define the understanding of roles and responsibilities (Smith et al. 2005). A RACI matrix is a grid that typically has activities or task on the left and functional roles on the top, where activities are the key steps in the process and functional roles are the duty to perform action or task (Jacka and Keller 2009: 257). Table 6 below exhibits an example RACI Matrix.

Table 6. Example RACI Matrix (adapted from Smith et al. 2005; Jacka and Keller 2009 and merged).

	Process Name	Roles of Participants					
		Mother	***Father***	***John***	***Sally***	***Mark***	***Kids***
Activities or Decision	Feed the dog	A	C	R			
	Play with dog	I	I	A			R
	Take dog to vet	R	A/R				C
	Morning walk	C		A/R	R		
	Evening walk	C		A/R		R	
	Wash dog	C		A/R			
	Clean up mess	C	A	R			

Vertical Analysis

Horizontal Analysis

To identify the issues in the RACI Matrix, vertical and horizontal analysis can be performed within the RACI Matrix by reviewing the Responsible and Accountable roles (Refer to Table 6 above). Vertical analysis is performed to examine the role and responsibilities of an individual/particular participant on the RACI Matrix against all the activities to ensure the participant has the right level of involvement. Horizontal analysis is performed for each activity to ensure proper roles and responsibility has been assigned to the participants. (Jacka and Keller 2009: 255-261).

Effective communication is necessary where many people are involved in the process. As people in the team are increasing and are across the geography using knowledge work to perform the activity is highlighted by Staats and Upton (2011). Also, further Staats and Upton (2011), expresses a good communication can be carried out by defining who should be communicated, how frequently and what, creating a shared understanding and resolving disagreements based on facts but not on opinions. According to Williams et al. (2017), effective communication and communication protocols varies

based on project specifics and business demands. To have a good plan for communication it should consist of three key elements - establishing roles and responsibilities, knowledge sharing among team members and stakeholders, and efficient response to emergency circumstance. In a project, communication determining who and what form of communication to be performed needs to be identified, and it can be performed and tackled by means of a RACI Matrix. To share knowledge among a team and stakeholders, establishing and having a common storage place with guidelines and managing logs that meet the legal and business requirements is important as per organization and based on the purpose. In order to avoid any crisis in a project and to have attention and response, having an escalation protocol helps team members or project to pursue more expertise or an alternative contact person to response. (Williams et al. 2017). Henceforth, a RACI Matrix could be used as a common tool to tackle and for effective communication.

Antonucci and Goeke (2011) argues, the persistent challenge in identifying appropriate responsibilities and business process environment is essential in the interest of business process management initiatives to be successful. Business process management needs consideration of firm specific business process knowledge and IT organizations' perspective to plan and manage the business process end-to-end be adopting a set of practices and procedures to develop a framework. As cited by Antonucci and Goeke (2011: 128), business process management was derived from technology-oriented concept to a management practice and now it is a common practice in process and customer centric organizations, where the objective of operational and strategic activities involves harmonizing people, management, process, technology and business practice. Also, IT roles are becoming business and process focused and moreover automated business process is driven by IT as its foundation. Thus, claim that performing business process management activities successfully in an organization requires strong IT competence in business process management and company specific business knowledge. (Antonucci and Goeke 2011). Cabanillas et al. (2018) also argue that the work can be done at the right time and by the right person by having an automated business process to coordinate the business process management.

According to Cabanillas et al. (2011), the RACI Matrix approach is a method that can be also used to serve as reference to responsibility assignment but not limiting to the activities to be executed. And also, RACI Matrix can be used to refer the approval of the work/job executed and also for communication among the defined roles according to the

scope defined in the responsibility chart or called the RACI Matrix, while keeping the business process environment into consideration in the organization.

To abridge, this section provided insights from the literature study on role theory, role and responsibility, responsibility assignment, RACI/RASCI Matrix, Responsibility charting, effective communication and automated business process using RACI. The following section describes the conceptual framework based on the literature study.

4.4 Conceptual Framework

This sub-section summarizes the key elements emphasizing best practices from the literature described in Section 4 and consolidates the significant elements into the conceptual framework for developing a component qualification process framework. This framework will be subsequently utilized in Section 5 for practically developing the component qualification process framework. Figure 22 visualizes the conceptual framework for this thesis summing up the main aspects required for developing a process framework for the case company.

As outlined in Figure 22, the conceptual framework consists of three parts for process development. The core part of the conceptual framework is *defining/designing business process*, which is fortified by *component qualification approached/processes* and *defining role, responsibilities and information flows*. These three parts are blended together to a develop a process framework.

The first part is component qualification approaches portrayed in Figure 22 focuses on four elements. Component selection and component qualification is a critical process that determines the right component is selected, right technology is opted and from the right supplier to meet the specification of the application. Component reliability testing is a qualification process that needs to be performed to validate the function of the component to meet the design requirement and functions as per the life of the product. Further during the qualification process, physics-of-failure is an important criterion to understand the failure environment, failure mode and failure mechanism that enables to understand the reliability of the component. Test strategy helps in determining what kind of component qualification test needs to be performed in order to qualify the component for production use in products.

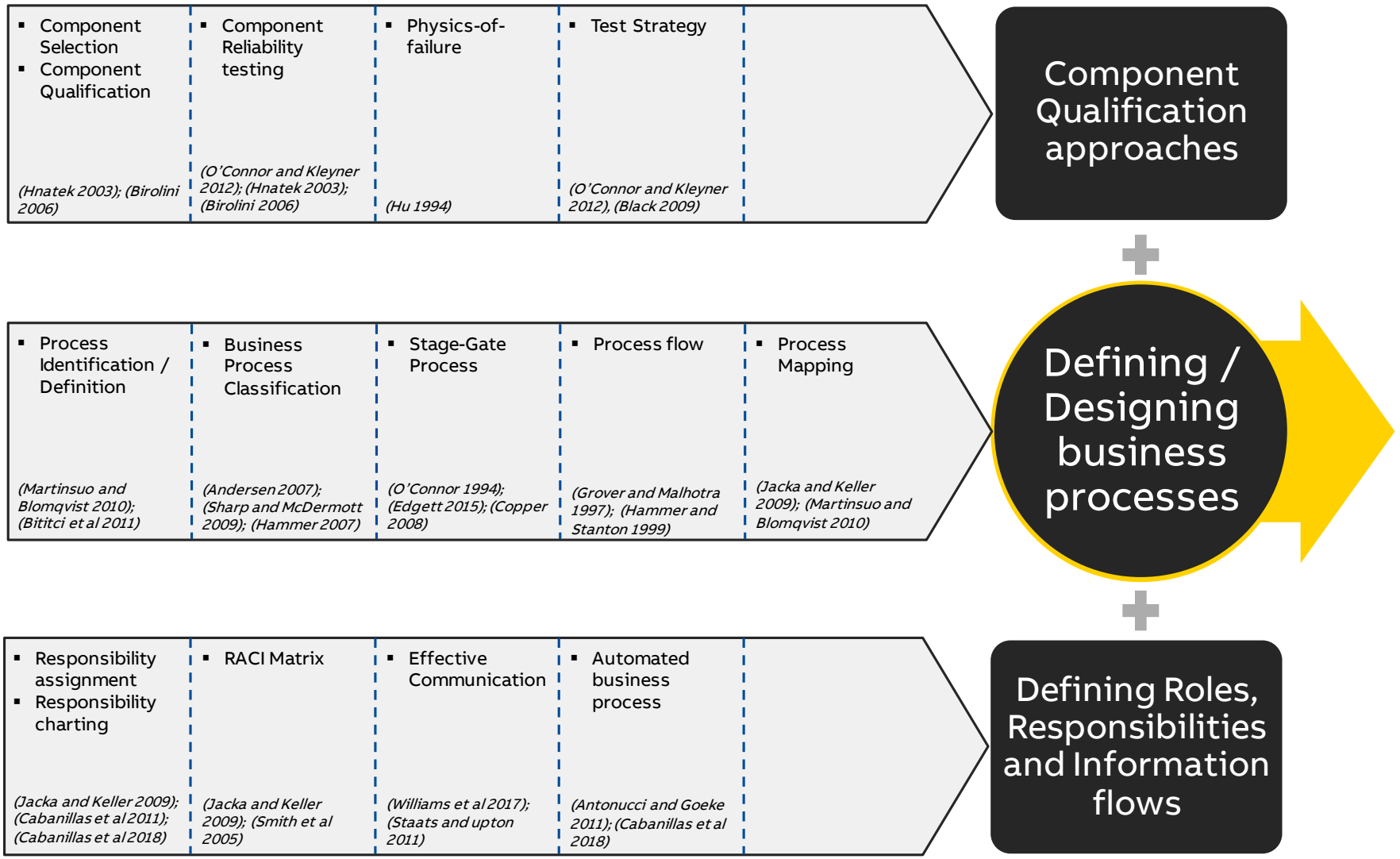


Figure 22. Conceptual Framework of this thesis.

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The second part portrayed in the conceptual framework is defining/designing business processes which consists of five elements. Process identification in the context of business needs and its environment is a primary task, which needs evaluation and analysis to understand its maturity for process definition. Further, the business process needs to be classified and aligned to meet the business objectives, goals and strategy. Considering the business environment and the need to qualify a new component (product) in the organization that could reduce cycle time, cost and enable successful and systematic phased-review approach is needed and it could be achieved through Stage-Gate process approach, which is scalable. Typically, various actors are involved in a process and determining the process flow needs integration vertically and horizontally in an organization. To achieve the desired outcome from the process chain needs process mapping.

The third part is defining roles, responsibilities and information flows, which consist of four elements in the conceptual framework. Responsibility assignment / chartings is a modeling mechanism that helps to plan, organize and coordinate and a systematic approach to formulate relationships in the process. The RACI Matrix helps to visualize individual's role within the process to identify who is responsible, accountable, consulted and informed. Effective communication is important in a process environment or within a team where various people are involved and hence defining who, how and what must be communicated, is important in the process. Business processes are automated by focusing IT as a foundation to manage an end-to-end business process.

Based on the best practices and theoretical foundation, the study further continues to build a component qualification process framework for the case company in Section 5.

5 Developing a Component Qualification Process

This section combines the findings of the current state analysis in Section 3.6 and conceptual framework in Section 4.4 to develop a proposal for component qualification process. The first part in this section provides a brief overview of the development stage. The second part describes the developing of a draft qualification process. The third part describes developing an initial qualification process with the stakeholders that forms Data 2. Finally, this section summarizes the developed initial proposal for a component qualification process.

5.1 Overview of the Development Stage

The developing of an initial proposal for component qualification process is synthesized based on: the outcome of current state analysis (Data 1), insights and best practices obtained from appropriate literature incorporated in a conceptual framework and, suggestions and insights obtained during developing an initial qualification process with stakeholders (Data 2). The key stakeholders during data 2 collection comprise of product engineers (PE), principal engineers, PE manager and SCM managers (refer to Table 2).

Primarily, the current state analysis uncovered several weaknesses and strengths in the existing component qualification process which shaped the direction of proposal building. The current state analysis revealed that the case company's component qualification process currently in practice cannot live up to the task to obtain the desired outcome. The process is not documented well and is not practiced uniformly across various product groups in the organization. The weaknesses identified during the current state analysis were summarized and grouped into categories, and four development areas were identified (Section 3.6, Figure 7): (i) Inefficient process workflow (ii) Lack of uniform process and methodology (iii) Feeble distribution of role and responsibilities, and (iv) Inefficient collaboration and communication.

The focus on the literature for best practices was elected accordingly based on the selected development areas to create the conceptual framework. Accordingly, to address the weaknesses identified in this study (Section 3.6, Figure 7) the conceptual framework is associated with three essential elements as presented in Figure 22. Those essential

elements in conceptual framework are: (a) component qualification approaches (b) defining/designing business process (c) defining roles, responsibilities and information flows. The aim is to address the identified weaknesses by focusing on developing an initial proposal for a component qualification process by applying the insights garnered and portrayed in the conceptual framework.

The proposal building stage in this study further continued as following. First, the results for current state analysis, suggestions obtained (during data 1) and conceptual framework were synthesized and analyzed to develop a draft qualification process. Second, the draft qualification process was presented to the key stakeholders in a workshop to develop an initial qualification process. The feedback, suggestions and inputs obtained from the stakeholders were consolidated to form Data 2 in this study. Third, the summary of initial proposal for component qualification process was delivered.

5.2 Developing a Draft Component Qualification Process

To develop a draft proposal for a component qualification process, the weaknesses identified during the current state analysis and the best practices obtained from the literature were utilized and merged to produce a draft qualification process that addresses the weaknesses and meets the business need for the case company. As described in Section 3.3, electrical and electronic components are of various types and each component is unique and they differ in terms of form, fit and function (FFF). Henceforth, the proposal for the component qualification process is generic in nature that could be adapted for any type of component and the significance of the process is, it can be adapted in all product groups in the case company.

The initial proposal consists of three elements described in the following sub-sections. First, an end-to-end business process for component qualification in the form of stage-gate model and a detailed workflow for each stage is proposed in Section 5.2.1. Second, responsibility assignment in the form of RACI Matrix is proposed in Section 5.2.2. Third, a component qualification process framework is proposed by blending the business process workflow and RACI into the stage-gate model.

5.2.1 Draft Proposal - End-to-End Business Process for Component Qualification

The objective of end-to-end business process for component qualification is to ensure the component qualification process is managed efficiently, executed effectively, enhance decision making, improve the speed and enhance information flow to the right stakeholders of the process. In short, the improved business process must create value when applied to performing component qualification effectively.

In this draft proposal, the entire perspective of the end-to-end business process for component qualification was developed in context by integrating the Stage-Gate model with the component qualification process is proposed in graphical form and depicted in Figure 23 below.

The business process for component qualification was identified in association with the existing process and insights obtained from the literature and further it was fused together to improve the end-to-end business process for component qualification. In this draft proposal stage-gate model is implemented. Each stage has a defined process workflow and at each gate decision are made to approve the particular stage. The stage-gate model proposed in the business process follows a lean approach overall.

As seen in Figure 23 below, the proposed draft business workflow consists of five stages and five gates. Stage 1 is Under Review (S1), Stage 2 is Trial on Going (S2), Stage 3 is Component Approval (S3), Stage 4 is Commercial Implementation (S4) and Stage 5 is Implemented and Verified (S5).

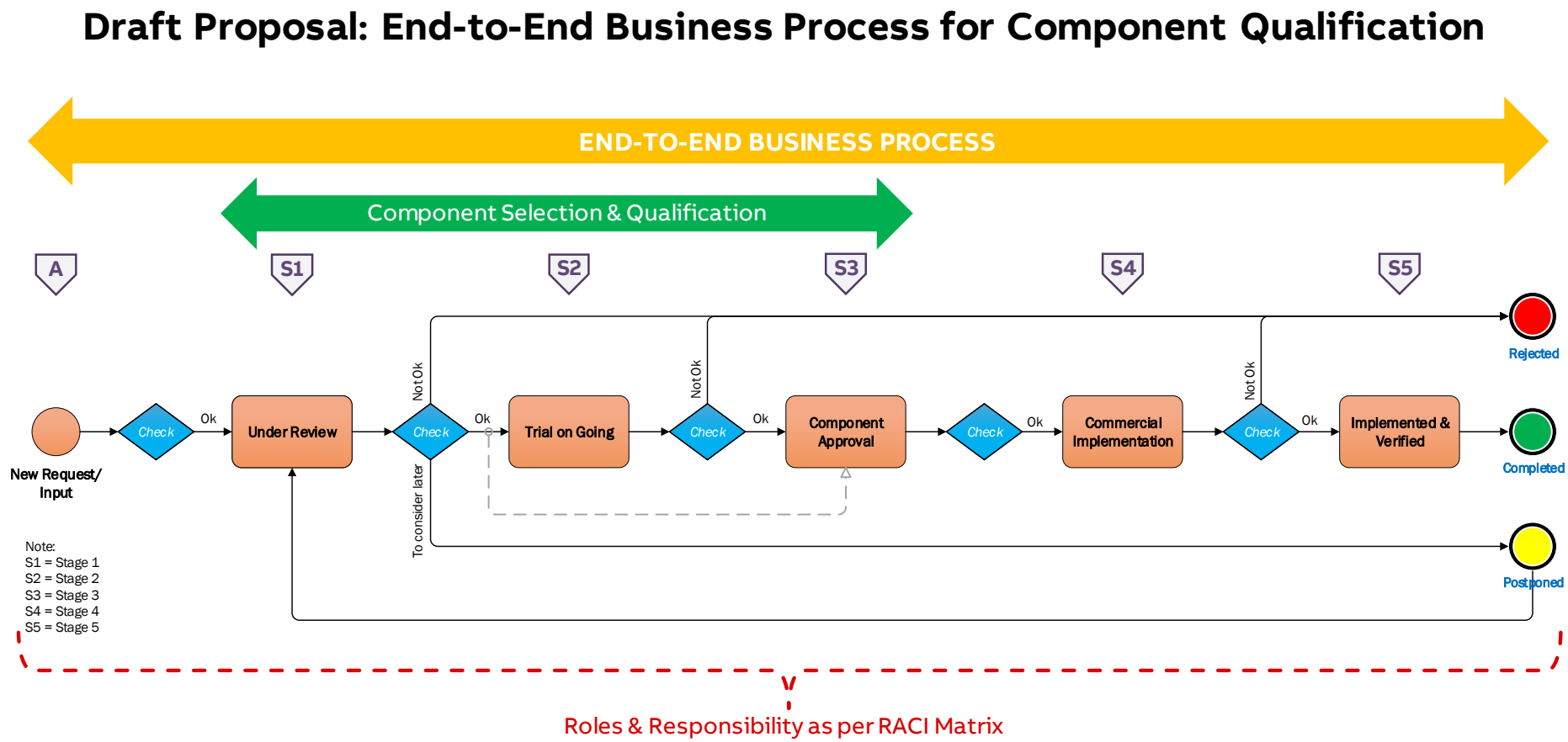

Figure 23. Draft Proposal – End-to-End Business Process for Component Qualification.

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As featured in Figure 23 above, the draft end-to-end business process for component qualification depicts the integration of the Stage-Gate model along with the business process identified to perform component qualification. The workflow consists of five stages and five gates, where the stages are exhibited in orange color boxes and the gates are marked in blue as decision points. This process could be adapted to all type of components, as this proposed end-to-end business process for component qualification is generic in nature.

The proposed workflow has an inbuilt project management technique in the form of the Stage-Gate model where the stages are divided by decision points. Prior to each stage the process must pass through a gate where a go/kill decision is made. The gate acts as a checkpoint and when a *go* decision is made at the gate the action plan for the next stage is approved, and thus the qualification process continues forward to achieve the desired outcome. If a *kill* decision is made, the process does not move forward, and the component request is flagged as rejected.

As Figure 23 depicts, component selection and component qualification is integrated in the proposed end-to-end business process which is performed during the under review stage, trial on going stage and component approval stage (from S1 to S3, refer to Figure 23). Also, with the integrated Stage-Gate model the process flow is sequential in nature and each stage has sub process or activities and they are very specific to the particular stage and the result of those sub process is taken into consideration at the gate for decision making. A draft proposal of a detailed workflow for each stage is presented in Figure 24 below.

As seen in Figure 24 below, the detailed workflow was developed by identifying all the key activities that are essential for each stage along with the practice followed in existing process which was analyzed during the current state analysis and best practices obtained from the literature study. Then further the identified key activity was rearranged to develop the workflow. Each stage has a dedicated workflow which is very specific to particular stage. The output of one stage passes through the gate where decision is made and actions for next stage is approved.

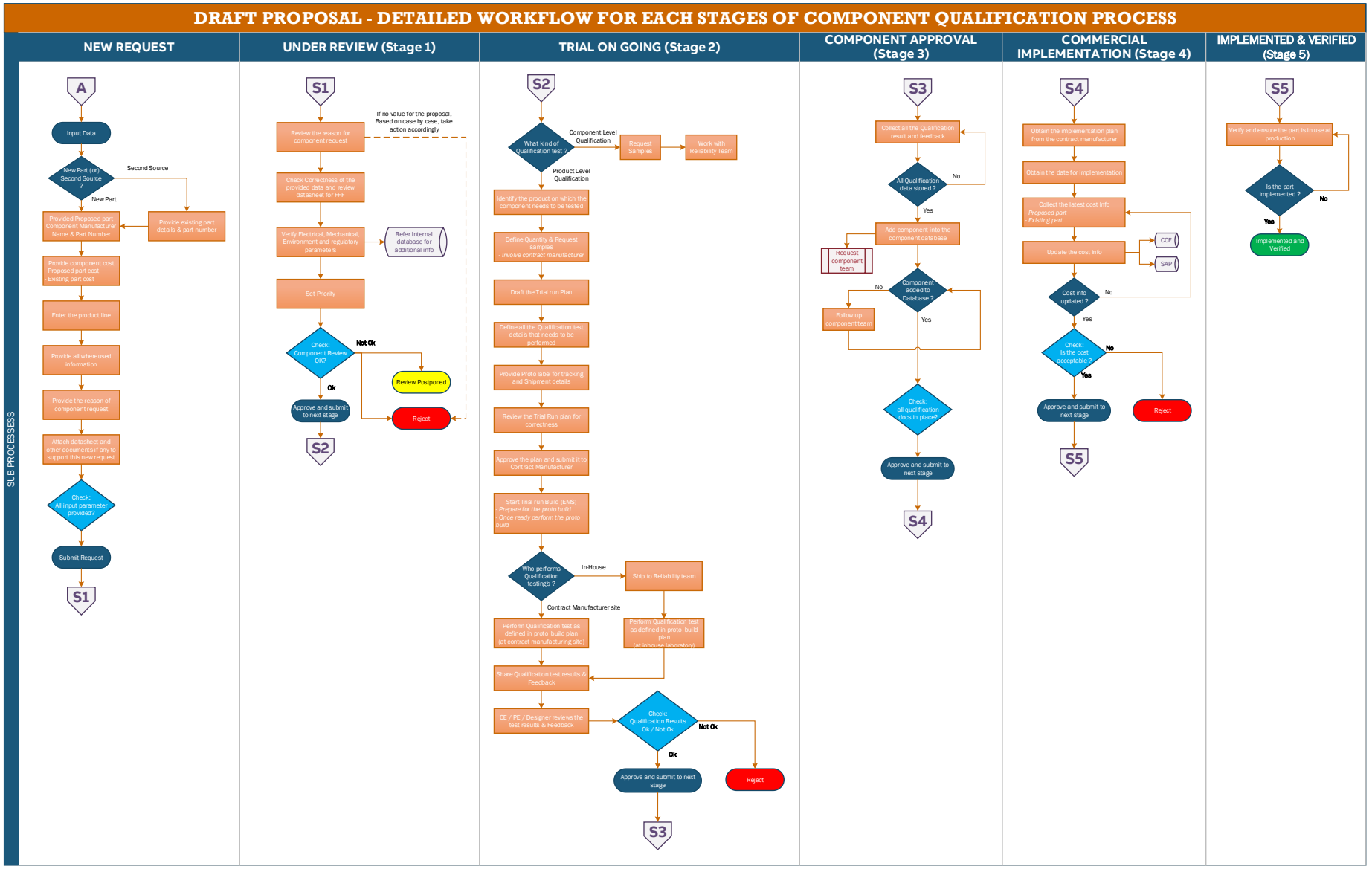

Figure 24. Draft Proposal - Detailed workflow for each stages of Component Qualification Process.

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Further in below sub-sections, the draft proposal of detailed workflow starts with input (new request) and subsequently the detailed workflow for each stage is discussed by reviewing the sub-processes identified and defined for fulfilling the needs of each stages separately.

5.2.1.1 New Request / Input

New request / input objective is to obtain all the pre-work or the prerequisites information about the component that needs component qualification to be performed. Figure 24 shows the sub-process or the activities in the form of workflow that needs to be followed during the new request, and this is the phase where input is obtained from the requestor. The whole component qualification process begins with the new request. In case company, the new request is typically submitted by external partners or internal design team or design engineers, when there arises a business need.

In order to submit the new component request for qualification, primarily the requestor has to ensure whether the request is for a new component or for an alternate component (replacement for an existing component). Accordingly, the component part number, manufacturing part number and component cost information details needs to be collected. If the request is an alternate component, then necessary case companies internal part number of the actual component and its necessary details must be collected. Subsequently, the requestor must provide the necessary where used information (in which products the component has been used), as this data helps to find out the right product owner from the product group. Along with the component specific information, the requestor is mandated to share the technical specification documents from the component supplier that will be used for reviewing, selecting and evaluating the requested component in the Under Review Stage (S1), also the requestor has to provide a valid reason for this new request that determines the priority status in the following stage.

The new request passes through a gate, which is a checkpoint where the mandated requirements are verified before the request is submitted to can be taken forward.

5.2.1.2 Under Review – Stage 1

Under review stage objective is to perform a feasibility study of the component initially to ensure the component meet the requirement and to set the priority according to the reason for request obtained from the requestor. The process workflow for Under Review stage (S1) is presented in Figure 24.

During this stage the requested component is studied to ensure the component meets the Form, Fit and Function (FFF) for the intended application. During the FFF study of the component electrical parameter, mechanical parameters, environmental parameters and regulatory requirements such as REACH, RoHS and Conflict Minerals is also reviewed to ensure the component is in compliance with regulations. If a component request is for an alternate component (i.e. replacement for an existing component), then the original component technical specification is compared against the new component request to ensure the requested part meet the FFF and could be accepted for further testing. Henceforth, once the component satisfies all the criteria of component selection, the reason for the requested component is reviewed to map the priority.

Mapping priority is an important element of this process, because priority determines its necessity to prioritize and establishes an importance. By establishing priority mapping, the request does not pile up and helps to focus on the important components. If a component does not meet the priority and could be considered later the request could be flagged as *Review Postponed*, which means the component request is possibility good to be considered for later review. If the component does not meet the selection criteria the component is flagged as *Rejected* and is not considered for any action further and the process ends.

If the component meets the selection criteria in under review stage, Further, it passes through a gate, which is a checkpoint where the fulfilment of mandated requirements is verified before the stage is approved. If the component reviewed meets the component selection process and if the stage is approved the process moves forward to Trial on Going Stage (S2).

5.2.1.3 Trial on Going – Stage 2

Trial on Going stage objective is to perform a component qualification test to verify and validate the components reliability. The qualification test can be either component level testing or product level testing. The process workflow for Trial on Going stage (S2) is presented in Figure 24.

Based on the type of component, the qualification test to be performed is determined. It can be either component level qualification or product level qualification. If the component is determined to perform a component level qualification test, component samples quantity is defined and requested from the component supplier or from contract manufacturing partners. The received samples are delivered to the reliability team to perform reliability testing at component level. The type of component level reliability testing to be performed varies based on the component and the details of possible testing is not discussed in the study as the focus in on process. Typically, the technique used in reliability testing is physics of failure. By using this technique, the components failure mechanism is analyzed to find out the failure site, failure mode and failure mechanism that helps to predict reliability and improve the products performance. Upon completion of this activity, a detailed qualification test report is generated and submitted.

To perform product level component qualification, it is essential to identify the products on which the component needs to be mounted to perform testing. Identifying the product (based on the where used information in New request stage) requires some detailed level of understanding with the right stakeholders in the case company. Further, the sample quantity is determined based on the product identified and the sample is requested from the component supplier or from contract manufacturing partners. As the testing is performed at product level, this needs a detailed plan to build the product in collaboration with the contract manufacturing partner. The draft plan to perform trail run is chalked down and followed by defining all the qualification tests to be performed. The trial run plan should have the information of the product to build, quantity to build, on what position the component to be tested should be mounted, shipping information, Proto label information, and the list of qualification test to be performed and by whom is drafted into the trial run plan. There are various types of product level testing such as Board level testing, In-circuit testing (ICT), Functional testing (FCT), High accelerated life testing (HALT), Electromagnetic interference testing (EMI), Electrostatic discharge test, Thermal cycle test etc. The type of product level reliability testing to be performed varies based

on the component and the product application. The details of testing and the type is not part of the scope in this study.

Trial run plan is reviewed for its correctness in collaboration with the contract manufacturing partners, the plan is released to contract manufacturers to start the trail run build. Upon completion of the trial run build, the contract manufacturer performs qualification test at manufacturing site (if any) as per the trial run plan and shares the results of qualification test. If there are any qualification tests that needs to be performed at case company (in-house laboratory) the built proto product is shipped according to the instruction as per the trail run plan and in-house reliability team perform the qualification tests as defined in the plan. Upon completion of this activity, a detailed qualification test report is generated and submitted by both parties, contract manufacturer and reliability team.

All the qualification test results are reviewed thoroughly as the stage at this phase passes through the gate for decision making. This is the most critical gate in the complete end-to-end component qualification process. If the test results are positive, the component qualification is approved to move forward to Component Approval Stage (S3). If the qualification test results are negative, the request is flagged a *Rejected* and the process ends.

5.2.1.4 Component Approval – Stage 3

Component Approval stage objective is to ensure all the component qualification test results are collected and stored in the repository and, the qualified component is added to the internal component database. The process workflow for component approval stage (S3) is presented in Figure 24.

In this stage, all the reports of qualification tests performed in the previous stage (Trial on Going) are collected and stored in the repository. If there are any missing reports, they are collected and stored as well. Then, the qualified component is added to the database, by sending a request to the component team. Upon completion, this stage passes through the gate, if all the test reports are in place and the component is added in the database, the gate is approved to move forward to the next stage. If it does not meet the requirement at the gate, the stage is not approved, rather the process runs into the loop in this stage until the mandated requirements are fulfilled.

5.2.1.5 Commercial Implementation – Stage 4

Commercial Implementation stage objective is to collect the latest cost information of the approved component and to obtain the plan for implementation in production. The process workflow for commercial implementation stage (S4) is presented in Figure 24.

As the products are manufactured by the contract manufacturing partners, it is necessary to collaborate with contract manufacturers to obtain the commercial implementation plan and the implementation date when the component will be used in production. At this point it is also important to obtain the cost information, as there could be possibly a change in price information as the component qualification process typically takes from a few weeks to several months. Upon receiving the cost information, it is added to the case company's database as per the internal process demands.

At this phase, the stage passed through the gate, and if the cost information obtained is acceptable, the stage is approved, and the process moves forward to Implemented and Verified (S5). If the cost information is not acceptable, the decision is no go, and the request is flagged and rejected, and the process ends.

5.2.1.6 Implemented and Verified – Stage 5

Implemented and Verified stage objective is to verify and ensure the commercially implemented qualified component is used in production on the products at the contract manufacturing sites. The process workflow for implemented and verified stage (S5) is presented in Figure 24.

This stage ensures the qualified part is used in production and the cost benefits are reflected on the commercial transactions between the case company and contract manufacturing partners. This ends the process.

5.2.2 Draft Proposal - Defining Roles, Responsibilities and information flows by adapting RACI Matrix

Based on the best practices obtained from literature study as described in Section 4.3, defining clear roles and responsibilities is essential in a business process and it provides clarity on individuals responsibility and accountability, enables to meet expectations,

aligns the project teams interest, improves process performance and enables effective communication and information flows. In this draft proposal, responsibility assignment / charting is developed in a systematic approach to formulate the relationship in the form of a RACI Matrix to exhibit who does what. Here, R stand for 'Responsible', A stand for 'Accountable', C stand for 'Consult' and I stand for 'Inform'. The draft proposal of RACI Matrix for component qualification process is presented in Figure 25 subsequently.

To chalk out the RACI matrix, first, the work process was identified, and the workflow was defined in detail by embedding the decision-making process in the form of stage-gate model as explained in Section 5.2.1. It is depicted in Figure 23 and Figure 24 accordingly. Secondly, the list of roles (stakeholders) involved in performing the tasks was identified because the component qualification process involved stakeholders from various cross functional departments in the case company. Third, a draft RACI Matrix was developed by listing the process/activities on the left side of the matrix and the top row consists of the role or the participant as depicted in Figure 25 below. During this process of responsibility assignment, first the R's were assigned, followed by A's, then C's and then I's.

Further, after the completion of responsibility assignment in the draft RACI Matrix, horizontal and vertical analysis was performed to identify if there are any issues persisting in responsibility charting. In vertical analysis, a single participant's role is looked upon across the process or activities defined or identified. During this analysis, the R's and A's are looked upon to ensure the participants involvement in the process is justifiable, i.e. either the participant has less or too much involvement. In horizontal analysis, on a specific process / activity the roles of all participant are analyzed, i.e. the R's, A's, C's and I's are analyzed. During the analysis of R's, if there are no R's then who is responsible is determined, if there are too many R's then the activities are stuck and not performed as the responsibility is scattered, hence the R's needs to be determined to ensure the execution is performed as planned. If there are too many C's, then it needs to be determined if they all need to be consulted. If too many A's, then there is a problem in accountability and hence, it is preferred only one A for each activity or process. If too many I's, it must be determined how frequently and when they need to be informed.

DRAFT PROPOSAL - RACI MATRIX FOR COMPONENT QUALIFICATION PROCESS (R = RESPONSIBILITY, A= ACCOUNTABILITY, C= CONSULT, I= INFORM)						
PROCESS / ACTIVITIES	**ROLE OF PARTICIPANTS**					
	Requestor (Internal or External)	**Component Engineer/ Product Line owners**	**Product Engineer / Principal Engineer / R&D Engineer**	**Reliability Engineer**	**Contract manufacturer**	**Sourcing**
New Request						
Updating all mandatory data - Component manufacturer and part number, Cost Info, updating Product Line and whereused Info, valid Reason for Request and providing technical datasheet	R/A	C	-	-	-	C
Attaching datasheet or technical documentation	R/A	C	-	-	-	C
Under Review						
Review input data	I	R	C/A	-	-	C
Electrical Specification Review with Datasheet	I	R	C/A	-	-	C
Set Priority	I	R	C/A	-	-	C
Approving / Rejecting the review (Stage approval)	I	R/A	C	-	-	-
Trial On Going						
Defining Qualification Test requirements	I	R	C/A	-	I	-
Product Indentification for Component Testing	I	R	C/A	-	I	-
Trial run plan - Draft	I	R	C/A	-	C	-
Sample Request	I	R	C/A	-	C	C
Qualification Test details	I	R	C/A	-	I	-
Proto Label and Shipping Information	I	R	C/A	-	I	-
Finalizing Trial run plan	I	R	C/A	I	I	-
Proto Build as per plan	I	C/A	C	I	R	-
Performing Qualification Test (@EMS)	I	A	C	I	R	-
Performing Qualification Test (@ In-House)	I	C	A	R	-	-
Qualification Test Results (EMS) & Manfacturing Report	I	C/A	C	-	R	-
Qualification Test Results (In-House)	I	C/A	C	R	-	-
Qualification Test Result Review	I	R	C/A	I	-	-
Approving / Rejecting Trial on Going (Stage approval)	I	R/A	C/A	I	I	-
Component Approved						
Collecting and Storing all Qualification data	-	R/A	C	-	-	-
Adding Qualified Component to database	-	R/A	C	-	-	-
Approving the component (Stage Approval)	I	R/A	I	I	I	I
Commercial Implementation						
Plan for Commercial Implementation	I	I	-	-	C	R/A
Date for Implementation	I	I	-	-	R	A/C
Collecting latest cost info	-	-	-	-	C	R/A
Updating cost info to Database	-	-	-	-	-	R/A
Approving/Rejecting (Stage approval)	-	I	-	-	I	R/A
Implemention - Verified & Approved						
Verify the part is used in production	-	-	-	-	C	R/A
Final Approval	I	I	I	-	I	R/A

Figure 25. Draft Proposal - RACI Matrix for Component Qualification Process.

During the development of the draft proposal of the RACI matrix depicted in Figure 25 above, it has been ensured the following: only one accountable (A) participant is assigned for each activity, only one responsible (R) participant is assigned for each activity. However, based on the business practice that is existing in the case company, in few activities' participant plays multiple roles and is marked as C/A (Consult and Accountable) and R/A (Responsible and Accountable) based on the optimized organization structure in the case organization (organization of case company not discussed in this study). By assigning I (inform) for each activity, it establishes the path for information flow and further helps to achieve an effective communication between the stakeholders involved in the process of component qualification.

Therefore, the proposed draft RACI Matrix can be used to show who does what and can be correlated or cross-reference with the process workflow which was proposed in Section 5.2.1 and depicted in Figure 24. Also, the proposed draft RACI can be used for better collaboration, and to ensure the participants understands their role and other's roles too. But however, it is recommended to be revisited at regular interval to keep it updated with the responsibility assignment. And, if any changes performed in the RACI needs to be well communicated to the stakeholders/participant.

Thus, in this draft proposal of RACI Matrix it favors to identify the defined the roles, responsibilities and information flow that is required to perform the component qualification process.

5.2.3 Draft Proposal - Component Qualification Process framework by integrating business process and RACI

The objective of the draft proposal for component qualification process framework is to depict what is done, by whom and in what sequence with key activities on each stage without overwhelming with details. In this draft process framework proposal, process workflow proposal draft (depicted in Figure 23, Figure 24) and the draft RACI Matrix proposed (depicted in Figure 25) is blended together to achieve the framework. The draft proposal for the component qualification process framework is exhibited in Figure 26 below.

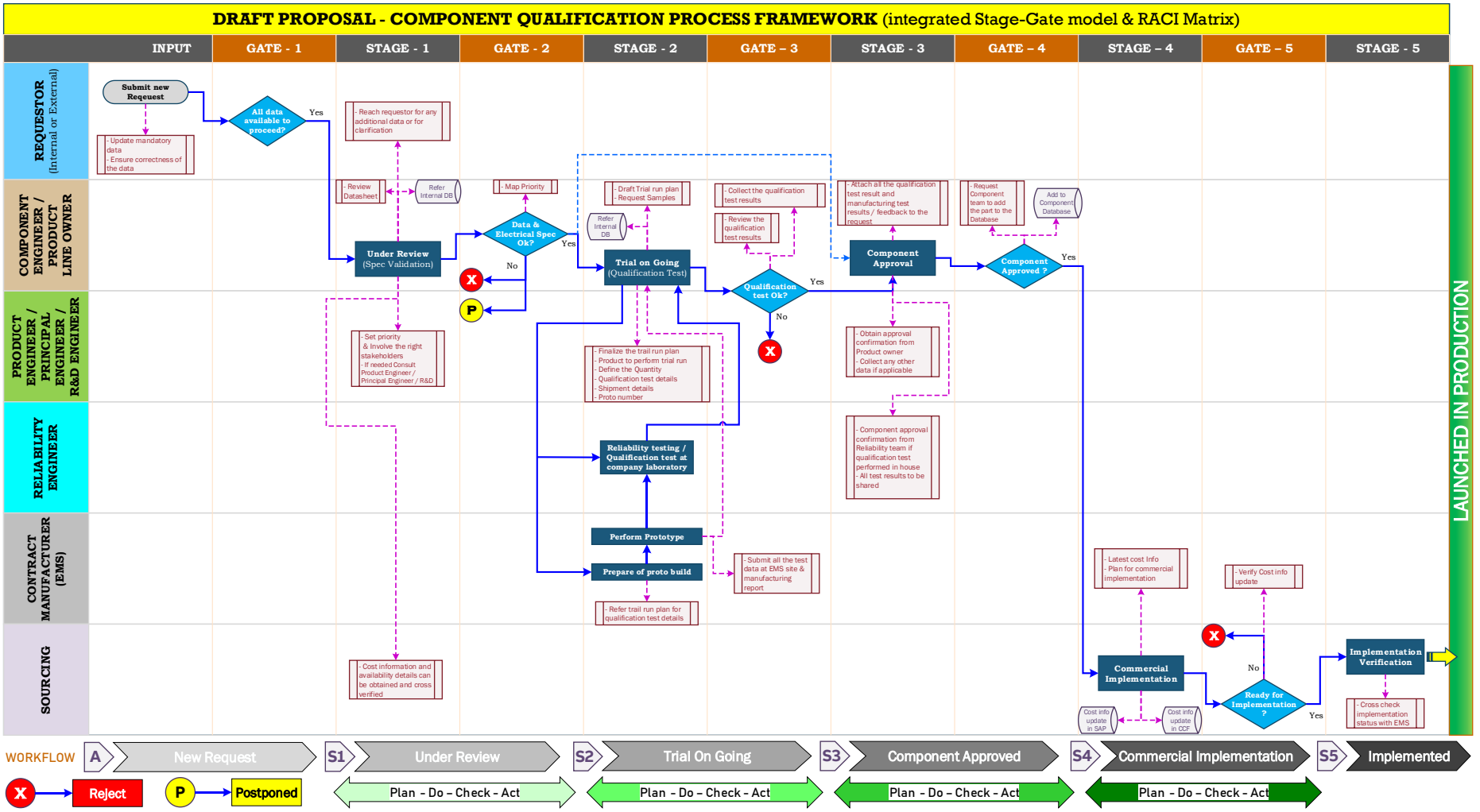

Figure 26. Draft Proposal - Component Qualification Process Framework.

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As seen in Figure 26, the swimlane diagram concept is adapted to integrate with the stage-gate model to achieve the framework. In this proposed draft component qualification process framework, it includes the participants (stakeholder) involved in the process placed left side vertically and stage-gate on the top horizontally. The stages of business process and the gates are mapped along the swimlane in accordance with the proposed draft RACI Matrix displayed in Figure 25.

As seen in Figure 26 above, the stages of business process flow horizontally in sequential manner along with the gate. The respective stage is mapped along with the respective responsible participant and the respective gate is mapped along with respective accountable participant as per the RACI Matrix proposed. In the proposed draft RACI matrix, if a stage or a gate has two responsible or accountable participants, then in the framework the rectangle box or decision box in their respective stage or gate is sandwiched between both participants (for example see gate 3 decision box in Figure 26). The sub-process or the activities for a particular stage flows vertically within the stage and the gate and is cross-functional, and this is shown at a generic level.

The developed draft process framework is scalable and generic in nature and is linked with the proposed end-to-end business process for component qualification draft as described in Section 5.2.1 (Figure 23 and Figure 24) and Proposed RACI Matrix draft in Section 5.2.2 (Figure 25). In the draft process framework proposed, the sub-process activity flows within the framework horizontally and vertically, and thus connecting cross-functional participants. Therefore, this proposed draft for a component qualification process framework is a fusion of end-to-end business process for component qualification, activities listed in detailed workflow diagram and RACI Matrix, and is generic in nature.

The study further continues to obtain stakeholder feedback, suggestions and inputs for the proposed draft process that was showcased in this section and feedback obtained is described in the following Section 5.3 below.

5.3 Stakeholder Feedback and Input to the Initial Proposal (Data 2)

The developed draft for end-to-end business process for component qualification (Figure 23), draft detailed workflow diagram (Figure 24), draft RACI matrix (Figure 25) and the draft process framework (Figure 26) for a component qualification process was presented to all the key stakeholders to obtain feedback and improvement comments in a workshop.

This section describes and presents the results of the workshop with the key stakeholders and the comments obtained from the key stakeholders establishes Data 2 of this thesis. The details of the participants for data 2 collection round is exhibited in Table 2. In the workshop, the review of developed draft proposal for component qualification process was performed in a sequential manner as the proposal is linked to one another. First, the proposed draft of end-to-end business process for component qualification was reviewed. Second, the proposed draft of detailed workflow was reviewed. Third, the proposed draft of RACI Matrix was reviewed. And finally, the proposed draft process framework was reviewed.

The stakeholders were satisfied with the draft proposal and it was acknowledged that the developed draft proposal fulfills the business need and depicts clearly the steps to be followed to perform the component qualification at process level. Overall, it was positive and favorable. However, there were a few minor improvement suggestions from the stakeholders, particularly to fine-tune and tweak the workflow and activities.

The improvement suggestions obtained from the workshop forms Data 2 in this study and those improvement suggestions are described in the following sub-sections and listed out in Appendix 3.

5.3.1 Improvement suggestion 1

In the proposed draft end-to-end business process for component qualification, the workflow diagram was missing the iterative process and subsequently it was missing in the proposed draft detailed workflow and in the proposed draft process framework.

First, at the gates when decision making takes place the process should not be killed, rather it has to be in a loop to find out the possibility of acceptance during the process

as suggested by the stakeholders. The loop was missing for new request, trail on going and component approval. Second, in the draft detailed workflow diagram, workflow was missing between the process at component level qualification, because while executing a component level qualification the process does not stops there, rather the component has to again undergo the process of product level testing based on the case handled. Third, in real life business context in the case company, when a component is in qualification test and if the results are negative, the component is not rejected immediately. The component qualification process runs into next iteration within the same stage, which is like a loop. This iterative step in the process varies based on case by case and purely depends on the type of component and the failure noticed during the event of qualification process. As stated by two stakeholders from the engineering team:

> *"A component is not rejected immediately until the failure is very evident. In case it is not clear, the component qualification will run into next iteration of qualification within the same stage. Hence, it must reflect in all corresponding diagrams" (Participant 1 & 2)*

> *"When a component level test is performed, there are cases there is still a business need that the same component has to undergo product level qualification test" (Participant 1)*

5.3.2 Improvement suggestion 2

In the detailed workflow diagram draft proposal, there was no segregation between the process workflow and the gate, as the readability of the workflow did not highlight the gate step explicitly. And, the reference of workflow from one stage to the next was not properly tagged with the respective stage. The stakeholder was interested in the readability of the workflow flow from a layman perspective for better understanding of the workflow diagram. As stated by one of the stakeholders:

> *"The workflow should show clearly the steps and it should be readable and should be clearly understandable" (Participant 2)*

5.3.3 Improvement suggestion 3

Postpone was correctly looped in the draft end-to-end business process for component qualification but was missing on the detailed workflow diagram and in process framework. If a request is flagged a 'Postponed' in under review stage (stage 1), the request for qualifying the component is still valid as it is not 'Rejected'. In the detailed workflow diagram proposal draft and in the process framework proposal draft, the loop to bring back the component qualification request to active state was not shown. As mentioned by a stakeholder:

> *"Review postponed means the component qualification request is still alive and hence there is a flow missing to bring it back" (Participant 1)*

5.3.4 Improvement suggestion 4

The proposed draft RACI matrix defines who must be informed for each activity and it was recommended by the stakeholders to show on the proposed draft process framework. This was a general recommendation from multiple stakeholders.

> *"On the process framework it good to have who has to be informed" (Participant 4)*

5.3.5 Improvement suggestion 5

As a general comment on the proposed draft process framework, the main business process flow color (i.e. the stage) must be differentiated with the sub-process or the activities. In addition, it was recommended to add some notes when the component qualification process skips the Trial on Going stage. This presents a good understanding while looking at the process framework in comparison with the end-to-end business process for component qualification diagram.

Next, the improvement suggestions provided by the stakeholders will be implemented to form the initial proposal and the summary of the initial proposal for a component qualification process is described in Section 5.4 below.

5.4 Summary of Initial Proposal for Component Qualification Process

Changes were incorporated to the draft proposal according to the stakeholders' improvement suggestions in order to develop the initial proposal. As mentioned in Section 5.3, The stakeholders had approved the draft proposal with minor improvement feedback and it was very evident during the workshop for data 2 round. The details of the changes performed are briefly described below.

According to Improvement suggestion 1, changes were implemented on the draft end-to-end business process for component qualification, detailed workflow diagram and process framework accordingly. The iterative loop was implemented in New request, Trial on Going (stage 2) and Component Approval (stage 3). Then the missing connection between the component level qualification and product level qualification was established to make the workflow, and an iterative loop was added from gate to 'start trial run build' in the Trial on going stage.

According to Improvement suggestion 2, changes were performed on the draft detailed workflow diagram, where the gate was differentiated from the actual workflow and the referencing with respect to the stages was tagged with the respective stages accordingly. By implementing this change the detailed workflow looks better and it has enhanced the ease of readability.

According to Improvement suggestion 3, changes were performed in both draft detailed workflow diagram and in process framework. The flow from 'postpone' back to 'under review' stage was established.

According to Improvement suggestion 4, changes were performed as per the stakeholder recommendation. A 'notify' activity was added to the draft process framework at end of each gate, which is in accordance with the RACI matrix in a generic level.

According to Improvement suggestion 5, changes were performed to change the visualization of sub process in Trial on Going stage in the draft process framework. In addition, as recommended by a stakeholder, a note was place above the workflow when the process skips the Trial on Going stage to illustrate the workflow with few cleanups for better readability.

The incorporated changes to the draft proposal are henceforth the initial proposal, which will be introduced in this section shortly.

The initial proposal for an end-to-end business process for component qualification is shown in Figure 27 below. The green arrows across Figure 27 indicate the area where changes were performed according to the improvement feedback.

Immediately after that, the initial proposal for Detailed workflow for each stage of component qualification process is shown in Figure 28 below. The blue arrows across the Figure 28 indicate the areas where changes were performed according to the improvement feedback.

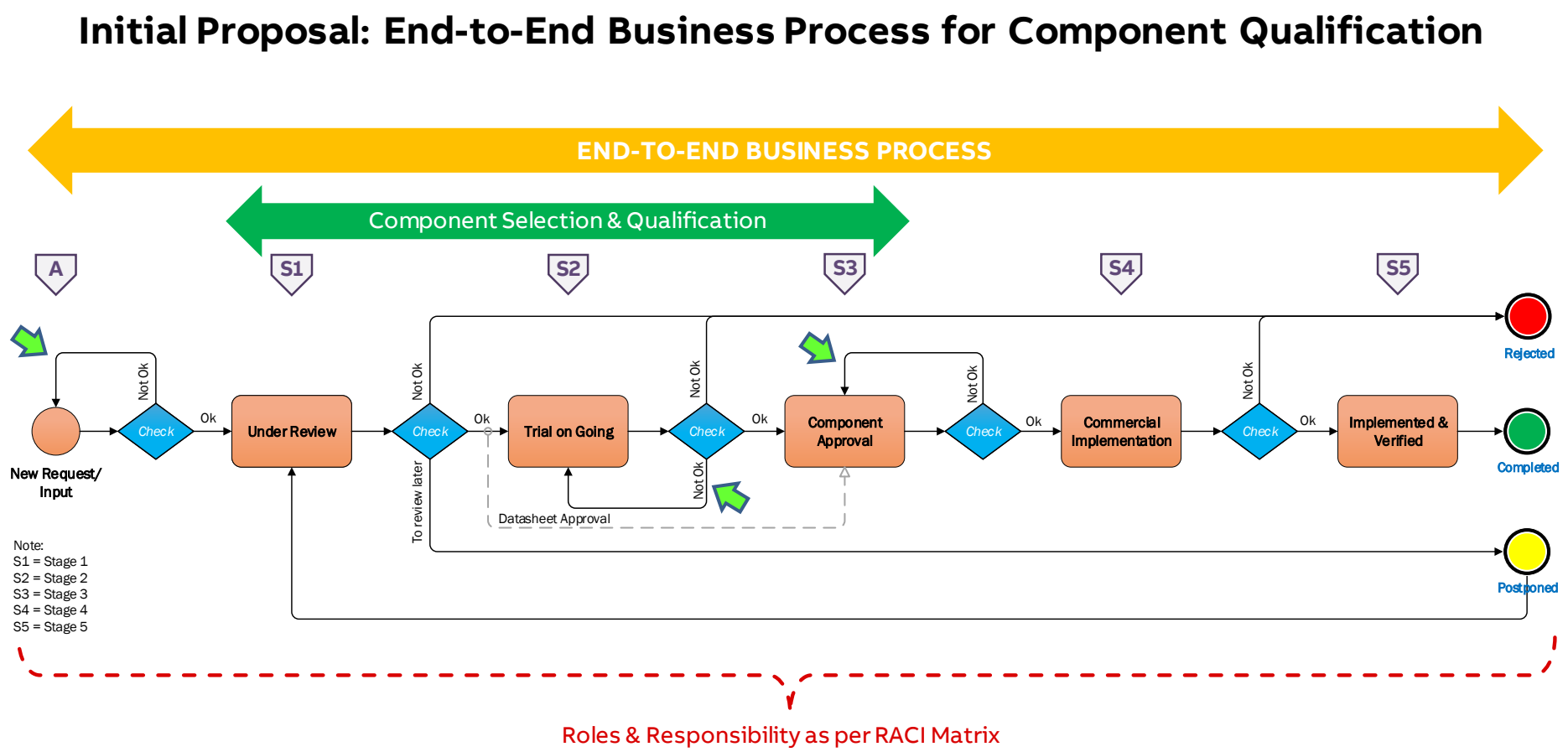

Figure 27. Initial Proposal – End-to-End Business Process for Component Qualification.

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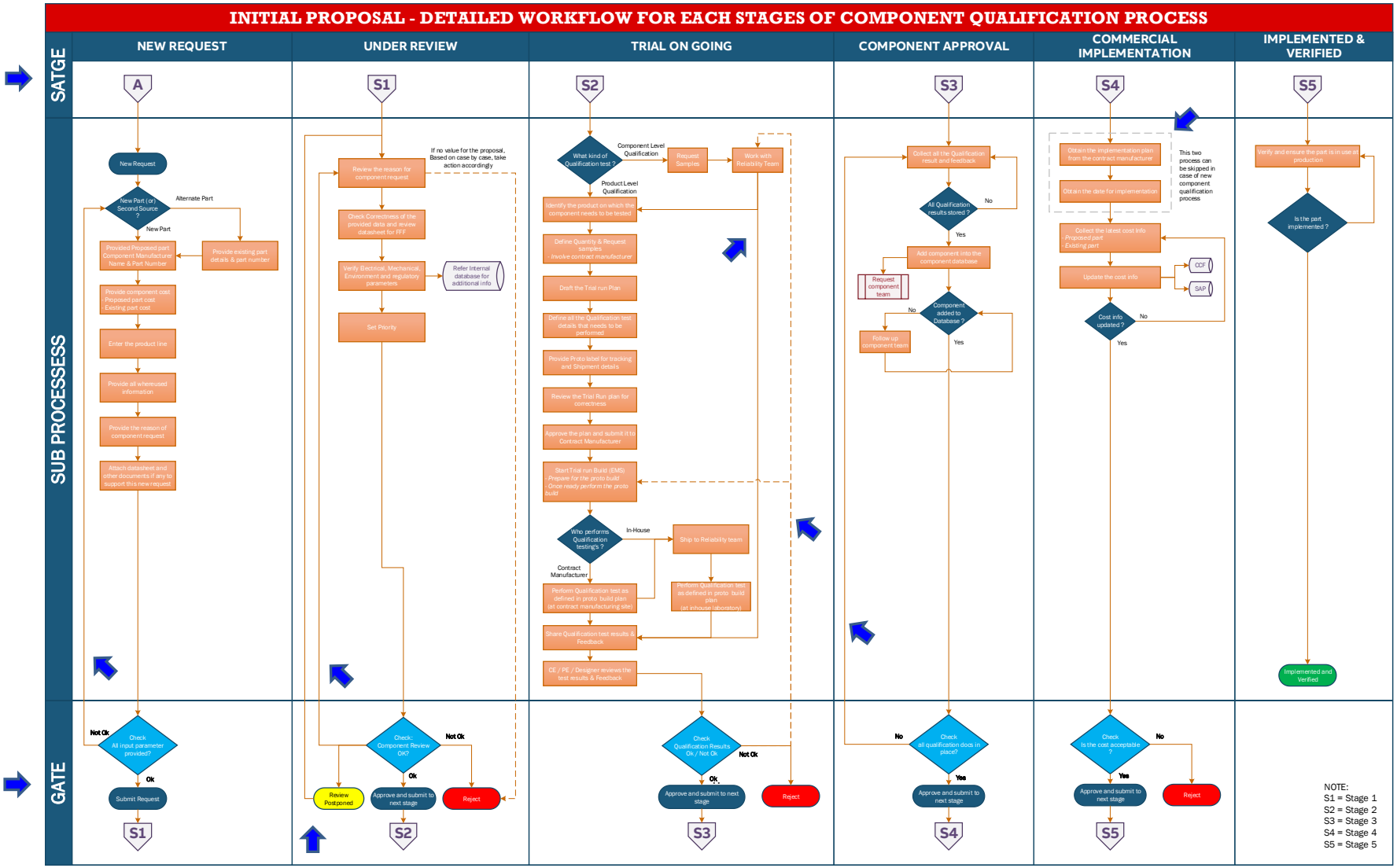

Figure 28. Initial Proposal – Detailed workflow for each stages of Component Qualification Process.

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The initial proposal for the component qualification process RACI Matrix is exhibited in Figure 29 below. There were no changes performed to the RACI Matrix data, as there was no comments and feedback obtained from stakeholders during the workshop for Data 2. But however, there was a typo error noticed on the stage name, which has been updated and highlighted with pink color arrow. Hence, the RACI Matrix contents are the same as in the draft proposal, with just a slight change in the heading and typo correction.

Immediately after that, the initial proposal for the Component qualification process framework is shown in Figure 30 below. The orange arrows across in Figure 30 indicate the areas where changes were performed according to the improvement feedback.

In summary, this section introduced the initial proposal for a component qualification process for the case company: (i) End-to-End Business Process for Component Qualification (Figure 27), (ii) Detailed Workflow for each stage of Component Qualification Process (Figure 28), (iii) RACI Matrix (Figure 29) and, (iv) Process Framework for Component Qualification (Figure 30).

Next, the end-to-end business process for component qualification presented in the initial proposal is validated by simulating it in a customized application software developed to handle the business process in the case company. This simulation is then evaluated internally in the case company with the key stakeholders. The results and feedback are described in Section 6 below.

INITIAL PROPOSAL - RACI MATRIX FOR COMPONENT QUALIFICATION PROCESS (R = RESPONSIBILITY, A= ACCOUNTABILITY, C= CONSULT, I= INFORM)						
PROCESS / ACTIVITIES	**ROLE OF PARTICIPANTS**					
	Requestor (Internal or External)	**Component Engineer/ Product Line owners**	**Product Engineer / Principal Engineer / R&D Engineer**	**Reliability Engineer**	**Contract manufacturer**	**Sourcing**
New Request						
Updating all mandatory data - Component manufacturer and part number, Cost Info, updating Product Line and whereused Info, valid Reason for Request and providing technical datasheet	R/A	C	-	-	-	C
Attaching datasheet or technical documentation	R/A	C	-	-	-	C
Under Review						
Review input data	I	R	C/A	-	-	C
Electrical Specification Review with Datasheet	I	R	C/A	-	-	C
Set Priority	I	R	C/A	-	-	C
Approving / Rejecting the review (Stage approval)	I	R/A	C	-	-	-
Trial On Going						
Defining Qualification Test requirements	I	R	C/A	-	I	-
Product Indentification for Component Testing	I	R	C/A	-	I	-
Trial run plan - Draft	I	R	C/A	-	C	-
Sample Request	I	R	C/A	-	C	C
Qualification Test details	I	R	C/A	-	I	-
Proto Label and Shipping Information	I	R	C/A	-	I	-
Finalizing Trial run plan	I	R	C/A	I	I	-
Proto Build as per plan	I	C/A	C	I	R	-
Performing Qualification Test (@EMS)	I	A	C	I	R	-
Performing Qualification Test (@ In-House)	I	C	A	R	-	-
Qualification Test Results (EMS) & Manfacturing Report	I	C/A	C	-	R	-
Qualification Test Results (In-House)	I	C/A	C	R	-	-
Qualification Test Result Review	I	R	C/A	I	-	-
Approving / Rejecting Trial on Going (Stage approval)	I	R/A	C/A	I	I	-
Component Approved						
Collecting and Storing all Qualification data	-	R/A	C	-	-	-
Adding Qualified Component to database	-	R/A	C	-	-	-
Approving the component (Stage Approval)	I	R/A	I	I	I	I
Commercial Implementation						
Plan for Commercial Implementation	I	I	-	-	C	R/A
Date for Implementation	I	I	-	-	R	A/C
Collecting latest cost info	-	-	-	-	C	R/A
Updating cost info to Database	-	-	-	-	-	R/A
Approving/Rejecting (Stage approval)	-	I	-	-	I	R/A
Implemented & Verified						
Verify the part is used in production	-	-	-	-	C	R/A
Final Approval	I	I	I	-	I	R/A

Figure 29. Initial Proposal – RACI Matrix for Component Qualification Process.

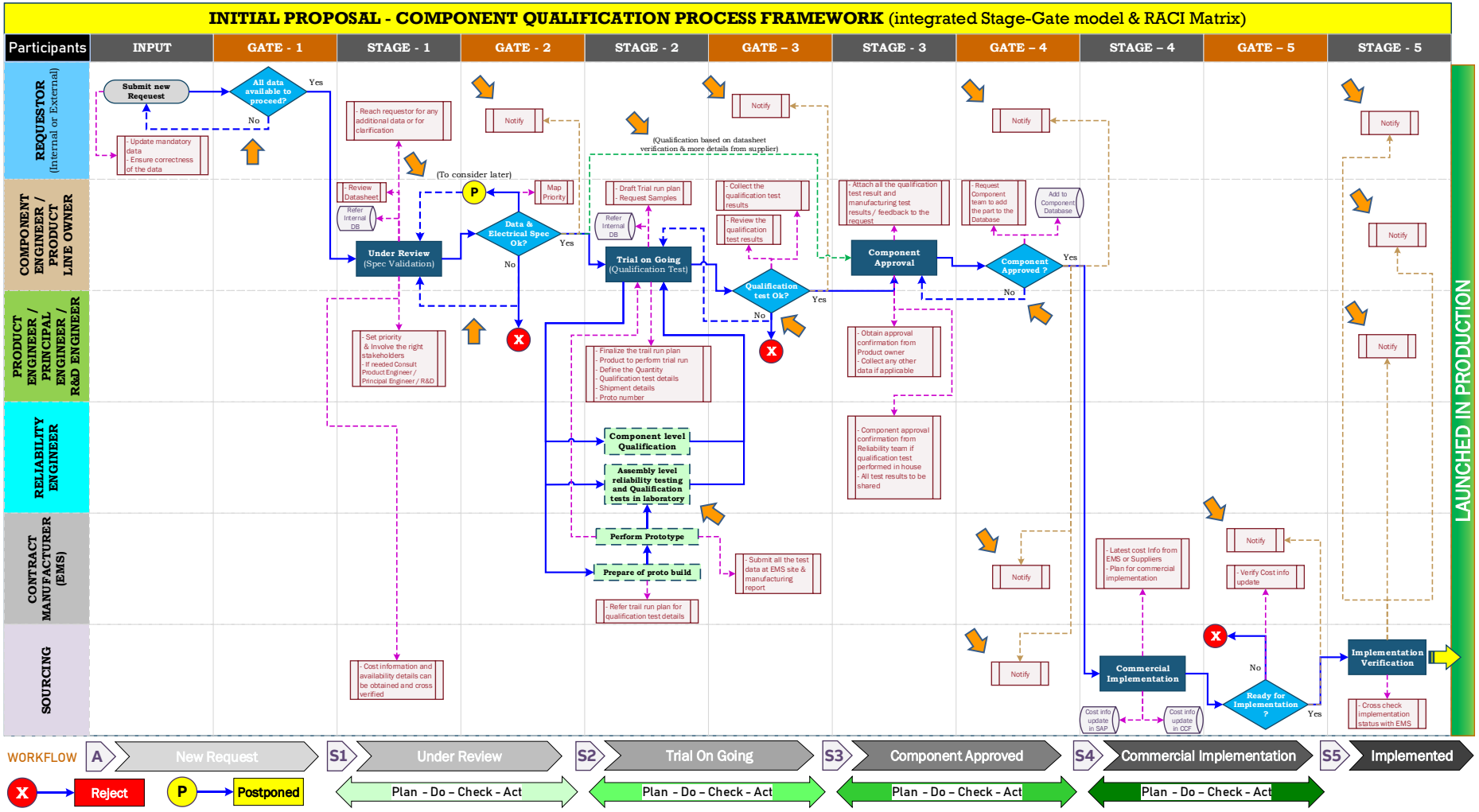

Figure 30. Initial Proposal – Component Qualification Process Framework.

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6 Simulating and Pilot Testing of the Proposed Component Qualification Process with a Custom-developed Application Software

This section reports on the results and feedback from validation. First, the section briefly overviews the validation stage. Second, the section briefly describes the development of a software application enabling to test the proposed component qualification process by simulation. Third, the section presents the results from validation discussions with the stakeholders. Forth, the section describes the summary of the proposed component qualification process.

6.1 Overview of the Validation Stage

The goal of validation is to develop the final proposal for the component qualification process for the case company that will be functional and ready for practical use, based on utilizing the validation feedback obtained from the key stakeholders.

The initial component qualification process proposed in Section 5.4 was validated by performing the following steps.

First to test the proposal in practice, a custom-developed software application was ordered that enabled to simulate the process. It was done since testing the proposed component qualification process in the business environment was not feasible due to a short time of this study. However, the proposed component qualification process was simulated via a custom-developed software application, and the results were demonstrated to the key stakeholders in the company for validation and feedback.

Second, the validation feedback and further developments (Data 3) were collected during the demonstration sessions and that form the data 3 in this study. This included the feedback, comments and inputs from the stakeholders.

Third, the summary of the proposed qualification process is described demonstrating how it makes a practical solution for component qualification process for the case company.

6.2 Simulation with a Custom-developed Software Application

To evaluate the proposed component qualification process workflow in the company's business environment, typically a real time end-to-end component qualification process would take about several weeks to several months and there would be participants involved from around the world. Henceforth, the proposed component qualification process was simulated via a custom-developed process management software application. This application software worked as an enabler to simulate the initial proposal because the promised outcome of this study is to deliver a final component qualification process that is functional and usable at the company to address the business needs.

In short, the Software development team was identified in the case company, and the requirement to develop the application software was provided to them in phases for each stage of the proposed process and its respective key activities. Multiple round of discussions happened between the Software development team to ensure the development to requirements. The developed process management application software was designed and aligned to be in accordance with the proposed process workflow as per Figure 27 and Figure 30.

The software application was developed to consist of five gates and stages in a sequential manner, as described in Section 5.2.1. In order to implement the gate functionality for decision making virtually in the application, all the list of key tasks that needs to be documented or followed up were identified from the proposed workflow in accordance with Figure 28. All those identified key task were made as mandatory fields in the application, so that the system will not allow the responsible decision maker to pass the stage unless all the mandatory defined fields are updated, which in turn acts virtually as a gate.

Also, in the software application, the role and responsibility assignment tagging were inbuilt in accordance with the proposed RACI chart in accordance with Figure 29.

Upon completion of the software development, the software application underwent a few rounds of testing to fix the software related bugs and to ensure the application works according the proposed component qualification process.

This application proved to be able to handle multiple component qualification requests and each request can be tracked and managed end-to-end as per the proposed component qualification process workflow. Moreover, the application also proved to be able to handle and store the necessary data that is needed for each stage or collected at each stage as a repository to enable full traceability of data.

Thus, the matured and final version of the application software was developed, and it successfully simulated the proposed component qualification process. The results demonstrated to the key stakeholders that the proposed component qualification process is a workable solution that utilizes a stage by stage approach. The simulation validates the initial proposal as shown in Section 5.4. Details of application software in the form of snapshot is presented in Appendix 4.

Summing up, the end-to-end component qualification process typically takes about several weeks to several months in the case company. Hence due to the tight schedule of the study, a real time process validation study in the form of pilot run was not performed in the case company and could not be waited. Thus, to ensure the proposed component qualification process is a workable solution for the company, testing and simulating the process with the help of custom developed application software was an effective way to perform validation of the process.

The simulation also clearly demonstrated the benefits of the proposed component qualification process including the following points: (a) the process to be followed is constant and repetitive, (b) it shortens process lifecycle, (c) it tracks and documents the tasks, (d) it monitors and optimizes performance, (e) it enables saving time and cost, and (f) it can integrate and collaborate various participants across geographies.

6.3 Validation Feedback and Further Developments (Data 3)

The initial component qualification process presented in Section 5.4, was also validated by conducting a validation session with the key stakeholders in the case company together with the process simulation. The lessons learned during the demonstration and the feedbacks obtained from the key stakeholders formed Data 3 collection round. The comments and feedbacks obtained from stakeholders are summarized and exhibited in Table 7 below.

Table 7. Data 3 collection - Feedbacks and comments from key stakeholders.

Stakeholders	Feedback	Description of comments provided
Respondent Group (1): - PE team (4) - MVD Principal Engineer - SD Principal Engineer - DS Principal Engineer - Manager – SCM	**Positive**	This process of stage-gate makes sense in approval process to control the process workflow
		It is good to have the RACI integrated into the process and it is very positive
		This new component qualification process looks good and detailed.
		This thesis study is different, and I like it, it is giving a practical solution.
		I like this approach of component qualification process and its approach; can this process be scalable to R&D / NPI projects as well for second source component qualification approval?
	Neutral	It is good to have a defined process, lets us take it in to use to see if there are any challenges.
Respondent Group (2): - MVD PE Manager - Global PE Manager	**Positive**	**Process is good and let's start to implement as pilot**. And, let us **update the proposed component qualification process into our information management system and linking it in our internal SharePoint site**.
	Neutral	Let's start to put it in practice now, as see how the process works in practice.
Respondent Group (3): - SCM Global Manager - Global PE Manager	**Positive**	The process is well structure, and correctly takes in account all the involved stakeholders
		Is much appreciated also the close loop done on the commercial side, asking the external stakeholder (EMS) to confirm the implementation date this is giving the possibility to both parties in case company sourcing and product maintenance to secure the economic advantage in the Costed BOM

As seen from Table 7, the feedback obtained from the key stakeholders was categorized as positive and neutral. Since there was no negative feedback obtained, it is not displayed in Table 7.

As seen from Table 7, the response and the feedback obtained from the stakeholders showed satisfaction with the initial proposal. Since, Data 3 collection did not bring any negative feedback from the stakeholders, and there was no action necessarily to be taken for performing any corrections to the initial proposal proposed in Section 5.4. However, there were minor feedbacks to improve the custom-developed software application provided as Data 3 and those feedbacks related to application software exhibited in Appendix 5.

The following section describes the summary of developed qualification process which is the outcome of this study.

6.4 Summary of the Proposed Component Qualification Process

The final component qualification process for the case company is identical to the initial proposal proposed in Figure 27, Figure 28, Figure 29, and Figure 30 in Section 5.4. There was no improvement feedback or suggestion provided by the key stakeholders during the validation of the process through simulation, hence there are no changes incorporated into the initial proposal.

To briefly summarize again, the final component qualification process displayed in Appendix 6 consist of (i) End-to-End Business Process for Component Qualification, (ii) Detailed workflow for each stages of Component Qualification Process, (iii) RACI Matrix for Component Qualification Process, and (iv) Component Qualification Process Framework.

The results from the current state analysis revealed the need for an efficient process for component qualification that would address the weaknesses identified (Figure 7). Best practice and ideas from the literature further guided the development of a component qualification process throughout from draft proposal to the final proposal. Therefore, the final component qualification process proposed is a working solution which is build based on a stage-gate model with a RACI matrix to provided clarity about the responsibility and its assignment. Fusion of both the process workflow and the RACI forms the process framework.

The proposed process addresses the identified weaknesses (Figure 7) of: (a) ‘Inefficient process workflow’ and (b) ‘Lack of uniform process and methodology´ by developing an end-to-end business process and a stage wise detailed workflow diagram. The other identified weaknesses of (c) ‘Feeble distribution of role and responsibility’ and (d) ‘Inefficient collaboration and communication’ are addressed by developing a RACI matrix. This ends the development of the component qualification process for the case company.

7 Discussion and Conclusions

This section describes the summary of the study and gives recommendation for next steps. After that, the section proceeds to trustworthiness evaluation.

7.1 Executive Summary

Electronic industry currently experiences hindrances due to component scarcity as the demand surpasses the supply. This imbalance situation in component market results in supply chain disruption, long-lead times that impact on-time delivery, delayed shipment and ultimately a huge surge in component pricing. In order to stay competitive and ensure the promise of quality and on-time delivery to customers of the company, new components and alternate components identified or request has to be qualified thoroughly in an efficient manner. If done, it would also enable the company to broaden its supply base and mitigate the risk of component scarcity for the case company.

In the case company, there is an existing process currently in practice to qualify a component, but it does not live up to the task to address the business needs and is not well documented. Therefore, to address the needs for qualifying a component efficiently, the case company needs *a well-defined component qualification process* that is agile in nature, aligned to business needs, and adaptable to the company's operational environment. Thus, the objective of this thesis was to develop the component qualification process that can be utilized and adapted across various product groups in the company.

The study was conducted using the Design research approach with qualitative data analysis by involving the case company stakeholders at all steps of the study. The study started with the current state analysis to identify the strengths and weaknesses of the existing process. Next, the study explored best practice and literature about building a component qualification process and merged the most relevant ideas into the conceptual framework. After that, by gathering input and feedback from the key stakeholders in the case company, the study proposed a new component qualification process. The methods used for data collection comprised internal document analysis, face to face interviews, workshops and telephonic discussions.

Based on the outcome from the current state analysis, the strengths and weaknesses in the existing process were identified with a clear indication that the existing process is

inefficient. The identified weaknesses related to: (a) an inefficient process workflow, (b) the lack of uniform process and methodology, (c) a feeble distribution of roles and responsibilities, and (d) inefficient collaboration and communication. The literature study explored these weaknesses to find best practice to address them. These ideas from literature were further merged into the conceptual framework for this study to develop a component qualification process as the proposal.

The proposed Component qualification process focusses on ensuring an efficient process workflow, enhance decision making, and enhance collaboration and information flow during the process execution. The proposed process is constructed by integrating a stage-gate model, having a sequential flow of stages and a detailed process workflow specific for each stage. The proposed process also identifies the key participants and key activities required to perform the component qualification process. Also, to establish role and responsibilities for the involved parties in the process, a responsibility assignment matrix was developed in the form of RACI chart. Furthermore, to have a component qualification process framework, the proposed end-to-end business process for component qualification and the responsibility assignment were merged together to build a process framework for component qualification.

The proposed component qualification process was tested and simulated using a custom-developed application software and was found to be functional. So far, the complete component qualification process was not tested on an actual electrical or electronic component in real time business environment. But it will be tested soon since the end-to-end component qualification process typically takes about several weeks to several months, which goes beyond the study time of this Thesis. However, based on the testing and simulation results, and also based on the feedback obtained from the key stakeholders from the case company, the proposed process was validated completely meeting the business needs and expectations of the case company.

When implemented, the proposed component qualification process will enable component qualification efficiently due to the stage-gate approach and clearly defined responsibilities, as well as its end-to-end visibility and traceability, and will bring benefits related to cost, quality and availability, which can be achieved swiftly. In the long run, the process performance can be measured and evaluated to ensure its capability to accomplish the desired goals.

7.2 Recommendations toward Implementation

The proposed component qualification process is a functional process based on validation performed in the form of simulation and it calls for further steps towards implementation. The proposal consists of the component qualification process with a defined workflow and the defined responsibility assignment matrix in the form of RACI chart. Based on the successful validation of the proposed process, recommendation by the researcher is as follows.

First, to bring the proposed component qualification process to be functional, it is important that the proposed process should be piloted in the case company in the form of pilot run.

Second, the developed component qualification process and the RACI matrix needs official documentation as per the case company's internal process and the new component qualification process has to be introduced across the various product groups.

Third, the proposed component qualification process must be taken into practice for immediate use in business environments. It will enable to rigorously test the proposed component qualification process. As a natural phenomenon, implementation may have some change resistance that needs to be mitigated.

Fourth, to facilitate the implementation and to address the change resistance, necessary trainings must be provided to all the participants across the case company who has their stake in the process explaining the detailed process workflow and the responsibility assignment matrix or RACI Matrix. Target training to change resistant audience is a must to achieve the desired outcome from the process.

Fifth, it is necessary to further enhance the application software which was used to simulate and test the process. Automated business process and its management can bring considerable value in handling the component qualification process. While the number of component requests for qualification increase and the application software will also enable the path to perform various statistical analysis.

Sixth, in the long run (during the piloting period), it is necessary to monitor, track and measure the efficiency of the process, to evaluate the component qualification process

yields the desired results and meets the objective and goals of the business. Also, its recommended to obtain feedback from the participants that could be used for further enhancements.

Finally, based on the evaluation of the process efficiency during the pilot run and the feedback obtained it is necessary to enhance the process by addressing the feedbacks received, and this is iterative in nature.

7.3 Thesis Trustworthiness Evaluation

The objective of the thesis is to develop a component qualification process which can be utilized across various product groups within the case company. The expected outcome from this study is a component qualification process.

The thesis was constructed according to the established research design by a step-by-step approach. Current state analysis was performed to benchmark the existing component qualification process and practice in the form of a fishbone diagram to identify the cause and effects in the process that helped to sort out the strengths and weaknesses. Literature study part consumed around three to four months to obtain best practices in association with the objective of the thesis that enables to form a conceptual framework for the study. The conceptual framework was effectively used for proposal building, together with the feedbacks obtained from the key stakeholders in the case company to ensure the validity of the proposal building. The study managed to accomplish the expected outcome by proposing a component qualification process and validated the process using a custom developed application software. The developed component qualification process is lean in function, and it is easily transferable or adaptable by different product groups in the case company because it is generic in nature.

During this study time, the developed component qualification process was not implemented for pilot run in the case company's business environment to receive a real time feedback, due to the nature of end-to-end component qualification process that takes about approximately several weeks to several months in real business environment. A pilot run of an end-to-end component qualification process with a real case, possibly would have added more advantage to validate the developed process in this study. Pilot run would have benefited the study to get more real time feedbacks from all the parties

involved in the process. The component qualification process includes active involvement of our external EMS partners (contract manufacturing), it would be good to get their feedback and their change resistance that could have been possibly provided more insights from the process operation point of view. All these factors could have possibility enabled to fine tune the developed and proposed component qualification process in this thesis.

According to Anderson et al. (2007), quality criteria in academic research for quantitative and qualitative is described by the terms related to 'validity' and 'trustworthiness'. Quantitative researchers prefer the term 'validity' and qualitative researchers prefer the term 'trustworthiness'. Also, Anderson et al. (2007) highlights, there are different reasons to perform research by practitioners. If the research is performed or organized to generate knowledge for distribution, then the criteria is for 'validity', and if the research is to address a problem within a process circumstances where the knowledge produced could be recycled, then the criteria is for 'trustworthiness'. (Anderson et al. 2007).

For qualitative research, Guba (1981) highlights the four aspects that are related to trustworthiness, and they are truth value, applicability, consistency and neutrality. They are mapped based on suitability with scientific terms and naturalistic terms accordingly and is exhibited in Table 8 below.

Table 8. Four aspects of trustworthiness (Source: Guba 1981).

Aspect	Scientific Term	Naturalistic Term
Truth Value	Internal Validity	Credibility
Applicability	External Validity / Generalizability	Transferability
Consistency	Reliability	Dependability
Neutrality	Objectivity	Confirmability

Accordingly, Shenton (2004) cites Guba (1981) and highlights, to produce the outcome in trustworthy and accurate manner the four criteria of trustworthiness is essential goal of qualitative research. The four criteria are credibility, transferability, dependability and confirmability. (Shenton 2004). And these four criteria of trustworthiness are applied here in this thesis evaluation along with the detailed provisions recommended by Shenton (2004).

Credibility can also be referred to internal validity (Table 8), where researchers endeavors to establish the study performed measures and assess the truth of the actual research findings. To establish trustworthiness, it is extremely important to guarantee the credibility. (Shenton 2004). The Table 9 below lists out the provisions recommended by Shenton (2004) to address the credibility criteria for trustworthiness and it is mapped based on the research performed by the author in this study.

Table 9. Evaluation of 'Credibility' - Criteria 1 for Trustworthiness in this thesis.

	Measures of Credibility	Applied in this thesis	Relevance in this research / Comments
CREDIBILITY	Adoption of appropriate, well recognized research methods	✓	Design research approach with qualitative data analysis methods was applied. Data collection was performed in the form of semi-structured interview, workshop, telephonic discussion to obtain the perceptions of the respondents. Also, internal documents were reviewed. Metropolia specified gate model was utilized.
	Development of early familiarity with culture of participating organizations	✓	This study was performed within the case company. Researcher and all participants utilized in data collection is from the case company. Hence, culture of the organization is well familiar all throughout the study.
	Random sampling of individuals serving as informants	!	Partially applied. Informant from the researchers' department was not randomly selected. But, informant from other product group was picked randomly based on their role held that concerns the study area.
	Triangulation via use of different methods, different types of informants and different sites	✓	Observation, interview data and internal documents are the data used. All informant is from the case company. But, informants were from various product groups across the case company.
	Tactics to help ensure honesty in informants	✓	Questions formulated was repeated for better understanding. If the respondent was not clear, or the answers was not clear, the same question was rephrased. But no special tactics was utilized. As the expectation is the informants are honest.
	Iterative questioning in data collection dialogues	✗	Not Applied
	Negative case analysis	✗	Not Applied
	Debriefing sessions between researcher and superiors	✓	Thesis guide from the case company was always included in all the workshops and discussions. Research progress was updated.
	Peer scrutiny of project	✓	Project was review by case company representative during each phase of development and received feedback. Study was overviewed by thesis instructor according to the research design progress.
	Use of "reflective commentary"	✗	Not Applied
	Description of background, qualifications and experience of the researcher	✗	Not Applied

	Member checks of data collected, and interpretations/theories formed	✓	The collective results of field data obtained from various product groups was consolidated to develop a cause and effect diagram. Later all the participant of the data collection was grouped in single workshop to review the strengths and weaknesses that shaped the study further. Key stakeholders always have been involved to propose and provide constructive feedbacks.
	Thick description of phenomenon under scrutiny	✓	Furnished business challenge, Current state analysis and literature review
	Examination of previous research to frame findings	✓	Best practices were collected through literature review and documented in Section 4.

Transferability can also be referred to external validity or generalizability (Table 8), and it makes certain by specifying conscientiously about the means of data collection in the research. It focuses in applicability and for the reader to decide whether it can be utilized in any other similar circumstances the exhibited findings can be rightly used in other environment or context. (Shenton 2004). The Table 10 below exhibits the measures recommended by Shenton (2004) to address the transferability criteria for trustworthiness and it is mapped based on the research performed by the author in this study.

Table 10. Evaluation of 'Transferability' – Criteria 2 for Trustworthiness in this thesis.

	Measures of Transferability	Applied in this thesis	Relevance in this research / Comments
TRANSFERABILITY	The number of organizations taking part in the study and where they are based	✓	Study consist of single organization, but however it involved and covered various product group within the same organization. Organization located in Finland.
	Any restrictions in the type of people who contributed data	✓	People contributed to the study are purely within the case company
	The number of participants involved in the fieldwork	✓	12 participants during current state analysis 8 participants during proposal building 12 participants during validation of the proposal
	The data collection methods that were employed	✓	Telephonic discussion, Semi structured interview, workshop and discussion, interview and internal documents.
	The number and length of the data collection sessions	✓	Current state Analysis (Data 1) – 3 workshops, 4 Interviews and 1 Telephonic discussion all together of 300 minutes Proposal Building (Data 2) – 1 workshop about 75 minutes Proposal validation (Data 3) – 3 workshops about 185 minutes
	The time-period over which the data was collected	✓	02/2019 – Current state analysis (Data 1) 04/2019 – Proposal building (Data 2) 04/ 2019 – Proposal validation (Data 3)

Dependability can also be referred to reliability (Table 8), and it is the aspect focused on consistency of the study. Dependability can be enhanced by providing a detailed report of process or practices followed in the research, that enables other researchers to execute similar methods to either obtain same or similar results. (Shenton 2004). The Table 11 below exhibits the measures of dependability recommended by Shenton (2004) for trustworthiness and it is mapped based on the research performed by the author in this study.

Table 11. Evaluation of 'Dependability' – Criteria 3 for Trustworthiness in this thesis.

	Measures of Dependability	Applied in this thesis	Relevance in this research / Comments
DEPENDABILITY	The research design and its implementation, describing what was planned and executed on a strategic level	✓	Described in Section 2.2 – Research Design
	The operational detail of data gathering, addressing the minutiae of what was done in the field	✓	Data gathering practice, data collection method and the duration of the event is described in Section 2.3 – Data collection and analysis
	Reflective appraisal of the project, evaluating the effectiveness of the process of inquiry undertaken.	✓	The same participants were utilized throughout the study during data collection and was co-created through feedback and discussion. The question used during interview was the same. Validation was performed to evaluate the effectiveness of the process analysis attempted.

Confirmability can also be referred to objectivity (Table 8), where the researcher guarantees the findings materializes from the informants and not based on researchers' willingness. (Shenton 2004). The Table 12 below exhibits the measures of confirmability recommended by Shenton (2004) for trustworthiness and it is mapped based on the research performed by the author in this study.

Table 12. Evaluation of 'Confirmability' – Criteria 4 for Trustworthiness in this thesis.

	Measures of Confirmability	Applied in this thesis	Relevance in this research / Comments
CONFIRMABILITY	Triangulation to reduce the effect of investigator bias	✓	Interviews, workshops, feedback and discussion was used in this practical research to obtain the understanding from different sources was later combined.
	Admission of researcher's beliefs and assumptions	!	Partially but not extensively
	Recognition of shortcomings in study's methods and their potential effects.	✓	Described in Section 7.2 and 7.3

	In-depth methodological description to allow integrity of research results to be scrutinized	✓	Described in the form of research method with a conceptual model in Section 2.2 and 2,3
	Use of diagrams to demonstrate “audit trail”	✓	Section 2.2 portrays the research design of this study. To illustrate and exhibit the finding usage of diagrams has been well utilized in the form of diagrams.

As noticed, Table 9, Table 10, Table 11 and Table 12 exhibits the evaluation of measures of each criteria (credibility, transferability, dependability and confirmability) mapped with the relevance in this study. And from the tables, it is evident that most of the provision of criteria characterized by Shenton (2004) are realized to an adequate level in the study based on the evaluation performed to acknowledge the level of trustworthiness. Therefore, it can be presumed the level of trustworthiness attained is convenient.

7.4 Closing Words

Growing needs for electronic component have caused the demand to surpass the supply. Today, the global electronic component market is volatile and surrounded with challenges that comprises mainly increased lead time, pricing uncertainty, component portfolio consolidation, counterfeit parts and global economy. This affects the case company; whose core business uses electrical and electronic components extensively.

Hence, for engineers and supply chain management professional, qualifying alternate components is vital to ensure the quality, reliability, availability and also to secure cost benefit. In short, it is critical and necessary in business to remain competitive. These circumstances call for a need to have an efficient component qualification process for the case company that helps to broaden its supply base to address the business need.

This thesis furnishes a component qualification process developed for the case company that is agile in nature, aligned to business needs and can be adaptable by different product groups in the case company. The outcome of this study together with recommendations for next steps for implementation will enable the case company to realize the value while taken into use across all the product groups in the case company.

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Appendices

Appendix 1: Field Notes (Data 1)

Respondent Group (1) - Workshop		
Details of the Informant		Product Engineers (4) / Principal Engineer (MD) / PE Manager (MD)
Duration of Interview		60 mins
Documentation Type		Field Notes
General Questions		**Answers**
What is your opinion about existing component qualification process? Is it good or bad or just OK?		Confidential – For internal use only
Is the existing process efficient and effective?		
What is you experience with the existing process in place?		
How do you see the process workflow?		
How is the communication along the process?		
How is the environment in the company to handle the qualification process		
Existing process flow	**Questions**	**Answers**
New Request	What are the strengths and weaknesses?	Confidential – For internal use only
Trail on Going	What are the strengths and weaknesses?	
Technical Approval	What are the strengths and weaknesses?	
Commercial Implementation	What are the strengths and weaknesses?	
Rejected	What are the strengths and weaknesses?	
General comments	**Answer**	
	Confidential – For internal use only	

Metropolia

Respondent Group (2) - Interview		
Details of the Informant		Principal Engineer (ID)
Duration of Interview		30 mins
Documentation Type		Field Notes
General Questions		**Answers**
What is your opinion about existing component qualification process? Is it good or bad or just OK?		Confidential – For internal use only
Is the existing process efficient & effective?		
What is you experience with the existing process in place?		
How do you see the process workflow?		
How is the communication along the process?		
How is the environment in the company to handle the qualification process		
Existing process flow	**Questions**	**Answers**
New Request	What are the strengths and weaknesses?	Confidential – For internal use only
Trail on Going	What are the strengths and weaknesses?	
Technical Approval	What are the strengths and weaknesses?	
Commercial Imple-mentation	What are the strengths and weaknesses?	
Rejected	What are the strengths and weaknesses?	
General comments	**Answer**	
	Confidential – For internal use only	

Respondent Group (3) - Interview	
Details of the Informant	Principal Engineer (SD)
Duration of Interview	30 mins
Documentation Type	Field Notes
General Questions	**Answers**
What is your opinion about existing component qualification process? Is it good or bad or just OK?	Confidential – For internal use only
Is the existing process efficient & effective?	
What is you experience with the existing process in place?	
How do you see the process workflow?	
How is the communication along the process?	
How is the environment in the company to handle the qualification process	

Existing process flow	Questions	Answers
New Request	What are the strengths and weaknesses?	Confidential – For internal use only
Trail on Going	What are the strengths and weaknesses?	
Technical Approval	What are the strengths and weaknesses?	
Commercial Implementation	What are the strengths and weaknesses?	
Rejected	What are the strengths and weaknesses?	
General comments	Answer	
	Confidential – For internal use only	

Respondent Group (4) - Interview	
Details of the Informant	Principal Engineer (DS)
Duration of Interview	30 mins
Documentation Type	Field Notes
General Questions	**Answers**
What is your opinion about existing component qualification process? Is it good or bad or just OK?	Confidential – For internal use only
Is the existing process efficient & effective?	
What is you experience with the existing process in place?	
How do you see the process workflow?	
How is the communication along the process?	
How is the environment in the company to handle the qualification process	

Existing process flow	Questions	Answers
New Request	What are the strengths and weaknesses?	Confidential – For internal use only
Trail on Going	What are the strengths and weaknesses?	
Technical Approval	What are the strengths and weaknesses?	
Commercial Implementation	What are the strengths and weaknesses?	
Rejected	What are the strengths and weaknesses?	
General comments	Answer	
	Confidential – For internal use only	

Metropolia

Respondent Group (5) - Interview		
Details of the Informant		R&D Manager
Duration of Interview		30 mins
Documentation Type		Field Notes
General Questions		**Answers**
What is your opinion about existing component qualification process? Is it good or bad or just OK?		Confidential – For internal use only
Is the existing process efficient & effective?		
What is you experience with the existing process in place?		
How do you see the process workflow?		
How is the communication along the process?		
How is the environment in the company to handle the qualification process		
Existing process flow	**Questions**	**Answers**
New Request	What are the strengths and weaknesses?	Confidential – For internal use only
Trail on Going	What are the strengths and weaknesses?	
Technical Approval	What are the strengths and weaknesses?	
Commercial Imple-mentation	What are the strengths and weaknesses?	
Rejected	What are the strengths and weaknesses?	
General comments	**Answer**	
	Confidential – For internal use only	

Respondent Group (6) - Telephonic Discussion and Email	
Details of the Informant	SCM Manager
Duration of Interview	15 mins
Documentation Type	Field Notes
General Questions	**Answers**
What is your opinion about existing component qualification process? Is it good or bad or just OK?	Confidential – For internal use only
Is the existing process efficient & effective?	
What is you experience with the existing process in place?	
How do you see the process workflow?	
How is the communication along the process?	
How is the environment in the company to handle the qualification process	

Existing process flow	Questions	Answers
New Request	What are the strengths and weaknesses?	Confidential – For internal use only
Trail on Going	What are the strengths and weaknesses?	
Technical Approval	What are the strengths and weaknesses?	
Commercial Implementation	What are the strengths and weaknesses?	
Rejected	What are the strengths and weaknesses?	
General comments	Answer	
	Confidential – For internal use only	

Respondent Group (7) - Review of Fishbone		
Details of the Informant	Product Engineers (4) / Principal Engineer (MD) / PE Manager (MD) / Principal Engineer (ID) / Principal Engineer (SD) / Principal Engineer (DS)	
Duration of Interview	60 mins	
Documentation Type	Field Notes	
Activity performed		Feedback
Review of consolidated Fishbone diagram and restructuring		None

Respondent Group (8) - Review of Fishbone		
Details of the Informant	SCM Global Manager / SCM Manager	
Duration of Interview	45 mins	
Documentation Type	Field Notes	
Activity performed		Feedback
Review of consolidated Fishbone diagram and restructuring		None

Fishbone diagram represented in Figure 4. Fishbone diagram - Cause and Effect analysis of existing process

Appendix 2: List of Reliability Approval Tests – (Source: Tekcan and Kirisken 2010)

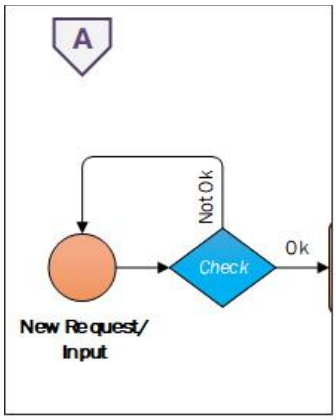
Test Procedure	Test Name	Type
Reliability Approval	Temperature Stress Test	Electrical
	Voltage Current Stress Test	Electrical
	Open/Short Circuit Test	Electrical
	ESD Test	Electrical
	Manual Spark Test	Electrical
	Laser Spark Test	Electrical
	Power Switch On/Off Test	Electrical
	Momentary Power Out Test	Electrical
	Surge Test Electrical 25	Electrical
	Voltage Dips, Short Interruption and Variation Test	Electrical
	Inrush Test	Electrical
	Lightning Surge Test	Electrical
	AC Mains Over Voltage Test	Electrical
	Loose Plug Test	Electrical
	Heat-Run Test	Environmental
	High Temperature Test	Environmental
	Low Temperature Test	Environmental
	Temperature Cycle Test	Environmental
	High Humidity Life Test	Environmental
	Vibration Test	Mechanical
	Wall Holder Strength Test	Mechanical
	Drop Test	Mechanical
	Unpackaged Shock Test (Fragility Test)	Mechanical
	Random Vibration Step Stressto Failure	Mechanical
Product Level Test-ing-Design Verifica-tion Tests(DVT)	Powered / Unpowered Temp Cycling	Electrical
	Combined High Temperature & Humidity Test	Environmental
	Thermal Shock Test	Environmental
	Temperature Step Stress to Failure	Environmental
	Operational High / Low Temp Humidity Test	Environmental

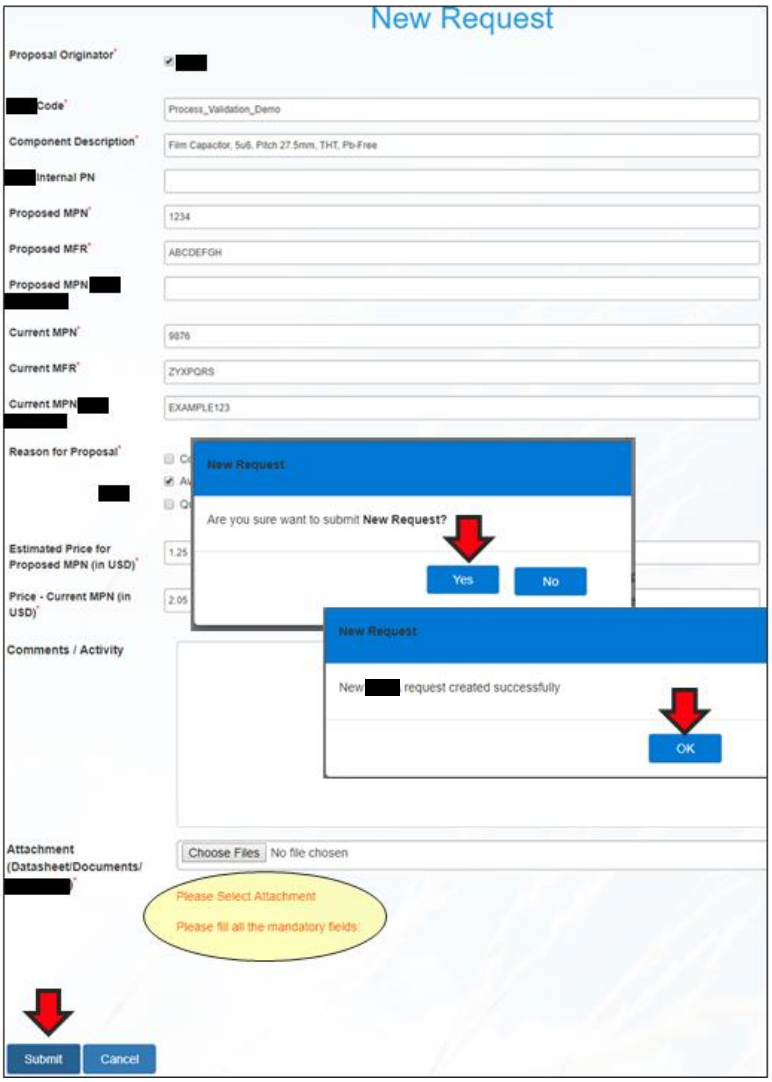
	High Humidity (Environmental Storage Test)	Environmental
	Constructional Inspection Test	Mechanical
Board Level Tests Early Life Period-ELP	Thermal Cycling Test	Environmental
	Random Vibration Test	Environmental
	High Humidity Test	Environmental
	Thermal Shock Test	Environmental
	Power On/Off Test	Electrical

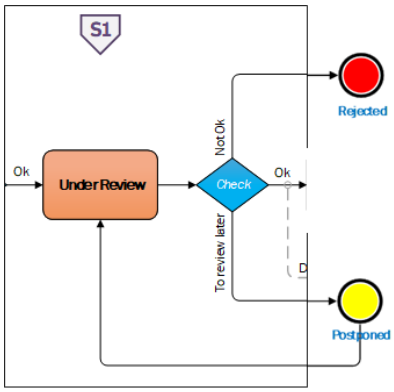
Appendix 3: Draft Proposal Improvement feedback (Data 2)

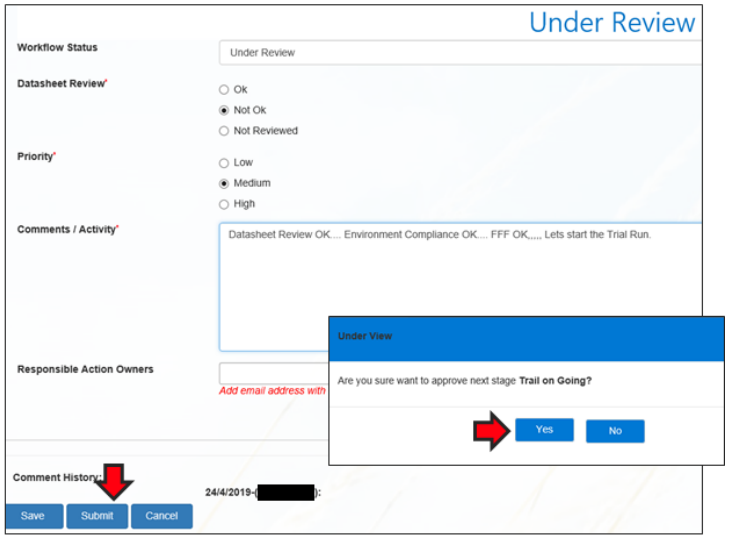
Draft proposal Review Workshop (Data 2)	
Participant Details	1) Product Engineers (2) 2) Principal Engineer (MD) 3) PE Manager (MD) 4) Principal Engineer (SD) 5) Principal Engineer (DS) 6) Manager SCM (2)
Improvement comments	**Comment Description**
Participant 1 & 2	A component is not rejected immediately until the failure is very evident. In case it is not clear, the component qualification will run into next iteration of qualification within the same stage. Hence, it must reflect in all corresponding diagrams
Participant 1	When a component level test is performed, there are cases there is still a business need that the same component has to undergo product level qualification test
Participant 2	The workflow should show clearly the steps and it should be readable and should be clearly understandable
Participant 1	Review postponed means the component qualification request is still alive and hence there is a flow missing to bring it back
Participant 4	On the process framework it good to have who has to be informed
Mostly everyone	main business process flow color must be differentiated with the sub-process or the activities, and add notes where ever possible to clarify the flow of process

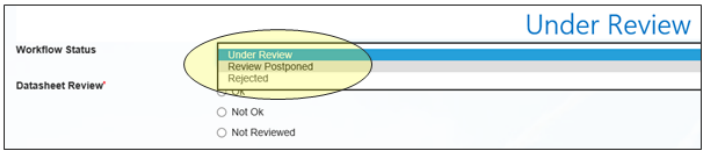
Appendix 4: Process validation using custom developed process management application software

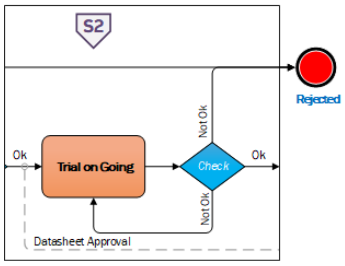


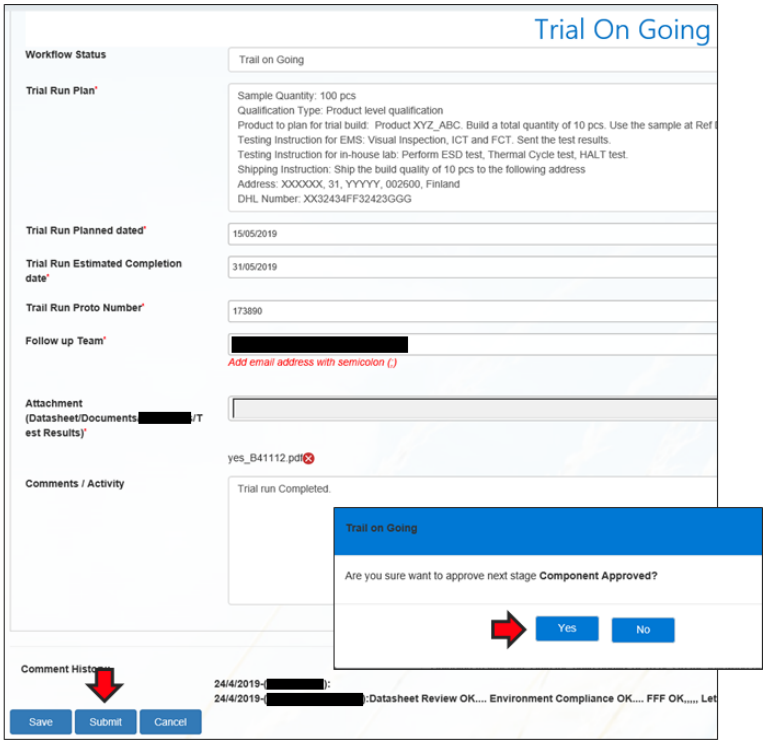


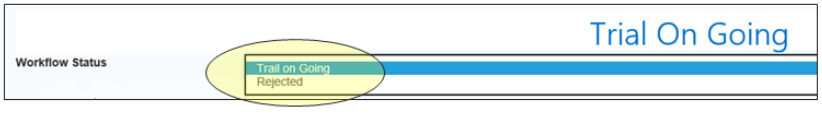

S1
Rejected
Not Ok
Ok
Under Review
Check
Ok
To review later
Postponed

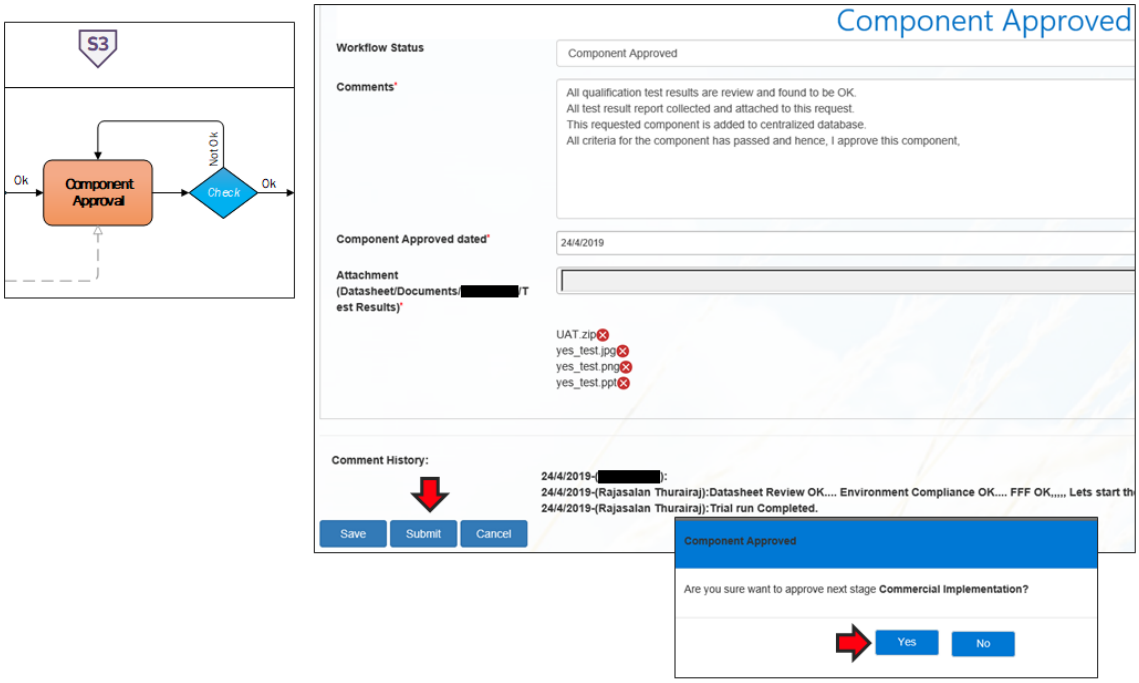

Under Review
Workflow Status
Under Review
Datasheet Review*
Ok
Not Ok
Not Reviewed
Priority*
Low
Medium
High
Comments / Activity*
Datasheet Review OK.... Environment Compliance OK.... FFF OK,,,, Lets start the Trial Run.
Responsible Action Owners
Add email address with
Under View
Are you sure want to approve next stage Trail on Going?
Yes
No
Comment History
Save
Submit
Cancel

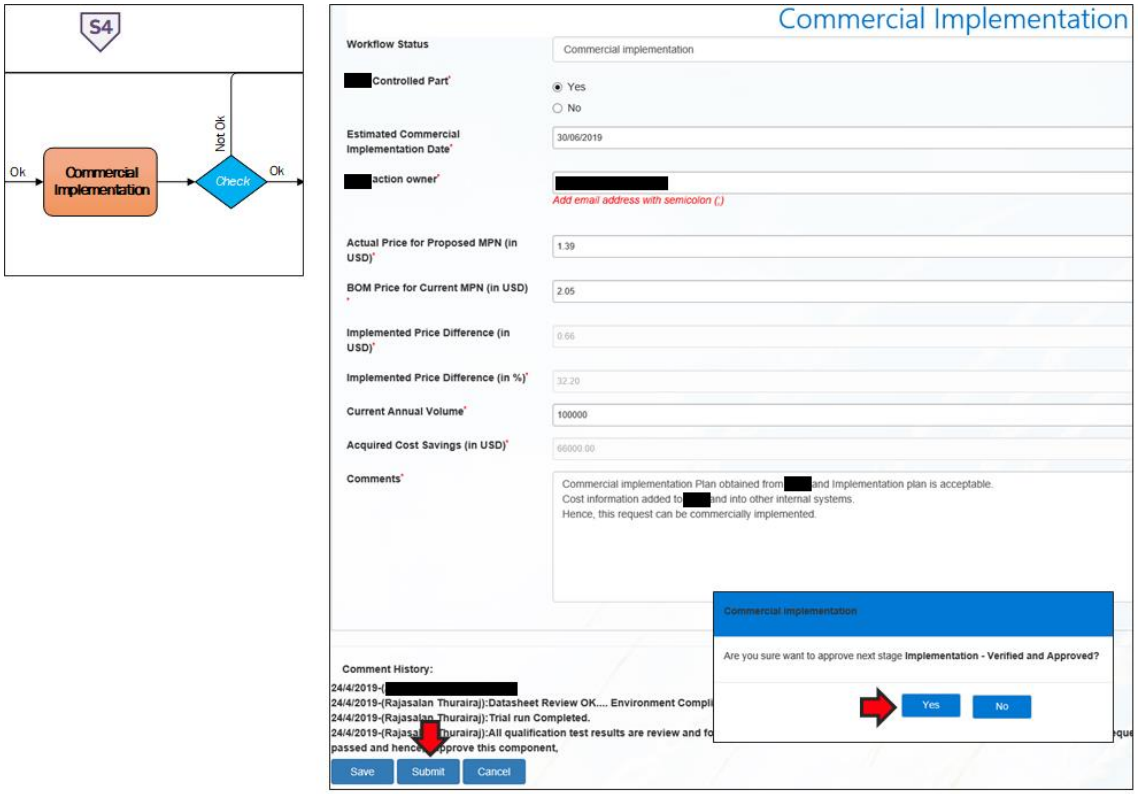

Under Review
Workflow Status
Under Review
Review Postponed
Rejected
Datasheet Review*
Not Ok
Not Reviewed

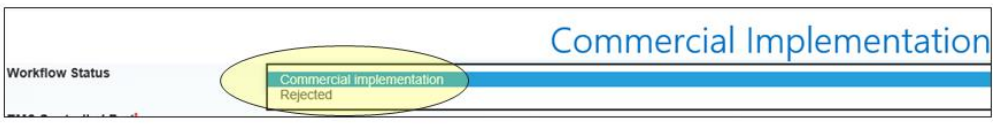

S2
Rejected
Not Ok
Ok
Trial on Going
Check
Ok
Not Ok
Datasheet Approval


Trial On Going
Workflow Status
Trail on Going
Trial Run Plan*
Sample Quantity: 100 pcs
Qualification Type: Product level qualification
Testing Instruction for EMS: Visual Inspection, ICT and FCT. Sent the test results.
Testing Instruction for in-house lab: Perform ESD test, Thermal Cycle test, HALT test.
Shipping Instruction: Ship the build quality of 10 pcs to the following address
Address: XXXXXX, 31, YYYYY, 002600, Finland
DHL Number: XX32434FF32423GGG
Trial Run Planned dated*
15/05/2019
Trial Run Estimated Completion date*
31/05/2019
Trail Run Proto Number*
173890
Follow up Team*
Add email address with semicolon (;)
Attachment (Datasheet/Documents /Test Results)*
yes_B41112.pdf
Comments / Activity
Trial run Completed.
Trail on Going
Are you sure want to approve next stage Component Approved?
Yes
No
Comment History
Save
Submit
Cancel


Trial On Going
Workflow Status
Trail on Going
Rejected


S3
Ok
Component Approval
Not Ok
Check
Ok
Component Approved
Workflow Status
Component Approved
Comments*
All qualification test results are review and found to be OK.
All test result report collected and attached to this request.
This requested component is added to centralized database.
All criteria for the component has passed and hence, I approve this component,
Component Approved dated*
24/4/2019
Attachment (Datasheet/Documents/[redacted]/Test Results)*
UAT.zip
yes_test.jpg
yes_test.png
yes_test.ppt
Comment History:
24/4/2019-([redacted]):
24/4/2019-(Rajasalan Thurairaj):Datasheet Review OK.... Environment Compliance OK.... FFF OK,,,,, Lets start th
24/4/2019-(Rajasalan Thurairaj):Trial run Completed.
Save
Submit
Cancel
Component Approved
Are you sure want to approve next stage Commercial Implementation?
Yes
No


S4
Ok
Commercial Implementation
Not Ok
Check
Ok
Commercial Implementation
Workflow Status
Commercial implementation
[redacted]Controlled Part*
Yes
No
Estimated Commercial Implementation Date*
30/06/2019
[redacted]action owner*
Add email address with semicolon (;)
Actual Price for Proposed MPN (in USD)*
1.39
BOM Price for Current MPN (in USD)*
2.05
Implemented Price Difference (in USD)*
0.66
Implemented Price Difference (in %)*
32.20
Current Annual Volume*
100000
Acquired Cost Savings (in USD)*
66000.00
Comments*
Commercial implementation Plan obtained from [redacted] and Implementation plan is acceptable.
Cost information added to [redacted] and into other internal systems.
Hence, this request can be commercially implemented.
Comment History:
24/4/2019-([redacted]
24/4/2019-(Rajasalan Thurairaj):Datasheet Review OK.... Environment Compli
24/4/2019-(Rajasalan Thurairaj):Trial run Completed.
24/4/2019-(Rajasalan Thurairaj):All qualification test results are review and fo
passed and hence, approve this component,
Save
Submit
Cancel
Commercial implementation
Are you sure want to approve next stage Implementation - Verified and Approved?
Yes
No


Commercial Implementation
Workflow Status
Commercial implementation
Rejected

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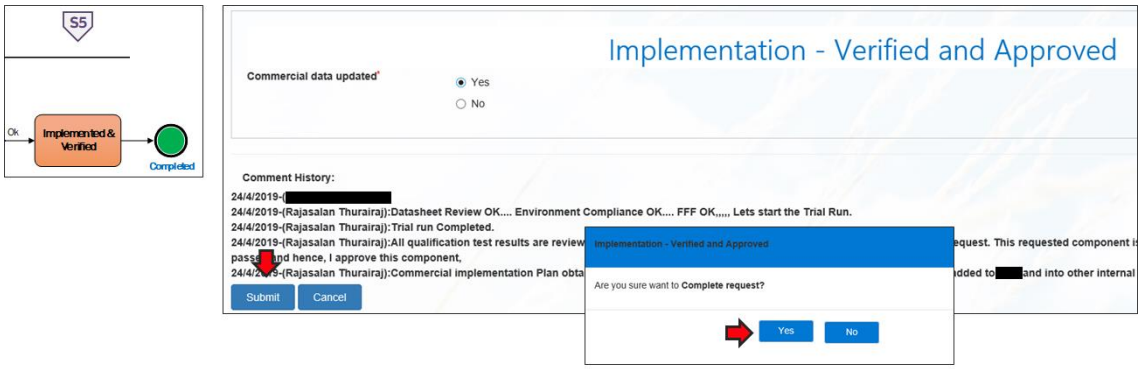

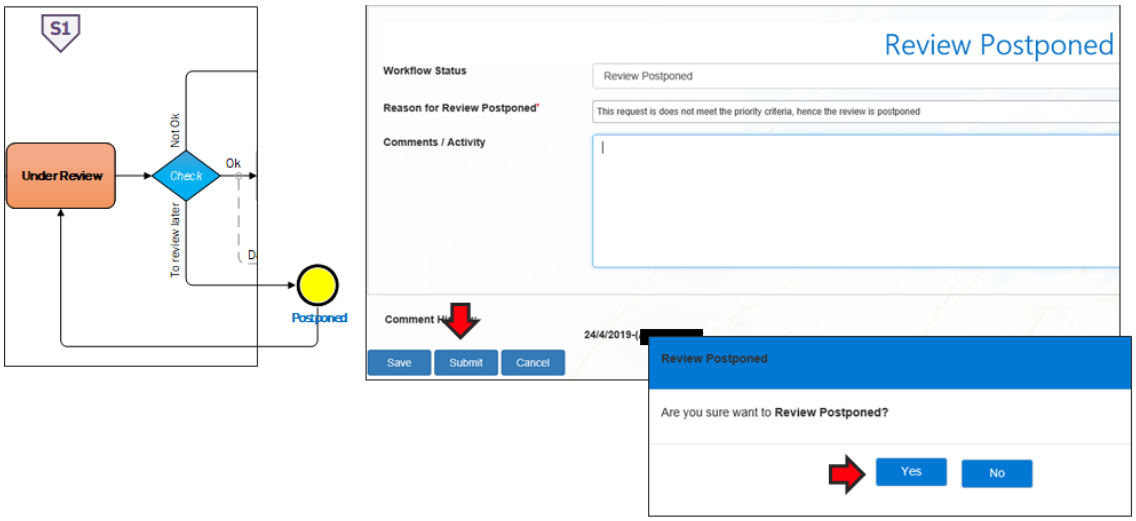

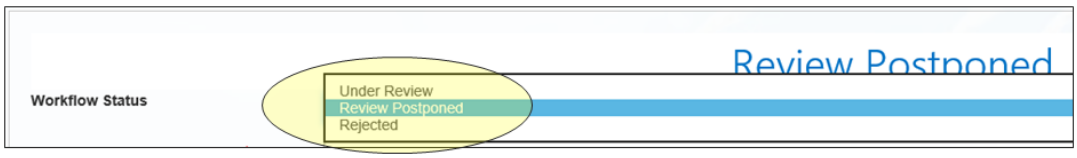

Automated email triggered from the custom developed application software to the stakeholders

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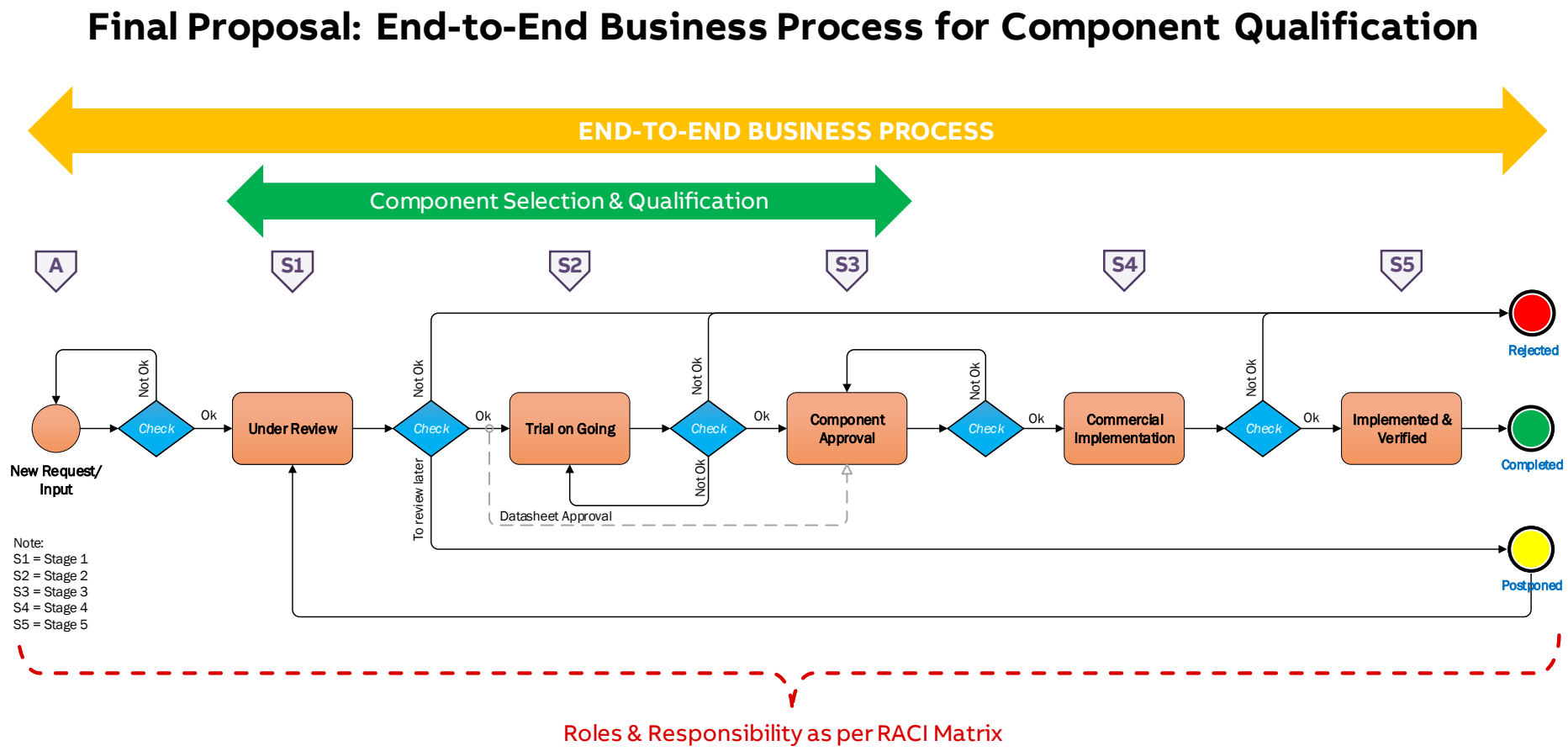
Appendix 5: Improvement feedback for custom developed application software

Improvement feedback for custom developed application software	
Stage / Status	**Feedback**
New Request	-Where used information search should be made possible to search with description - Code should be allowed to copy and paste - While copy and paste, application software should validate automatically
Under Review	None
Trial on Going	- Spelling mistake 'Trail' to be changed to 'Trial' - Trial run plan, edit option should be provided for external partners - Attachment should be allowed for external parties as well.
Component approval	- Spelling mistake 'Component Approved' to be changed to 'Component Approval' - Here it should allow to tag the next stage participant auto-matically' as the owner ship changes as per the proposed new component qualification process.
Commercial Implementation	- should also allow to tag mixed control parts
Implemented and Verified	- when selected 'No', the software should not allow to ap-prove the stage. - Even though if it has to be submitted, the approver has to provide reasons for approving
Postponed	- Status typo error, need correction
Rejected	None

Appendix 6: Final Proposal – Component Qualification Process for the case company



Final Proposal – End-to-End Business Process for Component Qualification.

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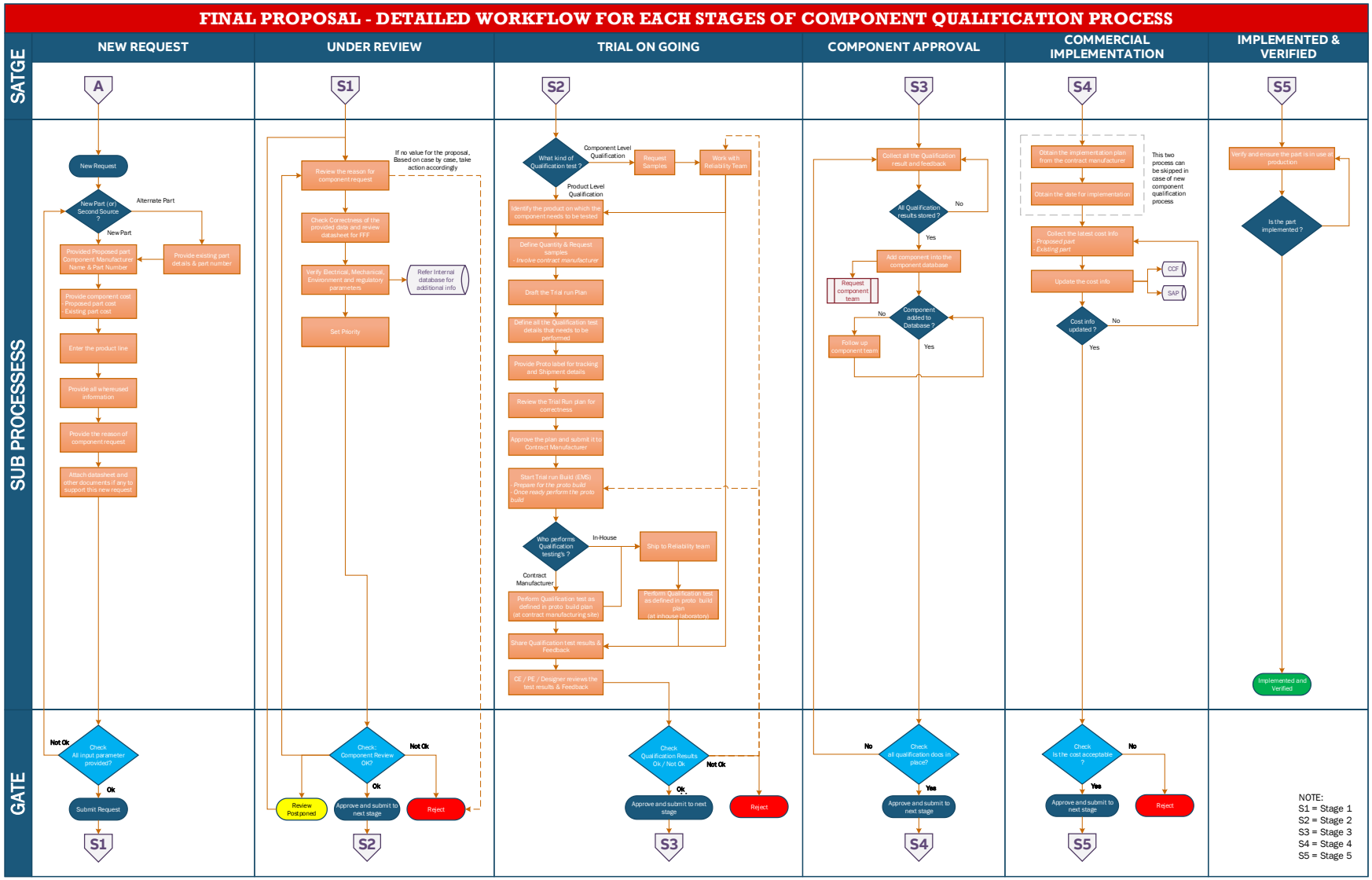

Final Proposal – Detailed workflow for each stages of Component Qualification Process.

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FINAL PROPOSAL - RACI MATRIX FOR COMPONENT QUALIFICATION PROCESS (R = RESPONSIBILITY, A= ACCOUNTABILITY, C= CONSULT, I= INFORM)						
PROCESS / ACTIVITIES	**ROLE OF PARTICIPANTS**					
	Requestor (Internal or External)	**Component Engineer/ Product Line owners**	**Product Engineer / Principal Engineer / R&D Engineer**	**Reliability Engineer**	**Contract manufacturer**	**Sourcing**
New Request						
Updating all mandatory data - Component manufacturer and part number, Cost Info, updating Product Line and whereused Info, valid Reason for Request and providing technical datasheet	R/A	C	-	-	-	C
Attaching datasheet or technical documentation	R/A	C	-	-	-	C
Under Review						
Review input data	I	R	C/A	-	-	C
Electrical Specification Review with Datasheet	I	R	C/A	-	-	C
Set Priority	I	R	C/A	-	-	C
Approving / Rejecting the review (Stage approval)	I	R/A	C	-	-	-
Trial On Going						
Defining Qualification Test requirements	I	R	C/A	-	I	-
Product Indentification for Component Testing	I	R	C/A	-	I	-
Trial run plan - Draft	I	R	C/A	-	C	-
Sample Request	I	R	C/A	-	C	C
Qualification Test details	I	R	C/A	-	I	-
Proto Label and Shipping Information	I	R	C/A	-	I	-
Finalizing Trial run plan	I	R	C/A	I	I	-
Proto Build as per plan	I	C/A	C	I	R	-
Performing Qualification Test (@EMS)	I	A	C	I	R	-
Performing Qualification Test (@ In-House)	I	C	A	R	-	-
Qualification Test Results (EMS) & Manfacturing Report	I	C/A	C	-	R	-
Qualification Test Results (In-House)	I	C/A	C	R	-	-
Qualification Test Result Review	I	R	C/A	I	-	-
Approving / Rejecting Trial on Going (Stage approval)	I	R/A	C/A	I	I	-
Component Approved						
Collecting and Storing all Qualification data	-	R/A	C	-	-	-
Adding Qualified Component to database	-	R/A	C	-	-	-
Approving the component (Stage Approval)	I	R/A	I	I	I	I
Commercial Implementation						
Plan for Commercial Implementation	I	I	-	-	C	R/A
Date for Implementation	I	I	-	-	R	A/C
Collecting latest cost info	-	-	-	-	C	R/A
Updating cost info to Database	-	-	-	-	-	R/A
Approving/Rejecting (Stage approval)	-	I	-	-	I	R/A
Implemented & Verified						
Verify the part is used in production	-	-	-	-	C	R/A
Final Approval	I	I	I	-	I	R/A

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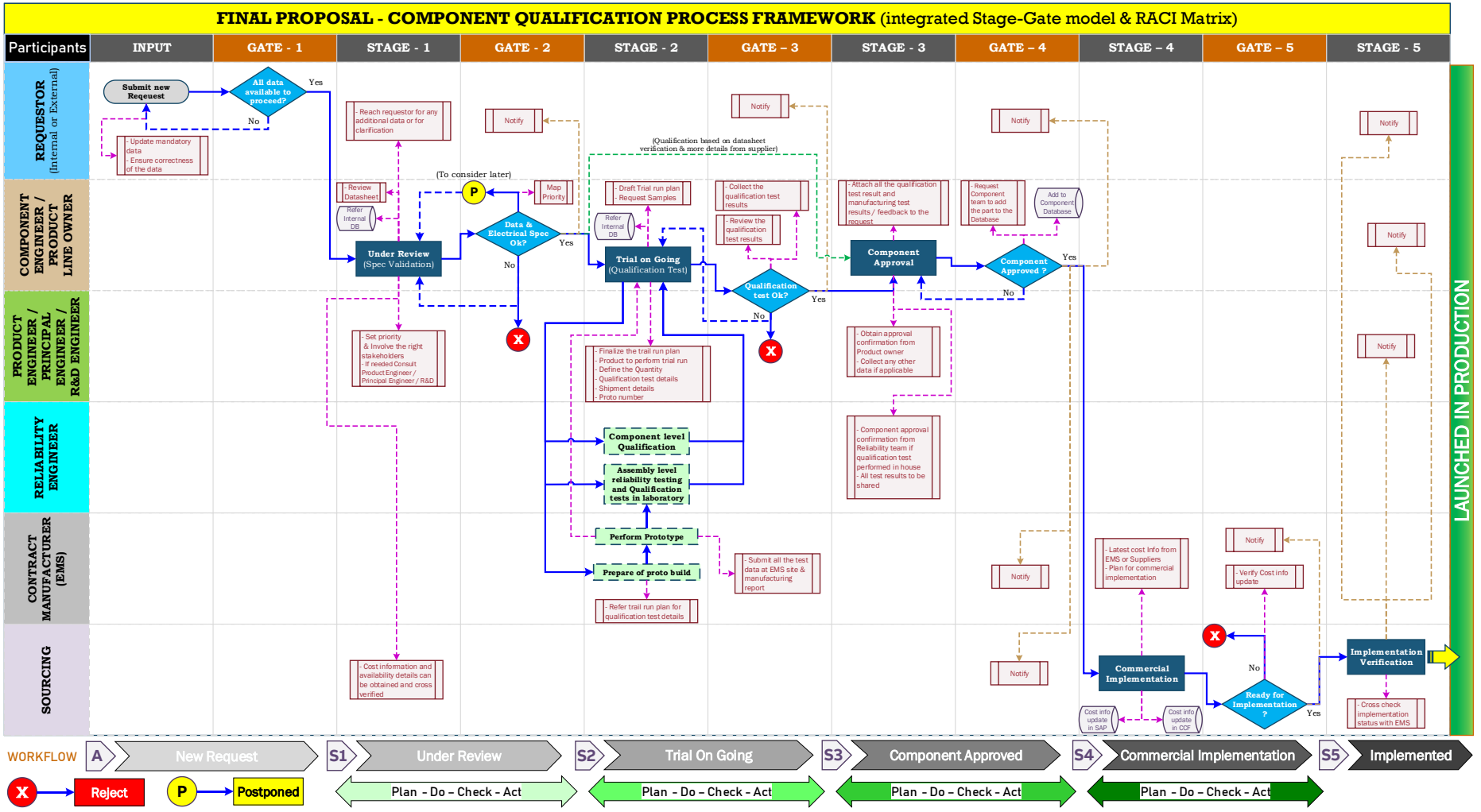

Final Proposal – Component Qualification Process Framework.

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