Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical & Industrial Engineering

Defect Reduction Using a Lean Six Sigma DMAIC Approach: A Case of 3F Manufacturing PLC

A Thesis Submitted to the School of Graduate Studies of Addis Ababa Institute of Technology, Addis Ababa University in partial fulfillment for the Degree of Master of Science in Industrial Engineering

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Declaration

I hereby declare that the work which is being presented in this thesis entitled Defect Reduction Using a Lean Six Sigma DMAIC Approach: A Case of 3F Manufacturing PLC is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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Abstract

Companies are forced by competitive pressures to look for ways to reduce defects while enhancing product quality. One of the best methods for corporate transformation is lean Six Sigma. This study seeks to give an empirical case study on the use of lean Six Sigma DMAIC approaches to reduce defects in a wood furniture company. The case company faces issues with the quality of its goods, which are reflected in its quality department and complaints from customers regarding the existence of defect rates of 59% in door product. Therefore, this study's objective is to reduce defects. To evaluate opportunities, present evidence for improvement, and identify possible benefits, the DMAIC technique is used in the study to look into the root causes of problems and suggest mitigation strategies. The result showed a significant decrease in the defect rate for door products. Previously, the defect rate stood at a concerning 59%; after effective interventions, it has dropped substantially to an impressive 22.96%. Through careful examination and rectification of underlying causes, it successfully identified and addressed the issues leading to defects. As a result, the number of defective doors produced has significantly decreased. Not only tackled defects but also made notable strides in improving process efficiency. The cycle time has witnessed a commendable reduction of 51 minutes, decreasing from 2114 minutes to 2063 minutes. To measure the consistency and reliability of our processes, it is important to utilize the sigma level. The sigma level has shown significant progress, improving from 2.6 to 3.2, considering a 1.5 sigma shift. This means that our process now operates within a narrower range of acceptable variations, ensuring greater consistency and reliability in the products. Even without factoring in the 1.5 sigma shift, the sigma level has improved from 1.18 to 1.7. This improvement is in terms of reducing variations and increasing process stability. With these outcomes, it is evident that Lean Six Sigma can indeed be applied for defect reduction in a furniture company, successfully reducing the defect rate, enhancing the overall quality of our products, and strengthening the reliability and consistency of our processes. During the research phase of the DMAIC process, a serious oversight was discovered; a lack of validation relative to the identified root causes. This omission may limit the achievement of intended goals and lead to ongoing processing difficulties.

Key words: LSS, DMAIC, value stream mapping, defect reduction

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List of Abbreviations

DMAIC – (Define-Measure-Analyze-Improve-Control)

DMAVIC-(Define-Measure-Analyze-Validation-Improve-Control)

VSM- Value Stream Mapping

LSS - Lean Six Sigma

SS- Six Sigma

CSA- Central statistics Agency

3F- Finfinnee Furniture Factory

NVA-Non-Value added Activity

VA-Value added Activity

SOP- Standard Operating Procedure

FGD- Focused Group Discussion

5W1H- (What, Why, How, Where, Who, When)

5S- (Sort, Set in order, Shine, Standardize, Sustain)

VAT-Value Added Time

NVAT-Non- Value Added Time

JIT-Just In Time

WIP- Work in Process

DPMO- Defect per Million Opportunity

SPC-Statistical Process Control

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I am profoundly grateful to the almighty God, whose boundless love, protection, blessings, and mercy have been a constant source of inspiration throughout my journey. His guidance has helped me overcome challenges and reach the completion of this work.

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CHAPTER ONE
INTRODUCTION AND BACKGROUND

1.1. Introduction

Many firms are dedicated to increasing product quality and process performance to achieve a number of bottom-line and strategic goals, such as profitability, market share, and competitiveness (Daniyan et al., 2022).To becoming a competitive shorter lead times, increased productivity, better resource utilization, improved quality, and lower operational costs are a key performance indicators (Kovács, 2018). To accomplish these goals, LSS attempts to increase transparency in the manufacturing process by identifying opportunities for problem solving, waste reduction, and process variability reduction (Luana Bonome Message Costa et al., 2021; Shivam Gupta et al., 2020) . Lean tools increase operational performance by minimizing non-value-added operations, which generates significant returns for the firm(Chavez et al., 2013).

The most widely used lean manufacturing tool for stimulating material and information flow on the shop floor is Value Stream Mapping (VSM). The instrument eliminate different categories of waste, including transportation, excess inventory, motion, waiting, over production, over process, and defects (Pathania et al., 2021) .Value stream mapping have major disadvantage in that it can only be used to analyze one product family at a time and is not cost-effective for all of the products in a given industry (Knoll et al., 2019). In order to achieve their bottom-line objectives of profitability, sustainability, market share, and competitiveness, many businesses today are increasingly on the lookout for ways to improve the performance of their processes and the quality of their products. In this era of globalization and rising market competition, The combination of high productivity and good quality is essential to every organization's existence (RJS Costa et al., 2017). The application of the Six Sigma methodology has resulted in significant benefits as Fortune 500 and several international businesses reported (Nakhai et al., 2009). Similarly Lean Six Sigma has its origins in the manufacturing industry and has proven to be a very effective business excellence methodology, regardless of the size or nature of the industry (Simanová and Sujová, 2022). Many continuous improvement approaches have emerged, expanding on the ideas of the earlier ones. The most well-known among those are lean manufacturing, six sigma, and lean six sigma. Most of them faced the failure of programs for continuous improvement in the manufacturing sector. These factors have been categorized into eight major categories, including expectations and motives, organizational culture and environment, the management's leadership, implementation approach, project management, training, and employee participation levels (McLean et al., 2017).

After 1950, Mr. Crosby popularized the idea of zero defects, which was regarded as a fundamental shift in the way that industrial quality control was conducted. There are numerous methods and tools for reducing defects which are utilizing scientific techniques (SPC), product design, production process flexibility, technology application (smart manufacturing, robotics), layout, inspection, maintaining strict quality control, and increasing the flow of communication. Some of the most potent and successful tools on the market for manufacturers to eliminate defects are Six Sigma, LSS, ISO 9000, TQM, and the 5 "S" Methodology. Each model has unique benefits and drawbacks. The major limitation of all models is that they are proposed based on the country's economic level, the nature and size of the company, the quality of data analysis, the ease of methodologies, the level of improvement, and mutual support. As a result, they fail to take into account the fact that Ethiopia's reality is very different from that of a more developed nation. But many studies strongly support the notion that integrating lean six-sigma produces better results than individuals at any stage and in any industry. However, this study aims to fill the gap by offering LSS after taking into account the realities of the country, particularly the issues faced by the 3F furniture manufacturing industry.

The company has more than ten production varieties. To accommodate client demand, employees put in six days of piecework a week. The business faces issues with the quality of its goods, which are reflected in its quality department and complaints from customers regarding the existence of defects. Because of these issues, this study aims to fill gaps by demonstrating that LSS and DMAIC-based problem solving are applicable in Ethiopia's wooden furniture industry. The best ways to reduce defects can then be found based on the results. To gain a better understanding of lean DMAIC, a case study implementation is carried out at the 3F Wood Furniture Company, which includes a survey of the starting scenario and subsequent DMAIC cycle implementation using lean tools. The aim of this research is to assist in identifying areas that could benefit from improvement.

1.2. Background

Companies in the furniture industry must compete with one another in order to survive in the industrial world as it develops. Maintaining product quality to ensure customers are satisfied with the company's offerings is one crucial component of a company's survival ability (Li et al., 2018).

The majority of Ethiopia's small-scale wood industries are found in furniture, joinery, and Ethiopia has produced wood and wood-related items for more than a century (Girma et al., 2021). Ethiopia's demand for wood products is rapidly increasing as a result of urbanization, population growth, and economic expansion (Lemenih and Kassa, 2014). To be competitive in an increasingly globalized market, pressure has been put on wood manufacturers to embrace innovative manufacturing techniques and management strategies that will shorten production cycles, improve quality, and lower costs(Czabke et al., 2008). Lean Six Sigma (LSS) is a corporate performance improvement strategy that combines the two disciplines of lean manufacturing and Six Sigma (Andersson et al., 2006). Lean Six Sigma is frequently used to direct organizational efficiency improvement and change initiatives due to its structured project approach and large set of tools for problem solving. The define, measure, analyze, improve, and control (DMAIC) technique is used in this methodical, data-driven approach to operational processes in order to reduce defects, errors, and other wastes (Vermaelen and Kovach, 2022). The number of rejections or defects in a product increases the investment in reworking it and the loss due to scrap (Abhilash, Thakkar, & Management, 2019). Rework is defined as work processes that must be completed more than once and have a significant cause for budget and schedule expansion. Rework is not a process that should be added because it degrades the effectiveness and quality of work (Isasare & Bhirud, 2018). Today, it is understood that the essential components of any business organization are the quality of products, customer services, customer satisfaction, and client retention. To achieve this goal, businesses should equip themselves by carefully analyzing their core competencies and their weaknesses in relation to their competitors' strengths and weaknesses. Any organization's fundamental goal is to maximize profits through the development of strong, long-lasting client relationships. To maintain competence and gain a competitive advantage in the market, the company must reshape itself as a chain that adds value to consumers by reducing defects and improving quality (Papasolomou et al., 2006). Finfinnee Furniture Factory (3F), a wood furniture manufacturer founded in 1959 in

Addis Ababa, Ethiopia's Oromia region of Alemgena is one of Ethiopia's furniture manufacturers. It is a private limited company, and its main products are door, sofas, beds, mattresses, dining tables, kitchen cabinet construction, and office work. These research is focus on these factory in order to reduce the defects of the selected product due to its severity of defect rate which is more describe in the problem statement and introduction.

1.3. Problem Statement

Products with good qualities are often able to obtain superior income through either a bigger market share or through higher prices. Products with uncompetitive features frequently have to be sold for less than the market price (Eldin, 2011). The core tasks of modern manufacturing systems are quality and production control (Colledani et al., 2014). Even though increasing profits is often seen as the primary goal of any organization, a number of obstacles are preventing this from happening. The severity of the issue differs amongst organizations. Every organization approaches the current issue differently. Therefore, it is important to pay more attention to locating, comprehending, and solving the issues (SHUKA, 2015). Defects affect 3F because there is no clear and integrated controlling mechanism. According to the quality department's one-year data (2021–2022) report, the company produces 10868 pieces in seven primary items, of which 1002 are defective. It indicates that defects account for 9.2% of its products, but the door product has the highest defect percentage (59%) out of the seven. The company's average process sigma level is 2.09 without 1.5 sigma shifts and 3.58 with 1.5 sigma shifts, and the sigma level of the single product which is the door product is 1.18 without 1.5 sigma shifts and 2.6 with 1.5 sigma shifts of defects per million opportunities. In this case, if the company has a sigma level of 2.09 without 1.5 sigma shifts, it means that their processes are producing defects at a rate of 308,537 per million opportunities. Indicates a process yield of approximately 69.1%, which is very far from the standard sigma level. Which is 3.4 defects per million opportunities (corresponding to a standard sigma level of 6), is considered to be a world-class process. Developing countries, on the other hand, may encounter obstacles such as a lack of infrastructure, access to technology, and experienced personnel, which may limit their capacity to achieve high sigma levels. It is nevertheless possible to improve process capabilities and attain higher sigma levels with the correct support and investment in quality management. Customers are proactive about quality, so focus on the impact of a defect to prevent a disastrous outcome

(Goyal et al., 2019). According to a CSA and Ethiopia Forestry Research Center report, there has been a significant improvement in the furniture industry. Although access to industrial sectors has improved, the quality burden is still significant, and the service utilization rate is still poor. Likewise, the competitiveness of the Ethiopian furniture industry is low, mainly due to poor quality. In addition, the LSS methodology has not been used to evaluate and enhance the settings for wood furniture in Ethiopia. This study suggests combining lean and SS in a synergistic way to reduce defects. It seeks to experiment with the DMAIC approach to reduce quality.

Similarly, the production process can be negatively impacted by defects and rework in a variety of ways. They might cause inefficiencies, delays, and cost overruns. They may also result in a loss of trust in the product or service, a reduction in customer satisfaction, and weaker quality control. As a result, in order to preserve quality and improvement, businesses must take action to reduce defects. Additionally, tracking and analyzing defects can help businesses look for patterns and potential solutions. Therefore, this study focuses on identifying and reducing the defects by taking corrective action. Evidently as shown below in Table 1, the company faces high defect percentages according to their one-year quality data. The case company's products come in more product varieties; however, each product has a high defect percentage ranging from 8 to 59%.

Table 1.1: Defect rates from one-year data (Source: 2021/2022 Quality report of case company)

S/N	Product Type	Defect rate
1	Door	59
2	Bed	14
3	Chair	8
4	Coffee Table	6
5	Sofa	3
6	Kitchen Cabinet	2
7	Mattress	1

The acceptable defect rate in the wood furniture industry, particularly in door production, can vary depending on the quality standards and requirements set by the manufacturer or customer. However, as a general rule of thumb, the acceptable defect rate in the wood furniture industry is typically around 5–10%. This means that up to 5–10% of the doors produced may have minor defects such as small knots, cracks, scratches or color variations and measurement variation. However, any defects that affect the structural integrity of the door or compromise its functionality should be considered unacceptable and should be reworked or rejected.

The American National Standards Institute (ANSI) has produced the ANSI/BIFMA (Business and Institutional Furniture Manufacturers Association) X5.1-2017 standard for acceptable defect rates in furniture goods. The acceptable defect rates for furniture goods are classified like critical 0 %, major defect up to 2.5 % and minor defect is up to 4 %.

These defect rates serve as quality control criteria, ensuring that furniture goods fulfil particular safety, appearance, and performance standards. In China, for example, the defect rate for wooden furniture has been set at 3%, whereas the rate for metal furniture is fixed at 5%. The Ministry of Industry and Trade in Vietnam has set a 2% defect rate for wooden furniture products. Similarly, the National Standardization Agency of Indonesia has set a 5% defect rate for wooden furniture. In fact, the real scenario in 3 F manufacturing plc is that the door product defect is more than half of the good products by 9%, so it does not need comparison, even to standards. It is a must to reduce the defect rate.

1.4. Research Questions

This study looks at examining the following basic research questions:

1. What and where are the contributors of defect?
2. What is the effect of lean six sigma DMAIC approach in defect reduction?
3. Which lean tools improve production quality performance by reducing defects?

1.5. Objectives of the Study

1.5.1. General Objective

The objective of this study is to reduce defects using the lean six-sigma DMAIC approach.

1.5.2. Specific Objective

The specific objectives of the study include the following:

1. To identify, categorize, and tackling defects
2. To apply the DMAIC concept of six-sigma to reduce defects
3. To apply the lean concept of waste minimization
4. To examine the effectiveness of the LSS for defect reduction

1.6. Scope of the Study

This research is conducted on 3F Furniture Company in order to reduce defects using lean six sigma and DMAIC approach. Thus, in this research, the existing defect is analyzed, and solutions for root causes are given by using the LSS methodology. Because the company has a quality problem, the company's management requires assistance in addressing the problem, so this research in 3F furniture was chosen as a case company in defect reduction using the lean six sigma methodology.

1.7. Limitations of the Study

The reason for only using one case company (a wood furniture company) in this study is that it can be difficult to generalize results from one case to others, and there have been few previous studies in these areas of the company in Ethiopia due to the fact that this literature survey is outside of the national nature of Ethiopian company culture. Lack of research in the field in Ethiopia was one of the limitations in getting literature compatible with the current level of manufacturing in the country. So the infrastructure, level of knowledge, leadership style, culture, level of economy, and other factors are not comparable to those in the country in which the research was carried out.

1.8. Significance of the Study

This research will benefit the company by reducing defects and rework costs, increasing revenue, increasing profitability, improving performance, improve the quality of products and service delivery by reducing the prolonged correction time. The findings of these studies have an advantage for researchers, policymakers, and practitioners in similar industries in the country at all levels to share experiences about lean six sigma (the lean DMAIC approach) for defect reduction.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

In this literature review, various articles, reviews, manuscripts, case studies, and reports are studied to gain a full understanding of the issue under research. The literature evaluations mostly concentrated on lean, Six Sigma, and the significance of integrating lean and Six Sigma, as well as the application of lean and Six Sigma in furniture and prior studies on lean Six Sigma in the furniture sector. As a result, gaps in the literature are found, as are areas that require additional research, and the significance of this specific topic is indicated.

2.2. Lean Tools and Six Sigma

Lean Theory: Lean is a continuous improvement approach that aims to reduce waste, boost the value provided to products (goods and/or services), and offer customers value (Gaspersz, 2008). There are five fundamental Lean principles, namely:

Understanding customer value: The value of the product or service is determined from the viewpoint of the customer, who desires a high-quality product at a reasonable price and prompt delivery.

Value stream analysis: It is necessary to identify value stream process mapping, or value flow process mapping, for each good or service.

Perfection: During the value-stream process, waste that doesn't add value should be eliminated.

Pull: Uses a pull system during processing to ensure that materials, information, and products flow smoothly and effectively throughout the value flow process.

Flow: To achieve excellence and continuous improvement, a variety of strategies and tools for improvement (tools and repair procedures) are explored.

Six Sigma: Six sigma is a method of continuous improvement that seeks to minimize process variations in order to improve the process's ability to produce products (goods or services) with no errors (zero defects, with a minimum target of 3.4 DPMO (Defect Per Million Opportunities) and to provide value for customers) (customer value) (Vivekananthamoorthy and Sankar, 2011).

Lean Manufacturing and Six Sigma (LSS): are two managerial methodologies that have been used in several businesses up to now. Lean Six Sigma (LSS) is a corporate performance improvement strategy that combines two approaches: lean manufacture and Six Sigma. Lean manufacturing, often known as lean, is a methodical way to find waste and improve it through continuous improvements (Andersson et al., 2006). Applying LSS is based on many principle, tools and methodology, especially on define, measure, analyze, improve, and control which is called as DMAIC. In conclusion, if lean is adopted without Six Sigma, there won't be enough instruments to fully capitalize on improvement. On the other hand, if Six Sigma is adopted without lean thinking, the improvement team would have access to a variety of tools but no strategy or framework to advance their application to a system (Pepper et al., 2010). Some studies that have developed the use of the Lean Six Sigma approach have found some perceptions that are not the same in implementing continuous improvement but the researchers approved that the integration of lean principles with Six Sigma methodology as a coherent approach to continuous improvement is successful (Anderson et al., 2015; Megawati et al., 2020).

Adopting the most recent production technologies is conceivable without taking extreme cost-cutting measures or laying off workers. The majority of sectors today consider operators as corporate assets (Pfeffer and Veiga, 1999). Reducing energy resources, consumables, and product rejection is possible through continuous improvement, process observation, and by the use of quality control tools (Farooq et al., 2017). The author (Guleria et al., 2021) conducted that by using lean six sigma tools VSM and DMAIC were chosen to enhance the processes and decrease rejection from 12% to 4%. The implementation of the Lean principles to increase operational efficiency and eliminate waste in various industries is increasing awareness like health care ,automotive industry , education , food processing industry and many other authors in furniture industries (Selim Ahmed et al., 2018; Gijo et al., 2018; Guerrero et al., 2017; Mahalingam and Management, 2018).

Lean Six Sigma (LSS) is the name for the combination of the Lean and Six Sigma methodologies (LSS). Lean six sigma (LSS) helps manufacturing companies achieve zero defects, optimum performance, increased product quality, and quick delivery at the lowest possible price, assisting businesses in meeting and exceeding the demands of customer futures (Selim Ahmed et al., 2018; Bazrkar et al., 2017; Gijo et al., 2018).

For efficient process mapping and the distinction between activities that bring value and those that don't, the lean manufacturing methodology is practical. On the other hand, the Six Sigma tool is a scientific, systematic, statistical, and smart technique that is appropriate for raising product quality, fostering innovation, and improving customer satisfaction (Vikash Gupta et al., 2018; Hekmatpanah et al., 2008; Krueger et al., 2014). Lean manufacturing, also known as lean, is a methodical strategy to identifying and eliminating waste through continuous improvements. Organizations use the lean manufacturing approach to reduce waste, and six-sigma techniques are used to boost production efficiency and product quality (Madsen et al., 2017; Mwacharo, 2013). When combined, these techniques aim to enhance an organization's quality while decreasing variation and waste (Guerrero et al., 2017). The LSS system for continuous improvement has been embraced by many businesses, however its application is not without risk, and the fundamental cause is leadership (McLean et al., 2017). But many researchers proved that the integration of lean and six sigma had a positive result, not in theory but rather in a practical way with proper implementation (Anderson et al., 2015; Daniyan et al., 2022; Ferreira et al., 2019; Guerrero et al., 2017; Guleria et al., 2021; John and Kadadevaramath, 2020; McLean et al., 2017; Megawati et al., 2020; Pathania et al., 2021; Pepper et al., 2010; Pranavi and Umasankar, 2021; Simanová and Sujová, 2022). But the mindset of the employer and employees is the biggest barrier to the implementation of LSS (Palange and Dhatrak, 2021). Therefore Lean principles and Six Sigma integration have proven successful in every industries. However, employers and employees' mindsets hinder LSS implementation, but proper implementation yields positive results.

2.3. Lean Six Sigma in Manufacturing Industry

Lean Six Sigma was initially used in manufacturing industries. However, as many researchers have stated recently, the application of LSS is also being used in other sectors. The manufacturing industries follow an approach to problem-solving used by Lean Six Sigma: DMAIC (Garg et al., 2020; Kansal and Singhal, 2017).

Define: This stage is the basis for all phases. At this phase, existing parameters are plotted, and the problem definition and defect identification are both clearly defined.

Measure: The DMAIC process then moves on to the measure phase. The processes that have the greatest impact on customers are all highlighted, and the defects that they generate are identified. During this phase, it's crucial to concentrate on the quality-critical variables, or those whose impact on the outcome is the greatest.

Analyze: This step forces the reader to ask, "Why?" It leads to the root cause of the process defects. Understanding the sources of the defects is the goal of this phase.

Improve: The goal of this phase is to come up with, develop, and implement strategies to control defects.

Control: This stage makes sure that all of the critical variables in the modified process are within an acceptable range. Standard operating procedures are created to maintain the current level of performance and ensure that it continues throughout time.

2.4. Why Lean Six Sigma

Lean, in general, benefits from standardizing solutions to frequent issues and emphasizing the client. Lean focuses on the entire value chain in an effort to stop sub-optimization. However, Lean lacks strength in organizational frameworks, plans for implementation, analytical tools, and quality control and improvement. On other hand Six-Sigma provides a well-organized organizational framework for its application as well as a disciplined, analytical, and logically sound approach to problem solving (Hsieh et al., 2012). Six Sigma is a statistical approach that seeks to minimize variation in any operation (Chakravorty and Shah, 2012) reduce the cost of goods and services, boost profitability, and satisfy more customers (Drohomeretski et al., 2014) Measure defects, boost product quality, and lower defects to 3.4 parts per million opportunities in an organization (Cafiso et al., 2020; Francescatto et al., 2022; Lee et al., 2010). In reality, applying Six Sigma in isolation cannot eliminate all forms of waste from the process, and applying Lean management alone cannot statistically regulate the process and eliminate variation from the process (Corbett, 2011). Therefore, some businesses have chosen to combine the two approaches in order to address their respective shortcomings when used separately, as well as to create a more potent continuous improvement and process optimization strategy (Bhuiyan et al., 2006). Therefore, combining these two approaches increases the organization's effectiveness and efficiency and speeds up the achievement of greater performance compared to doing them separately (Krishnan et al., 2020; Megawati et al., 2020; Muhammad et al., 2022; Salah et al., 2010). Lean tools are included into the Six Sigma DMAIC approach through the LSS framework to help with defect and waste reduction (Guerrero et al., 2017; Swarnakar and Vinodh, 2016). Therefor the application of Lean and Six Sigma approaches improved efficiency, operational effectiveness, and financial performance across the organization (Ali Ahmed et al., 2022; Cima et al., 2011; Urbina et al., 2022). Therefore, the goal of this research is to reduce defects and process variability while increasing process output and quality to meet customer expectations.

2.5. Defects in Furniture Industry

Many factory give different names for different defect types according to their nature of production and level of understanding. But according to Window & Door Manufacturers Association (2013) Defect are classified in technical language available in the Industry Standard for Interior Architectural Wood-Stile and Rail- Doors glossary:

Table 2.1: Classification of defects; technical terminology available in the glossary of the Industry Standard for Interior Architectural Wood Stile and Rail Doors.

Class no.	Class description	Types of defects
1	Handling, sanding and veneer surface related defects	Scratches and dents, knife marks, veneer tears/cracks/checks, uneven/ over-sanded veneer, orbital sander marks, veneer edge tears, timber chip-offs/cracks, cross sanding marks
2	Lamination related defects	Lamination glue, superglue, veneer edge delamination, veneer bubble delamination, debris under veneer, putty/filler material, veneer tape trace, veneer splice/joint gap, veneer short of edge, veneer overhang, veneer overlap, compression marks
3	Machining and construction related defects	Profile shoulder not straight, rough machining surface, edge strip out of spec, sharp edges, panel to profile gap, kink on profile, edge strip gaps at ends, rounded edge/corner, chatter marks, bowed stile, slanted/uneven panel profile
4	Assembly related defects	Joint gaps, clipped/creased panel veneer, door not square, loose panels, foam left on door, misaligned mullions
5	Type 1 defects - raw material related defects	Pinhole, blemish/dark color/mineral streak/iron stains, flaky veneer, knots, transparent veneer, white/dis coloured stripe
6	Repair related defects	Water stains, bad repair
7	Others (dirt, packing and pest related defects)	Dirt/ink stains, loose bifold spacer/protruding nails, nail on panel, hinge problem, carton press mark, borer/weevil infestation

(Tan, 2019)

Author's analysis:

To summarize, Lean focuses on removing waste and increasing value throughout the value chain, but it lacks an organizational framework. Six Sigma is a structured strategy to problem solving that focuses on decreasing process variation and errors, but it may not remove all types of waste. Lean Six Sigma combines the benefits of both Lean and Six Sigma, providing an effective framework for implementing Lean principles and applying structured problem-solving to minimize defects, increase performance and discover process inefficiencies.

Summary of reviewed literatures

Articles, case studies, books and reviews from various websites make up the reviewed literature. For this study, 68 pieces of literature were reviewed. Among the total literatures 55 of them are on lean, six sigma and LSS, 13 of others are other related. However, only 11 of the articles had a direct bearing on the subject of this study which means defect reduction in furniture industries. Based on their respective analyses and discussions, these 11 literatures works differ in their objectives, methods and structures.

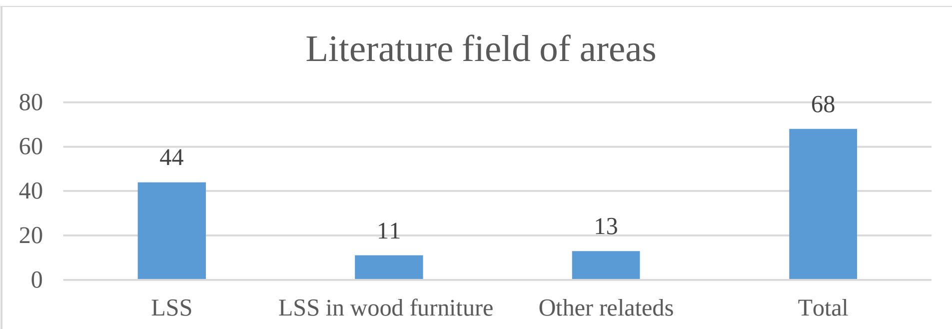


Figure 2.1: Literature fields

Summary of literatures based on their objectives

Table 2. 2: Objectives of reviewed literatures (source: Author's analysis)

No.	Authors	Objective of the study
1	Simanová & Sujová, (2022) , Chakravorty & Shah, (2012)	Process improvement
2	Girma, Abate, & Development, (2021)	Ethiopian wood products demand and supply situation
3	Czabke, Hansen, & Doolen, (2008)	Improving competitiveness
4	SHUKA, (2015)	Analysing value chain
5	Abhilash, Thakkar, & Management, (2019), Megawati, Wicaksono, & Nurkertamanda, (2020) , Guleria, Pathania, Bhatti, Rojhe, & Mahto, (2021) ,	Defect reduction

	Guerrero et al., (2017), Pranavi & Umasankar, (2021), Urbina, Gutierrez, Tejada, & Huamani, (2022)	

Those studies resulted in different outcomes by using the concept of lean six-sigma methodology. Researchers have found various outcomes when using Lean Six Sigma in the manufacturing industry. Some of the outcomes include a reduction in defects, increased efficiency and productivity, improved customer satisfaction, reduced lead times, improved quality control, and increased profitability. Additionally, Lean Six Sigma has been found to help organizations become more agile, responsive, and adaptable to changing market conditions, which can lead to long-term success and sustainability. However, it's important to note that the outcomes of implementing Lean Six-Sigma depend on various factors, including the specific implementation, the culture and workforce of the organization, leadership and the industry and market conditions. Most of the reviewed literature is concerned with the fact that Lean Six Sigma is a methodology that is used to reduce defects and improve overall process efficiency. As such, it is not surprising that many studies focus on defect reduction through the use of Lean Six Sigma. By identifying the root causes of defects and implementing targeted improvements, organizations can reduce waste, improve quality, and increase customer satisfaction. However, it is worth noting that Lean Six Sigma can also be used for a range of other purposes, such as process optimization, cost reduction, and customer experience improvement. Ultimately, the specific focus of this research is on defect reduction in the context in which the methodology is being applied.

2.6. Research Literature Gaps

From the aforementioned literature, it appears that several studies have been conducted on the implementation of lean Six Sigma in the manufacturing industry. The majority of studies have been concerned with reducing the amount of waste specially defect and have been conducted on the implementation of lean six-sigma in the manufacturing industry. This illustrates how extended waste has a negative impact on manufacturing industry standards. From 11 literatures that directly bearing to wood industries only two of the evaluated literatures are from Ethiopia, and even those two are not directly related to the furniture industry due to the scarcity of studies in these sectors. Based on a methodical evaluation of the literature, some of the articles have insufficient reviews, not defining the problem clearly and limited analysis. And all the articles that used DAMIC methodology have lack of validation next to the analyze phase. Based on this review the researches develop a framework that, by addressing the gaps described above and add a new step on the DMAIC phase which is called “Validation” and the new approach is called DMAVIC. By these new phase it it’s better to address the problems of the case company which is called 3F furniture.

Table 2.3: Summery of literature gaps

No.	Author	Objective	Strength	Limitation
1	Pranavi & Umasankar, (2021)	Defect reduction	Root cause analysis is good	Very few literatures are reviewed Weak definition of problem in define phase
2	Guerrero et al., (2017)	Defect reduction	The way he integrates defects with rework cost	In analysis stage there is no verification and validation of root causes & in the VSM is not mapped only activities are noted. Finally the control phase is not clearly put with new VSM
3	Megawati, Wicaksono, & Nurkertamanda, (2020)	Defect reduction	Clearly state DMAIC phase of the problem integrating with necessary lean tools	No validation and verification of root causes

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Methodology

The research's methodology is a case study technique that integrates Six Sigma DMAIC (define, measure, analyze, improve, and control) principles with Lean tools (Ricciardi et al., 2020). The case study method was applied because it is adaptable in terms of design and application, allowing for both quantitative and qualitative investigation of specific organizational phenomena (Krueger et al., 2014; Mahalingam and Management, 2018; Merriam and Grenier, 2019; Sanchez-Marquez et al., 2020). Because of using a case study approach is that it makes it easier to collect data for comparison analysis and direct observations in any organization's setting (Ganesh et al., 2019; John and Kadadevaramath, 2020). Illustrate some of the key components of the case study methodology, such as problem identification and quantification, choosing the best strategy for solving the problem, data collection and analysis, implementing the developed solution, and presenting the findings and implications to the relevant parties (John and Kadadevaramath, 2020). Case study method is also used to develop new ideas, supplement existing theories with knowledge, explain the situation from a different angle, or even investigate a new paradigm (Gijo and Antony, 2019).

3.2. Research Framework

A preliminary assessment is done to get a general overview of the defect. Following the preliminary assessment, a problem statement is stated with the objective of defect reduction in 3F furniture through lean six sigma methodologies. The research framework depicts the progression of this study, beginning with the preliminary assessment and observation and ending with the final result. The framework demonstrates how data was collected, analyzed, and which tools were used for improvement.

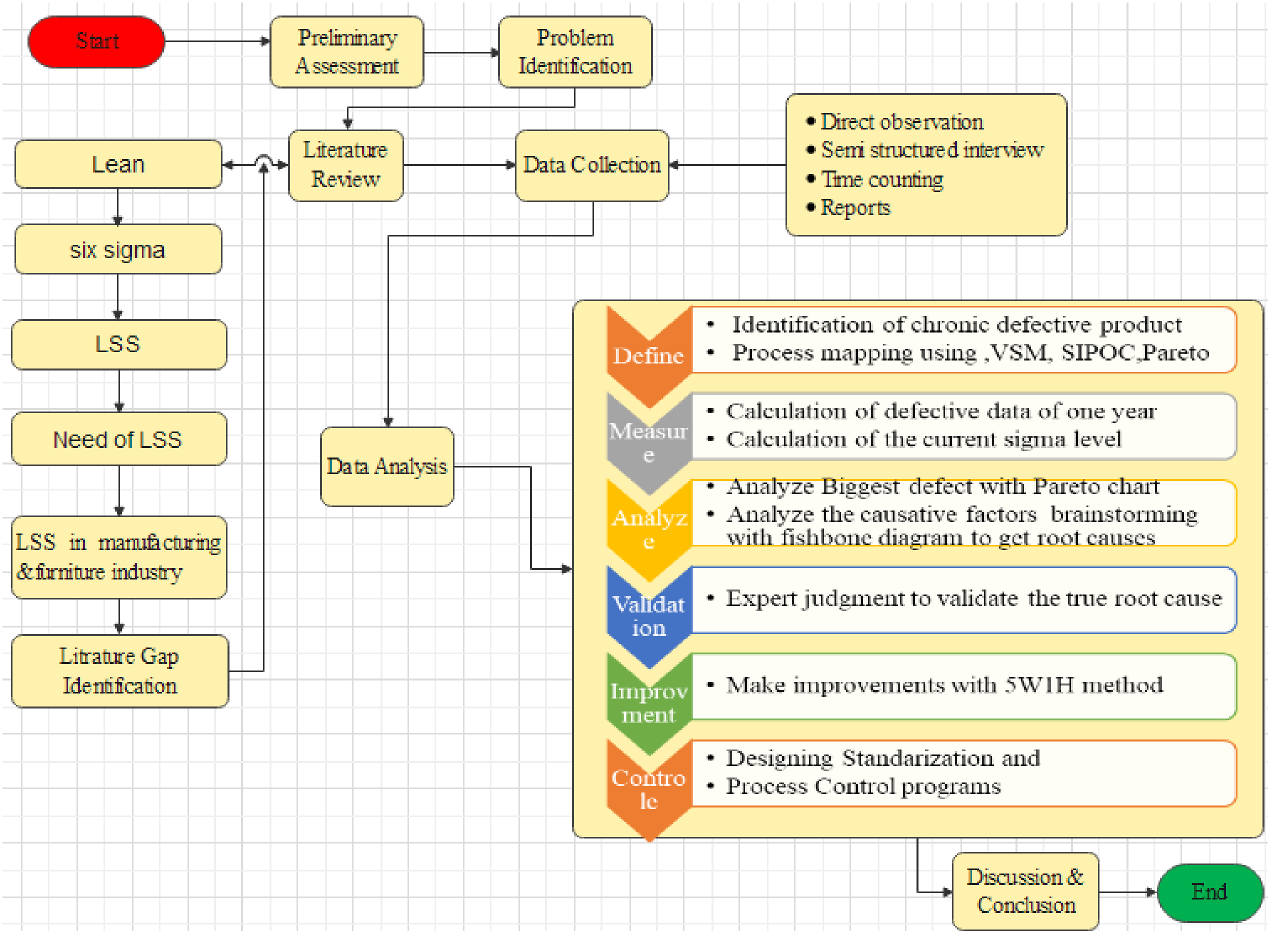


Figure 3.1: Research framework

3.1.1. Ethical Considerations

Before the start of data collection, ethical approval and clearance were obtained from AAiT, and supportive letters were delivered to data sources in the study area. The objectives of the research were clearly communicated to the selected company, and the researcher let them know to agree if they got uncomfortable in the process of their participation. Any data obtained from the case company was kept confidential, including information related to the research. The researcher expressed the confidentiality of key information at the beginning of each approach.

3.1.2. Data Collection

This study employs both qualitative and quantitative data collection methods as well as primary and secondary data sources. As Primary sources include direct observation, semi-structured interviews, and time counting. In addition, as a secondary data source, different literature, journals, reviews, and reports from the company are referred.

Reviewed Literature:

The literature review examines many papers, reviews, journals, case studies, and reports in order to gain a full understanding of the research topic under consideration. The literature evaluations mostly focused on lean manufacturing, Six Sigma, and the significance of integrating lean and Six Sigma, as well as the application of lean and Six Sigma in wood furniture and past studies on lean and Six Sigma in wood furniture. As a result, gaps in the literature are being identified as areas that require additional researching and significance of this particular research has been identified.

Observation:

The observed variables in this section are how the process is organized and prioritized, the production process flow, the value stream map, defects on product types, the assignment of professionals, defect percentages of each product type, the layout, and so on. A value stream map and SIPOC analysis are done after tracking all of these variables to diagram and document the product flow or flow of supplies to determine where value is added and waste is occurring. Instruments such as a video camera and a stopwatch are used to observe some of the variables.

Interview:

To determine the areas to be explored in the factory, a semi-structured interview is developed. Quality and production supervisors and managers, operators, designers, and site workers were interviewed.

Interview structure:

A semi-structured interview is planned based on the literature research. The interviews have two parts, and they are designed to meet the first two objectives of the study.

Part I: This section of the interview is set up to provide broad information about the factory. It comprises inquiries regarding how the factory's existing system is constructed, the number of products included in the production, and so on. These interviews are designed for management personnel.

Part II: This section of the interview is developed for quality and production supervisors to examine potential areas of wasteful operations and information about defect rates of each product within the factory.

Time study: The time that it takes to get served in the care units is recorded using a stop watch. In order to calculate the value-added time, non-value-added time and cycle time of the production process.

Focused Group Discussion:

After the semi structured interview a focused group discussion is applied. The major aim of the focused group discussion is to identify the causes of defective products based on quality data provided by the factory, which contains probable causes, and to determine which of the possible causes the genuine cause is or root cause. Quality and production deputy managers, quality and production supervisors, operators, design makers, and site employees are the center of the discussion.

3.1.3. Data Analysis

The DMAIC approach is used for the data analysis, which is as follows:

Phase 1: Define: The first step of the DMAIC approach is to define the project charter, which defines the improvement team's focus, scope, direction, and the problem to be addressed through a process map and an analysis of the quality of the process.

The lean tools to define the problem are Pareto to identify the biggest defect and process map to provide an overview of the whole process, and analyze what is required to meet quality standards. SIPOC is used to understand the inputs, the outputs, and the process in general, the general process map of the company is drawn.

Phase 2: Measure: in this phase to quantify and better understand the primary quality issues that need to be addressed, as well as to build a system for assessing quality and process variation. So the calculation of defective data from a specific month, as well as the calculation of the current sigma level, is measured at this stage. Under the time study, the researcher used a stopwatch to record the time products are forced to spend to be passed one process to next process, a check sheet for data collection and VSM have been used to analyze the current situation of the process. Those tools help to narrow down the problem and to determine value adding activities and non-value adding activities (wastes) within the processes.

Phase 3: Analyze: the process to identify the underlying causes of variation and poor performance (defects). Identify the various causes of the underlying defects that are prioritized in the define phase as the most severe problems. Analyze the most significant defect using a Pareto chart and identify the main causes using a cause-and-effect diagram and why-why analysis by brainstorming in a focused group discussion. Following validation of the root cause, the validity of the cause must be verified.

Phase 4: Validation: DMAIC is a problem-solving methodology widely used in Six Sigma projects. It stands for Define, Measure, Analyze, Improve, and Control. The DMAIC process is used to identify and solve problems within an organization by defining the problem, gathering data, analyzing the data to determine the root cause of the problem, implementing improvements, and controlling the process to ensure the problem does not occur again. DMAIC is designed to help teams systematically identify problems and improve processes to achieve better quality, reduce costs, increase efficiency, and optimize customer satisfaction.

Skipping validation in problem solving can be a mistake, as it increases the risk of implementing ineffective solutions. Validation is the process of verifying whether a proposed solution effectively addresses the identified problem. It involves testing and evaluating the proposed solution in a controlled setting to determine its effectiveness and suitability for solving the problem. Without validation, there is no guarantee that the proposed solution will work as intended or solve the identified problem. This increases the risk of wasted resources, time, and effort. Additionally, it can lead to unintended consequences that could create new problems or exacerbate existing ones.

Validation is an essential part of the problem-solving process, as it ensures that the solution is effective, feasible, and acceptable to the stakeholders. Therefore, it is important to include validation in any problem-solving approach to ensure that the selected solution is the best possible option.

Validation of the root causes refers to the process of confirming that the underlying factors or reasons identified as the primary causes of a problem or issue are indeed accurate and factual. It involves collecting data, analyzing evidence, and conducting tests to determine whether the root causes are valid and supported by empirical evidence. Validation of the root causes is an important step in problem-solving and helps ensure that the corrective actions taken are effective in addressing the problem and preventing its recurrence.

Phase 5: Improve: Improve quality performance by addressing and eliminating the root causes identified in phase three. In this step, 5W1H and 5S is used.

In this phase of DMAIC mostly employs lean standard tools for problem solving. During this phase, the researcher restructured the process to ensure optimal resource utilization. This stage includes 5S implementation, time standardization via time study, and designing a new value stream mapping.

Phase 6: Control: Improved quality performance and future process performance will be maintained in a control strategy to document what is required to maintain an enhanced process at its current level. By comparing the results with the starting scenario, if the result is promising, maintain the results by using 5S to build a workplace that is conducive to visual control and by following standard operating procedures (SOP) for process activities.

Table 3.1: Analysis used for the research

No	**Data analysis tools**	**Inputs for analysis**	**Necessity**	**Expected results**
1	Pareto analysis	Ishikawa diagram	To prioritize problems	Determination of major defect rates
2	SIPOC	Observation of processes, interview results from management personnel's and employees and company documents	To show the a system (inputs and outputs of process, products and suppliers)	Problem area identification
3	Process mapping	Observation of the existing system	To clearly understand the process under investigation	To understanding where wastes are in the process
4	Timestudy	Time recording using stopwatch	To know how much time different activities take	Average cycle time and average work in process
5	VSM	Time study	To understand the wastes from VA and NVA times	VA,NVA, cycle time
6	Cause and effect diagram	From FGD results and value stream mapping	To explore possible causes of certain problems	Root Causes of a certain problem
7	SOP	Time study, quality result	To measure whether the process is capable or not before and after improvement	Process variation and defect percentage

Table 3.2: Software used for the research

No.	**Software's used for analysis**

1	QI Macros	To generate control charts, Pareto, SIPOC, fish bone diagram and value stream mapping

3.1.4. Data Validation

The outcomes of the cause-and-effect diagram reveal potential root causes. The identified root causes must then be validated in order to ascertain whether they are real or false. A gemba walk, data collection plan, and analysis, are all steps in the process of validating the fundamental causes. Validation aims to get confirmation of the root causes in order to prior to allocating resources to countermeasure and remedy the issue, Improvement activities can be prioritized depending on the impact each root cause has on the issue once the root causes have been verified and identified.

3.2. Discussion, Conclusion and Recommendations

These sections comprise the research study's last sessions. The research study results produced from the collected and analyzed data are given in this session. In the first three steps, the DMAIC roadmap and associated tools are supposed to produce a well-defined and analyzed problem. These issues are quantified using Pareto, time studies, cause-and-effect diagrams, and VSM. The time study provided both value-added and non-value-added time. The performance of a certain process was then diagnosed using control charts, and the relevant influence factors were identified using Pareto analysis. The fourth stage of DMAIC anticipates an ideal process configuration, reduced process difficulties, reduced waiting time, and a new process map using time study and VSM. The findings are interpreted, their relevance is thoroughly examined in the discussion section, as are ideas for future research, and the findings are logically synthesized. Those findings aided the researcher in exploring potential modifications that may be done to further develop the research's issues, which are recommendations. Finally, the conclusion is offered with the purpose of explaining the overall research contributions based on the data acquired.

3.3. Sampling Technique and Procedures

Purposive sampling (the planned selection of product providers such as designers, management personnel, production supervisors, quality supervisors, and selected experienced workers) is used by the researcher to save time and money. The sample is chosen for the investigator's convenience. Respondents are frequently chosen because they are at the right place at the appropriate time.

CHAPTER FOUR

DATA PRESENTATION and ANALYSIS

This chapter presents the semi-structured interview analysis and results, as well as the time measurement data. Based on the research objectives, the data is properly summarized and presented.

4.1. Background of Finfinnee furniture factory (3F)

Fine Furniture Factory (3F), a wood furniture manufacturer founded in 1959 in Addis Ababa, Ethiopia's Oromia region of Alemgena, is one of Ethiopia's furniture manufacturers. It is a private limited company, and its main products are sofas, beds, mattresses, dining tables, construction, and office furniture. There are 280 total employees.

4.2. Data collection results

Based on the obtained data, the outcomes of the focused group discussion, semi structured interview, and time measurement are presented. The interview takes place in February 2015. E.C. product types and their defect rates, customer complaints, higher-defective product types, and highly demanded product types are known from the findings of the interviews.

4.3. Data analysis

The DMAIC approach, as mentioned in the methodology session, is a prominent methodology that many researchers use in lean six sigma. Based on the literature investigated that is directly linked to the case of this research, the researcher reviewed each one based on its methodological approach and objective. And creates a DMAIC road map to address the issues in the scenario under consideration. A DMAIC road map is required to analyze and improve processes in the furniture sector. So, using that framework, extensive data is gathered and analyzed. The framework for this research is depicted here.

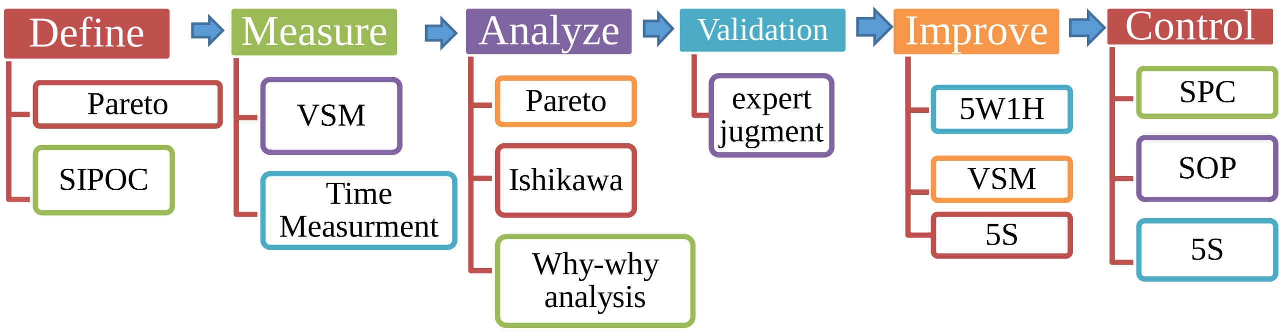


Figure 4.1: DMAVIC framework (Source: Author's Analysis)

DMAVIC ROAD MAP

In LSS there is a road like define, measure, analysis, improvement and control and but in this paper validation is added and the new road map is called DMAVIC and as follow:

Define:

Since the study is based on defect reduction, it is vital to define defects from a suitable standpoint. Many practitioner's mix up the terms defect, nonconformity, and defective. It demonstrates that during the registration or measurement of defects, people may make an error that misleads the study. Thus, defining each term reduces ambiguity and increases data reliability. The term defect refers to nonconformities that could jeopardize the product's safety or effectiveness. Defects are more likely to occur than defective products or nonconformities. Defective refers to a nonconforming product that contains one or more defects. As a result, nonconformity refers to components or products that do not fulfil standards.

As discussed in earlier chapters, Six Sigma's DMAIC roadmap is used together with lean tools to reduce defects. The first stage of DMAIC is "define, which is used to choose and define an issue. On these stages, there are Pareto, process mapping, and SIPOC to define the problem. Pareto is used to determine the most common defected product type; process map is used to understand what the present process in production looks like; and SIPOC is used to understand the inputs, outputs, and overall process.

Firstly, a focused group was assigned to realize the study, which is oriented towards defect reduction. Accordingly, the focus group has been selected to identify all product types and their defect rates from secondary data and their experience. And then, through brainstorming, the focus group members identified 8 defect types, which frequently occurred. The data available in the quality control department is collected to cross-check that the identified defect type really happened and was registered. To know the customer's complaint about quality, the sales department also collects customer feedback about their products. By combining all three stakeholder's reflections, major defects, which mostly occur in the floor, are identified as below.

Description of Product Selection

The company currently produces different types of furniture (coffee table, kitchen cabinet, door, sofa, mattress, bed, and chair). Ethiopians are currently in high demand for houses, especially condominiums. So in order to satisfy the high demands of the customer, select the product type based on the current product demand (highly demanded by customers) and resolve the number of defects and rework rates of that product, which were selected by Pareto and with expert judgments.

Pareto to give priority: It is difficult to solve many issues at a time. So, giving priority to solving the highest defected product type is important due to time and financial limitations and also to bring effective results.

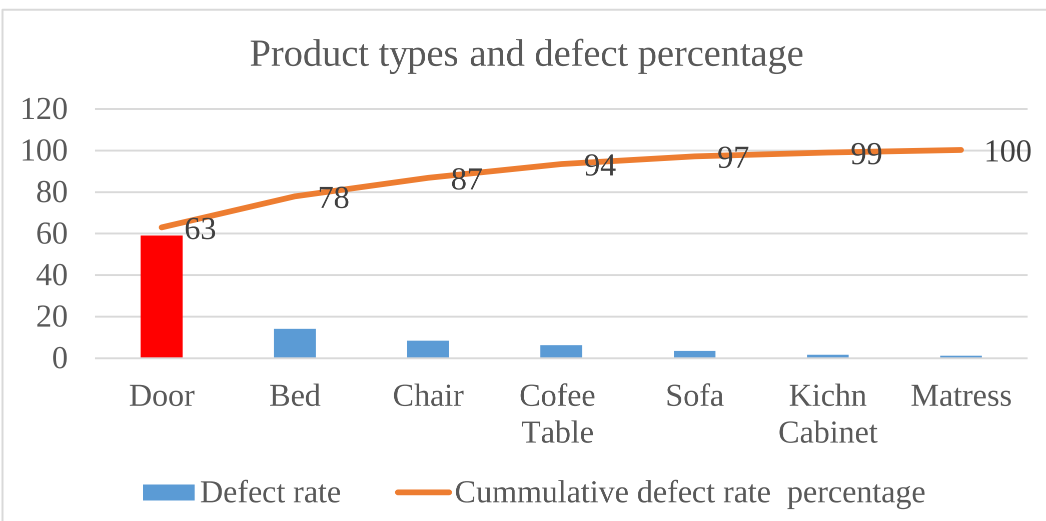


Figure 4.2: Pareto for product type (Source: 2021-2022 company products)

Using the above figure, it is easy to determine which types of products had the most problems. The Pareto Diagram shows the 80/20 rule, which initially said that 80 percent of outcomes costs come from 20% of product types. As a result, the implication is that addressing the major problem will significantly decrease the problem. Beside this, the experts and company managers also agreed that giving priority to the most defective product, which is Door, which covers 59% of defects from its total product and the study is rounding on door product.

Defect types and its occurrence frequency

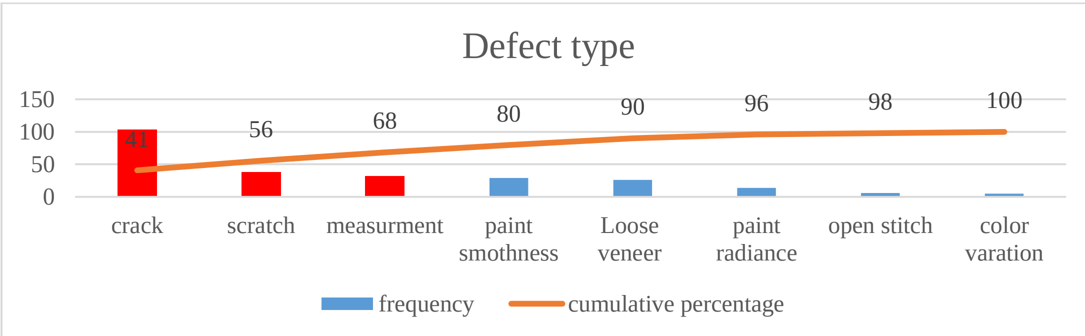


Figure 4.3: Defect types and its occurrence frequency (Source: 2021-2022 company products)

From the data gathered in the above Pareto diagram crack, scratch and measurement are the highest defect types which have a high possibility for improvement. Knowing the cause for occurrence and making countermeasure is the next process.

SIPOC analysis: SIPOC is used to understand the inputs, the outputs, and the process in general. In the SIPOC the manufacturing process of doors from inputs to the finished product. The SIPOC diagram is shown below:

S	I	P	O	C
Suppliers	**Inputs**	**Process**	**Outputs**	**Customers**
Designers (customer specification) Raw material store Accessory store	Design MDF Veneer Cola Solid Wood Machine Man power electricity	Preparing cutting list Requesting raw material Selecting raw material Designing Cutting Joining Grooving Covering with veneer Coating Sanding(Manual and Machine) First coating	Door Handling and transporting	External (Apartment, Condominium) Internal (warehouse)

		Inspection Final coating Final inspection		

Figure 4.4: SIPOC of door products (Author's observation)

Measure:

Sigma level calculation

Knowing the DPMO level helps in determining the process's sigma level. First of all, the amount of defect in the workplace should be known. Then, depending on the production process, opportunities for a defective product should be known. According to the data obtained from the company's quality department, a product has passed three physical checks. However, prior to computing DPMO, several assumptions should be made to clear up the ambiguity between defect and scrap.

Assumptions

- Despite the fact that the company does not have a documented standard for an authorized defect quantity, they orally instruct operators not to manufacture a defect greater than 5% of the allowance.
- Start-up loss has not exceeded 0.5 meter for MDF and 5 items for veneer, accounting for around 0.5% of total production. Power outages cause 1% of overall production to be defective and machine breakdown 0.5 %.

By considering the above assumption, the total amount of defect in the company in major products is 1002

Using the below formula we come up with DPMO amount

$$\text{DPMO} = \left[\frac{total\ number\ of\ defects}{no.of\ produced * opportunities\ for\ defect}\right] * 10^{6}$$

$$\text{DPMO} = \left[\frac{1002}{10868*5}\right] * 10^{6} = 18439.45528$$

Using six sigma tables as a reference (see appendix A) and by interpolation the company sigma level lies at 2.09 for without 1.5σ shift and 3.58 for with 1.5σ shift.

And for door only

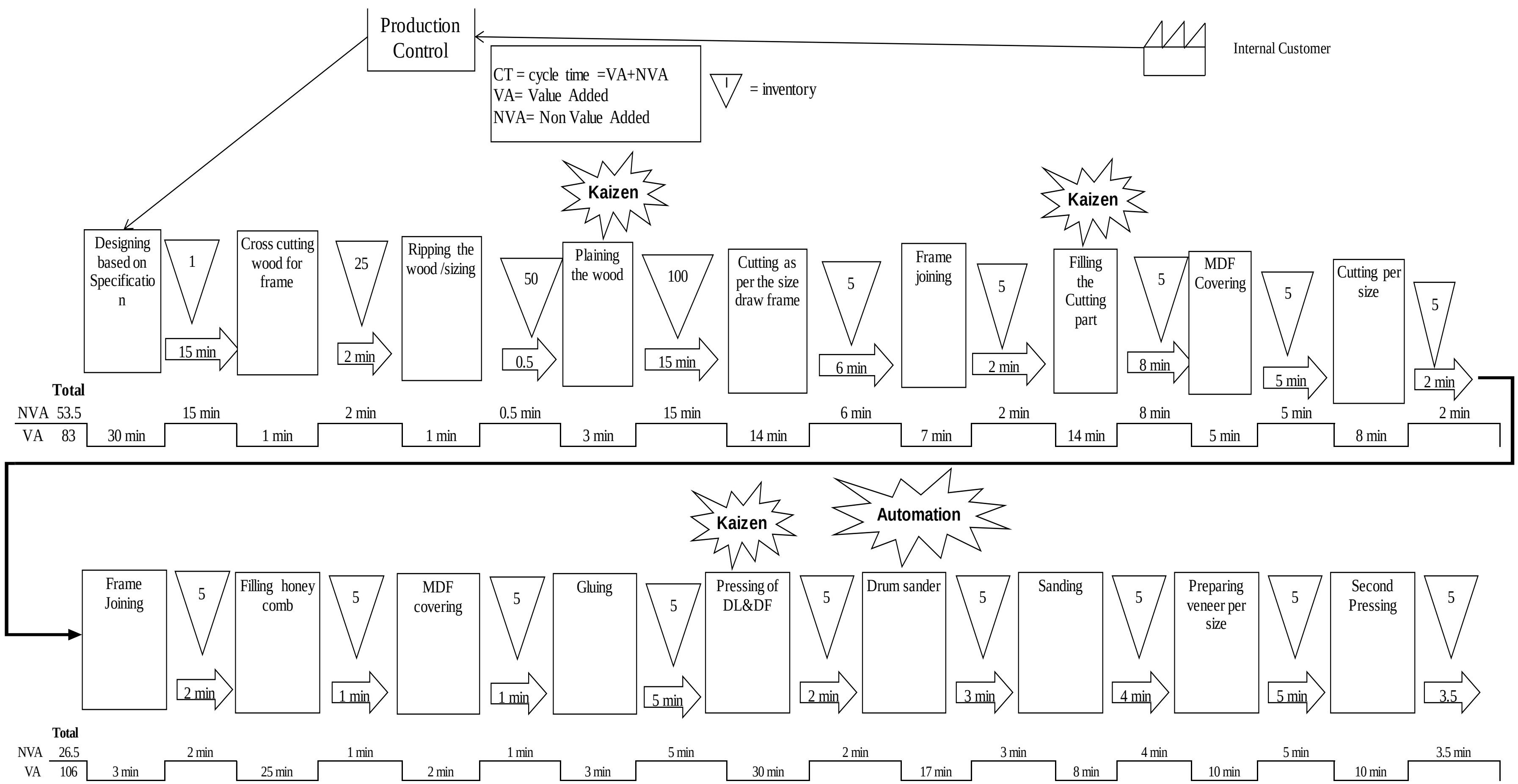
$$\text{DPMO} = \left[\frac{264}{470*5}\right] * 10^6 = 118297.8723$$

Using six sigma table as a reference (see appendix A) and by interpolation the company sigma level lies at 1.18 for without 1.5σ shift and 2.6 for with 1.5σ shift. In this scenario, the company's Sigma level is estimated through interpolation (estimating values between known data points) to be 1.18 with a 1.5 (standard deviation) shift. This signifies that the process can function at a low Sigma level, indicating a larger level of errors or deviations within the process. However, when a 1.5 shift is considered (adding an additional 1.5 to the process), the Sigma level rises to 2.6. This indicates that as the process evolves, it becomes more capable and exhibits fewer flaws or deviations compared to without 1.5 Sigma shift. It is vital to remember that having a higher sigma level is generally beneficial because it signifies greater process quality and performance.

Value stream Mapping (VSM): Value stream mapping (VSM) is a map that clearly illustrates both value-added and non-value-added operations in a process. It is a widely used lean tool that helps significantly in the identification of waste inside different operations or processes.

VSM of Door Production:

Value stream mapping shows the value-adding activities and the non-value-adding activities. The VSM of door production starts with giving the request for design to the production personnel and ends with delivering the product to the warehouse. Non-value-adding activities in door production: waiting by finding trolleys because of the limited number of trolleys in the production; long transportation from one stream to the next step. As shown below in the table, cycle time in door production is 2112 minutes.


Production Control
Internal Customer
CT = cycle time =VA+NVA
VA= Value Added
NVA= Non Value Added
I = inventory
Kaizen
Kaizen
Designing based on Specification
Cross cutting wood for frame
Ripping the wood /sizing
Plaining the wood
Cutting as per the size draw frame
Frame joining
Filling the Cutting part
MDF Covering
Cutting per size
1
25
50
100
5
5
5
5
5
15 min
2 min
0.5
15 min
6 min
2 min
8 min
5 min
2 min
Total
NVA 53.5
VA 83
30 min
15 min
1 min
2 min
1 min
0.5 min
3 min
15 min
14 min
6 min
7 min
2 min
14 min
8 min
5 min
5 min
8 min
2 min
Kaizen
Automation
Frame Joining
Filling honey comb
MDF covering
Gluing
Pressing of DL&DF
Drum sander
Sanding
Preparing veneer per size
Second Pressing
5
5
5
5
5
5
5
5
5
2 min
1 min
1 min
5 min
2 min
3 min
4 min
5 min
3.5
Total
NVA 26.5
VA 106
3 min
2 min
25 min
1 min
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3.5 min

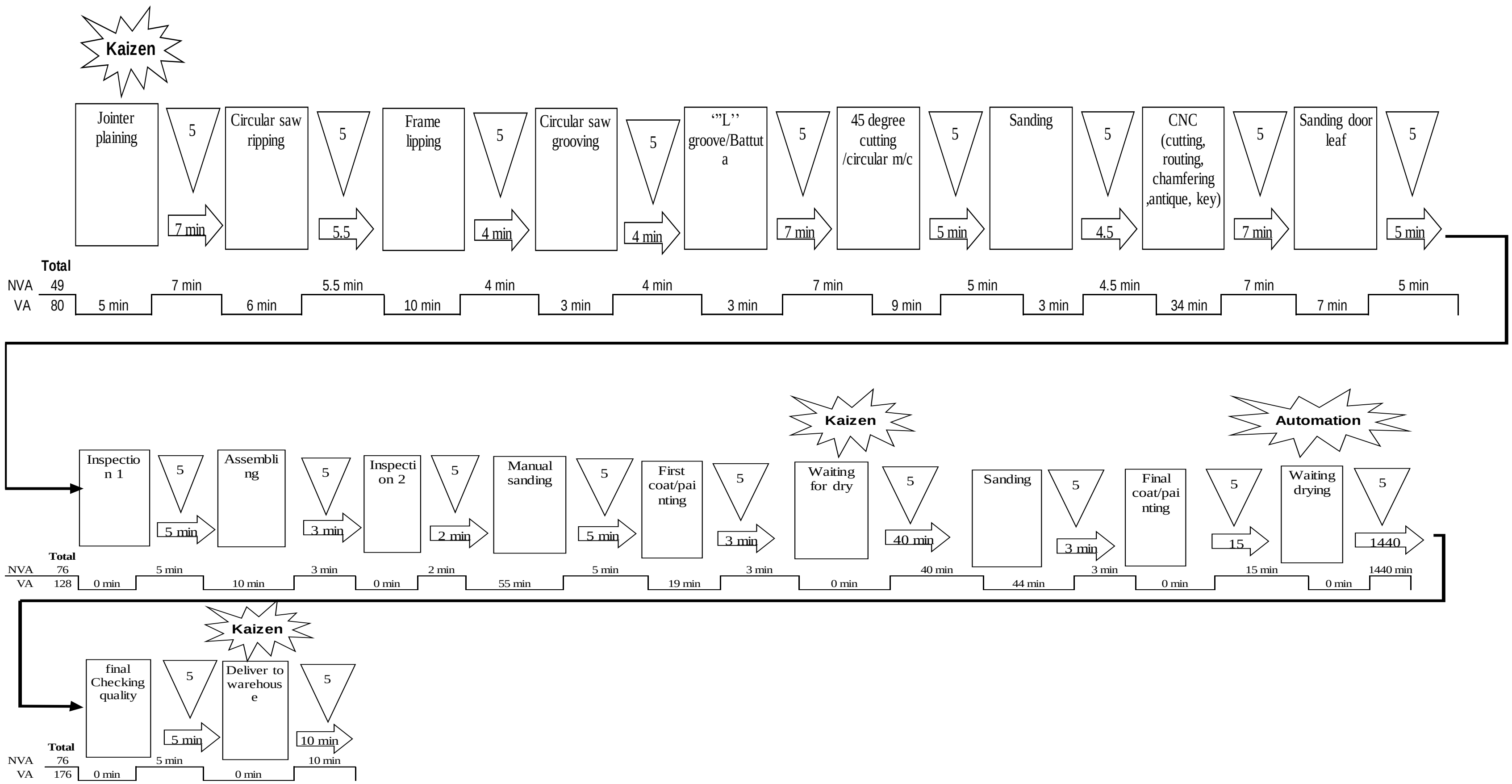


Figure 4.5: VSM of door production (Author's observation)

Analyzing the current situation

It is preferable to analyze the present production process for the above process map and VSM. The following table summarizes all of the data on the process map and VSM.

Table 4.1: Summary of VSM and Time measurement

S/n	**Summarized Process**	**VAT**	**NVAT**	**Cycle time**	**From the NVAT**	
					Transportation minute	**Waiting time**
1	Preparation	70	30.5	100.5	5	7
2	Door frame	40	21	61	4	3
3	Door Leaf	155	65.5	220.5	27	10
4	CNC	34	7	41	3	2
5	Sanding door leaf	7	5	12	2	3
6	Inspection 1		5	5		
7	Assembling	10	3	13		0.5
8	Inspection 2		2	2		
9	Manual sanding	55	5	60	3	1.5
10	First coat/painting	19	3	22	1	0.5
11	Waiting for dry		40	40		30
12	Sanding	44	3	47		
13	Final coat/painting		15	15		3
14	Waiting drying		1440	1440		960
15	Checking final quality		3	3		
16	Deliver to warehouse		30	30	17	6

From the above table non value add time is hold both transportation, waiting and other nonproductive times. This is done by time measurement.

Table 4.2: Summary of value-added and non-value added time

Activity	Time per minute	Percentage
Value adding	434	21%
Non value adding	1678	79%
Total	2114	

Table 4.3: non value added time coverage

Non value adding	Time per minute	Percentage
Transportation minute	62	6%
Waiting	1026.5	61%
Others	589.5	35%
Total	1678	

From the above table, 21 percent of the total time is value-added time and 79 percent of the rest is non-value-added time, but the reason that the non-value-added time is extremely high is not only that people are not paying attention to work, but some activities that are non-value-added but cannot be totally eliminated (supporting) but can be reduced (waiting for drying) hold the highest value. That is why the non-value-added time is high, but other non-productive time is in the Gemba that must be reduced and eliminated. From the non-value-added time, most of the time is covered by waiting, which is 61%; transportation is 6%; and 35% is covered by others. The result show non value activity affects the productivity of the company besides the cost of the defect in the door production.

Analyze:

The objective of this phase is to find out, validate, and select the root cause for elimination. Root cause analysis identifies a significant number of potential root causes of the company's problems. In this stage the underlying causes of variation and poor performance (defects) is identified. In the definition phase of DMAIC, the main issues of the company are selected by prioritizing them using a Pareto diagram. Then the selected defect types are scratch, crack, and measurement problems. Besides these the other issues that are selected to improve the variation is the waiting time.

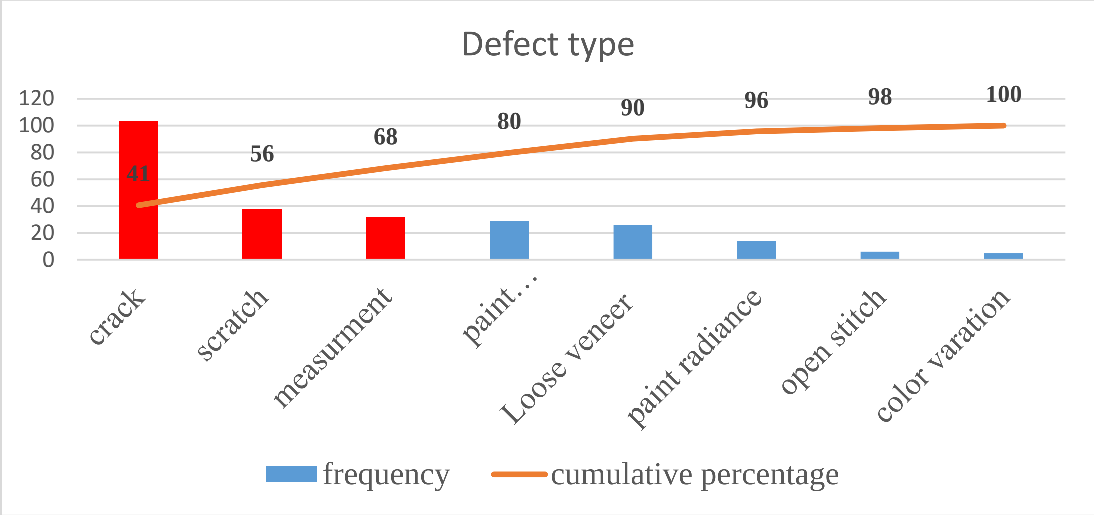


Figure 4.6: Prioritized Defect types for the defect reduction

Ishikawa diagram

Ishikawa diagram (cause and effect) diagram analyses the causes of the problems with the three main defect sources in door production. Which are cracking, scratch and measurement? The causes of these problems are analyzed by interviewing and focused group discussion.

Analysis on Cracking

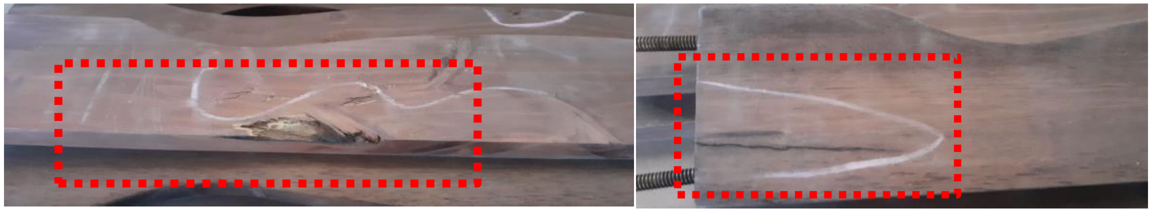


Figure 4.7: Crack of the MDF

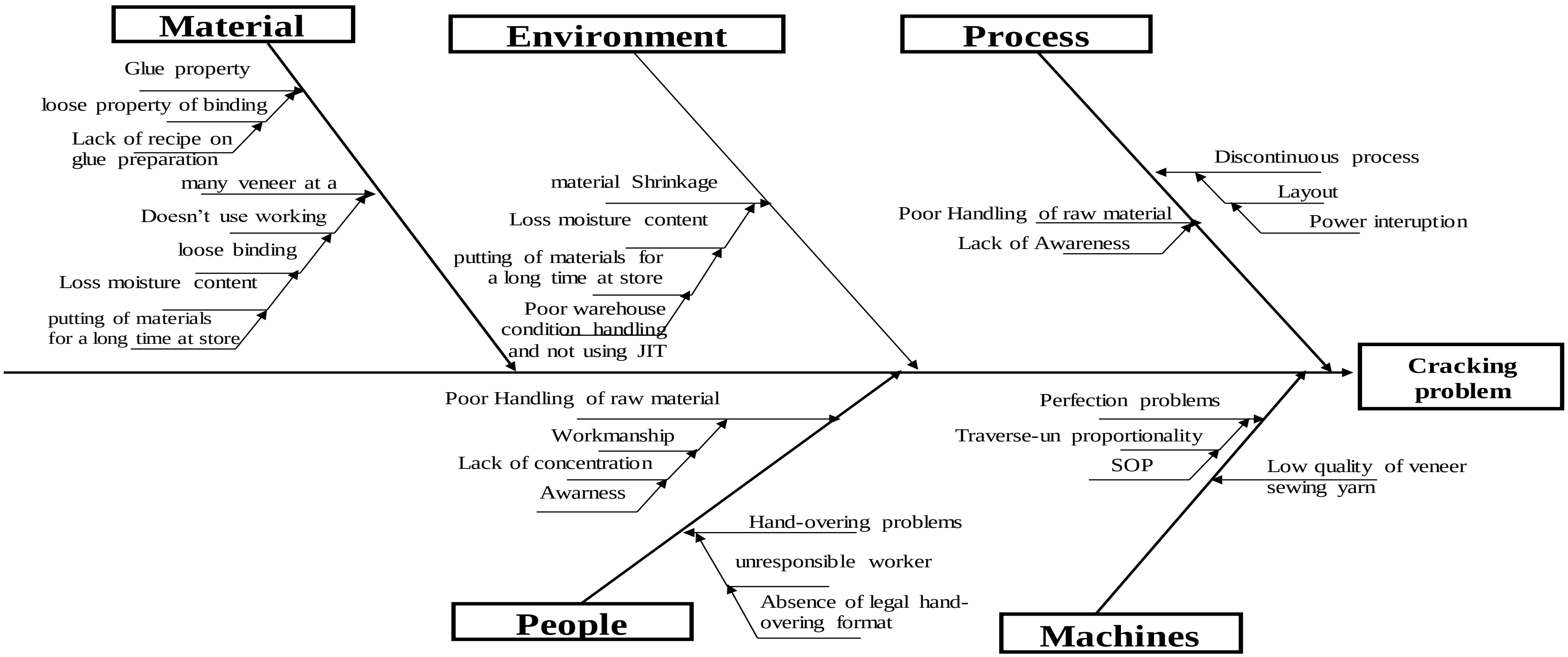


Figure 4. 8: Ishikawa diagram for cracking of door

Analysis on Scratch

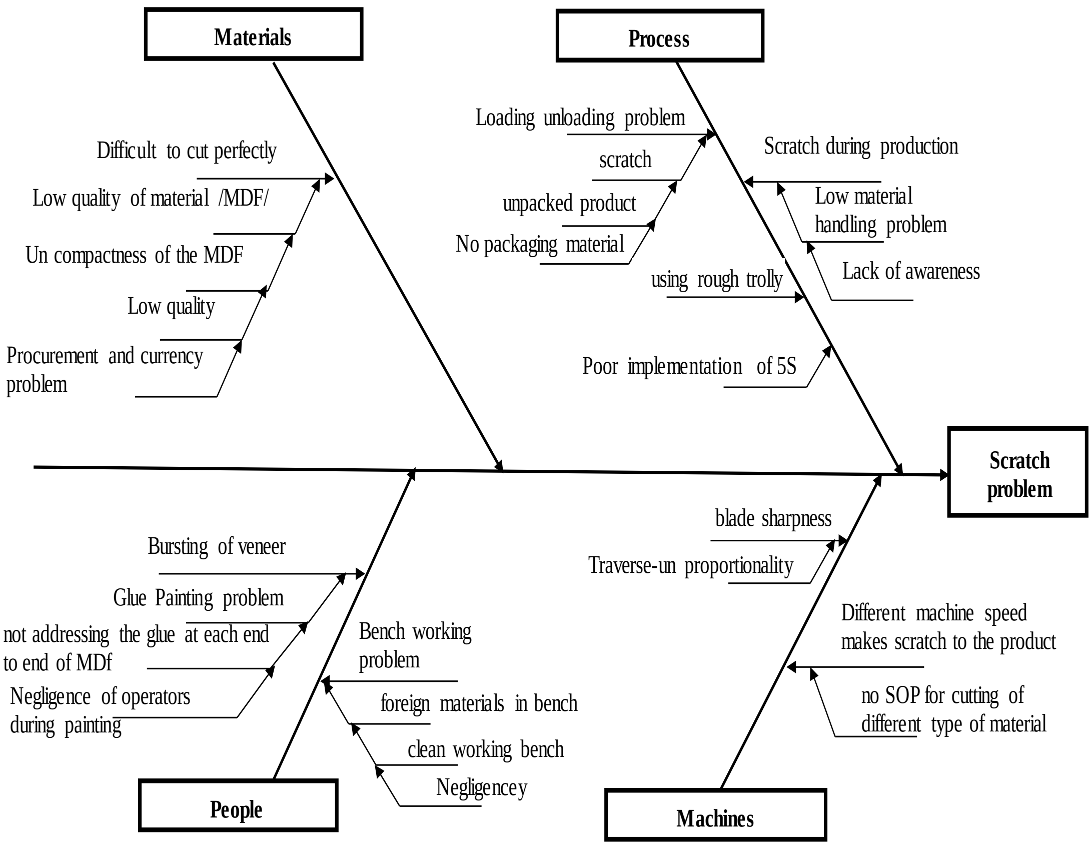


Figure 4.9: Ishikawa diagram for scratch

Analysis on Measurement

The defects that come from measurement cases usually come from many causes.

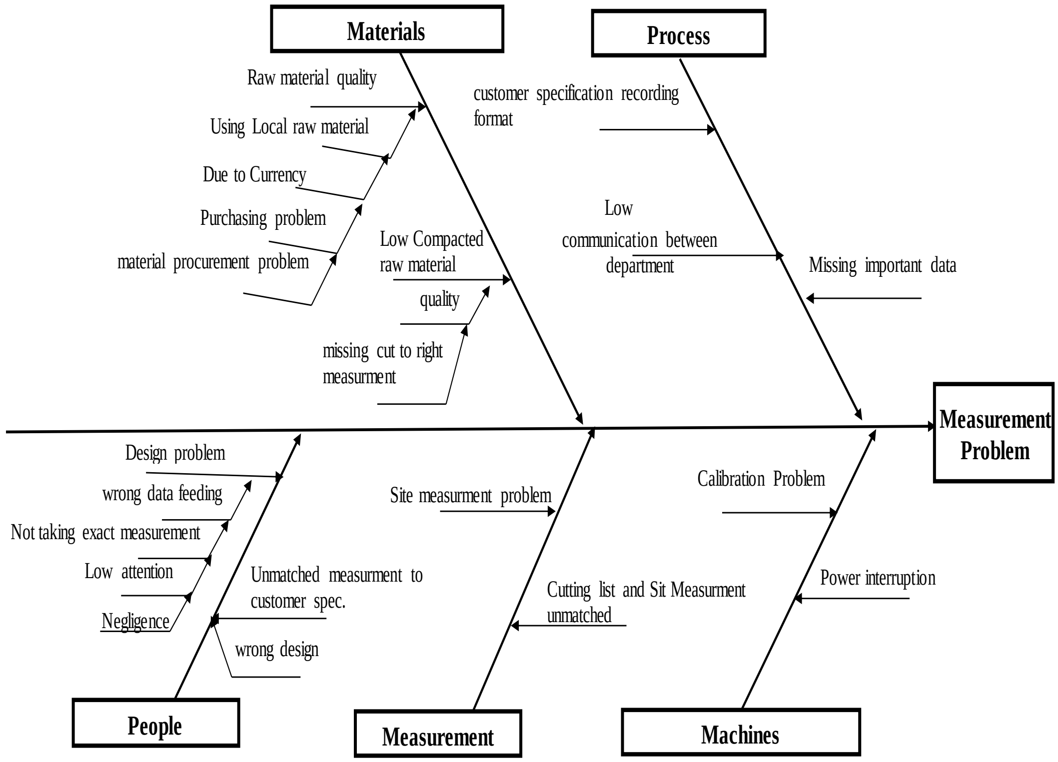


Figure 4.10: Ishikawa diagram for measurement

Analysis on Waiting

Most of the waiting of time waste have many contributors but as it mentioned from the time measurement the non-value added time is covered by transportation waste, waiting by finding trolley besides the distance and machine layout problem. So waiting is solved by purchasing enough trolley and maintaining the existing trolleys.

From the above diagram there is possible causes and root causes of the main defect cases. But it is better to elaborate these cases in why –why analysis to understand the causes in advance (Appendix F).

Validation:

Summary of Root Causes and Validation of the root causes:

First of all, in the above why-why table, the root causes are identified with the help of focused group discussion by experienced employees, and a summary of the root causes is made. Because of some factors have common causes that are the same as others, and simultaneously, the counter of one is also the remedial to the other, the summarized root cause analysis is as follows:

Table 4.4: Summary of root causes

Types of defect	Root cause
Measurement	Negligence of employees at taking measurement during designing process
	Missing of alignment during cutting due to there is no machine calibration standard
	Not having well communication between department
Scratch problem	Prolonged use of blade
	Poor implementation of 5S
	Absence of hand-over of work in process (WIP) between operations
	Absence of packaging materials for all product components
	Bursting of veneer due to improper addressing of the glue at each end to end of MDf by Negligence of operators during painting
	low quality/low compactness of the MDF/ due procurement and currency problem
	Un maintained pallet
Cracking problem	Material shrinkage because of putting materials for a long time at store in Poor handling of warehouse condition and not using JIT
	There is no glue preparation SOP/working by experience
	Problem of blade sharpness
	Procurement problem
	Absence of a legal hand-over format

Experienced workers can play a valuable role in helping to identify the root causes of problems, but it is important to note that their perspective may be limited by their own biases and assumptions. So it is important to involve a diverse range of stakeholders (including workers at all levels of experience, managers, and subject matter experts) in the problem-solving process to ensure that all perspectives are taken into account and that the root cause analysis is as accurate and comprehensive as possible. Additionally, it can be helpful to use data and other objective sources of information to verify the root causes identified by individuals. All the above root causes have been validated by experts and experienced workers. In addition, the causes are validated by seeing the scenario through the gemba walk before putting in the countermeasures.

Improvement:

The fourth stage of DMAIC is improvement. The existing defect types are identified, their root causes are also analyzed, and countermeasures for each root cause are set to improve variation and defects. And the process of implementation of the countermeasure is described by the 5W1H method.

5W1H:

Table 4.5: 5W1H of the improvement

What? Types defects	Why? Root cause	How? Counter Measure	How should it be done	Where? Should it be done?	Who? Should be responsible ?	When? should it be done
Measurement problem	Negligence of employees at taking measurement during designing process	Develop Customer Specification Format	Preparing the format and use them properly	Both production and design department	Designers & researcher	March 01/2023
	Missing of alignment during cutting due to there is no machine calibration standard	Set standard time for calibration	By refereeing machine operation standard	Production department	Production leaders	March 01/2023
	Not having well communication between department	Create smooth communication between production department and design department	Before production the respective department must check and approval the(design, cutting list)	Both production and design department	All	February 01/2023
Scratch problem	Prolonged use of blade	Chang the blade /set standard time for changing bladder)	Set standard by referring their service life	Production department	Production leaders	March 01/2023
	Poor implementation of 5S	Implement 5s in row material and finished	By Appling 5s meted ology	row material and finished store	employees and researcher	January 01/2023

		store				
	Absence hand-over of Work in Process(WIP) between operation	Develop hand-over of WIP product between operation and production process controlling format (to create accountability in each section)	By preparing format and implement accordingly	Production section	Production supervisors and researcher	April 01/2023
	Absence of Packaging materials to all product components	Use appropriate protective material (packaging)	Packing properly the finished product	Production section	Production and quality in charge	March 01/2023
	Bursting of veneer due to improper addressing of the glue at each end to end of MDf by negligence of operators during painting	Properly addressing when gluing the MDF and put a checking point	Lying MDf and gluing genuinely with considering the impact	Production section	Respective operators	April 20/2023
	Low quality/ low compactness of the MDF/ due procurement and currency problem	Set Standard procurement method/SOP	Preparing material quality standards for purchasing	Procurement	Purchaser	April 01/2023
	Un maintained pallet	Maintain pallet properly	Smoothing and even add more pallets	Production and warehouse	All operators	April 01/2023
Cracking problem	Material shrinkage because of putting materials for a long time at	Implement 5s	Applying 5s technic in store and implement FIFO method	Row material store	Material handling dpt.	February 01/2023

	store in Poor handling of warehouse condition and not using JIT					
	There is no glue preparation SOP/working by experience	Prepare simple and clear SOP for glue preparation	Refer international glue preparation standard (recipe)	Production	Operators /glue mixers	May 01/2023
	Problem of blade sharpness	Chang the blade (set standard time for blade change)	Set standard by referring their service life	Production	Supervisors	April 01/2023
	Absence of a legal hand-over format	Prepare hand over format for each section	pling quality assurance system	Production	Quality persons	February 20/2023

The improvement stage is crucial in DMAIC as it is where action takes place and changes are made to address the identified problem. It is important to gather feedback at this stage and continuously evaluate the solution to ensure it is achieving the desired results. So after brainstorming potential solutions to the problem and identifying root causes, conducting a validation to identify the root causes of the problem and setting the best solutions for addressing the problem based on data and analysis, creating a plan for implementing the solution to ensure its effectiveness, and monitoring its progress were the main activities in this phase of DMAIC.

Implementation of 5S: The 5S methodology plays a significant role in the "Improve" phase. The 5S stand for (sort, set in order, shine, Standardize, and sustain,) and they aim to create an organized, efficient, and visually controlled workplace. Here's how the activities was done in the workplace with it relates to DMAIC:

1. Sort: This step involves identifying and removing unnecessary items from the workspace. It helps eliminate a large amount of work in process that makes the working environment difficult to move for people and materials, improve material flow, and efficiency by keeping only essential items.

2. Set in Order: Once the workspace is sorted, this step focuses on arranging necessary items in a logical and ergonomic manner. It includes labelling, organizing, and creating a visually intuitive workspace layout. Wood chips, boxes containing paint, hammers, wood nails, rivets, iron plates, finished goods, and work in process are placed in their own place.

3. Shine: The shine step is all about cleanliness and maintenance. It emphasizes regular cleaning, proper storage, and preventative maintenance to ensure optimal working conditions for machines and trolleys. Activities in this step include the cleaning of foreign materials that make the final product scratch problem.

4. Standardize: Standardization involves creating guidelines, procedures, and visual controls to maintain the improvements made in the earlier steps. In this step, training of operators how to maintain the first three activities(3S), cleaning the machine from scrap leftover from wood chips and equipment used so that the tool's performance remains good when using it, and making procedures and a cleaning schedule for each worker.

5. Sustain: The last step, sustain, is about continuously reinforcing the improvements made and making them a part of everyday work culture. It involves regular audits, training, and employee engagement to ensure the 5S practices are sustained in the long term. There are SOPs that were followed, and following these procedures is practiced and evaluated as an improvement.

Improved Defect Rate Products: Based on the given data in Table 14, it is observed that after the implementation of the countermeasures, the defect rate of the product decreased from 59% to 22.96%. This reduction in the defect rate suggests that the intervention was effective in addressing the root causes of the defects.

Table 4.6: Quality data of produced amount and its defect (source: 3 month data of case company)

Produced amount of door	Defective amount	Defect rate
135	31	22.96 %

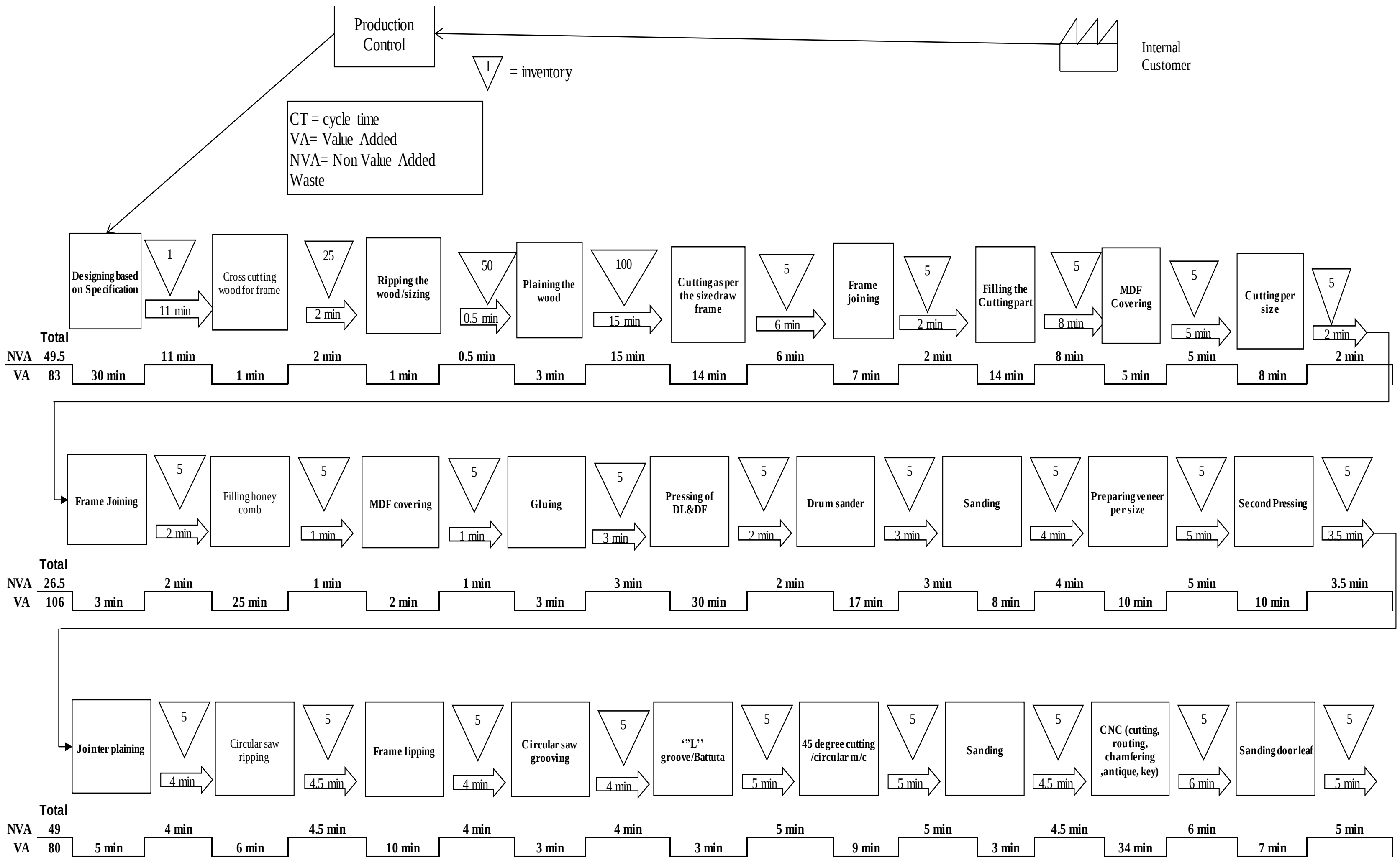
Defect Rate = (Defective Amount / Produced Amount) * 100

Defect Rate = $\frac{31}{135} * 100$ = 22.96%

Before implementing the countermeasures, the defect rate was 59%, implying that 59 out of every 100 doors manufactured were defective. However, after the countermeasures were implemented, the defect rate reduced significantly to 22.96%, which means that around 23 out of every 100 doors manufactured were defective. This enormous decrease in the defect rate demonstrates that the countermeasures taken were effective in enhancing product quality. It implies that the fundamental causes of the defects were effectively identified and rectified, resulting in fewer defective doors being manufactured. As a result, based on the data, it is possible to conclude that the intervention was effective in lowering the product's defect rate and enhancing its overall quality. According to the results, the sigma level has improved from 2.6 to 3.2, a 1.5 sigma shift. This means that the process is now more consistent and reliable because it operates within a closer range of acceptable variations. Furthermore, the sigma level has also improved from 1.18 to 1.7 without a 1.5-sigma shift. This shows that, even without considering the 1.5 sigma shift, the process has improved in terms of reducing variations and becoming more stable.

Improved value stream map of door production:

By finding the waste steps in the production and making the corrective action for each waste by giving prior to counter without automation and getting better results, the value stream map is improved. The countermeasures that are used to remove waiting for drying need much money due to the cost of drying machinery, so the research counter is focused on the easily achievable and unnecessary waiting.



Production Control
Internal Customer
I = inventory
CT = cycle time
VA= Value Added
NVA= Non Value Added Waste
Designing based on Specification
1
11 min
Cross cutting wood for frame
25
2 min
Ripping the wood/sizing
50
0.5 min
Plaining the wood
100
15 min
Cutting as per the size draw frame
5
6 min
Frame joining
5
2 min
Filling the Cutting part
5
8 min
MDF Covering
5
5 min
Cutting per size
5
2 min
Total
NVA 49.5
VA 83
30 min
11 min
1 min
2 min
1 min
0.5 min
3 min
15 min
14 min
6 min
7 min
2 min
14 min
8 min
5 min
5 min
8 min
2 min
Frame Joining
5
2 min
Filling honey comb
5
1 min
MDF covering
5
1 min
Gluing
5
3 min
Pressing of DL&DF
5
2 min
Drum sander
5
3 min
Sanding
5
4 min
Preparing veneer per size
5
5 min
Second Pressing
5
3.5 min
Total
NVA 26.5
VA 106
3 min
2 min
25 min
1 min
2 min
1 min
3 min
3 min
30 min
2 min
17 min
3 min
8 min
4 min
10 min
5 min
10 min
3.5 min
Jointer plaining
5
4 min
Circular saw ripping
5
4.5 min
Frame lipping
5
4 min
Circular saw grooving
5
4 min
‘"L" groove/Battuta
5
5 min
45 degree cutting /circular m/c
5
5 min
Sanding
5
4.5 min
CNC (cutting, routing, chamfering ,antique, key)
5
6 min
Sanding door leaf
5
5 min
Total
NVA 49
VA 80
5 min
4 min
6 min
4.5 min
10 min
4 min
3 min
4 min
3 min
5 min
9 min
5 min
3 min
4.5 min
34 min
6 min
7 min
5 min

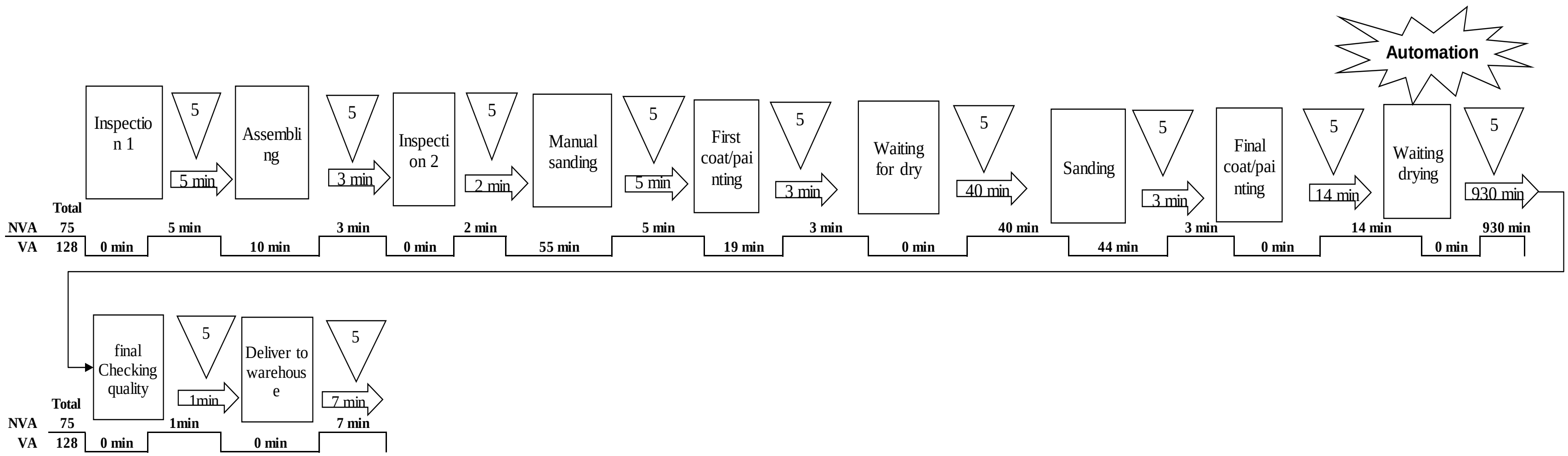


Figure 4.11: VSM of future stats (improved)

From the above VSM the summary of time measurement after improvement is:

Table 4.7: Summary of VSM and Time measurement after implementation

Summarized Process	Value add time	Non value added time	Cycle time	From the NVAT	
				Transportation minute	waiting
Preparation	70	26.5	96.5	5	3
Door frame	40	21	61	4	3
Door Leaf	155	56.5	211.5	15	1
CNC	34	7	41	1	2
Sanding door leaf	7	3	10	2	1
Inspection 1		5	5		
Assembling	10	3	13		0.5
Inspection 2		2	2		
Manual sanding	55	5	60	3	1.5
First coat/painting	19	3	22	1	0.5
Waiting for dry		40	40		30
Sanding	44	3	47		
Final coat/painting		14	14		2
Waiting drying		1410	1410		930
Checking final quality		3	3		
Deliver to warehouse		27	27	17	3
Total	434	1629	2063	48	977.5

Table 4.8: Summary of improved value-added and non-value added time

Activity	Time Measurement		Improved /Reduced Minute
	Before	After	
value adding	434	434	51 minute
Non value adding	1680	1629	
Cycle time	2114	2063	

By reducing the waiting time, adding the trolley and maintaining the existing trolley, and by rearrange one machine, the waste is improved. From the above table, it is possible to analyze the activity and time measurement before and after an improvement in the process. Before the improvement, the cycle time was 2114 minutes, which decreased to 2063 minutes after the improvement. This indicates that the process has become more efficient after the improvement, resulting in a reduction of 51 minutes in the cycle time. The value-adding activities in the process were 434 minutes before and after the improvement, which indicates that the improvements did not directly impact the value-adding activities. On the other hand, non-value-adding activities decreased from 1680 minutes before the improvement to 1629 minutes after the improvement. This indicates that the process improvement has yielded a reduction in non-value-adding activities, resulting in a more efficient process. Overall, the improvements made in the process led to a more efficient process with a reduction in cycle time and non-value-adding activities. However, the value-adding activities remained the same.

Table 4.9: Improved non value added time

Non value adding Activities	Time Measurement		Percentage	
Transportation time	Before	After	Before	After
	62 minute	48 minute	4%	3%
Waiting time	1026.5 minute	977.5 minute	61%	60%

Based on the above table, there were two non-value-adding activities measured: transportation time and waiting time. It's important to reduce non-value-adding activities as they do not contribute to the overall productivity or efficiency of a process. In terms of transportation time, there was a 14-minute reduction from 62 minutes to 48 minutes. This equates to a 4% decrease in transportation time. While this may seem insignificant, small improvements in non-value-adding activities can lead to significant improvements in overall productivity. Therefore, this reduction is still a positive change. In terms of waiting time, there was a slightly larger reduction from 1026.5 minutes to 977.5 minutes, a 49-minute reduction. However, the percentage improvement was only 1%, from 61% to 60%. This suggests that waiting time is still a significant non-value-adding activity in the process. Overall, even though there were improvements in transportation time and waiting time, there is still room for further improvement in reducing non-value-adding activities to increase overall productivity and efficiency.

Control:

Control is the last phase of the DMAIC and is used to keep or maintain the results or sustain the improvements by monitoring, documenting standard operating procedures (SOPs), training, and skill development. During the analysis, stage, some of the problems in the production process that lead to defects are: lack of handover, unnecessary materials on the production floor, lack of punctuality due to lack of clear formats to receive orders and specifications, use of blades without its standard service time, waiting of trolleys by finding them due to disorganized placement of each item, feeding of measurements without cross-checking of the customer order and the site measurement, rough pallets, disorganized work place due to lack of 5S implementation, and lack of packing materials for the final product. Generally Production defects that occur due to a lack of machine usage procedures or work procedures in producing wooden pallets and a lack of supervision. To overcome this, it can be done by doing good work in procedures and formats in every part of the production process.

The results of the study are controlled by preparing a standard operating procedure (SOP), which is a guideline that contains standard operating procedures in an organization that are required to ensure that every decision, step, handover format, or action taken by employees of an organization can run effectively, consistently, and systematically, which is integrating the last steps of the 5S called sustaining by giving training about the 5S, implementing visual management, regularly reviewing performance, and continuously improving by sustaining the achieved results. Some of the controlling mechanisms are in the appendix.

4.4. Discussion

Lean Six Sigma (LSS) strategy implementation has proven to be effective across industries. It aids in the identification and quantification of production process challenges, resulting in improvements in quality, productivity and company profitability. LSS is a powerful strategy for optimal operations and driving overall organizational performance. According to the authors, using an LSS approach in a wood furniture company could be a significant step forward in the development of better production practices(Guerrero et al., 2017). And another author Anderson et al., (2015) and Megawati et al (2020) although justify that the Lean Six Sigma technique yields positive results, the Sigma level achieved is just 3.7 and remains far from level 6, because his research is currently focused on the most serious defects and achievable countermeasures is a pilot improvement. Furthermore According to a study done by Megawati (2020), the most serious defect found was the peeling off of the edge veneer, which reached a 3.5 Sigma level. After three months of adopting the DMAIC approach, this problem was successfully minimized, resulting in a Sigma level increase to 4.3. Furthermore, the total quality performance improved from 3.3 to 3.7. These findings show that implementing the Lean Six Sigma methodology was beneficial in improving the process's quality performance. But addressing knowledge, culture, and human attitude concerns effectively is critical for the effective implementation of Lean and lean six sigma, especially in firms with limited resources {Abu, 2022}. Therefore applying LSS have a positive result but its successfulness is by overcoming some challenges. In this study defect rate data has been collected for different product types in the company as a preliminary data assessment, and prior to collecting the data with the highest defect rate, which is a door product, to reduce this defect rate, data has been collected from focus group discussions and different management staff to know about the contributors to this defective product. From the collected quality data, the current defect rate of the door product is 59%, which is the highest percentage of defects among the other products of the company. After the preliminary data collection leads to one product, the researchers focus on the reduction of defects in door products, and the causes of the defects are scratch, scrap, and wrong measurement.

The DMAIC road map is experienced in this research. On the define stage of the roadmap Pareto analysis, process mapping and SIPOC are done to prioritize, understand, and define the problem. In the measurement stage of DMAIC time measurement and VSM, lean tools have been used, and different non-value-added activities have been identified in the stream map, such as transportation and waiting time due to a disorganized workplace, and lack of automation in the drying of painted products and improper allocation and shortage of trolleys.

Besides this, the sigma level of the product was also calculated. In the analyze phase of DMAIC, the possible causes and root causes among the possible cases are identified (which are discussed in detail in the analysis part. One special thing that is added to this paper is a validation before going to the improvement phase of the DAMIC by expert's opinions and gemba through. I just add one point in the DMAIC phase when I find research gaps, which is that there is no validation that the root causes are really true root causes before going to the improvement phase. Inappropriately identifying root causes can have negative effects, such as implementing inefficient remedies and wasting precious resources. During the research phase of the DMAIC process, a serious oversight was discovered: a lack of validation relative to the identified root causes. This omission may limit the achievement of intended goals and lead to ongoing processing difficulties. It is critical to consider problems such as time restrictions, limited resources, and a lack of understanding about the need for root cause validation. Incorporating a validation phase before moving on can produce significant benefits and increase the likelihood of success. Finally, by adding this validation step to the DMAIC phase, I called it DMAVIC, and this framework brings a significant result in defect reduction in this study. In the improvement stage, the 5W1H and 5S are practiced, and after this, the final stage of DMAIC is control, which is done through SOP.

This study aims to demonstrate the effectiveness of Lean Six Sigma in the DMAIC (Define, Measure, Analyze, Improve, and Control) approach by including core Lean techniques such as Value Stream Mapping (VSM), Pareto analysis, Fishbone diagrams, Why-Why analysis, 5S, and process mapping. The VSM measurements reveal that the value-added time was constant both before and after the improvement. However, there was a decrease in non-value-adding time due to some adjustments to the production flow and implementing 5S, showing an increase in efficiency. The cycle time, which reflects the overall time required for a process, also decreased following the change, emphasizing boosted productivity and reducing wasted time even more. The modification appears to have had a favorable impact on the process by lowering non-value-added operations and total cycle time. Depending on the exact context of the activity being monitored, this could lead to increased productivity and possibly increased customer satisfaction. However, the reduction in cycle time is not significant because of the waiting time for the drying of the final painted product at room temperature, but if they use some other technology, it will decrease significantly. The study illustrates the potential of Lean Six Sigma to streamline processes, identify root causes of inefficiencies, priorities improvement opportunities, and reduce defects and waste in organizations by combining these techniques. The overall results in this research is summarized in table (4.10):

Table 4.10: Improvements before and after DMAVIC

Activities	Before DMAVIC	After the DMAVIC	Improvement
Defect(door)	59 %	22.96%	The difference is 36.04 and improved by 61.1 %
Cycle time	2114 minute	2063 minute	51 minute
Sigma level	1.18 without 1.5 sigma shift and 2.6 with 1.5 sigma shift	1.7 without 1.5 sigma shift and 3.2 with 1.5 sigma shift	Which is closer to the standard

The above table shows that the integration of lean and six sigma in the DMAVIC approach in this research brings significant results. In general, DMAIC is an excellent methodology for understanding variation and waste in the furniture industry as well as improving processes and quality.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

In today's world, ensuring the manufacturing of high-quality products is critical. This is especially important considering the scarcity of resources, which is a prevalent problem in developing countries like Ethiopia. The furniture industry is primarily reliant on imports, and locally created goods sometimes have a high defect rate. Competing under such conditions becomes difficult, making it critical to increase quality and reduce defects. This ensures not just satisfied customers but also the development of a strong brand reputation, which leads to long-term success.

Based on the data processing and problem-solving analysis conducted, several conclusions can be drawn. Initially, the company's assessment revealed that the defect rate of the doors was 59%, the cycle time was 2114 minutes, and the sigma level reached 1.18 without a 1.5 sigma shift or 2.6 with it. However, after implementing proposed improvement solutions, significant progress was observed. The defect rate decreased to 22.96%, the cycle time reduced to 2063 minutes, and the sigma level improved to 1.7 without a 1.5 sigma shift or 3.2 with it. This represents a remarkable improvement which is 61.1% improvement in defects. These findings indicate that the door production process has become more efficient and the overall product quality has improved. Additionally, the achieved sigma value at the quality inspection stage indicates that the company is approaching the desired standards.

Reduce the defect rate in the furniture company from 59% to 22.96%. This improvement is significant for the organization since it improves quality control and customer happiness. Furthermore, other companies in the same industry can use the research findings to improve their own defect rates and overall performance. Policymakers and researchers in the furniture sector would benefit from this research since it explains how lean six-sigma approaches might be used to attain similar results. Finally, the researcher concluded that in this study validating root causes play a crucial role to shorten the DMAIC implementation period to achieve faster results and integrating lean and six-sigma can significantly reduce defects in furniture factories and that the DMAIC methodology should be implemented in the furniture factory sector.

5.2. Recommendations

Based on the research findings and data obtained, the researcher makes the following recommendations:

- Maintaining a strong sense of ownership, sticking to carefully designed operational procedures and formats, and ensuring thorough cross-checking of data prior to production reduces faults.
- The drying time of the door is excessive, and the waiting time to dry increases the production cycle time. Drying durations may vary depending on the type of paint, weather conditions, and the number of coats applied. For the most accurate information, always refer to the specific paint product's instructions. Employing fast-drying paints or incorporating infrared drying technology (if the company can afford it) can further reduce the waiting time.
- Adjusting the layout of a manufacturing process can result in various advantages, including higher efficiency and reduced defects. By Reduce distances designing a layout that follows a logical flow pattern facilitates the smooth movement of products and materials, by organizing workstations.

5.3. Future Study area

This research considers the reduction of defects by identifying the main contributors to the increase in one product in the company, but it does not consider the impact that has on other parameters like customer satisfaction, productivity, employee morale, etc. So as a future study area, the researcher suggests the impact of defect reduction on all stakeholders.

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APPENDICES

Appendix A: **DPMO: Sigma Level Table**

	Without 1.5 sigma shift			With 1.5 sigma shift		
Sigma Level	DPMO	Yield	Defect Rate	DPMO	Yield	Defect Rate
1	317310	68.2690000%	31.7310000%	697612	30.23880%	69.76120%
1.1	271332	72.8668000%	27.1332000%	660082	33.99180%	66.00820%
1.2	230139	76.9861000%	23.0139000%	621378	37.86220%	62.13780%
1.3	193601	80.6399000%	19.3601000%	581814	41.81860%	58.18140%
1.4	161513	83.8487000%	16.1513000%	541693	45.83070%	54.16930%
1.5	133614	86.6386000%	13.3614000%	501349	49.86510%	50.13490%
1.6	109598	89.0402000%	10.9598000%	461139	53.88610%	46.11390%
1.7	89130	91.0870000%	8.9130000%	421427	57.85730%	42.14270%
1.8	71860	92.8140000%	7.1860000%	382572	61.74280%	38.25720%
1.9	57432	94.2568000%	5.7432000%	344915	65.50850%	34.49150%
2	45500	95.4500000%	4.5500000%	308770	69.12300%	30.87700%
2.1	35728	96.4272000%	3.5728000%	274412	72.55880%	27.44120%
2.2	27806	97.2194000%	2.7806000%	242071	75.79290%	24.20710%
2.3	21448	97.8552000%	2.1448000%	211927	78.80730%	21.19270%
2.4	16395	98.3605000%	1.6395000%	184108	81.58920%	18.41080%
2.5	12419	98.7581000%	1.2419000%	158686	84.13140%	15.86860%
2.6	9322	99.0678000%	0.9322000%	135686	86.43140%	13.56860%
2.7	6934	99.3066000%	0.6934000%	115083	88.49170%	11.50830%
2.8	5110	99.4890000%	0.5110000%	96809	90.31910%	9.68090%
2.9	3731	99.6269000%	0.3731000%	80762	91.92380%	8.07620%
3	2699	99.7301000%	0.2699000%	66810	93.31900%	6.68100%
3.1	1935	99.8065000%	0.1935000%	54801	94.51990%	5.48010%
3.2	1374	99.8626000%	0.1374000%	44566	95.54340%	4.45660%
3.3	966	99.9034000%	0.0966000%	35931	96.40690%	3.59310%
3.4	673	99.9327000%	0.0673000%	28716	97.12840%	2.87160%
3.5	465	99.9535000%	0.0465000%	22750	97.72500%	2.27500%
3.6	318	99.9682000%	0.0318000%	17864	98.21360%	1.78640%
3.7	215	99.9785000%	0.0215000%	13903	98.60970%	1.39030%
3.8	144	99.9856000%	0.0144000%	10724	98.92760%	1.07240%
3.9	96	99.9904000%	0.0096000%	8197	99.18030%	0.81970%
4	63	99.9937000%	0.0063000%	6209	99.37910%	0.62090%
4.1	41	99.9959000%	0.0041000%	4661	99.53390%	0.46610%
4.2	26	99.9974000%	0.0026000%	3467	99.65330%	0.34670%
4.3	17	99.9983000%	0.0017000%	2555	99.74450%	0.25550%
4.4	10	99.9990000%	0.0010000%	1865	99.81350%	0.18650%
4.5	6	99.9994000%	0.0006000%	1349	99.86510%	0.13490%
4.6	4	99.9996000%	0.0004000%	967	99.90330%	0.09670%
4.7	2	99.9998000%	0.0002000%	687	99.93130%	0.06870%
4.8	1	99.9999000%	0.0001000%	483	99.95170%	0.04830%
4.9	0.96	99.9999040%	0.0000960%	336	99.96640%	0.03360%
5	0.574	99.9999426%	0.0000574%	232	99.97680%	0.02320%
5.1	0.34	99.9999660%	0.0000340%	159	99.98410%	0.01590%
5.2	0.2	99.9999800%	0.0000200%	107	99.98930%	0.01070%
5.3	0.116	99.9999884%	0.0000116%	72	99.99280%	0.00720%
5.4	0.067	99.9999933%	0.0000067%	48	99.99520%	0.00480%

5.5	0.038	99.9999962%	0.0000038%	31	99.99690%	0.00310%
5.6	0.021	99.9999979%	0.0000021%	20	99.99800%	0.00200%
5.7	0.012	99.9999988%	0.0000012%	13.35	99.99867%	0.00134%
5.8	0.007	99.9999993%	0.0000007%	8.55	99.99915%	0.00086%
5.9	0.004	99.9999996%	0.0000004%	5.42	99.99946%	0.00054%
6	0.002	99.9999998%	0.0000002%	3.4	99.99966%	0.00034%

Appendix B: **Customer Specification Format**

Customer Name	Phone no.				Address	Prepared by ;------
						Date ;- ---------
Order type	Quantity and color type				Final Measurement	
					Date ;--------------- Prepared by ;-----------	
	Wooden	Colored	Laminate	Mixed	Site measured	If not measured, specify the reason
K. cabinet						
Cupboard						
Shown Rack						
In .Door						
Salon						
Cu. Name	Phone no.				Address	Prepared by
						Date

Appendix C: **Hand over format from process delivery section**

Company name Finfinnee furniture factory										Date ………….
Product type	Detailed components	(√)	Quantity	Quality checking parameter						Remark
				Colour	Lengths	Width	defect			
							Has	Absence		

Appendix D: **Quality control process chart (for quality section)**

Quality control process chart for finished product					Product type ________________		
Company name 3F	Quality checker ………………..			Quality inspection date----------			
Product part	Item to be	Specification	Checking instrument	Checking point	Action taken	If fail the	Picture

	checked				Fail	Pass	main reason	

Appendix E: Hand **over format from process to process**

Internal hand overing format			Section ________________________	
S/n	Product type	Total	Missing part	Remark

Appendix F: **Why-Why Analysis:**

Problems	Why 1	Why 2	Why 3	Why 4	Why 5
Wrong measurement	Design problem and wrong data feeding	Not taking exact measurement	Low attention when taking a measurement	Negligence of the employee	Prepare format
	Missing alignment	Calibration Problem Power interruption	The is no machine calibration standard	Set standard time for celebration	
	Raw material quality	Using Local raw material	Due to Currency Purchasing problem	There is no SOP in raw material procurement	SOP Use alternative suppliers
	Make insufficient and/or wrong design (Specification)	Not making design based on exact customer site measurement	During site measurement not recording important data and notes sufficiently that aid to design work	Not having standardized formats to record all data and information during site measurement (customer specification recording format)	Prepare clear Customer specification data collection format
Scratch problem	Perfection problems	Traverse-un proportionality	Cutter sharpness problem	problem of blade sharpness	Prolonged use of blade
	Loading unloading problem	Defects during transportation of finished product	Poor protection of products during transportation	Loading finished products without packaging material	Absence of Packaging materials to all product components
		Scratch during production	During raw material transportation from store to production	Low material handling problem	Lack of awareness about the consequences

Problems	Why 1	Why 2	Why 3	Why 4	Why 5
	Finished product and row material temporary storage problem	Disorganized arrangement	Not Use the existing pallets properly	Poor implementation of 5S	
	Bursting of veneer	Glue Painting problem	not addressing the glue at each end to end of MDf	Negligence of operators during painting	
	Bench working problem	There is foreign materials in bench working	Not properly clean working environment	Carelessness of operators	
	Pallet problem	Pallets are not smooth	Unmaintained pallet		
	Waiting of the painted MDF rather than immediately take to press machine after painting glue	Not Following working Standards	Lack of accountability and SOP	Prepare working standard (SOP)	
	Not using right types of blade	Absence of Professionals	Lack of Skill training		
	Machine speed	Different machine speed makes scratch to the product	There is no SOP for cutting of different type of material		
	Low quality of material /MDF/	Difficult to cut perfectly	Compactness of the MDF	Low quality	Procurement and currency problem
Crack problem	material Shrinkage	Loss moisture content	Due to putting of materials for a long time at store	Poor warehouse condition handling and not using JIT	

Problems	Why 1	Why 2	Why 3	Why 4	Why 5
	Poor Handling of raw material	Awareness			
	Low quality of veneer sewing yarn				
	Perfection problems	Traverse-un proportionality	Cutter sharpness problem	problem of blade sharpness	
	No one responsible for problems	Hand-overing problems	Absence of legal hand-overing format		
	Glue property	No standards for glue preparation	Because the glue type different from time to time	Lack of recipe on glue preparation	There is no glue preparation standard
	makes loose property of binding	Painting many veneer at a time by glue	Doesn't use working procedure		
	Workmanship	Lack of concentration	Not skilled person		
	Open seam	High temperature of machine	There is no sop		