Title- The relevant aspects of Lean to ensure reliability in electronic hardware development: Case organization-Bosch Rexroth, Mellansel.
Abstract

Product development is considered an important key factor in the fourth industrial revolution (Industry 4.0) as products are becoming more competitive and complex due to market competition. Currently, customer satisfaction mostly depends on product reliability especially when it comes to electronics hardware. From the early stages of electronic hardware development, product development team have to maintain high reliability by reducing mistakes as it is deeply related with the cost of the final product. In this above scenario, LPD can play an important role which deal covers all aspects of a product's development including reliability, from gathering and generating ideas, to assessing success potential, to building concepts, evaluating them, detailing the product, testing, developing, and handing it over for manufacture. From the literature, it shows that the framework for achieving reliability in line with LPD in electronic hardware is very limited. Hence, the author in this research considers that the different aspects of reliability with LPD needs to be identified and framed to have a reliable product, especially for electronics hardware development.

To fulfill the research objectives, the authors conducted a literature review to identify the relevant aspects of lean to achieve reliability in electronic hardware development. Then all the relevant aspects were framed in a framework. Further, a single case study was conducted in Bosch Rexroth, and interviews were taken from the selected case organization to explore and justify the relevant aspects of lean. Different views of the interviewee were presented in data analysis section and at the end, the conclusion is presented to show the relevancy of the selected aspects based on the interviews, theoretical implications, practical implications, and future research.

Keywords- Lean, LE (lean enterprise), Product Development, LPD (lean product development), PPD (Product and process development), Reliability, Hardware.
Acknowledgments

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Finally, to our family members, we would like to say this is a bit emotional and it’s a dedication to you for all the moral support. THANK YOU all.

Halmstad, June 2023

Lijo Johnson Kanjiraparambil                                Pallab Barua
List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>LE</td>
<td>Lean Enterprise</td>
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<tr>
<td>LPD</td>
<td>Lean product development</td>
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<td>PPD</td>
<td>Product and process development</td>
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<tr>
<td>CRM</td>
<td>Customer relationship management</td>
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<tr>
<td>HRM</td>
<td>Human resource management</td>
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<tr>
<td>MCL</td>
<td>Management commitment and leadership</td>
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<tr>
<td>TQM</td>
<td>Total quality management</td>
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<tr>
<td>SCM</td>
<td>Supply chain management</td>
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<tr>
<td>CE</td>
<td>Concurrent Engineering</td>
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<tr>
<td>CI</td>
<td>Continuous improvement</td>
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<tr>
<td>PLC</td>
<td>Programmable logic controller</td>
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<tr>
<td>TPM</td>
<td>Total productive maintenance</td>
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<tr>
<td>KM</td>
<td>Knowledge management</td>
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<tr>
<td>JIT</td>
<td>Just-in-time</td>
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<tr>
<td>ITM</td>
<td>Information technology management</td>
</tr>
<tr>
<td>STA</td>
<td>Security threat analysis</td>
</tr>
<tr>
<td>PRM</td>
<td>Product management</td>
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<tr>
<td>ECR</td>
<td>Engineering change request</td>
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<tr>
<td>PCB</td>
<td>Printed circuit board</td>
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<tr>
<td>FMEA</td>
<td>Failure mode and effect analysis</td>
</tr>
</tbody>
</table>
# Table of Contents

1. **Introduction** .................................................................................................................. 1  
   1.1 Background .................................................................................................................. 1  
   1.2 Problematization ......................................................................................................... 3  
   1.3 Thesis layout .............................................................................................................. 5  

2. **Theoretical framework** ................................................................................................. 7  

3. **Literature review** ......................................................................................................... 8  
   3.1 Reliability .................................................................................................................... 8  
      3.1.1 Reliability Engineering .......................................................................................... 8  
   3.2 Lean ............................................................................................................................. 14  
      3.2.1 Muda/wastes ......................................................................................................... 14  
         3.2.1.1 Overproduction .............................................................................................. 14  
         3.2.1.2 Waste of time on hand (waiting) ..................................................................... 15  
         3.2.1.3 Waste in Transportation ................................................................................. 15  
         3.2.1.4 Waste in Processing ....................................................................................... 15  
         3.2.1.5 Waste of stock in hand (inventory) ................................................................. 15  
         3.2.1.6 Waste of movements (motion) ....................................................................... 15  
         3.2.1.7 Waste of making defective product .................................................................. 16  
      3.2.2 Lean Principles ....................................................................................................... 17  
         3.2.2.1 Value ............................................................................................................... 17  
         3.2.2.2 Value stream .................................................................................................... 18  
         3.2.2.3 Flow ................................................................................................................ 18  
         3.2.2.4 Pull .................................................................................................................... 18  
         3.2.2.5 Perfection ......................................................................................................... 19  
   3.3 **Product Development** ............................................................................................. 19  
      3.3.1 Idea generation ..................................................................................................... 19  
      3.3.2 Idea screening ....................................................................................................... 19  
      3.3.3 Concept development ......................................................................................... 20  
      3.3.4 Concept testing .................................................................................................... 20  
      3.3.5 Business analysis ............................................................................................... 20
3.1.2 Reliability activities applied in the lifecycle of commercial airplanes ........................................ 12
3.1.3 Concept map of reliability engineering ..................................................................................... 13
3.2.1 Types of Muda/waste .................................................................................................................. 16
3.2.2 Lean Principles .......................................................................................................................... 17
3.4.1 The conceptual lean PPD Model ............................................................................................... 21
3.4.2 Toyota Production System ......................................................................................................... 22
3.4.1 Integrated conceptual framework of product reliability ............................................................. 24

List of tables
1.2.1 LPD enablers and problems........................................................................................................ 4
4.1.1 An overview of the theoretical framework ................................................................................. 30
5.1.6.1 The number of interviews that were conducted to gather the empirical data ................. 42
5.4.1 A sample of coding the gathered primary data .......................................................................... 46
1. INTRODUCTION

Here, the authors provided some background information about product development, reliability and lean manufacturing as an intro to the topic. The problematization and purposes of the research are covered to have better understanding and further linkage within the topic. Problematization is also intended to feature the gap identified, which in turn lead to the research question. Towards the end, the thesis layout is presented to provide a representation of the structure.

1.1 BACKGROUND

Industry 4.0; the fourth industrial revolution is considered a new paradigm shift to not only realize smart products but also to generate smart products and it is a combination of internet technologies and future-oriented technologies in the field of smart objects which is later found on under the product development concepts (Rauch et al., 2016). Product development becomes an essential key area for the manufacturing industry to drive commercialization and growth, and the concept of product development refers to all the activities involved in designing, creating, and delivering a product, from identifying a market opportunity to delivering it (Patil et al., 2017). In recent decades, the market becomes more competitive, products and processes become more complex, and consumer satisfaction is placed more importance on product reliability, apparently lack of reliability means it may have a number of undesirable consequences, including safety, competitiveness, maintenance costs, brand reputation, and brand value (Paganin & Borsato, 2017).

Reliability can be defined as “the probability that a component, device, system or process will perform its intended function without failure for a given time when operated correctly in a specified environment” (Waghmode & Patil, 2016). Reliability has several characteristics, including the knowledge of probability of success, durability, dependability, quality over time, and availability which should be considered at the initial stages of PD process (Crossley, 2007; Paganin & Borsato, 2017). By obtaining and considering all this knowledge in PD process, manufacturing firms can improve product quality and reliability by facilitating the reuse of knowledge and resources to assist engineers in developing new products (Zhenyong et al., 2020). For example— electronic hardware development usually needs to be secured and it is important to maintain high quality or reliability from the early stages of hardware development process, since mistakes from
production can be costly as well as quality affects the product's perceived functionality (Berg et al., 2020). As a result, the most significant impacts of the product development process is the cost of the final product (Jasti & Kodali, 2014). Before going to the further elaboration of electronic hardware, it is important to know the history of electronics industry, although it is a huge area and it is not possible to mention the systematic history of electronic industry (Bhuyan, 2016). Bhuyan also stated that history of electronic hardware industry was begun mainly with the invention of vacuum tube which was invented by an English physicist named Jarnes Alnbrose Fieming in 1904 and the era of modern electronics industry started basically after the two world wars when the world was facing economical crisis and the political leader felt the importance of researching more on electronics.

Electronic hardware development has become increasingly intricate and demanding in recent times due to various factors which includes a scarcity of components, reduced lifespan, rapid technological progress, difficulties associated with modularization in electronics, the necessity for system upgrades, compatibility concerns, and challenges related to integration (Chan & Ip, 2011; Relich, 2016).

Hardware development teams can make it possible to reduce costs, improve reliability (quality) can reduce delivery times with flow and pull systems of lean (Sofio, 2023) as bulk production always requires detailed product development concepts which can affect costs, quality and delivery times (Grijota et al., 2021). Here, “Lean is– an improvement philosophy which focuses on the creation of value and the elimination of waste has provided substantial improvement and gains to manufacturing and other sectors” (Khan et al., 2015). Hence, lean is not only a collection of tactics, but also a principal approach to creating new products (Ries, 2011).

In short, the goal of Lean is to develop a picture of the current state in order to identify waste, improving efficiency and reliability and calculate lead times in PD process (Pinheiro & De Toledo, 2016). Therefore, lean and product development can be a combined approach of creating value out of knowledge and learning, which connects people, processes, and technology (Hejazi et al., 2020). According to the lean concept in PD, the ideal is to provide customers (both internal and external) with exactly what they need to accomplish their goals without wasting any resources; waste can be defined as any cost incurred, which does not reduce the value delivered when it is eliminated (Powell et al., 2014). By using the LPD process, a best prototype can be developed for
further analysis and a shorter lead time can be achieved for delivering the product to the customer (Jasti & Kodali, 2014).

1.2 Problematization

Reliability of a product is a crucial factor to consider since there are so many options available from global players and the new product life span decreased significantly due to technological advancements, increasing customer demands, and global competition (Chan & Ip, 2011; Relich, 2016, Jasti & Kodali, 2014). Especially when it comes to electronic hardware development, it is really harder as not only the human resources are required but also the materials are equally important and ultimately, third-party participation is required, resulting in additional costs in terms of time and money (Consortium, 2019). Hardware development processes assumed stable requirements and that all design work could be done at once, but in reality, requirements changed throughout the project and technology, customer needs, and market conditions all changed (Maarit, 2016).

Here, different scientific papers from different timelines are presented to observe the state of reliability. Rosenthal (1992), Cooper (2000), and Swink and Song (2007) discussed product testing as a common factor for reliable product development process. It's necessary to ensure the reliability of the overall system by the testing of product since a successful embedded product development project depends heavily on the maturation of hardware, how the design evolves after receiving feedback on the design created and tested (Maarit, 2016). Although the reliability of electronics hardware components can be influenced by multiple factors, including short circuits, open circuits, degraded performance, functional failures, and the frequency at which these failures occur, making it challenging to design a system that takes into account the specific failure modes and their likelihood of occurrence (Misra 2008). Therefore, Alvarez (2015) argued that the scope is very limited to achieve the zero-faulty product if there are noticeable missing tools such as reliability.

In this above scenario, LPD can play an important role which deal covers all aspects of a product's development including reliability, from gathering and generating ideas, to assessing success potential, to building concepts, evaluating them, detailing the product, testing, developing, and handing it over for manufacture (Rauch et al., 2016). Although LPD also became vague at times
since there is numerous practices and principles involved with LPD (Wang et al., 2012). As a result, Manufacturing industries are facing increasing pressure to compete on improving product reliability while satisfying the time to develop new products for the marketplace (Zhenyong et al., 2020) and the main challenging task becomes now for a manufacturing industry is to select a suitable LPD framework. For an example- Jasti and Kodali (2014) analysed 35 different LPD frameworks via reliability and validity test but unfortunately they couldn’t find a single suitable LPD frameworks for manufacturing industry and according to them the question arises “which LPD framework will be suitable for the manufacturing industry in this modern era?”. Finding the suitable LPD framework might be challenging but there are some other LPD problems related to reliability which is identified by Tortorella et al., (2016) and to solve these problems they proposed few LPD enablers which are as follows-

<table>
<thead>
<tr>
<th>LPD Enablers</th>
<th>LPD problems</th>
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<tbody>
<tr>
<td>1- Set based concurrent engineering,</td>
<td>1- To achieve true cross-functional integration</td>
</tr>
<tr>
<td>2- Value focus,</td>
<td>2- Lack of communication and feedback</td>
</tr>
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<td>3- Knowledge focus and continuous improvement culture</td>
<td>3- Lack of product portfolio strategy</td>
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<td></td>
<td>4- LPD performance measurement system</td>
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<td></td>
<td>5- No IT integration</td>
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<td></td>
<td>6- Lack of knowledge reutilization</td>
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Table 1.2.1- LPD enablers and problems (Tortorella et al., 2016)

Although Tortorella et al., (2016) claimed that counteraction of those enablers to the mentioned problems is bit unclear especially due to lack of evidence and they also raised a question here is - in which way the enablers can be handy to cover the identified problems concerning reliability in PD process? So, there is clearly a research gap between LPD enablers and their influence on LPD problems in terms of product reliability.

From above discussion, it is quite clear that not only the role of lean in product development is an essential part for manufacturing industry to reduce the lead time and increase the efficiency but also at the same time it is important to consider the aspects of reliability in the product development process. It has already been seen that selecting a LPD framework with the respective industry is challenging as well as the LPD problems when considering reliability. Furthermore, while
researchers such as Rauch et al., (2016) showed the comparison between Industry 4.0 and LPD, Wang et al., (2012) introduced LPD framework via step by step process through value and waste analysis, Jasti and Kodali (2014) analysed different LPD frameworks for manufacturing industry and Tortorella et al., (2016) identified few LPD enablers regarding some LPD problems but the research on a framework for achieving reliability for electronic hardware with LPD is very limited. Therefore, the author in this research considering that the different aspects of reliability with LPD needs to be identified and framed to have reliable product, especially for electronics hardware development.

**Research purposes**

Keeping focus on ‘Reliability’ as a research gap, the authors in this research seek to explore the following research question as part of their effort to understand the cohesion between lean and reliability in product development and to make an integrated conceptual framework for a reliable electronic hardware development.

**Research question**

What are the relevant LPD aspects and how to integrate them for a reliable electronic hardware development?

### 1.3 Thesis layout

The authors followed a structure which is presented here to have a clear visual for the readers.

**Theoretical framework**- This section is providing a visual representation of relevant topics related to this thesis.

**Literature review**- In this part, the authors described different theory such as Reliability engineering, LE, Lean PPD model, an overview of theoretical framework and finally a conceptual framework is presented at the end of this section.

**Methodological choices**- Here, a description of research methodology is presented along with Research design. The research design includes the following- Qualitative research, Deductive approach, Research strategy, Case Selection, Case organization, Data collection procedure, Data analysis procedure, Quality of research findings, Research ethics.
Findings and analysis- In this section, all the gathered data is analysed through coding and discussed in three main categories such as people, process and technology.

Conclusion and discussion- The conclusion and discussion section of the study provides a concise summary of the significant findings, along with general reflections on how these results relate to the conceptual framework for achieving reliable product. Additionally, the section highlights the theoretical implications, practical implications and limitations of the study in a comprehensive manner. The section concludes by offering suggestions for future research directions.
2. Theoretical framework

The purpose of this section is primarily to provide an overview of what is to be discussed in the following section. As shown in the following diagram, two large portions are representing two different areas. A portion on the right depicts Lean and PD, while the portion on the left depicts Product Reliability with all the relevant frameworks. They both share a common area in the middle where all the relevant common aspects are presented. The next chapter literature review was described according to the diagram.

![Diagram of Conceptual Framework]

**Figure 2.1** - Three foundations of conceptual framework

Source: Kanjiraparambil L. J, Barua P. (The authors of this thesis)
3. Literature review

Here, the authors tried to explore the theoretical frameworks with the help of the existing theories from the relevant literature. A brief overview of reliability and LPD is presented in this section. Then both part is aligned to explore LPD framework where reliability engineering will be the focused area. The purpose of this section is mainly to enrich the knowledge regarding lean, product development and to understand the cohesion between lean and product development in terms of reliability which will assist the author in developing a conceptual framework.

3.1 Reliability

Recent decades have seen a rise in studies on product reliability owing to increasing competitiveness, complex products, and consumer satisfaction (Paganin & Borsato, 2017). To ensure the desired product reliability, a system approach must be taken both in selecting new product development projects and from the business perspective (Relich, 2016). According to Zio, (2009); the word "reliability" was first recorded in the 1800s, but it referred to a person rather than a technical system. Over time, reliability has become an important attribute, both qualitatively and quantitatively. Social, cultural, and technological changes over the past two centuries have led to the need for a rational framework and quantitative treatment of the reliability of engineered systems and plants. For instance- In the past, when the military developed or modified a product, they would test it for reliability over a long period of time to make sure it met their requirements. Once the product passed the tests, it was delivered to the military with proof that it was reliable. But this process was costly which creates a lot of drawbacks (Kerscher et al., 1998). As a result, reliability engineering has emerged as a scientific discipline (Zio, 2009).

3.1.1 Reliability Engineering

Reliability engineering seeks to develop methods and tools for evaluating and demonstrating reliability, maintainability, availability, and safety of components, equipment, and systems, as well as supporting manufacturers in integrating these characteristics into their products (Held et al., 2006). According to Misra (2008); the objectives of reliability engineering are as follows-

- To prevent product or system failures.
- To identify and check the failure mechanisms.
- To identify ways in which failures can be reduced.
- To improve future designs, methods of estimating reliability, as well as analyzing reliability data.

Held et al. (2006) considered reliability as one of the foundational pillars for the successful technical products and they also argued that when reliability is high, development costs are higher, and operating costs are lower, so the optimum cost is between exceptionally low and extremely high reliability (see-Figure 3.1.1.1) though it is not possible to get a 100% reliable product as reliability can never be 100% (Misra, 2008). Waghmode and Patil (2016) emphasized on ‘reliability analysis’ which is crucial for managing product/system failures, as poor reliability can have undesirable consequences, while life cycle cost analysis is necessary to understand the cost implications over the operational life of the product/system.

![Figure 3.1.1.1 - Generic correlation between life cycle cost and reliability,](source)

Meeker and Escoba (2004) emphasized on the significance of a comprehensive approach to reliability that includes statistical analysis, data collection, and proactive maintenance and repair strategies. Zio (2009) opined reliability engineering also meant to the service and satisfaction of the customer after receiving it, which requires the interrelated processes involved in ensuring availability, including those related to hardware, software etc. Zio (2009) also discussed that
modern systems are becoming more complex and interconnected, making traditional reliability engineering methods inadequate and new challenges faced by reliability engineering include incorporating human and organizational factors, addressing cybersecurity threats, and managing uncertainty.

Paganin and Borsato (2017) expressed the same opinion as designing products with a large number of uncertainties in the early stages of the process can pose a challenge to reliability estimation, making it necessary to explore alternative approaches to traditional reliability forecasting models. Paganin and Borsato (2017) conducted a critical review of design for reliability and identified that DFR (design for reliability) approach has grown significantly and implementing Design for Reliability (DFR) in product development can help identify issues with prototyping, reduce costs, decrease field failure rates, and speed up product launch, but this requires reliability and quality-focused activities throughout the development cycle to achieve stability, repeatability, and maturity in testing. According to Silverman (2013), to implement the DFR program successfully following attributes have to keep under consideration:

- Prior to starting the program, set goals and then develop a plan to reach them.
- Assigning reliability goals to the design team with the reliability team acting as mentors.
- Establish metrics by which the company can measure its position with respect to the previously set goals.
- Create a Reliability Plan (not only a test plan) to guide your program.

In line with uncertainty issues, Kabir and Papadopoulos (2018) highlighted a very popular part of reliability engineering nowadays which is known as Fuzzy set theory and this is a Probabilistic risk assessment approach to manage the uncertainty. They discussed how fuzzy sets have been applied in safety and reliability engineering, such as in risk analysis, fault diagnosis, and reliability assessment. Kabir and Papadopoulos (2018) opined that Fuzzy sets allow for the representation of uncertain or imprecise information by assigning a degree of membership to each element of a set, ranging from fully belonging to not belonging at all (e.g. value between 0 and 1) and include different types of approaches such as Fault Tree Analysis (FTA), Failure Mode and Effects Analysis (FMEA), and Event Tree Analysis (ETA). Moreover, a safety analysis approach is also proposed by Zhao et al., (2022) during severe accidents using dynamic fault trees, which takes into account the dynamic behavior of the system over time and the interactions between components. They accomplished a case study on a nuclear reactor and highlighted the importance of considering
dynamic factors (e.g. timing and sequence of events, the control mechanisms in the system, the response of the system to changing external conditions, and the failure modes and degradation of components over time) in safety analysis.

In line with cybersecurity issues, Alanen et al., (2022) presented a Security threat analysis (STA) method to identify potential security threats to an industrial control system which assists to identify potential threats, analyze the impact of those threats, and recommending countermeasures to mitigate the risks. STA ontology includes various stages such as- Vulnerability, origin, threat, threatening action, attacker capability, attacker intent, threat consequence, countermeasures, impact, risk etc.

Popović (2019) claimed that companies often mimic their competitors' reliability claims without understanding the actual differences in process results, leading to unnecessary costs and losses from customer complaints or decreased demand. He also promoted the American reliability approach which considers reliability design (reliability of systems and components of process results), reliability planning (test plan, warranty plan, forecasting plan, product or service guarantee plan), and reliability testing (checking true reliability via experiment under higher loads). For instance- In aviation industry there is a huge amount of application of electronics hardware, and they maintain some reliability activities. According to ZIO et al., (2019), the aviation industry is a successful example for implementing the reliability engineering and the lifecycle of commercial airplanes is comprised of three phases - design and development, manufacturing, and operation (see- figure 3.1.1.2) - and various reliability-related engineering activities are performed in each phase to ensure final reliability levels. In the design and development phase, reliability analysis and design techniques are used to determine design solutions that meet reliability requirements, followed by verification and validation. Typically, reliability analysis is concerned with failures occurring over time and Alghamdi, (2023) discussed about a new statistical method of reliability analysis i.e. competing risks model which involves maximum likelihood estimation and hypothesis testing to make inferences about the distribution parameters, survival functions, and hazard rates of the lifetime with the help of simulated and real-time data.

In the manufacturing phase, quality assurance techniques are used to maintain the inherent reliability of the design solution, while fault diagnosis and maintenance ensure operational
reliability in the operation phase. Maintenance is identified as an important issues of reliability engineering by Gámiz et al., (2023) to check the health state of any electronics component. Gámiz et al., (2023) presented Hidden Markov model applications mainly in two areas-

- Reliability modelling-Hidden Markov Models can be used to analyze the health state of a system over time using observed data, such as sensor measurements.
- Maintenance optimization- Hidden Markov Models can be used to make maintenance decisions by predicting when maintenance should be done based on the system's health state over time.

ZIO et al., (2019) also emphasizes on the importance of continuous improvement (Total quality management, lean manufacturing etc.) in the use of reliability technologies in civil aviation industry.

![Diagram of Reliability activities applied in lifecycle of commercial airplanes]

**Figure 3.1.1.2** - Reliability activities applied in lifecycle of commercial airplanes

Source-(ZIO et al., 2019)
3.1.1.2 Concept map of Reliability Engineering

![Concept map of reliability engineering](image)

**Figure 3.1.1.3-** Concept map of reliability engineering

Source: Kanjiraparambil L. J, Barua P. (The authors of this thesis)
3.2 Lean

The roots of Lean can be traced back to Venice in the 1450s, not Henry Ford or Toyota in the 1900s as many people believe and by eliminating waste and streamlining processes, Lean aims to save time, space, materials, and money (Lean Enterprise Institute, 2021). After the 2nd world war, Eiji Toyoda and Taiichi Ohno at the Toyota motor company pioneered the lean concepts followed by almost all Japanese companies and helped them to face the shortages of capital, drastic changes in customer requirements and to build their economy stronger (Jasti et al., 2020; Womack et al., 1991, p.11). However, the lean production became familiarized after releasing the book named “The machine that changed the world” by Womack et al., 1990 (Jasti et al., 2020). Lean production as “lean” because it uses half of everything in a factory, half of the manufacturing space, half the tools, half of the engineering hours to develop a new product in half the time which is having less defects and greater variety (Womack et al., 1991).

3.2.1 Muda/Waste

“Muda” the only Japanese word we should know which means “waste”, specifically any kind of human activity which absorb resources instead of creating value is defined as waste (Womack & Jones, 1996). There are seven types of wastes identified at the Toyota production system which are as follows—waste of overproduction, waste of time on hand (waiting), waste in transportation, waste in processing, waste of stock in hand (inventory), waste of movements (motion), waste of making defective products (Ohno, 2019). These seven types of wastes explained below from Ohno’s perspective-

3.2.1.1 Overproduction

This is identified as a worst and terrible waste among all the wastes in business. To overcome this challenges Taiichi Ohno claimed, it requires revolution in consciousness which means a change of attitude and viewpoint by business people. When a worker do not have anything to do, he tries to do something else instead of waiting. In this case, the waiting is hidden. If it happens repeatedly, inventory will start to accumulate in the production lines and finally the inventory have to move which is totally a waste. This phenomena is defined as a overproduction at Toyota production system and it is recognised as a worst enemy of manufacturing industry as it hides another wastes (Ohno, 2019).
3.2.1.2 Waste of time on hand (waiting)- According to Ohno, waiting is a form of waste. Slowing down production and reducing efficiency are two reasons why waiting is considered waste. Workers can be less productive and incur higher costs when they have to wait for materials or equipment, or when production processes are delayed (Ohno, 2019).

3.2.1.3 Waste in transportation- In Ohno's view, transportation is a form of waste because it adds no value to the product and can cause inefficiencies in production. When products are moved from one location to another without any value-added activities taking place during transportation, it is considered transportation waste. Because of this, excess inventory can be created, lead times can increase, and storage costs can increase (Ohno, 2019).

3.2.1.4 Waste in processing- Ohno argues that processing waste can be reduced by focusing on activities that add value to the product and avoiding those that do not. Processing waste has a significant negative impact on productivity. Because of unnecessary steps in production process, production time increases which ultimately reduces the productivity and increases the costs for the organization. The waste of processing also can increase the lead times, which causes late deliveries and makes the customer dissatisfied. Moreover, processing waste can lead to increased inventory levels by which excess inventory can accumulate, tying up resources and increasing the costs associated with storage and handling (Ohno, 2019).

3.2.1.5 Waste of stock in hand (inventory)- Excess inventory is a source of various types of negative consequences which causes unnecessary space blocking. The most significant impact of this waste is cost associated with the storage handling. The another impact of this waste is the reduction of flexibility. When excess inventory occurs, it can create impact on the ability of the organization to respond quickly according to customer demand or market conditions. Quality of the product also can be reduced as errors and defects in the production process may go unnoticed because of excess inventory (Ohno, 2019).

3.2.1.6 Waste of movements (motion)- In Taiichi Ohno's view, waste of movements, or unnecessary motion, threatens the efficiency of production systems. The movements of the worker can be divided into two categories-

a. Waste - The unnecessary and repetitious movement have to be be eliminated immediately.

   For example- waiting for or stacking subassemblies.
b. Work - There are two types of work done by the employees. One is value-added and another one is non-value-added work. Value-added work refers some kinds of processing work which adds value. The higher the ratio of processing work, the greater the efficiency of the organization.

Non-value-added work can be claimed as waste in conventional way. For instance- walking to pick parts, operating push buttons etc.

The significant negative impact of waste on movements are reducing productivity, increasing risk of injury and lead times (Ohno, 2019).

3.2.1.7 Waste of making defective products - High production efficiency greatly depends on preventing the recurrence of defective products. Problems early in the process always result in defective products later on. The result would be waste - defective parts on the one hand and large inventories of parts that not immediately needed on the other. This affects directly productivity and profitability of the organization (Ohno, 2019).

![Figure 3.2.1- Types of Muda/waste, Source-(Ohno, 2019)](image-url)
3.2.2 Lean principles- Fortunately, there is a powerful antidote to muda/waste: lean thinking; which allows us to specify value, set up value-creating actions in the most effective order, conduct these activities without interruption whenever someone asks, and do them more efficiently (Womack & Jones, 1996). Lean thinking also provides a way to make work more satisfying by providing immediate feedback on efforts to convert muda into value which is based on five principles: value, value stream, flow, pull, and perfection where identifying value is the main key principle (Womack & Jones, 1996, p.15).

Figure 3.2.2- Lean principles (Womack & Jones, 1996).

3.2.2.1 Value- Value is the most critical part of lean thinking. The concept of Lean thinking requires a conscious effort to define value by engaging in a dialogue with specific customers to understand the products they need and their willingness to pay for them. This process involves ignoring existing assets and technologies and rethinking firms on a product-line basis with strong, dedicated product teams. To achieve this, the role of technical experts in the firm needs to be redefined, and the location of value creation needs to be reconsidered. Although implementing these changes cannot happen instantly, it is necessary to have a clear understanding of what is required to avoid skewed definitions of value. By redefining value in terms of specific
products with specific capabilities offered at specific prices, firms can achieve lean thinking and streamline their processes to meet the needs of their customers while reducing waste.

Therefore, specifying value is the most critical and important part in lean thinking otherwise it will be same as providing wrong product or service which is known as Muda from above discussion. (Womack & Jones, 1996)

3.2.2.2 Value stream- The value stream encompasses all the actions required to bring a product through the three critical management tasks of any business: problem-solving (Concept to detailed design and engineering to production launch), information management (Order taking to delivery) and physical transformation (Raw materials to final product). Lean thinking involves identifying the entire value stream for each product, a step which is rarely attempted by firms but can expose significant amounts of waste. Value stream analysis typically reveals three types of actions occurring along the value stream: steps that unambiguously create value, steps that create no value but are unavoidable with current technologies and production assets, and steps that create no value and are immediately avoidable. Hence, the complete set of value stream activities required to create a product including design, production, sales, and delivery to the righthand of the customer. This organizational mechanism is called Lean enterprise. (Womack & Jones, 1996)

3.2.2.3 Flow- Once the value is specified and the value stream is performed by lean enterprise, the next phase of lean thinking will be started i.e. Flow. The principle of flow is all about ensuring that products or services move smoothly and efficiently through the production process, from start to finish, without any interruptions or delays. Flow doesn’t inspire departmentalization, overproduction or large batch production, it inspires to produce in a continuous flow based on when and what is needed. In this scenario, waste can be minimized and efficiency can be maximized. The idea behind flow is to create a continuous and streamlined production process, where each step in the process is closely connected to the next. This allows for more efficient use of resources and helps to eliminate waste, as products move through the production process as quickly and efficiently as possible. (Womack & Jones, 1996)

3.2.2.4 Pull- The pull principle is presented as an alternative to traditional push production systems, where products are produced in large quantities without any consideration of demand. By implementing a pull system, organizations can avoid producing excess inventory,
reduce the amount of capital tied up in unused inventory, and minimize the costs associated with storing and managing inventory. (Womack & Jones, 1996)

3.2.2.5 Perfection - The principle of perfection is based on the idea that an organization should continuously strive to improve its processes and eliminate waste, with the ultimate goal of achieving perfection. In order to achieve perfection, organizations must adopt a culture of continuous improvement and empower their employees to identify and eliminate waste in all aspects of the production process. The principle of perfection also emphasizes the importance of transparency with the all stakeholders. This involves not only improving the production process, but also developing and maintaining strong relationships with customers, suppliers, and employees. (Womack & Jones, 1996)

3.3 Product development

Product development is a crucial weapon for a company's survival and success in competitive markets as it helps to penetrate the product, build and retain customer relationships, and yield profits, but it involves inter-departmental communication among designers, engineers, and marketing personnel (Chan & Ip, 2011). Product development have a vast amount of practices in industry but it still will be wasteful if there is not enough awareness among the practitioners (Rossi & Terzi, 2017). Therefore, Chan & Ip, (2011) proposed a dynamic decision support system tool by which customer purchasing behavior and customer lifetime value estimation can be predicted and it helps an organization to develop the suitable product for the customer. A product can be developed in two ways: first, by developing something into a more advanced form, or by adapting an existing product or service, or, secondly, by inventing or creating something entirely new (Patil et al., 2017). According to Dandekar et al., (2019); there are eight stages involved in the product development process which area as follows-

3.3.1 Idea generation - The organization forms a team to come up with multiple solutions for a problem that was identified through a market survey. The focus of this stage is to generate as many ideas as possible through rigorous brainstorming sessions, without criticizing any single idea.

3.3.2 Idea screening - In this stage, careful filtration of the ideas generated in the earlier stage should be conducted. The aim is to accept the best solutions and eliminate the poor ones.
The strategy is to proceed with only one or two solutions for the next stage, after evaluating and selecting the most viable options.

3.3.3 Concept development - In this stage, the screened idea is transformed into a product concept, which is a detailed version of the product idea.

3.3.4 Concept testing - In this stage, it is crucial to test the product concept with potential customers. The concept should be presented to the target market to gather feedback and insights.

3.3.5 Business analysis - This stage is critical for every organization as it involves fixing the landmarks and milestones of the product development process, as well as the time required for completion. It also requires careful analysis of the impacts of delays and the product's time of arrival in the market. This helps to ensure that the product is completed within the specified time and has a successful launch, ultimately leading to higher customer satisfaction and revenue generation for the organization.

3.3.6 Product Development - This phase involves creating a prototype, testing it, making changes, and producing a pilot version.

3.3.7 Market testing - In the market testing phase, product samples are presented to consumer groups through exhibitions or trials for selected customers to gather feedback.

3.3.8 Commercialization - After receiving feedback from market testing, make necessary modifications and determine promotional policies for the product. Develop distribution channels based on potential customers.

3.4 Lean product development (LPD)

While the PD team works without considering the customer's value, there will be a tremendous value gap between the product and the customers which will ultimately lead a product to failure (Khan et al., 2011). Therefore, a lean transformation of product and process development is necessary on understanding and defining value in PD (Khan et al., 2015). Lermen et al., (2018) suggested that it requires proper knowledge and sufficient practice to adopt the lean principles in product development.
Ashaab et al., (2010), Sorli et al., (2010), Khan et al., (2011), Tortorella et al., (2016) and Ashaab et al., (2016) discussed about similar Lean product and process development model where they identified the elements of building blocks and core enablers. Khan et al., (2011) presented a definition of LPD by identifying five core enablers of Toyota which is as follows- ‘Lean PD is value-focused PD. Value is a broad term used to define stakeholder needs and desires. SBCE (Set-based Concurrent engineering) is a strategic and convergent PD process guided by consistent technical leadership throughout. SBCE enables the focus on value and in particular knowledge and learning. Continuous improvement is the culture and an outcome of the SBCE learning process’. In short, it is a total complete package model of LPD.

![Figure 3.4.1 - The conceptual lean PPD model. Source-(Khan et al., 2011)](image)

Wangwacharakul et al., (2014) made a comparison between Japanese and Swedish LPD systems where they emphasized especially on those contextual factors (e.g. continuous improvement, cross functional work, operational development, leadership etc.) which are highly dependent on human, cultural, and organizational aspects for successful sustainable implementation of Lean in different cultural contexts. Moreover, they claimed that Swedish supportive management style fits well to lean thinking as Bosch Rexroth does.

According to Wang et al., (2012), there are three main key area required to establish the LPD by effective management with best performance which are as follows: experience for design collection and feedback tools/techniques, product design, development tools/techniques, chief
engineer and organization tools/techniques. Moreover, Pinheiro and De Toledo (2016) proposed five principles for lean product development-

1- Defining the problems of the customer and identifying the proper action to solve the problem.
2- Develop a process faster that can integrate the identified functions into a product with low cost and high quality.
3- To reveal a great product solution, eliminate all waste and unnecessary costs.
4- Engage the customer throughout the development process by listening frequently and interactively.
5- Provide methods and tools for continual cost reduction both within their business practices and in their culture.

LPD principles are mainly in line with the product development process and LPD shares the similar concepts of Toyota production system, but Morgan and Liker (2006) stated that Toyota Production System is an integrate system of people, process and technology(Liker & Morgan, 2011).

Figure 3.4.2- Toyota Production System
Source-(Liker & Morgan, 2011)
There is no question that all authors discussed the main elements of LPD model almost exactly the same way. Lean PPD model and Toyota production system shares the similar concepts but only difference is LPD model is based on product development process and Toyota production system is based on manufacturing. Both the model emphasizes on people, process and technology which involves continuous improvement culture by identifying and eliminating waste, reducing time-to-market, and testing and validating product assumptions through rapid experimentation and customer feedback. Moreover, both models aim to create high-quality products in the most efficient and cost-effective way possible by identifying and eliminating any unnecessary or non-value-adding activities.

3.5 Lean enterprise framework

According to Womack and Jones (1996); the organizational mechanism which consists of a complete set of value stream activities to create a product including design, production, sales, and delivery to the righthand of the customer is called Lean enterprise. A lack of understanding of LE principles by managers and a lack of knowledge of LE principles by employees have prevented many organizations from obtaining the full benefits of implementing LE principles (Anand & Kodali, 2009). Several issues contribute to the aforementioned problems, including the inadequacy of comprehensive lists of lean principles, practices, and techniques (to be called elements from now on), and the absence of a comprehensive framework containing all the elements (Jasti et al., 2020). Jasti et al., (2020) proposed a comprehensive lean enterprise framework consists of 13 pillars which is closely related to the product reliability in manufacturing. To overcome the limitations of current LE frameworks, this framework was developed after consulting with academicians, practitioners and consultants. The 13 pillars are summarized below-

3.5.1 Management commitment and leadership- The Management Commitment and Leadership (MCL) approach focuses on guiding and influencing employees to achieve an organization’s goals, mission, and vision. Effective leadership involves developing strategies for implementing changes, decision making, resource allocation, creating a trustworthy environment, motivating employees, initiating the vision across the organization, and encouraging continuous learning and development. MCL is an essential element in advanced manufacturing philosophy, and 23% of existing frameworks include it as a key component. Therefore, MCL is proposed as one of the pillars of the framework. (Jasti et al., 2020).
Human resource management- Human resource management (HRM) is crucial for the success of any organization. The tools, technologies, and culture adopted by an organization are only effective if employees are committed to implementing them. Therefore, The key to producing reliable products lies in the ability to compete effectively, urging nations and organizations to align their systems, policies, and resources to foster continuous improvement in both reliability and productivity, with human resources being the most crucial asset for achieving these goals(Anton Arulrajah, 2017). This investment should include job design, knowledge training programs, financial benefits, and recognition initiatives. HRM is considered one of the pillars of LE frameworks, with 26% of existing frameworks including it as an element. (Jasti et al., 2020)
3.5.3 Continuous improvement- Continuous Improvement (CI) is an effective tool for enhancing organizational output performance. It involves a culture of sustained improvement by eliminating failures in all systems and processes of an organization, as well as improvement initiatives that increase successes and reduce failures. The success of lean practices depends on people being able to identify and solve complex industrial problems, and it also relies on continuously improving business processes by fully involving employees in all systems and processes as quickly as possible(Kaur et al., 2023). Meeker & Escoba (2004) also highlights the concept of "continuous improvement" through the implementation of design changes, cost reduction strategies, and maintaining quality in production processes to enhance product or service quality and reliability. The main goal is to achieve incremental improvements in products, processes, and services with teamwork across the organization. As a result of its significance, 18 Lean Enterprise (LE) frameworks (approximately 59%) have proposed it as an element for implementing LE frameworks. Therefore, CI is suggested as one of the pillars for LE framework implementation in organizations. (Jasti et al., 2020)

3.5.4 Total quality management- Total Quality Management (TQM) is a crucial component of lean production, aiming to reduce poor quality costs by eliminating defects through improvement processes and most organizations believe that TQM is essential for achieving manufacturing excellence through quality and productivity improvements(Jasti et al., 2020). In the international realm of green development, TQM is focused on delivering higher quality products, faster delivery, and competitive prices to meet heightened customer expectations(Xiao et al., 2023). TQM is an essential part of reducing the risk and increasing the safety(ZIO et al., 2019). The literature has proven TQM's significance as an essential characteristic of a world-class manufacturing organization, and around 23% of Lean Enterprise (LE) frameworks have proposed TQM-related elements. Therefore, TQM is one of the pillars of implementing LE (Jasti et al., 2020)

3.5.5 Supply chain management- In the 1990s, manufacturing organizations began recognizing the impact of suppliers on organizational success, as timely delivery at the right place and price became a challenge(Soni et al., 2019). Supply Chain Management (SCM) emerged as a means to achieve these goals and has become crucial in today's business landscape. Establishing long-term relationships with suppliers and working together as business partners is essential, as
vendors' knowledge and experience are valuable in designing and producing high-quality products and responding quickly to market needs. Around 25% of Lean Enterprise (LE) frameworks propose SCM as a significant element in achieving LE excellence. SCM performance is a vital foundation for gaining a competitive edge in the global market, making it one of the pillars to achieve LE excellence. (Jasti et al., 2020)

3.5.6 Customer relationship management—Successful organizations achieve their success by delivering products and services that exceed the expectations of all stakeholders involved in the product life cycle, including both internal and external customers. While external customers are those who buy the organization's products, internal customers are part of the organization. Many organizations apply the 80:20 rule to identify the top 20% of customers and analyze their specific needs to provide flexible manufacturing and deliver products with special discounts, service arrangements, and warranties to maintain long-term relationships with them (Grant & Schlesinger, 1995). Customer relationship management (CRM) has been identified as one of the pillars in the LE framework, as 26% of researchers have considered CRM-related elements in their frameworks. (Jasti et al., 2020)

3.5.7 Total productive maintenance—Many organizations view maintenance as a cost center rather than a profit center, but successful organizations recognize the importance of adopting the best maintenance practices to minimize waste. Total productive maintenance (TPM) has replaced traditional maintenance systems, and TPM-implemented organizations exhibit efficient operations, computerized maintenance management, and continuous partnership between operations and maintenance teams. Such organizations also have excellent process management and organized systems. Around 39% of frameworks have proposed TPM as an element in existing LE frameworks, making it a crucial pillar in achieving excellence. The present study also proposed TPM as a pillar of the LE framework. (Jasti et al., 2020)

3.5.8 Concurrent engineering—According to Deshpande (2018), the technical dimensions of CE practices are defined as a set of technology, design, and composition-related components that promote effective management of CE practices. The success of modern organizations depends on how many new products are released and how many of these products succeed in the marketplace (Jasti et al., 2020). Product development involves designing a product that meets customer needs, producing it, and releasing it to the market. Time-to-market is a critical
parameter for a good product development process. CE has an impact on significant reduction in new product development costs, as well as better quality products according to customer needs (Mallampati et al., 2018). Traditional product development processes rely on a single idea, whereas concurrent engineering (CE) processes collect multiple solutions and converge them to reach a final solution. CE has been proven to provide the best solutions with less time to market than other product development processes. Therefore, CE is considered a pillar in the proposed LE framework. (Jasti et al., 2020)

3.5.9 Knowledge management- Organizational resources, particularly information and explicit knowledge, are essential for developing a learning organization. Researchers have emphasized the importance of knowledge management (KM) in maintaining a successful business and organizational learning methodology for generating innovative ideas and promoting growth. While creating and sustaining a market position is crucial for organizational success, it also depends on key resources and capabilities. However, few researchers have considered KM as a factor in achieving LE excellence. An analysis of lean product development frameworks showed that KM is one of the pillars to achieve excellence in product development, leading to its proposal as a pillar for achieving excellence in the LE organization. (Jasti et al., 2020)

3.5.10 Standardization- Standardization involves the use of common products, processes, and components to meet various requirements. This approach can enhance productivity, reduce the number of managing reference points, decrease stock levels, and simplify manufacturing systems. Optimal standardization of internal products will not alter the characteristics of the end product from the customer's perspective and can also result in an optimal design in terms of cost. Approximately 52% of frameworks have identified standardization as a critical element for achieving LE excellence, leading to its inclusion as one of the pillars in the LE framework. (Jasti et al., 2020)

3.5.11 Elimination of wastes- Toyota engineers have identified and attempted to eliminate unnecessary waste and activities in their production line to reduce setup time and defects. Ohno categorized waste into seven types and recommended avoiding them by using common sense instead of advanced technology (Ohno, 2019). About 70% of the LE frameworks suggest eliminating waste as a crucial element in achieving LE excellence. Therefore, waste elimination is proposed as a pillar in implementing LE frameworks in organizations. (Jasti et al., 2020)
3.5.12 Just in Time (JIT) - Just in Time (JIT) is a concept of producing and delivering finished goods, subassemblies, fabricated parts, and purchased materials just in time to be transformed into the next stage of production or finished goods. JIT helps to reduce inventory, improve quality and productivity, enhance supplier and customer relationships, increase inventory turnover, and reduce workspace. JIT is proposed as one of the pillars to achieve excellence in LE, as 30% of the frameworks have proposed JIT as an element. Many researchers have also proved the effectiveness of JIT in reducing inventory levels and improving the overall productivity and quality of the organization. (Jasti et al., 2020)

3.5.13 Information technology management- The effective flow of information is crucial in complex manufacturing systems and supply chain activities. Information technology management (ITM) can control information flow within and across organizations and improve communication effectiveness in supply chain activities. ITM is proposed as a pillar for implementing LE framework, although only a few researchers have used it in the considered frameworks (Jasti et al., 2020).

From above discussion it is clear that Lean enterprise is a management philosophy that strives to maximize efficiency and minimize waste for the benefit of customers which is based on the principles of lean manufacturing and originated in Toyota's production system(Ohno, 2019). Lean enterprise aims to achieve reliability by reducing variability and improving process stability(Womack et al., 1991).

Therefore, lean enterprise aim to eliminate waste, improve efficiency, and reduce variability, which are all associated with reliability. With a focus on continuous improvement, total quality management, this approach can help organizations to build reliable products and services.
4. Literature integration

4.1 An overview of the theoretical framework

The authors divided the all the major elements into three categories based on the model of Toyota production system- People, Process and Technology (See- Table 4.1.1). These three key aspects is a combined approach (Hejazi et al., 2020; Liker & Morgan, 2011) which represent the total integration system of all the major elements. Then rest of the major elements were identified under three sub-categories- Reliability, LPD, LE. First of all, the major approaches of achieving reliability were collected which is commonly discussed in the literatures such as DFR, Fuzzy sets, STA and Hidden Markov model (Paganin & Borsato, 2017, Silverman, 2013, Kabir & Papadopoulos, 2018, Zhao et al., 2022, Alanen et al., 2022). Secondly, continuous improvement, tools & technology, concurrent Engineering were identified as a major elements under the LPD sub-category as these three elements commonly shared by the all the authors (Ashaab et al., 2010, Sorli et al., 2010, Khan et al., 2011, Ashaab et al., 2016). Thirdly, management commitment and leadership, customer relationship management, continuous improvement, human resource management, concurrent engineering, total quality management and standardization were identified as the most essential elements under LE model (Womack & Jones, 1996, Jasti et al., 2020, ZIO et al., 2019, Soni et al., 2019, Grant & Schlesinger, 1995, Mallampati et al., 2018) since all these elements was mostly recommended by different authors.
### Key Aspects

<table>
<thead>
<tr>
<th>People</th>
<th>Reliability</th>
<th>LPD</th>
<th>LE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous improvement</td>
<td>Reliability activities e.g. DFR, Fuzzy sets, STA, Hidden Markov model etc.</td>
<td>Continuous improvement</td>
<td>Management commitment &amp; leadership, Customer relationship management, Continuous improvement, Human resource management</td>
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<tr>
<td></td>
<td></td>
<td>Continuous improvement</td>
<td>Continuous improvement, Total Quality management, Supply chain management</td>
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<tr>
<td></td>
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<td>Tools &amp; technology, Concurrent Engineering</td>
<td>Concurrent Engineering</td>
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**Table- 4.1.1 An overview of the theoretical framework**

#### 4.2 Integrated conceptual theoretical framework of product reliability

The final consolidated model of product reliability is developed by combining all the theoretical points discussed earlier. Figure 4.2.1 below shows the final consolidated model of product reliability.
Figure 4.2.1- Integrated conceptual framework of product reliability.

Source- Kanjiraparambil L. J, Barua P. (The authors of this thesis)

The proposed model combines elements from LE, Lean PPD, and the Toyota Production System to achieve product reliability. To build this framework, the authors of this thesis followed a step by step process according to the guidelines of (Van Der Waldt, 2020). Firstly, the authors of this thesis chose the topic which describes the field of the study. Secondly, the title was constructed by identifying the main components such as product reliability and LPD. Thirdly, All the related key concepts and aspects were isolated by relevant literature review. Finally, the conceptual framework was constructed by identifying the relevant aspects of product reliability such as Management Commitment and Leadership, Customer relationship management, Continuous improvement, Human Resource Management, Reliability Activities, Concurrent Engineering, Total quality management, Supply Chain Management and Tools and technology.
5. Research methodology

The methodology is used by the authors is presented in this chapter. The research methodology was identified basically based on the research question (What are the relevant LPD aspects and how to integrate them for a reliable electronic hardware development?). In this thesis, the authors also explored the relationship between the lean and reliability in product development and then to build a conceptual theoretical framework for product reliability. It includes an explanation of research choice, research approach, research strategy, case organization, data collection and data analysis.

5.1 Research design

5.1.1 Qualitative research

The authors of this thesis conducted a qualitative research with various highly experienced industry experts to have a better insights and to address the research question of this thesis as it involves exploring how individuals perceive a particular issue through interviews or discussions that generate non-numeric results, providing a more complete view of individual perspectives and opinions than statistics alone (Akyıldız & Ahmed, 2021). In this research, there are two different fields such as reliability and LPD although they are interrelated with each other. Both of the field have their own several aspects which is already shown in the theoretical part and all these aspects is related to different department professionals. Therefore, it is important to know the different departmental professional perceptions, opinions and their experiences to identify and validate the relevant aspects of reliability. As a result, the authors are determined to do the qualitative research or an in-depth exploration of the experiences and perspectives of different departmental officials involved in the development of electronic hardware products as it emphasizes to describe attitudes, feelings, and perceptions in a detailed manner (Tong et al., 2012).

5.1.2 Deductive approach

The authors intention of this thesis was primarily to explore the relation between LPD and reliability and finally to address the research question. As we have seen in the theoretical section, there is a lot of aspects found in the literatures regarding LPD (Ashaab et al., 2010, Sorli et al., 2010, Khan et al., 2011, Tortorella et al., 2016 & Ashaab et al., 2016), LE (Womack & Jones, 1996, Jasti et al., 2020, ZIO et al., 2019, Soni et al., 2019, Grant & Schlesinger, 1995, Mallampati et al., 2018), and reliability (Paganin & Borsato 2017, Silverman 2013, Kabir & Papadopoulos
2018, Zhao et al., 2022, Alanen et al., 2022). All the aspects from those literatures are interconnected in line with reliability but the literatures are unable to show the clear relationship among them its having lack of information regarding the framework of product reliability.

Hence, the authors in this research put an effort for literature review and finally for making an integrated conceptual framework by combining all the main aspects. To build the theoretical framework, almost 100 papers were read by the authors and few papers were excluded because of not having the proper relevancy. Different search strings were used for collecting the literatures such as ‘Emerald’, ‘Scopus’, ‘Science Direct’. The keywords used for searching the literatures are mentioned as follows- ‘Lean product development’, ‘Reliability Engineering’, ‘LPD AND Electronic hardware’, ‘LPD AND (reliability OR probability OR quality OR durability)’ etc.

Then, firstly theory was adapted from different relevant literatures and based on this, the authors in this thesis build the research strategy to test the theory which is known as deductive approach(Saunders et al., 2019). Since, the theory is already established in the literatures for this thesis, so deductive approach is suitable for this scenario. Additionally, several meetings with high level professionals and brainstorming sessions with the supervisor were required to formulate the suitable research question and integrated conceptual framework.

### 5.1.3 Research strategy

In order to identify the relevant aspects of reliability and to validate the integrated conceptual framework, a case study was chosen for research strategy. Basically, the purpose of a case study is to understand why a decision is made, how it is implemented, and how it is impacted(Lodgaard et al., 2018; Yin, 2009). When the boundaries between phenomenon and context are not clearly defined, a case study investigates a contemporary phenomenon within its real-life context (Yin, 2003). Currently, the authors of the thesis are examining the relationships between the two phenomena; LPD aspects and reliable electronic hardware development. This situation makes it necessary for insights into LPD aspects to be identified as a setting for reliable electronic hardware development. As case study allows researchers to explore organizations or individuals through communities, interventions, relationships, or programs(Yin, 2003) and it also allows the researchers to get a proper understanding on a specific research phenomena(Saunders et al., 2007). Hence, the authors followed case study approach as the problem related to this research is very unique. The case organization also focuses on developing reliable electronic hardware, similar to
the research interests of the authors. As a result, it is more appropriate for conducting a single case study in this scenario.

5.1.4 Case Selection

Case selection is a highly important phase in the research process to get a better result from the case study. Case company selected based on the three following criteria-

1. Well established organization

Bosch Rexroth AG is an engineering firm based in Lohr am main in Germany. It is the result of a merger on 1 May 2001, between Mannesmann Rexroth AG and the Automation Technology Business Unit of Robert Bosch GmbH, and is a wholly owned subsidiary of Robert Bosch GmbH (History of Bosch Rexroth, 2023). Hägglunds in Mellansel, Sweden, is a part of Bosch Rexroth which is a global company belonging to the Bosch Group. The production facility in Mellansel is home to the Bosch Rexroth business unit Large Hydraulic Drives head office and the main production for Hägglunds. Hägglunds customers are located all over the world and therefore Hägglunds sales and service team are present in about 30 countries (Hägglunds Antriebssysteme, 2023).

2. Company to follow Lean principles

Hägglunds works in accordance with the Bosch production system (BPS), which is Bosch’s own lean management reference model. BPS is a method for structuring the entire valued-added chain with a forward-thinking and networked approach where the focus is the elimination of all waste in all firm activities. The LEAN production methodology of 5S is included in BPS and has been implemented in the factory in Mellansel.

3. Product reliability importance for the product portfolio

Bosch Rexroth is one of the world’s leading suppliers of drive and control technologies and a global partner for machine and plant engineering worldwide. Bosch Rexroth committed to delivering reliable and effective solutions that help the customers to succeed. Hydraulic direct drives from Hägglunds give you a straight path to high performance, through shaft-mounted hydraulic motors, freely placed drive units and intelligent control. Powerful, compact, and utterly reliable, Hägglund’s drive systems change the game in the toughest applications. Hägglunds drive
solutions, which have stood out for decades with their performance and uncompromising reliability.

But selecting a case is not enough because it is also important to select the interview participants carefully. As the empirical data will be constructed on the actions and reflections of this population, it is crucial to choose the right entity with the right population (Eisenhardt, 1989). Moreover, the selected participants also should have an interest to the research phenomena.

5.2 Case organization

Bosch Rexroth AG is an engineering firm based in Lohr am Main in Germany. It is the result of a merger on 1 May 2001, between Mannesmann Rexroth AG and the Automation Technology Business Unit of Robert Bosch GmbH, and is a wholly owned subsidiary of Robert Bosch GmbH (Bosch Rexroth. WE MOVE. YOU WIN., 2023).

Hägglunds and DC-HD @ Mellansel, Sweden: DC-HD is one of Bosch Rexroths nine business units. In Mellansel you find the Head Office and Main Production of Hägglunds (DC-HD) Products and Solutions.

The authors in this thesis conducted their thesis with one of the five product teams within DC-HD, called ‘Automation and Digital services’ under global engineering. Hence, this product team is responsible for the electronic hardware products such as control systems, drive systems, condition monitoring etc. Authors also refers to DC-HD and or Hägglunds throughout instead of Bosch Rexroth. Although we are aware DC-HD, Hägglunds is one of the business units of Bosch Rexroth, we opted to mention so. The reason is our interviews and data collections were fully based on DC-HD, Hägglunds at Mellansel, Sweden.

Bosch Rexroth is one of the world’s leading suppliers of drive and control technologies and a global partner for machine and plant engineering worldwide. Bosch Rexroth committed to delivering reliable and effective solutions that help the customers to succeed. Bosch Rexroth’s innovative products and services enable their customers to move everything that needs to be moved with ease and efficiency, helping them to win in their
respective industries. With the focus on digital innovation, sustainability, and own people, company not just moving things instead moving industries to make our planet a better place. Company given a caption for it as, “WE MOVE. YOU WIN” (*Bosch Rexroth. WE MOVE. YOU WIN.*, 2023).

Hydraulic direct drives from Hägglunds give you a straight path to high performance, through shaft-mounted hydraulic motors, freely placed drive units and intelligent control. Powerful, compact, and utterly reliable, Hägglund’s drive systems change the game in the toughest applications. Hägglunds drive solutions, which have stood out for decades with their performance and uncompromising reliability.

**Bosch Rexroth History** (*History of Bosch Rexroth*, 2023)

The origin of Bosch Rexroth's long history is influenced by constant movement. It all started with a water-powered hammer mill, followed by an iron foundry in Lohr am Main, Germany. Bosch Rexroth’s unique industry expertise has become synonymous with tailored solutions.

1795 – 1964 (Move from iron foundry to hydraulic solutions)

From forging iron out of ore to a foundry for cast iron, Rexroth entered the hydraulics market in the 1950s and laid the foundation to become a global market leader.

1965 – 1995 (Move from hydraulics to multi-technology provider)

The company expands its portfolio with electrical drives and controls, axial piston pumps and motors, linear and assembly technologies and develops into a full provider of industrial and mobile hydraulics.

1996 – 2000 (Move to provide integrated multi-technology solutions)

Rexroth develops multi-technological solutions to overcome the limits of single technologies, unlocking the progress in semi-conductors and software for all technologies to increase productivity and flexibility.
2001 – 2016 (Move to one brand for software driven and interconnectible Drive and Control solutions)

The merger of Mannesmann Rexroth with Bosch Automationstechnik establishes a global leader for Drive and Control solutions. They reach new levels of seamless integration of all relevant technologies for improved energy efficiency and safety.

2017 – today (Move into the future of digital transformation)

Bosch Rexroth drives the digital transformation of the Factory of the Future, exceeds the limits with Connected Hydraulics and sets the stage for Transforming Mobile Machines. All products and solutions contribute to a more sustainable development of machines, manufacturing, and daily life.

**History of Hägglunds (DC-HD) at Mellansel, Sweden** *(Hägglunds Antriebssysteme, 2023)*

Hägglunds Direct Drive Systems

Hägglunds direct drive systems has a history that goes back to 1966 when the factory in Mellansel opened. 2008 The Hägglunds group becomes part of Bosch Rexroth. In 2017, Bosch Rexroth reorganizes and Bosch Rexroth Mellansel becomes a business unit, under the name DC-HD.

DC-HD is one of the business units within Bosch Rexroth, producing the largest and most powerful drive systems that help the customers to increase their productivity. Hägglunds products and solutions are known for its quality and reliability. And the people behind them are known for their knowledge and experience. People who take pride in keeping customer promises, and who add customer value in all steps, from start to final delivery. Hägglunds customers are found where the conditions are tough, like mines and marine environments. For example, the drive systems are used to recycle, produce sugar, oil, rubber,
plastic, and pulp and paper. Hägglunds Drive Systems are making it possible for them to be best in class and run profitable businesses. They provide value to customers by providing smart, digital solutions that we call Hägglunds Inside Intelligence. Hägglunds are top class when it comes to service, within DC-HD they provide their customers with their original spare parts, and certified specialists provide service and repair of Hägglunds Products and Systems. Hägglunds got a long experience in service and maintenance, and they take care of their customers with local presence and dedication. The focus is always to secure the drive for their customers.

**DC-HD facts:**
Approximately 650 employees, where of almost 350 in Mellansel. More than 40 sale units around the world. Apart from Hägglunds, Rineer is a separate product family within DC-HD. It is found in the USA. Hägglunds has a customization location in Columbus, USA.

### 5.3 Data collection procedure

In this thesis, a single case study approach is followed to gather the data. In case study approach, data can be collected by using different methods such as interviews, focus group, survey data etc. An interview can be a useful method that will yield different results from a formal questionnaire (Byrne & Searle, 2003). As a method, interviews were chosen because it allows the researcher to get a better understanding of what participants experience and to explain the connection between reliability and LPD. Moreover, throughout the interviews, the researcher can gather extensive data, build connections, influence participants, tackle inquiries, and employ visual aids to enhance question understanding (Sekaran & Bougie, 2016). Given these advantages, the primary focus of the authors in this study was centered on gathering primary data through interviews.

At the initial stages of literature analysis, the authors of this thesis booked the interview schedule with the selected interviewee of Bosch Rexroth which was one of the challenging tasks for the authors as all of the interviewee are having very busy schedule throughout the year. Basically, total eight interviews were conducted from different departmental professionals. It will be briefly discussed in the following section how the data were collected.
Primary data

In this thesis, the authors intended to gather the data through semi-structured interviews as the authors wanted to have an open discussion with the interviewees to know in depth about their perspectives and out of the prepared questionnaire, the authors also generated a plethora of follow up question (how/why) during the interview. The reason is to choose semi-structured interviews because it entails a situation in which the interviewer possesses a set of questions structured in the general format of an interview schedule but has the flexibility to modify the order of these questions (Bryman & Bell, 2011). Moreover, the interviewer has the option to request additional questions that they deem important. The authors of this thesis opted for semi-structured interviews because they not only enable the collection of information without constraining respondents' responses but also facilitate seamless movement between different sections depending on the natural course of the conversation.

In addition, the authors also wanted to discuss concerns that the interviewee felt were pertinent (Longhurst, 2003). In short, the authors of this thesis set up a goal i.e. to create an informal setting in which the interviewee could be open and provide rich details (Yin, 2009). All pre-scheduled interviews were held at onsite physically with the possibility of remote joining via Microsoft teams. As a result, the authors were having a crystal-clear view on the interviewees to observe their responses. The authors in this thesis are deeply pleased to have the positive responses of all the interviewees towards their effort.

The profile of all interviewee is presented below-

**Interviewee 1**

Interviewee 1 is working as a Head of engineering for one out of eight Business Units (BU) in Bosch Rexroth. Responsible for BU Profit and Loss for certain portfolio segment. The Head of Engineering carries product liability and compliance responsibility and also to ensure the products builds and maintain current state of art.

**Interviewee 2**

Interviewee 2 is working as a Quality Manager for the Business Unit DC-HD. His responsibility is to ensure that a well-functioning systematic quality work within DC-HD that contributes to achieving the business unit’s goals.
**Interviewee 3**

Interviewee 3 is working as a Service Product Manager in the Automation and Digitalization team and the Drive Unit team. He drives the service-related topics in the teams but also have the responsibility for pricing, technical support components etc. related to the components in our products.

**Interviewee 4**

Interviewee 4 is currently working as head of ENP in engineering department, P stands for product teams. Responsible for five product teams within global engineering. So responsible of continues improvements on existing products and developing new products within five product units. Overall product responsibility from concept developments till phasing out. In addition, needs to ensure team having required competency and educate with required training to enhance the knowledge. Also, a 'process owner', who describe and write the processes. Process owner with the support of process specialists from different teams, ensure the process are placed say in line with Lean.

**Interviewee 5**

Interviewee 5 is an electronics engineer, working with Hägglunds- Bosch Rexroth since 1985, for the last 38 years. Had many roles, but mostly related to electronics order handling that is technically supporting customer needs on developed control system devices over the years. Worked also as a group manager in order handling earlier but currently working as member in core engineering team within Automation and digital services. In addition, supporting the electronics and control system orders coming in as regular, also technical clarifications for the offers.

**Interviewee 6**

Interviewee 6 is a procurement and production planner at LOG12 in Bosch Rexroth plant in Mällansel at the drive unit side. Also, a member in Automation and digital services team, representing technical procurement.

**Interviewee 7**

Interviewee 7 is working in Bosch Rexroth Mällansel for the past reach 8 years. Been in different areas like Sales, Logistics, and trainings, but currently working as a Product owner within Automation and digital services team. Responsible for the life cycle of control system and
condition monitoring within DC-HD. Working in a cross functional team taking care of products and also product development. Overall responsibility and ownership of product portfolio, that means responsible from the development of product all the way through life cycle until it reaches end of life. On top of it responsible and having ownership of cross functional product team. Guide and prioritize the activities within the team. Planning and execution of portfolio strategies and finally handling internal customers including country units.

**Interviewee 8**

Interviewee 8 is currently working as the HR manager for DC-HD, Mellansel. DC-HD have a global responsibility, but her scope is limited to DC-HD Mellansel. She is having good education background in HRM and more than 15 years of experience in same field. Also worked in France about three years in the past and have an international connectivity. Always having responsibility to motivate and coach the employees for their career growth and knowledge enhancements.

The total number of interviews with details are presented below-
<table>
<thead>
<tr>
<th>Date</th>
<th>Interview No.</th>
<th>Title</th>
<th>Location</th>
<th>Duration (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th May 2023</td>
<td>Interviewee 01</td>
<td>Senior Executive from Global Engineering department</td>
<td>Bosch Rexroth Head quarters, Mellansel</td>
<td>52 minutes</td>
</tr>
<tr>
<td>10th May 2023</td>
<td>Interviewee 02</td>
<td>Senior Executive from Quality department</td>
<td>Bosch Rexroth Head quarters, Mellansel</td>
<td>39 minutes</td>
</tr>
<tr>
<td>11th May 2023</td>
<td>Interviewee 03</td>
<td>Senior Executive from Service department</td>
<td>Bosch Rexroth Head quarters, Mellansel</td>
<td>43 minutes</td>
</tr>
<tr>
<td>11th May 2023</td>
<td>Interviewee 04</td>
<td>Senior Executive from Engineering production department</td>
<td>Bosch Rexroth Head quarters, Mellansel</td>
<td>54 minutes</td>
</tr>
<tr>
<td>11th May 2023</td>
<td>Interviewee 05</td>
<td>Executive from Engineering</td>
<td>Bosch Rexroth Head quarters, Mellansel</td>
<td>50 minutes</td>
</tr>
<tr>
<td>12th May 2023</td>
<td>Interviewee 06</td>
<td>Executive from Procurement</td>
<td>Bosch Rexroth Head quarters, Mellansel</td>
<td>39 minutes</td>
</tr>
<tr>
<td>17th May 2023</td>
<td>Interviewee 07</td>
<td>Senior Executive from Sales &amp; product management department</td>
<td>Microsoft Teams</td>
<td>48 Minutes</td>
</tr>
<tr>
<td>22nd May 2023</td>
<td>Interviewee 08</td>
<td>Senior Executive from HR department</td>
<td>Bosch Rexroth Head quarters, Mellansel</td>
<td>57 Minutes</td>
</tr>
</tbody>
</table>

Table 5.1.6.1 - The number of interviews that were conducted to gather the empirical data.
The manuscripts for the interviews are mentioned in Appendix 1 (For two interviewees). The authors of this thesis selected total eight different departments which are closely connected with the integrated conceptual framework such as- Global Engineering, Engineering production, Quality management, Procurement, Human resource, Product management, Service management, Core engineering and development. The study is conducted with different professional of the selected case organization through several interviews as they posses the expertise this field and they also posses the strategy of the organizations. The selected interviewees are having many years of experience in the relevant field and they hold important management position in the mentioned case company. There is no doubt that all selected interviewees have the capability for making the decision on their own. This research attempted to conduct interview with management with different backgrounds who are mostly associated with aspects of integrated framework. For instance- HR department is closely connected with people aspects, Quality department is closely connected with the process aspects. To do that as much as information was gathered from each department. Additionally, interviews were customized by the authors for interviewee based on their expertise and departments. Basically, the interview manuscripts were designed based on the three key aspects- People, Process and Technology (See Table- 2.7.1 An overview of theoretical framework). Before starting the interview, the interview guidelines were provided to the interviewee regarding the confidentiality and recording of video. According to (Bryman & Bell, 2011), one of the most important responsibility for the researchers is to maintain strict confidentiality and protect the privacy of the respondents with regard to the information shared. By taking consideration this major point, the authors asked permission from the interviewees about the recording of videos. Few interviewees were agreed to have a direct interview and few were agreed to have a both audio/video recordings. In this study, every interviewee was assured anonymity in terms of revealing their real names. However, while all respondents had no problems to state their names, but as per supervisor suggestions lead us to the decision to maintain anonymity for all the interviewees. Most importantly, the authors of the thesis are from two different origin and English is the main language to communicate with each other. However, it is equally important to consider the interviewees level of comfort when communicating in the English language. The authors of thesis ensured about their comfortability of speaking in same language.

Coming to the point of interview manuscripts, all the interview manuscripts were started with short introduction of their core responsibilities and their experiences. Then the main discussion part was
initiated. The interview manuscripts were planned, directed, and recorded and handed to the interviewee advanced to produce valid and reliable data (Saunders et al., 2009). In order to create a comfortable atmosphere during the interview, the authors adjusted the questions by restating or rephrasing them, ensuring a thorough understanding of the responses and making sure that every aspect of the conversation was clear for both the interviewer and the respondent. As a result, all the interviewee got the preliminary ideas about the questionnaire and it helped them to understand properly the research phenomena. Moreover, after transcribing the data, all the data were sent to the responsible interviewee again to have a further check and to make correction. In accordance with the agreement during the interview, they emphasized specific points that must remain confidential and not be disclosed. Subsequently, the final version of the transcribed data was formulated accordingly. Therefore, the privacy of the interviewees are well protected and the relevancy of discussion was excellent and related exactly to the point.

5.4 Data analysis procedure

In this study, the authors mainly focused to identify the relevant aspects for achieving product reliability with lean product development and to answer the research question- What are the relevant LPD aspects and how to integrate them for a reliable electronic hardware development? The authors conducted a study where they gathered information from company officials about the aspects they consider while striving for reliability. These aspects likely encompassed various factors or areas that influenced the company's ability to achieve reliability in its operations. The study aimed to analyze and understand the specific issues faced by companies in their pursuit of reliability, providing insights of conceptual framework.

As it mentioned before, all the relevant aspects to product reliability were identified in the theoretical section and integrated into a conceptual framework. As a result, next step data analysis was initiated. Analyzing qualitative data is tricky because there's so much information, but the researcher have to transcribe it, organize it, and test it to find patterns and make sense of it (Bryman & Bell, 2007). Therefore, the next step in this section was to code the information in the findings from primary data and match it with the theme and literature. Coding involves categorizing empirical data into meaningful components with labels that relate to the theoretical framework's potential significance (Bryman & Bell, 2007).
To code the interviews, the authors of this research divided all the aspects gathered from the primary data into three key events- People, process and technology (Hejazi et al., 2020, Liker & Morgan, 2011). All these three key events are deeply related to the theoretical framework as we have seen previously and the identified relevant aspects for the conceptual framework are divided under these three key events (See Table- 2.7.1 An overview of theoretical framework). It helped the authors to analyse the data and to get a more clear view of the results (Ven, 2007). The initial column was completed with these three crucial events. The second column was filled with the relevant aspects which were identified from literature. The first column is closely connected to the second column since the second column indicates the aspects that fall under specific key events. The third column was completed by filling the source of data. The fourth column representing the quotes of interviewees. Here, the authors of the thesis picked direct statements and filled in the fourth column. Of utmost significance, the fourth column emphasized pertinent points extracted from the interviewee quotes, demonstrating their alignment with the existing literature. Then the fifth column represented the relevant literature which is connected with the quotes of the interviewee. At the end, the sixth column was filled with the conclusion.

A sample of coding the interview is presented below in Table-5.1.7.
<table>
<thead>
<tr>
<th>Key events</th>
<th>Relevant aspects</th>
<th>Source of data</th>
<th>Quotes of interviewee</th>
<th>Related literature</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management commitment &amp; leadership</td>
<td>Interviewee 1</td>
<td>&quot;Management commitment and leadership which is having two principles- coaching &amp; leadership. Leadership is more about setting directions and coaching ensures the directions understood &amp; implemented.&quot;</td>
<td>The Management Commitment and Leadership (MCL) approach focuses on guiding and influencing employees to achieve an organization's goals, mission, and vision(Jasti et al., 2020)</td>
<td>In line with the literature</td>
<td></td>
</tr>
<tr>
<td>Customer relationship management</td>
<td>Interviewee 3</td>
<td>&quot;Customer relationship management. To know your customers is the most important to be successful. On a competitive market you need to understand the customers need and how to help solve their problems.&quot;</td>
<td>Successful organizations achieve their success by delivering products and services that exceed the expectations of all stakeholders involved in the product life cycle, including both internal and external customers (Jasti et al., 2020)</td>
<td>Well aligned with the literature</td>
<td></td>
</tr>
<tr>
<td>Continuous improvement</td>
<td>Interviewee 8</td>
<td>&quot;HR majorly starts from individual level and so, continuous improvement in HRM could be contributing to product reliability as a supporting partner with many other departments, on different aspects.&quot;</td>
<td>The success of lean practices depends on people being able to identify and solve complex industrial problems, and it also relies on continuously improving business processes by fully involving employees in all systems and processes as quickly as possible(Kaur et al., 2023)</td>
<td>In line with the literature</td>
<td></td>
</tr>
<tr>
<td>Human resource management</td>
<td>Interviewee 8</td>
<td>&quot;In Bosch we educate employees to follow 'code of conduct' which is directly implemented in product reliability.&quot;</td>
<td>Producing reliable products lies in the ability to compete effectively, urging nations and organizations to align their systems, policies, and resources(Anton Ardrajah, 2017)</td>
<td>In line with the literature</td>
<td></td>
</tr>
<tr>
<td>Reliability activities</td>
<td>Interviewee 2</td>
<td>&quot;Hägglunds (Bosch Rexroth) is ISO 9001 certified company and following quality management standards. FMEA, another example, a well know standard mechanism for technical risk management. DFR - Not only for electronic hardware, but also for overall hardware, STA again a standard following when it comes to software and embedded hardware.&quot;</td>
<td>DFR (design for reliability) approach has grown significantly &amp; implementing in product development can help identify issues with prototyping(Pagamin &amp; Borsato 2017). Kabir &amp; Papadopoulos (2018) highlighted a very popular part of reliability engineering nowadays which is known as Fuzzy set theory (FMEA) and this is a Probabilistic risk assessment approach to manage the uncertainty.</td>
<td>Well aligned with the literature</td>
<td></td>
</tr>
<tr>
<td>Continuous improvement</td>
<td>Interviewee 4</td>
<td>&quot;Product, way of working, process etc. can always improve. We learn more, tools, computer programs can always continually improve. Adding more features &amp; functionalities to existing products and integrate new features are some examples to continuous improvement with products.&quot;</td>
<td>The concept of &quot;continuous improvement&quot; through the implementation of design changes, cost reduction strategies, and maintaining quality in production processes to enhance product or service quality and reliability(Meeker &amp; Escoba 2004)</td>
<td>In line with the literature</td>
<td></td>
</tr>
<tr>
<td>Total quality management</td>
<td>Interviewee 2</td>
<td>&quot;Total Quality Management as a quality management framework is based on building in its long-term principles and sustainable quality improvements. This is also in line with its principle that focus on processes, customer focus and fact-based decisions&quot;</td>
<td>TQM is focused on delivering higher quality products, faster delivery, and competitive prices to meet heightened customer expectations(Xiao et al., 2023)</td>
<td>In line with the literature</td>
<td></td>
</tr>
<tr>
<td>Supply chain management</td>
<td>Interviewee 6</td>
<td>&quot;we take feedback from suppliers and vendors, also internal and external feedbacks make us to find improvement areas&quot;</td>
<td>Establishing long-term relationships with suppliers and working together as business partners is essential, as vendors’ knowledge and experience are valuable in designing and producing high-quality products and responding quickly to market needs(Jasti et al., 2020)</td>
<td>In line with the literature</td>
<td></td>
</tr>
<tr>
<td>Tools &amp; technology</td>
<td>Interviewee 1</td>
<td>&quot;Technology that use electronic hardware having shorter life cycles, especially with business to consumer (B2C). Hägglunds- Bosch Rexroth still have life cycle at least 10-15 yrs, however it's definitely a challenge now.&quot;</td>
<td>Reliability of a product is a crucial factor to consider since there are so many options available from global players and the new product life span decreased significantly due to technological advancements, increasing customer demands, and global competition(Chan &amp; Ip, 2011; Relich, 2016; Jasti &amp; Kodali, 2014).</td>
<td>Well aligned with the literature</td>
<td></td>
</tr>
<tr>
<td>Concurrent Engineering</td>
<td>Interviewee 5</td>
<td>&quot;Concurrent engineering term more correlates with parallel work, it can definitely increase the efficiency and can reduce time.&quot;</td>
<td>Concurrent Engineering has an impact on significant reduction in new product development costs, as well as better quality products according to customer needs(Mallampati et al., 2018).</td>
<td>In line with the literature</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.4.1- A sample of coding the gathered primary data.
5.5 Quality of research findings

After gathering the data, it is important to measure the quality of the research by trustworthiness. According to Krefting (1991); there are four ways to measure the trustworthiness of the research such as credibility, transferability, dependability and confirmability.

Credibility is shaped by various factors including informant contact, researcher interests and perceptions, interview process, and unexplained inconsistencies(Krefting, 1991). In this case, the authors put effort to know about the background of the interviewee so it helped to remove the inconsistencies between the participants and interview questions. It assists to maintain the degree of alignment between the authors generated theoretical ideas and their collected data(Bryman & Bell, 2011). This is the main reason for the authors in this research to make a semi-structured interview and all the questions were customised based on the interviewee profile so that reliable data could be generated.

Transferability pertains to the extent to which the findings can be applied to different situations(Krefting, 1991). When it comes to transferability, it is crucial to offer contextual details about cases, enabling others to determine the relevance of the findings for their own purposes. In this study, the authors have provided an explanation for their choice of cases in the methodology section, along with a well-defined research objective and a comprehensive account of how the data was collected.

Now coming to the point of dependability, it refers the consistency of the research and the consistency of the research can be showed by elaborating the data collection and data analysis process(Krefting, 1991). The authors tried to describe detailed methods of data collection and analysis methods so that dependability of the research can be established.

At last, confirmability does not refer to the researchers' objectivity, but rather to the confirmability of the data and interpretations(Krefting, 1991). In this research, the utilization of recorded video files played a crucial role in maintaining a strong level of confirmability. By directly observing the expressions of the informants and transcribing the recordings, the author was able to iteratively review and validate the data before documenting it. Furthermore, during the coding phase, careful
analysis of the informants' quotes was conducted to ensure accurate categorization under the appropriate "code" or keyword.

5.6 Research ethics

Research ethics is considered as a crucial side for every research as it pertains to ethical considerations and obligations associated with the research topic, design, data access, data collection, data storage, data analysis, and drawing conclusions (Saunders et al., 2009). Keeping in mind about the ethical consideration, the authors in this research established a well communications with the participants and the authors intention was made very clear to the participants that this research is going to be published in university. Most interestingly, the case organization also showed an interest to publish this research officially in their website. Moreover, the authors made an explanation before the interview about the research phenomena and the purpose of the research to all the participants as the research topic might have not well familiarized with all. As Saunders et al., (2009) mentioned the advantages of the recording the interview and taking the permissions for recording is under ethical consideration. Hence, the authors asked the permission from all the participants before starting the interview and as an interview guideline the authors in this research asked all the participants if any confidentiality have to maintain during the interview or not. The authors also made clear to all the participants that in any case if the participants want to change any statement after the interview, they can contact with the authors directly. To make it more easy and comfortable for all the participants, all the transcribed data were further sent to the participants to have a cross check. The authors also ensured that these data only will be used for this particular research.
6. Findings and analysis

The focus of this section is on presenting the findings derived from the interviews conducted with the participants. Therefore, it showcases the empirical data obtained from these interviews. Initially, a concise overview is provided, highlighting the background and professional expertise of the interviewees in the respective field. Subsequently, the collected data is described, emphasizing the information relevant to the research question- What are the relevant LPD aspects and how to integrate them for a reliable electronic hardware development?

6.1 Interview results

In this section, the quotes of the selected participants are summarised based on three key aspects- People, Process and Technology for data analysis.

The perspectives of all the interviewee shows that the case organization and the people of the organizations having positive attitude towards the lean principles. The authors in this research asked a common question to every interviewee about their thinking towards ‘lean principles’ as this is one of the primary condition to select the case organization. All the interviewee agreed that lean is a crucial aspect for achieving reliability and they are well familiarized with the lean principles.

For an example- interviewee 2’s statement provided below-

‘We frequently use lean within the quality department such as the PDCA (plan-do-check-act) structure and Root Cause Analysis (RCA) within problem solving’- Interviewee 2.

Even though interviewee 1 opined that the connections are less strong between lean and product reliability. According to interviewee 1, lean focuses on reducing wastes and its having less influence on product reliability. Additionally, interviewee 1 mentioned lean is not iterative way of doing and its mainly related to continuous improvement.

‘Lean principles influence the way people work and how extends Lean principles supporting product reliability engineering. Lean principles are less iterative, so not incorporated to feedback the stresses learning in the products. Instead of iterative ways cooperating with continuous improvements’- Interviewee 1.
6.1.1 Category: People

In theoretical section, Table- 2.7.1 (An overview of theoretical framework), the authors of this research categorized Management commitment and leadership, Customer relationship management, Continuous improvement and Human resource management under people key aspects as all these aspects are deeply related to people. The way of coding the interview also became easier for the authors because of the categorization.

6.1.1.1 Management commitment and leadership

The view interviewee 1, 7, 4 have provided a valuable insights of management commitment and leadership aspects. All of them are agreed that management commitment and leadership is an essential aspect for achieving a reliable product and they are also following the aspect in their daily activities.

According to interviewee 1, management commitment and leadership which they are following is having two principles-coaching and leadership. Interviewee 1 also provides an excellent insight which helped the authors to understand the differences between these two principles.

‘KATA is followed to implement the management commitment and leadership which is having two principles- coaching and leadership. Leadership is more about setting directions and coaching ensures the directions understood and implemented’- Interviewee 1

The view of interviewee 4 about MCL is all about maintaining close communication and regular interaction with the team, providing guidance, being open to feedback and collaborative problem-solving, identifying competency requirements, offering training opportunities, and fostering transparency, approachability, and trust form the basis of effectively managing a larger team.

‘For me it’s being close to the team and realize how the things are progressing, try to get into the team meetings regularly, being open, reachable etc. We also have strategy work, so team knows the roadmap for coming years. So, the individuals know the competencies required and can plan development areas during the period. Transparency, approachable and trusting the team are my way of handling bigger team ’- Interviewee 4.

According to interviewee 7, management commitment and leadership is a crucial part for driving an organization in the same way towards the organizations mission and vision. Interviewee 7 also emphasized that management strategies are important to consider to have a better direction.
‘Management and employees should move in same directions to achieve the Lean aspects. Because to implement and get things going you need money, support, resources. And if MCL is missing it's really hard to drive. If there no overall management strategies, then there won't be any direction. For e.g: we have five product teams and all five products teams can have different strategies. So, setting up from top and breaking it to down from top to bottom is important to move in same direction’- **Interviewee 7**.

### 6.1.1.2 Customer Relationship Management

Interviewee 3 and 7 shared the same view for customer relationship management aspect. Interviewee 3 emphasized on the customer relationship to become successful in this competitive market. Interviewee 3 also prioritized customer communication and support through a tool InTouch. This assists them to make service activities well-documented, and customer feedback helps them enhance products reliability.

‘To know your customers is the most important to be successful. On a competitive market you need to understand the customers need and how to help solve their problems’- **Interviewee 3**.

‘To be in close contact with our customers and be there when they need us. We collect (when allowed) information regarding service needs through a tool called InTouch. All service activities are documented, and customers feedback could be sent back to our plant for continuous improvement of our products and components.’ - **Interviewee 3**.

On the other hand, interviewee 7 shared some deep valuable insights regarding the customer relationship management. Interviewee 7 mentioned their focus mainly on project-based sales, not component sales, emphasizing the importance of strong business relationships. Close contact with customers, machine builders, and consultants is crucial for securing big projects. Moreover, they are also using some tools to facilitate collaboration, feedback collection, and annual discussions for product improvements and reliability.

‘We don't sell components instead project based in our business. So having a business relationship is really important. So, need to keep close contacts with customers, machine builders and consultant firms in the countries are very important for us. It's not only for selling our products but also get feed back to identify the improvement areas on product and reliability.'
CRM tool- Robin, where all country units share potential sales and leads from the customers, in addition feedback system follows by sales and service team.’ - Interviewee 7.

Interviewee 7 also discussed some issues or challenges they faced which is raised by the customers and how they incorporate those feedback or complaints to make the product more reliable. According to interviewee 7, customers and country units can report complaints or unmet expectations through a template form. Experts analyze the issues, and if necessary, production or product changes are made promptly. But most complaints are minor, immediate action and responsible handling foster customer appreciation and support. Feedback in the sales process is gathered through wish and demand lists, while an internal team uses Engineering Change Requests (ECRs) for reliability improvements. Customers tend to be conservative, but strategies are in place to address component and hardware lifespan issues by adopting hardware-independent software solutions. The challenge lies in replacing or updating control system hardware, so utilizing standard hardware like a PLC from the market is considered as part of the hardware-independent strategy.

‘In our plant, customers and country units can fill a template form, if any expected functionalities not met or if they find some complaints. Then the experts will look into it for a fix, and if we find and changes in production or products considering will take up further as immediate ’ - Interviewee 7.

‘We also have wish and demand lists which are one way to take the feedbacks through the sales processes. We also have something called ECR- Engineering change request (majorly for mechanical hardware) from an internal team who works on reliability improvements. But when it comes to the component issues or hardware life span issues, we are trying to follow some strategies’ - Interviewee 7.

There are other important factors to consider in customer relationship management such as warranty coverage which is also mostly related with the product reliability. Informant 3 provided a clear idea about how they determine, track and analyse the warranty coverage.

‘This process is handled by our customer complaint team that works in the service organization. They get all cases from the sales units through the flexite system. The evaluation of cases is done
together with the colleagues at technical support and if needed with the colleagues at engineering department. They analyze if the cases are within the warranty or not’ - Interviewee 3.

‘Through flexite we can take out statistics of the cases and through that see trends. If an unusual pattern appears and our quality people fear, we may have a recurring problem that should bring the topic into our product teams for them to do the analyze and solve the problem if there is one’ - Interviewee 3.

### 6.1.1.3 Continuous Improvement

The authors in this research tried to make cohesion of continuous improvement during the interview with maximum interviewee as continuous improvement is related to each key aspect. It is such a tool which can be utilized almost in every area. In this part ‘Continuous improvement’ got positive responses from the interviewee 8 who is mostly related to the people aspects. Interviewee 8 agreed that continuous improvement assist the employee to become more and more better. According to informant 8, HR’s role in continuous improvement involves enhancing people and processes, which indirectly improves reliability through competencies, standardization, and data handling, making HR a supportive partner across departments for overall product reliability.

‘It’s actually HR daily job to make continuous improvements. When people and processes are improved, it can automatically add to the reliability possibly in terms of competencies, standardization, personal data handling etc. HR majorly starts from individual level, and so, continuous improvement in HRM could be contributing to product reliability as a supporting partner with many other departments, on different aspects’ - Interviewee 8.

### 6.1.1.4 Human Resource Management

Human resource management is also identified as an essential aspect for any organization as it helps to adopt new technologies, tools and culture by driving the employees in one direction(Jasti et al., 2020). To make it very clear about the importance of HRM, interviewee 8 provided an example where she mentioned that HR plays a vital role in ensuring product reliability by implementing and enforcing a ‘code of conduct,' educating employees from the beginning to foster the necessary competencies for innovation and aligning with strategic goals set by the company's founders and HR.
'One example, in Bosch we educate employees to follow 'code of conduct' which is directly implemented in product reliability. HR is enabling this code of conduct to keep it up within the organization. In Bosch HR also educate the employees from the start, this is one way of making required competencies to innovate and maintain reliable products.' - Interviewee 8.

Additionally, change management is a sub-aspect under HRM found in literature which is also widely discussed by the interviewee 1 and 8.

According to interviewee 1, change management is crucial for organizational success which is related to leadership, but when considering product reliability, a systematic approach and learning journey are necessary. Strategies should balance data-driven approaches, sustainability, and transparency, while allowing for a transition period. Outsourcing components, such as buying a PLC instead of designing a PCB, can address reliability issues. interviewee 1 mainly emphasizing on changing the strategies for electronic hardware products as the electronic hardware components are having less life span and much reliability issues due to technological advancement, increasing customer demands, and global competition (Chan & Ip, 2011; Relich, 2016, Jasti & Kodali, 2014) which is already discussed in problematization part.

interviewee 1 presented a strategy regarding change management i.e. outsourcing electronic hardware component can be solution for the organization rather than making by their own as otherwise it needs to change and update all the time according to customer demands and technological demands.

‘Absolutely an important aspect but considering product reliability to an extend depending on how systematically working with product reliability. Also need to organize a learning journey or change management to introduce certain principles and way of working. Considering all, the strategy with change management is tricky but few currently follows 1. Be very transparent 2. Ensure risk been seen and trusted 3. Allow transition period. As an example, to tackle components issue, instead of design own PCB and making within us, buy a PLC from market for the control system. This can solve the issue with components, PCB designs, testing etc rather can rely on supplier’ - Interviewee 1.

On the other hand, according to interviewee 8, change management within the organization involves utilizing various systems and processes such as TIA, forums, and risk assessment to
identify and address changes, mitigate risks, provide coaching and training support, while leveraging internal resources like the learning portal and 'Docupedia' to simplify the process.

‘We normally discuss which are the changes who all are involved or affected, then find the risks involved, make it transparent, motivate, provide required coaching support, trainings etc to have a smooth transition. Learning portal and ‘Docupedia’ within the company with possible access to all giving a chance to learn and get the knowledge on any topics, this is also making the change management less complicated within organization.’ - Interviewee 8.

6.1.2 Category: Process

In theoretical section, Table- 2.7.1 (An overview of theoretical framework), the authors of this research categorized Reliability activities, Continuous improvement, Total quality management, Supply chain management, Build-measure-learn loop under process key aspects as all these aspects are deeply related to process.

6.1.2.1 Reliability activities

In theoretical section, the authors identified some reliability activities such as DFR, Fuzzy sets, STA etc. which are frequently performed by an organization to make a product more reliable. According to interviewee 1, they follow some quality management standards such as FMEA (identified under Fuzzy sets in literature), DFR, STA etc. interviewee 1 also illustrates which one where to use.

‘Hägglunds is ISO 9001 certified company and following quality management standards. FMEA another example, a well know standard mechanism for technical risk management. DFR- Not only for electronic hardware, but also for overall hardware. STA again a standard following when it comes to software and embedded hardware’- Interviewee 1.

6.1.2.2 Continuous improvement

Most of the informants shows the positive responses towards the continuous improvement based on their activities. In their perspective, it is so important to consider especially for achieving product reliability. For an example, interviewee 5 considered ‘continuous improvement’ aspects especially for monitoring of product performance and if any issues occured then it can be solved.
'Strongly agree with continuous improvement, but if a product is reliable and performing well better not to touch, but when the performance getting lack the improvement must be explored. So continues improvement is kind of continues monitoring of the performance and act on improvements as and when required’- Interviewee 5.

Similarly, interviewee 6 also considered ‘continuous improvement’ as an essential aspect to work around it. According to interviewee 6, they continuously take feedback from all the stakeholders which helped them to continually improve in every area.

‘In our department, we take feedback from suppliers and vendors, also internal and external feedbacks make us to find improvement areas. We target to work around our processes and criteria, there is also a possibility to combine the feedback forms through ERP-SAP system. So, our processes are transparent, systematic and importantly always working on improvement areas. So continuous improvement is an essential aspect for us and we always work around it’- interviewee 6.

Interviewee 4 shared same opinion as interviewee 5 and 6. According to interviewee 4, continuous improvement is crucial for enhancing products, processes, and ways of working, and incorporating customer feedback and knowledge plays a significant role in achieving product reliability and overall improvement.

‘Product, way of working, process etc. can always improve. We learn more, tools, computer programs can always continually improve. Adding more features and functionalities to existing products and integrate new features are some examples to continuous improvement with products. So, continuous improvement points are one way or another complimenting product reliability too’- Interviewee 4.

6.1.2.3 Total quality management

The goal of total quality management is to continually improve design processes and manufacturing plans(Stewart et al., 2020). Interviewee 2 provided an excellent insight regarding total quality management in line with product reliability. Interviewee 2 mentioned that the total quality management is a customer focused tool to achieve promised reliability.
‘Total Quality Management as a quality management framework is based on building in its long-term principles and sustainable quality improvements. This is also in line with its principle that focus on processes, customer focus and fact-based decisions. Since reliability is based on the evaluation of whether the product or service has delivered its previously promised quality over time, it can be seen as a good measure of how robust the various principal areas are and have how good they have been implemented within an organization’ - Interviewee 2.

Additionally, interviewee 2 emphasized on ‘standardization’ of process to achieve the product reliability in TQM. Here, the authors of this research considering standardization under total quality management as also informant 5 mentioned standardization is mainly the area for quality department.

‘Standardization is followed majorly with the quality team in tests for example to identify the wrong one’ - Interviewee 5.

Standardization involves the use of common products, processes, and components to meet various requirements and approx. 52% of frameworks have identified standardization as a critical element for achieving LE excellence, leading to its inclusion as one of the pillars in the LE framework (Jasti et al., 2020). According to interviewee 2, Standardization enhances process improvement by minimizing errors and deviations, particularly in tasks involving subjective evaluations, ultimately leading to greater efficiency and reliability.

‘Standardization as an element for process improvement is beneficial for many reasons. E.g., when we standardize something, we reduce the potential error and/or the deviation in that process especially, when the task includes a subjective evaluation’ - Interviewee 2.

Interviewee 5 also discussed the importance of ‘standardization’ and mentioned standardization is crucial for quality testing, ensuring consistent handling of electronic hardware families according to established rules, standards, and processes documented in Bosch Rexroth's 'Docupedia,' including adherence to parameter limits and proper documentation of test results.

‘Standardization is connecting to electronic hardware we got different families like Spider, ICP, CM, CMP etc. In ideal world those all need to be handled same way following the rules, standards and processes like for configurations, testing etc. We also have those documented correctly in our internal Bosch Rexroth documentation called 'Docupedia'. In the electronic world we also have
set values for the parameters which need to follow the standardized way, and can't go beyond or below the limits it's allowed. Individual test results are also normally documented’ - Interviewee 5.

6.1.2.4 Supply chain management

Supply Chain Management (SCM) arose in the 1990s as manufacturing organizations acknowledged the significance of suppliers in achieving timely, cost-effective delivery and has since become indispensable in the contemporary business environment (Jasti et al., 2020, Soni et al., 2019). According to interviewee 6, in Supply Chain Management (SCM), the procurement of correct materials (including raw materials, components, and interfaces) holds great importance as it directly impacts the quality and reliability of products, highlighting the need for meticulous attention to material selection to ensure optimal performance and reliability, even if the design is sound.

‘SCM is a vast area covered many aspects of procurement. Correct materials (raw materials, components, interfaces etc) normally having high priority since it's important to meet the expected quality and reliability of products. Even though the design is made correctly, the wrong selection of materials can deviate the expected performance and reliability. So, it's normally to be taken seriously’ - Interviewee 6.

Interviewee 6 discussed also about the effect of ‘standardization’ in supply chain management to be more efficient, error-free, transparent, high level of quality, independent, easy to analyse etc.

‘One reason is that our work routines at procurement need to be standardized as much as possible, because then the system will run independently. Also easy to cross-function, like handling other departments in case of emergency, absence and so on. Again, standardized routines can faster what we do on most occasions. So, when routines are standardized and specified systematically it can be more efficient, error-free, transparent, high level of quality, independent, easy to analyse etc. Yes, the ERP-SAP system complimenting the procurement flow and process standardization’ - Interviewee 6.
6.1.3 Category: Technology

6.1.3.1 Tools and technology

Interviewee 4 and 5 considered ‘tools and technology’ as one of the important areas to focus for product reliability. Interviewee 4 discussed that having a structured approach, utilizing appropriate tools and technology, and prioritizing the resolution of identified issues in the right order allows for effective handling and improvement of product reliability alongside quality, through calculations, simulations, stress application, verification, and testing.

‘I as a process owner have guidelines how to handle in structure way taking advantage of tools and technology to ensure the product reliability, which may be one aspect along with quality other side. With correct selections of tools and technology for calculating, simulating, applying stresses, verifying, testing we can achieve product reliability to an extend’ - Interviewee 4.

According to interviewee 5, in the context of automation and digitalization, the utilization of tools and technology allows for streamlined processes, reduced human errors, improved quality, and increased reliability through the automation of tasks, resulting in enhanced efficiency and reduced reliance on manual work.

‘Tools and technology is very important for our business related to automation. We normally call it as digital change or digitalization. For an example you enter the details once then you have tools to automate it. We have configured where we extract info and use digital change or tools with respective algorithms for avoiding risk of human errors. That would increase the quality and reliability. Ultimately reduce the manual works and automate which is simply more reliable’- Interviewee 5.

There are also some disadvantages of technological advancements such as product life span is decreasing (Chan & Ip, 2011; Relich, 2016, Jasti & Kodali, 2014). In line with this, interviewee 1 was agree with the statement and mentioned that the utilization of latest technological developments requires shorter innovation cycles.

‘If we have to utilize the latest technological developments in innovations then we need to find a way to shorten the innovation cycles’- Interviewee 1.
6.1.3.2 Concurrent Engineering

The success of an organization mostly depends on how much of their product are succeed in the market (Jasti et al., 2020). A focus on time-to-market is crucial in product development, as it enables significant cost reduction and the production of higher quality products that align with customer requirements (Mallampati et al., 2018). In short, to become succeed in the market, product have to be in market timely by reducing cost and with efficient production where concurrent engineering mainly involved. Interviewee 5 also shared the same opinion regarding concurrent engineering to have a reliable product with efficient production.

‘Concurrent engineering term more correlates with parallel work, it can definitely increase the efficiency and can reduce time. May be yes in the aspects of parallel testing and doing partial tests than a full development test so that it can reduce the risks giving more errors at the end. because to test the hardware you also need the firmware or a software. So maybe in that way it is contributing to reliability too’ - Interviewee 5.
7. Conclusion and discussion

The focus of this section is on presenting the conclusion based on the research question. To answer the research question, the authors of this thesis tried to gather the main ideas from the data analysis section to answer the research question. Moreover, the theoretical implication, practical implication and limitations of the study. Finally, the authors also provided some insights on future research possibilities.

7.1 Addressing the research question

The thesis is intended to accomplish by answering the following research question i.e. What are the relevant LPD aspects and how to integrate them for a reliable electronic hardware development? Furthermore, the purpose of the thesis is also fulfilled by exploring the cohesion between LPD and reliability. In this section, the three main key aspects people, process and technology will be discussed in a summary based on all data analysis and the integrated conceptual framework is presented again for better understanding with the conclusion.

From the data analysis section, it is evident that all the questionnaire related to the people category have provided an excellent insight which is clearly supporting the elements of conceptual framework. The elements of integrated conceptual framework under people category such as Management commitment and leadership, Customer relationship management, Continuous improvement and Human resource management are all covered during the interview process. All the interviewees were agreed to the mentioned aspects. The study found that Management commitment and leadership, characterized by coaching and leadership principles, involve maintaining close communication, providing guidance, embracing feedback, fostering
transparency and trust, identifying competency requirements, offering training opportunities, and utilizing collaborative problem-solving to effectively manage a larger team and drive the organization towards its mission and vision. It was also found that establishing a successful **customer relationship** in a competitive market requires maintaining close contact with customers, machine builders, and consultants, while utilizing collaboration tools, feedback collection, and annual discussions to enhance product improvements and reliability. Moreover, the study showed that **Continuous improvement** fosters the growth of employees by enhancing competencies, standardizing processes, and improving data handling, enabling HR to serve as a supportive partner across departments and contribute to overall product reliability. One important sub-aspect was identified under **Human Resource Management** during the interview i.e. change management, it is very crucial for organizational success which involves different processes to identify and address changes, mitigate risks, provide coaching and training support.

Now, coming to the category **process** is having reliability activities, continuous improvement, concurrent engineering, total quality management, supply chain management and build-measure-learn loop. The study found that the selected organization follows some quality standards to make the product more reliable which is called **Reliability activities**. For instance- Fuzzy sets (FMEA), DFR (design for reliability) etc. They also follow **Total Quality Management** which is basically a customer focused tool and ‘standardization’ found as another crucial sub-aspect under this to make a product more reliable by reducing errors and making process improvements. During the interview, the authors of this thesis focused on **Continuous improvement** to maximum interviewee and the interviewees acknowledged that it is crucial for enhancing products, processes, and ways of working, with a particular focus on monitoring product performance, promptly addressing any issues, and incorporating valuable feedback from stakeholders, which collectively contribute to achieving product reliability and overall improvement. It was also found that selecting the right materials is crucial for product quality and reliability, regardless of a well-designed product, as it directly impacts performance, emphasizing the need for careful material procurement. This responsibility goes to **Supply Chain Management** and standardization can be implemented here as informant mentioned that to be more efficient, error-free, transparent, high level of quality, independent, easy to analyse in SCM, standardization is necessary.
The Technology category was deeply considered by the interviewee as well as in literature also. Informant mentioned that a structured approach, along with the use of suitable tools and technology, is key to effectively managing and improving product reliability and quality. This involves addressing identified issues in a prioritized manner through calculations, simulations, stress application, verification, and testing. Additionally, in the realm of automation and digitalization, the adoption of tools and technology enables streamlined processes, minimizes human errors, enhances quality, and boosts reliability through task automation. Consequently, this leads to improved efficiency and reduced reliance on manual work. But time to time in market or parallel working strategy to make a product more reliable, then it refers to Concurrent Engineering which was also identified as one of the relevant aspects in this study.

The overall effort to address the research question covered a literature review finding the relevant aspects of LPD in the context of Reliability. Then the authors of this thesis implemented their own integrated conceptual framework from literature, followed by the data collection which was majorly in the form of interviews within the case organization. The identified framework more closure to an iterative way of handling Lean for reliability. For example, few elements in the framework like continuous improvement, customer relationship management, concurrent engineering are supporting to an extend that handling Lean in an iterative method. Iterative or Agile way of working is little away from conventional Lean methodologies. However, the authors recommending an iterative way of Lean or even a hybrid methodology could be more efficient way for PD, especially for current era in electronic hardware world. Hence, the authors proposing the mentioned integrated framework for a reliable electronic hardware development.

7.2 Theoretical implications

In theory section, there are mainly four key areas discussed- Reliability Engineering, LPD, Toyota production system, Lean enterprise framework. As it is discussed before in the theoretical section, researchers discussed throughout the LPD aspects very closely (Ashaab et al., 2010, Sorli et al., 2010, Khan et al., 2011, Tortorella et al., 2016 and Ashaab et al., 2016, Womack & Jones, 1996, Jasti et al., 2020, ZIO et al., 2019, Soni et al., 2019, Grant & Schlesinger, 1995, Mallampati et al., 2018), although the framework for achieving reliability in line with LPD aspects is very limited. As a result, the authors of this thesis implemented a conceptual theoretical framework by identifying the relevant aspects of LPD for electronic hardware development. The new framework
that is presented in this thesis shows what aspects have to consider to achieve product reliability especially for electronic hardware and how to integrate them in a framework. This reliability framework is very crucial to consider since the outcome of technology advancement is still unpredictable which leads reliable electronic hardware development to a high level of uncertainty.

7.3 Practical implications

The authors of this thesis considered the findings can be utilized by an organization to make their product more reliable. The proposed conceptual framework can be implemented by top management to get a better result. As we seen in the data analysis section, interviewees mentioned about some strategies which probably might not be a permanent solution. Therefore, the authors of this thesis considered this one as a gap and proposing this integrated conceptual framework to get a reliable product.

7.4 Research limitations

The authors found few limitations within the research majorly considering the constraints on time, accessibility, reachability etc. One limitation was the data collection limited to one case organization, even though the authors made certain criteria to identify an ideal one. One more limitation was being Lean as a vast philosophy and there are many frameworks under this umbrella, we could still miss few other relevant aspects in the context of Reliability.

7.5 Future research scope

As referred in section 7.1, the framework elements are relevant LPD aspect for a reliable product development. Being LPD is a vast area to research and so the authors could have missed some aspects in the context of reliability, and that can be a future research area. This research findings were close to an iterative approach of LPD aspects. In line with this, the authors of this thesis also got a supportive statement from interviewee 1 during the interview. Considering the same, the authors hereby recommend that ‘Agile way of Lean’ can also be a future research area to explore.
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Appendix-01

Interview guide

The purpose of creating the interview guide is to ensure the research question is addressed effectively. The few questions provided here serve as an example for conducting the interviews, with three sample interview scripts included. It is important to acknowledge that additional questions were posed to the other interviewees during the actual interviews.

Initial questions for all interviewees

Question- Could you please brief about yourself (major roles and responsibilities, in a very short)?

Question- Does Hägglunds Bosch Rexroth follow the Lean principles for product development?

Interview manuscripts for interviewee working as Global Engineering Head

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<tr>
<th>Interview Questionnaire</th>
<th>Mode of answering</th>
<th>Answering</th>
<th>Purpose</th>
<th>Planned evaluation</th>
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<tr>
<td>1. Could you please brief about yourself (major roles &amp; responsibilities, in a very short)? Do you handle any customers directly?</td>
<td>Free text</td>
<td>Landstorm Anders, working last 8 years in Bosch Rexroth Malmö. Born in different areas like Sales, Logistics and trainings, but currently working as a Product owner within Automation and digital services team. Responsible for the life cycle of control system &amp; condition monitoring within DC-HD. Working in a cross functional team taking care of products &amp; also product development. Overall responsibility and ownership of product portfolio, that means responsible from the development of product all the way through life cycle until it scrap it. On top of it responsible and having ownership of cross functional product team. Guide and prioritize the activities within the team. Planning and execution of portfolio strategies. Customers are internal and external are through the respective sales team.</td>
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<td>2. Do you believe that product reliability having impacts on sales? If yes, how?</td>
<td>Yes/No</td>
<td>Yes, huge impact. We are well known in market for quality and reliability and of course the price is not cheapest instead quite expensive. But our trade mark is quality &amp; reliability. Many or most of the systems are working 24X7. E.g. One machine mostly on production line, for example in pulp and paper industry if machine stop in between it can make a huge loss as the pulp can get solid inside machine, and so reliability of our products are expected to be on top for most of our customers.</td>
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<td>3. Do you consider Customer relationship management is essential for improving reliability? If yes, why? Also do you have any tools, especially for CRM?</td>
<td>Yes/No &amp; Free text</td>
<td>Yes, We don’t sell components instead project based in our business. So having a business relationship is really important. Usually it’s big projects and lot of money involved and mostly after a long contracts we get the project. So keeping the close contacts with customers, machine builders and consultants firms in the counties are very important for us. It’s not only for selling our products but also get feed back to identify the improvement areas on product and reliability. Yes, CRM tool- Robin, where all country units share potential sales and leads from the customers, in addition feed back system follows by sales and service team. Feedbacks from country units based on customer &amp; consultants inputs, sales &amp; service team make the wish &amp; demand list. These lists will be discussed very seriously at least once in a year to look at the improvement areas in terms of reliability, add on features etc.</td>
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<td>4. Did you experience any challenges or concerns, raised by the customers regarding product reliability? If yes, how do you address them? Possibly one example?</td>
<td>Yes/No &amp; Free text</td>
<td>In Malmöland customers and country units can fill a template form, if any expected functionalities not met or if they find some complaints. Then the experts will look into it for a fix, and if we find changes in production or products considering will take up further as immediate. E.g. There was a leakage in motor due to an issue with sealing ring, which in turn made an issue on the reliability of particular product. Then we figured out how to move forward and immediately made a campaign with customers to identify the motors affected and send out our service technicians to replace it. Even it was an issue the relation with customers became more stronger when we took the responsibility and fixing it immediately. All the customers appreciated especially being straight and support correctly. But this is one rare case if not mostly are small complaints.</td>
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<td>5. How do you incorporate customer feedback on product reliability into the sales process, especially considering the current life span issues with electronic hardwares?</td>
<td>Free text</td>
<td>As mentioned wish &amp; demand list are one way to take the feedbacks through the sales processes. We also have something called BCR. Engineering change requesting for mechanical hardwares from an internal team who works on reliability improvements. Then concerning to reliability, most of our customers are conservative and we really want to move out and experiment new. But when it comes to the compressor houses or hardware life span issues, we are trying to follow some strategies. That means try to be more hardware independent software solutions. It’s quite challenging to replace control system/hardware products to replace or update everyone where the mechanical system are much reliable and stands for many years. So the idea is to go for standard hardware to use from market, e.g. a PLC and follow the hardware independent strategy.</td>
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<td>6. 'Management commitment &amp; Leadership' is noticed as one of the essential elements in Lean philosophy, do you agree to that? If yes, can you briefly mention few points related (e.g. Guiding &amp; influencing, developing strategies, trainings, vision &amp; mission etc)?</td>
<td>Yes/No &amp; Free text</td>
<td>Yes, Working a lot with Lean and to get things going as per philosophy MCLL is very important. Management and employees should move in same direction to achieve the Lean aspects. Because to implement and get things going you need money, support, resources. And if MCLL is missing it’s really hard to drive. In PRM we have yearly product strategy, but in the end we also need a business strategy from management. If there is no overall management strategies, then there won’t be any direction. For eg we have five product teams and all five product teams can have different strategies. So setting up from top and breaking it down from top to bottom is important to move in same direction.</td>
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One author of this thesis is pursuing his Masters’s degree in Industrial Management and Innovation, at Halmstad University since 2021. He is also an Electronics and instrumentation engineer who received his bachelor’s degree in 2004. Currently, he is working as an advanced automation engineer at Bosch Rexroth in Sweden. Earlier, he also worked in Siemens (SBT, India), Panasonic India (Firepro) and MTS (Oman).

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