



Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

(Department of Industrial Engineering- Graduate Studies)

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the Degree of Masters of Science in Industrial Engineering

Entitled with:

IMPROVEMENTS OF PRODUCTION LINE EFFICIENCY OF GARMENT SEWING SECTION WITH AN INTEGRATED APPROACH OF LEAN SIX-SIGMA (LSS): *in the case Evertop Sport-wear company (under Bole-lemi Industrial park)*

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March 2021

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This is to certify that the thesis prepared by Abraham Wondale, entitled: “IMPROVEMENTS OF PRODUCTION LINE EFFICIENCY OF GARMENT SEWING SECTION WITH AN INTEGRATED APPROACH OF LEAN SIX-SIGMA (LSS)” in a case of Bole-Lemi Industrial Parks (Evertop Sport-wear company) and submitted in partial fulfillment of the requirements for the degree of Master of Science (in Industrial Engineering stream) complies with the regulations of the University and meets the accepted standards concerning originality and quality.

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Declarations

I, Abraham Wondale, declared that the work which is being presented in this thesis entitled “IMPROVEMENTS OF PRODUCTION LINE EFFICIENCY OF GARMENT SEWING SECTION WITH AN INTEGRATED APPROACH OF LEAN SIX-SIGMA (LSS)” is original work of my own and has not been presented for a degree of any other university and all the resources of references used for the thesis have been strictly acknowledged.

(Signature)

(Date)

Acknowledgment

My heartfelt passion and gratitude are belonging to the holy creator God who gave me the power and strength to start and finish the whole part of this study. My appreciation goes to my advisor (Dr. Merertu W.) and co-advisor (Mr. Daniel A.) for their sustained support, effort, and constructive input idea development. There are also stakeholders to be given many thanks and honors such as the Evertop company production manager and production department supervisors (especially Eyob T.) who were welcomed to visit and conduct my preliminary and survey studies to the company they are working in.

Lastly, I would like to thank Addis Ababa Institute of Technology (AAiT) staff and administrators for arranging facilities and pre-conditions in the two years of my academic session.

Abstract

The organizational effectiveness of textile, garment, and apparel manufacturing industries are measured through their production line efficiency and workers' performance. By its nature, these manufacturing industries are involved with a large workforce, complex operations, and several sequential production lines. As a result, different principles, methodology, and techniques have been implemented in parallel to the production process to enhance and integrate the uses of these resources. Specifically, in garment industries, sewing sections are considered as the most critical working zone because of large resource movements and significant chances of defects and reworks occurrences. As a result, this research is focused on the efficiency and performance analysis of sewing production lines of the case company.

The case company described under this study has got a significant challenges on its sewing production operations. The figurative data analysed on this section indicated that several production wastes and defects on products are generated as it is lacking of consistency and poor workers performances. As a result, frequently, the line efficiency of this section is registered for lower and varying results in every production sessions compared to company's targets.

Therefore, the study under this paper has assured that the integrated applications of lean and six-sigma (LSS) methodology has been preferred to tackle-down these constraints of production efficiency and workers' performance level. Besides that, the joint uses of these methodologies are brought fundamental changes to the overall production process of the company and the integration can help to take-over the advantages of both. LSS is an approach that combines the philosophies, principles, and tools of both methodologies. Lean manufacturing operates through the principles of waste minimization and non-value adding activities by process optimization. Six-sigma is also known for minimization of process variation by the reduction of defects within the given standards.

In conclusion, this study has got a considerable results on enhancing workers performance levels in each sewing operations for raising its line efficiency. Besides to that, a successful conceptual draft of the lean six sigma (LSS) model has been developed and validated for the satisfactory level of those production line efficiency and workers performance improvement.

Keywords: Lean six sigma Line efficiency Performance Sewing-line Garments

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CHAPTER ONE

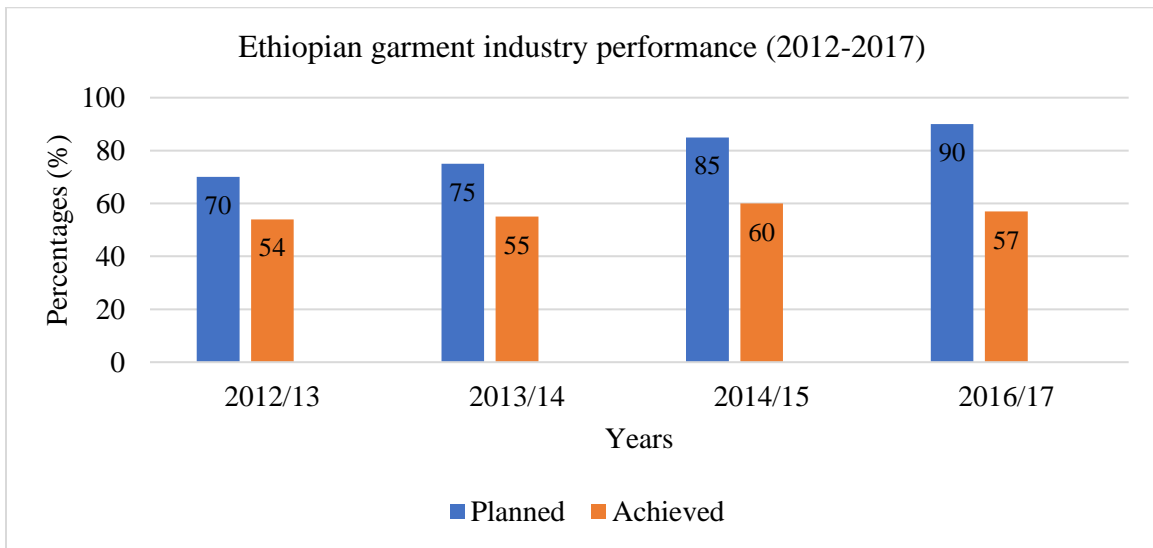
1. Introduction and Background of the Study

1.1 Introduction

Before the introduction and expansions of garments and fabric cloths, humans were used a few cloth-like fragments on their parts of the body a million's years ago, (Gilligan, 2019). Typically, the ancient people were used hand-made cloths to protect themselves from the external environment and hazards. Through time, clothing becomes a way of expressing culture, fashions, and modernizations. Dramatically, the industrial revolution in the 20th century paved the way for emerging of various textile and apparel industries that can make garments and ready-made clothes. After the incident, the textile and garment industries have been expanded in different parts of the world. Earlier in the 1990s, the developed nations were autonomously leading and controlling the world's textile and apparel manufacturing and exports (Diriba, et al., 2019). However, this was not long-lasting, the International Textiles and Clothing Bureau (ITCB) reports of 2019 indicated that after 2002 the developing countries like China, India, Vietnam, and Bangladeshi become leading the international textile and apparel manufacturing by a 62.2% of the total growth. Several reasons such as availability of quality raw-material, cheap and excess labor force, geographical and strategic locations of countries, took contributed to the shifting of the business.

Ethiopia has got its first textile and garment industry in 1939 in the regime of Emperor Haile Selassie in the city of Dire Dawa. According to (Wagaye & Walle, 2018) there are about 38 active textile industries and 84 garment factories owned in the government and privates. Currently, the number is increasing dramatically to get the advantages of government incentives, raw-material access, low-cost energy supply, and cheap-labor. In the last 5 to 6 years, the textile and apparel industry of Ethiopia has grown at an average of 51% and more than 65 international textile investment projects have been licensed for foreign investors. The Minister for the industry of the country has a projected vision of generating \$30 billion from this sector at the end of 2025. On the other side, recent studies have revealed that this sector is facing several observable and hidden challenges. For instance, the studies (Legesse & Singh, 2014, Haile, 2016, Demissie, et al., 2017) witnessed that the reasons for obstacles and slow growths of textile and garment manufacturing are vertical and loose supply chain integration, technology, shortages of well-skilled labor, poor raw-material quality, production process-related problems, and internal management issues. As a

result, the contribution of Ethiopia to the world market export becomes less than 1% of the share and repeatedly shocked by the international market competitions. The planned and actual performance on the textile and garment industry has been showing a very large gap in every production year. For instance, whenever we seen the production and export rate of the country between 2013-2017, the sector could not achieve its pre-established goals (ETDI, 2018).



1.2 Background and Justification of the Study

The world textile and apparel business sector has been showing several ups and downs to have current situations. But still, there are enormous internal and external challenges facing production performance issues and resulting in low productivity and inefficiency. Developing countries like Ethiopia are working relentlessly to control and overcome these obstacles. Different studies have been conducted in the area to identify and tackle these internal and external factors. The study of (Diriba et al., 2019), concluded its thought as, policy improvement, technical and supervisory skill development, novelty and developing indigenous knowledge, learning from the world-leading countries, etc. would be the ways for recuperation. Again, (Khurana, 2018) forwarded ideas for the successful global competitions of Ethiopian domestic companies, there should be clear and feasible linkages between stakeholders, academia, industries, and beneficiaries of this business. On the other hand, scholars also believe that improving the ways of the production process, implementing tools and techniques, setting KPIs, internal management, and efficient usages of resources can be a get track for improvements (Sorri, 2010, Rajput et al, 2018). According to the study of (Demissie et al., 2017) development of a quality mode framework can have a significant

impact on the improvements and minimize the above-stated major problems of the sector. When we have a deep look into the apparel industry which is a major concern of this study, improving production line efficiency and enhancing workers' daily performance level will be the key for achieving the company's business goal. A production line consists of different resources, such as labor, raw-material (WIP), machines, and time. The study of (Rajput et al., 2018) revealed that to have a higher line efficiency, developing line balancing and time study techniques would help to distribute workloads and resources evenly along the production lines. Again in the works of (Kitaw, et al., 2010, Jilcha, et al., 2015, Tesfaye, 2019) simulation techniques are preferred to control production line resources efficiently and effectively. Besides that, there are also scholars implementing various techniques and principles of integrating both production and management philosophies for better production line efficiency and optimized resource usages. For instance, the study of (Olanrewaju, et al., 2019) discussed that the integrated applications of lean and six sigma (LSS) would not be neglected in the production efficiency improvement and management activities. LSS can be applied to a wide range of organizational business activities. However, for effective workers' performance improvement and overall production line control, LSS can also bring a significant change in the company manufacturing processes. Turning back to our case study, the textile and garment industries has to identify basic production and management related problems and challenges for the successful implementations of various improvement techniques. This study is going to discover those production related challenges such as workers performance improvement, production line efficiency enhancements and so on.

1.3 Statements of the Problem (the case company)

The preliminary study indicated that more than 400 workers are engaged in 9 active production lines with an overall line efficiency of 47.3% and production rates of 1,000-1,300 fleece and classic types of sport-wear per day. However, the company could not keep track of its production rates in day-to-day operations for several reasons. Particularly, the assembly line known as sewing sections, repeatedly achieved for least workers' performance and sourced for higher defects and reworks. The sewing line is also taking 44% of the total workers in the company and become the suspicious department of all because most wastes and defects production are generating from this section. This section is also known as money-making zone of the company, however, its labor intensiveness and presences of several sophisticated assembly operations, this company could not get the pre-established benefits.

The study made under the classic type of sport-wear product are more complex and took most resources than the fleece one. As a result, overall production line efficiency and workers' performance level is assessed for this product. Based on the fact observed there are inherited production line efficiency challenges from the type of process and the operator's perspective. Among these, process variation or inconsistency, workers' problems, poor resource control, and poor management commitments can take most portions of the gaps. However, in the following described chart, the level of the production line efficiency and workers performance has been examined from the company's recent reports. Therefore, the study will discover major issues of this production line (for the sewing operation) to make an analysis and concludes for similar others.

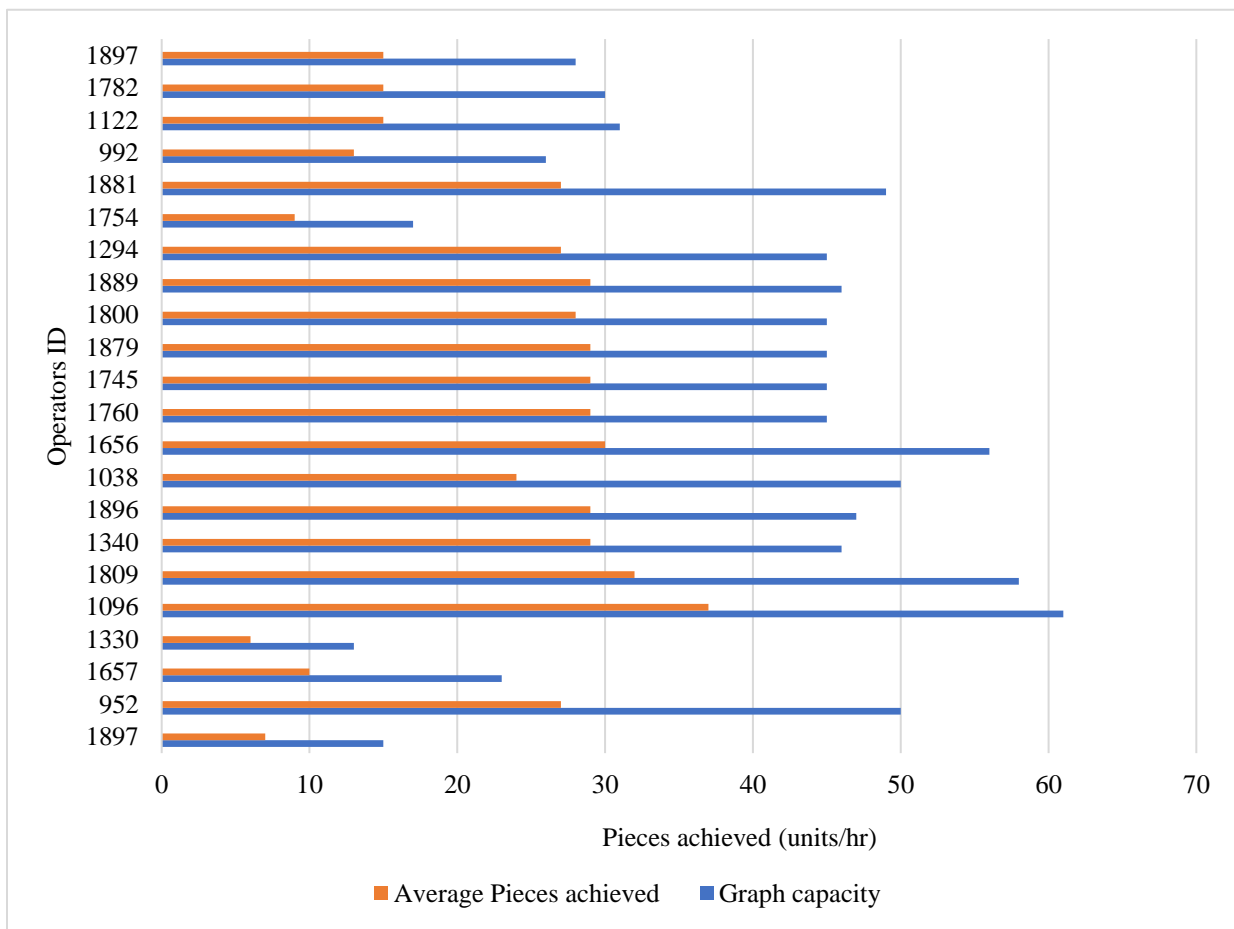


Figure 1: Preliminary assessments of sewing operations performance (for classic sport-wear)

Since the number of pieces assembled per hour is registered in the last operations ‘Collar T/S’ using an LST assembling machine. As a result, 15 pieces of classic sport wears are produced every hour by the last operator.

$$\text{Line efficiency} = \frac{\text{Total output per day per line} * \text{Standard minute values (SMV)}}{\text{Total manpower per line} * \text{working minute per day}} * 100$$

$$\text{Line efficiency} = \frac{15 * 8.75 * 41.68}{22 * 8.75 * 60} * 100 = 47.3\%$$

1.4 Objectives of the Research

1.4.1 General Objective

The general objective of the study is going to improve production line efficiency and workers' performance level, particularly in the sewing line by using an integrated approach of lean six sigma (LSS) methodology.

1.4.2 Specific Objective

- To measure and control production line efficiency and performance challenges.
- To identify, categorize, and tackling production line wastes.
- To apply DMAIC of the six sigma concept in the minimization of the defect.
- To apply the lean concept of waste minimization in the production line.
- To coordinate both lean and six sigma approaches for production improvement.

1.5 Research questions

- How to measure and control production line efficiency and workers' performance level in the textile and garment industry.
- At what level does the production line efficiency and workers' performance will affect the production operations of the company?
- How to possible in minimizing production wastes and defects by applying lean six sigma methodology effectively?
- How to align lean six sigma methodology for effective performance improvement?

1.6 Scope of the Study

In the textile and garment industry, there are different internal and external observable challenges affecting the productivity and competitiveness of the organization. However, this study, it is going to be addressed in-depth internal factors specifically those production line efficiency performance obstacles. As a result, the study is demarcated on utilizing and efficient uses of resources (such as man, machine, time, and raw material) along the production lines with the development of lean and six sigma approaches.

1.7 Deliverable of the Study

This research is believed to put a blue-print on the area of the production line performance and efficiency improvement to the case and other similar companies. On the other side, similar upcoming researchers could take it as referencing material for their tasks.

1.8 Ethical Considerations

A high prior and dignity has been given for participants during communications and data exchanging sessions. The private name, secret, and life history of individuals are restricted to states in this paper. Company data reports, profits and losses, interviews, policies, and other confidential issues will be asked for the goodwill of the company's and personal interests before documentation. In general, the voluntary participation of respondents during the study is highly appreciated and acknowledged.

1.9 Organizations of the Research

The research will be structured and categorized into five main chapters. **In chapter one**, an introduction and background of the study are discussed with a clear justification. Besides, a brief discussion on problem statements, research questions, basic research objectives, scope, and significance of the research is explained. **Chapter two** of the research will be covered a systematic literature review analysis with arguing, and discussions of issues. **In chapter three**, the research design approach and methods of data collection, data analysis, and interpretation techniques, determining sampling size, and ethical considerations will be considered. **Chapter four** of the research will present the proposed model development and alternative solutions for solving problems based on the analysis and results in chapter three. **In chapter five**, which is a conclusion and recommendation part of the research depending on the outcomes obtained.

CHAPTER TWO

2. Literature Review

2.1 Introduction

Production line efficiency improvements must be the key concern for any industrial organization. Line efficiency is nothing but it is all the capabilities of producing products or parts based on the theoretical references or goals in the given production sessions specifically on the production line (Tesfaye, 2019). Textile and apparel manufacturing industry, production line efficiency is measured through how production resources are well-converted to the desired outputs. These resources are known as labor, machines, material, and time which are considered as the basis for production startups. Industries' production systems or manufacturing lines can be categorized under manual, semi-automated, and automated production systems (Araya, 2018). The production system of textile or garment industries is highly characterized by the semi-automated system and integrated through various production lines with multiple operational activities. Several concepts and theories have been developed and forwarded on how to enhance production line operational efficiency. For instance, the line balancing concept has been contributing a lot through modeling and developing alternative resource combinations for efficient production line yields (Jilcha, et al., 2015 & Tesfaye, 2019). Significantly, line balancing will help to level-up all the resources smoothly along the lines for optimum production output. According to (Umarani & Valase, 2017), the ultimate goal of line balancing is to develop decisions on how to assign and distribute tasks over workstations or grouping resources so that idle time can be minimized and shorten production cycle time can be achieved. However, this is not always easy to bring efficiency, because re-balancing will disturb the whole production system and can affect the working environment. On the contrary, several studies have suggested that better and efficient resource utilization would be achieved by implementing different philosophical approaches to the manufacturing system. The work of (Kulkarni, 2016) reveals that a successful implementation of lean tools such as 5Ss and the 7QC tools will have a positive impact on the production line efficiency. Moreover, the integration made in statistical process control, overall equipment efficiency, and autonomous maintenance lead to the continuous improvement of process control and production equipment efficiency (Azizi, 2015 & Aman, et al., 2017). Besides to that, production line efficiency is the sum of every aspect of stages in the production process, for instance, how the materials are flow,

how the workers are acting, what is the condition of machine and equipment, and the cycle time for the speed of production.

2.2 Production line Vs Workers performance

A production line can be a group of workstations in which many human and physical resources are available. Production line efficiency is frequently shocked by the sourcing of defects and reworks, poor quality, bottlenecks and starvations, and workers' inefficiency due to skills and process complexity (Rajput et al., 2018). Again, the study of (Ahmed & Chowdhury, 2018) revealed that the presence of large working inventories, unnecessary handling, and movements, the distance from receiving to needle check are contributing to inefficiency in the sewing section department. As a result, several studies suggested that choosing and implementing effective tools and techniques will be significant to achieve better integration of man, machine, material, and methods. The continuous, inter-dependent and sequential production system of the textile industry will impose its impacts on the production line and workstations. A lean manufacturing technique has been forwarded for better production process control, especially minimizations of un-evenness of workloads and production of wastes (Samrejongroj et al., 2014; Leyva et al., 2018). The work of (Rajput et al., 2018) witnessed that integrated applications of time study, visual management, and work standards techniques are also essential tools for efficiency and overall productivity improvement. On the other hand, some scholars believe that production line efficiency can be increased through effective assembly line balancing techniques. In the works of (Kitaw et al., 2010; Araya, 2018; Tesfaye, 2019) a considerable result has been obtained on the minimizations of longer production lead time, shorter cycle time, minimum bottlenecks through developing alternative scenarios using a simulation modeling techniques.

Recently, there are also studies working on integrating the concepts of lean manufacturing and six sigma's (LSS) together for improving the production line efficiency and individual performance level. This can be witnessed in the work of (Olanrewaju, et al., 2019) and (Rodrigues N., et al., 2017) that LSS can effectively track-down production wastes (non-value adding) and level of defect generations by its nature of qualitatively and quantitatively analysis of on-going operational activities.

2.3 Lean six sigma (LSS) integration model frameworks

The integration of lean six sigma is not an old concept. The linkages of lean manufacturing and the six-sigma concept has begun in 1997 in the BAE system which was an aerospace industry (Olanrewaju, et al., 2019 in Smith, et al., 2001). But still, there are challenges in the availability of well-written literature in this area. According to (Ruben, et al., 2017), few articles were published on the manufacturing organizations using the applications and concepts of LSS, but later after 2002, the publications on the area of integrating LSS in both manufacturing and service sectors has been grown rapidly. After recent years, LSS has become a successful methodology in manufacturing organizations, especially in textile and apparel industries because of obtaining dramatic results in cost, quality, and time by focusing on improved production line efficiency and reduced process variability (Rodrigues Nogueira et al., 2017).

The integration of lean and six sigma is focused on gaining the solutions from the shortcoming of both (Salah, Rahim, & Carretero, 2010). Six sigmas' is targeted for variation reductions and lean works for minimization production wastes non-value adding activities. Scholars concurred that the joined benefits will be obtained through developing a successful lean six sigma (LSS) implementation model.

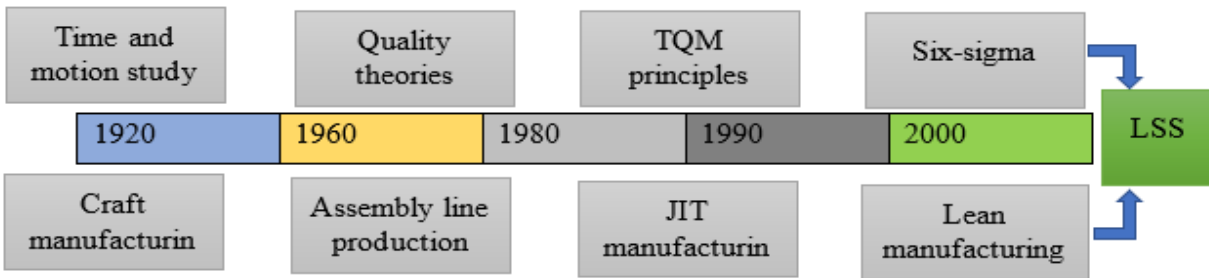


Figure 2: Evolution of lean six sigma (Source: Ruben et al., 2017)

Six sigma (6 δ), one of the most interesting and effective continuous improvement programs which have been firstly implemented in Motorola corporation in 1987 and later to many other U.S companies (Mousa, 2013). Now, the profitability of adopting six-sigma is witnessed by several manufacturing industries and becomes the fighting weapon especially in improving and controlling the production process within its limits or specifications. The concept of six-sigma is more elaborated in the three definitions; it is a measure of quality that means the number of defects produced is four or less in a million opportunities. Second, six-sigma is considered as a philosophy

and business improvement strategy, and the third one is that six-sigma works relentlessly in finding and eliminating the causes for production process variations and minimizing defects that will depress the customers (Antony, et al., 2016). On the other side, after the downfall of the U.S automobile leading position in 1955, a manufacturing system so-called ‘lean’ become replacing the older mass production system and successfully implemented in the Toyota automotive industry (Womack, et al., 1990). Lean is targeted at minimizing or eliminating non-value-adding activities and operations called wastes (Muda). Production wastes are identified and classified into seven groups sometimes they can be eight (Pepper & Spedding, 2010; Ahmed & Chowdhury, 2018).

Researchers have developed different frameworks for the successful implementation of these two broad concepts. The research of (Teli & Gaikwad, 2018) discussed and argued that the five phases called (DMAIC) would be the only means of adoption technique framework. On the other side (Rodrigues Nogueira et al., 2017) revealed that whatever the framework is, the core objectives is the same and can be further improved by adding more methods and field of studies. Scholars are still discussing the challenges and significance of integrating both lean and six-sigma in manufacturing organizations. For instance, (Pepper & Spedding, 2010) discussed that lean and six sigma paves a way forward for continuous improvement, six-sigma can aid the lean system through boosting up and leveraging tools, techniques, and methods to create a more leaned system. The fusions will replace the stand-alone significance of these two approaches so that power tools can be developed and implemented.

Table 1: A comparative advantages of Lean-Six sigma (source: G.Muthukumaran, 2013)

Issues/Problems/Objectives	Lean manufacturing	Six-sigma	Lean six sigma (LSS)
Focuses on customer value stream	Yes	No	Yes
Focuses on creating a visual workplace	Yes	No	Yes
Creates standard worksheets	Yes	No	Yes
Attacks work-in-process inventory	Yes	No	Yes
Focuses on good housekeeping	Yes	No	Yes
Process control planning and monitoring Focuses	No	Yes	Yes

Focuses on reducing variation and achieve uniform process outputs	No	Yes	Yes
Focuses heavily on the application of statistical tools and techniques	No	Yes	Yes
Employs a structured, rigorous and well- planned problem-solving methodology	No	Yes	Yes
Attacks waste due to waiting, over-processing, motion, overproduction, etc.	Yes	No	Yes

The significance of integration is elaborated in the study of (G.Muthukumaran, 2013) that the gaps or limitations observed can be filled over one another, which means that six sigma can provide statistical analysis of process efficiency at the same time lean delivers process flow optimization techniques. Again, (Salah, et al., 2010) argue and present several ways of approaches to lean six-sigma integrations and their applications.

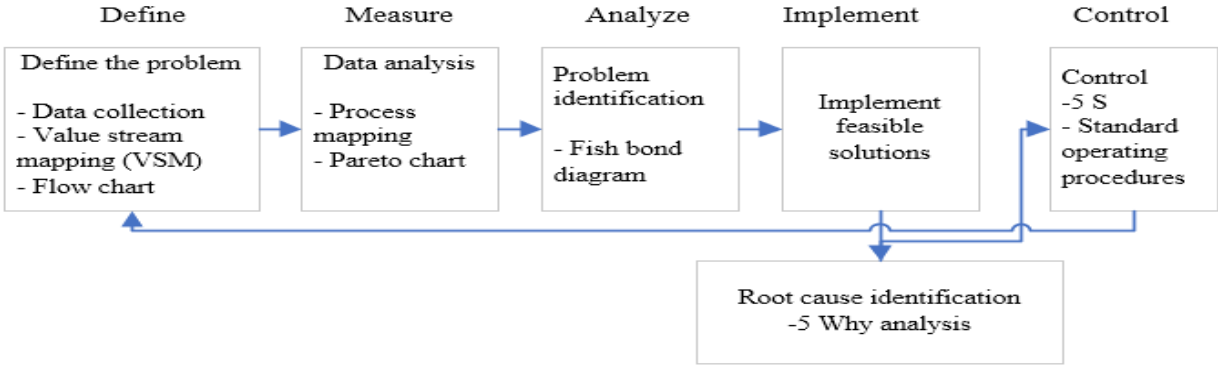


Figure 3: The DMAIC Methodology LSS Framework (Teli & Gaikwad, 2018)

2.4 Key performance indicators (KPIs) of the Textile and apparel industry

(Alhuraish, et al., 2017; and Montgomery 2016) stated that for the successful implementation or integration of lean and six-sigma concepts, first companies must come up with a clear awareness of identifying the critical success factors. Boosting the theme, (Costa, et al., 2018) elaborates on the challenges of lean six-sigma implementation from the internal and external aspects calling it as barriers, the nature, and culture of different companies are among the barriers next to humans so that companies must have set-up their CSF for measuring and tackling those issues.

The performance factors can be broadly classified as internal and external factors. The internal factors are highly associated and linked with inside the company's day-to-day operations and the external factors are those beyond the company's scope which can affect either directly or indirectly (Sorri, 2010). Most often, the textile manufacturing industries evaluate their performance through managerial and production level (shop-floor) key performance indicators. The KPIs are used as a diagnostic tool for signaling the status and performance evaluations and improvements (Spahija et al., 2012). The factory level performance indicators such as line efficiency, man-to-machine ratio, cut-to-ship ratio, employee turnover rate, and absenteeism, etc. are the most repeatedly and widely used. Besides, the efficiency of cutting, sewing, and finishing departments are among the top-rated performance improvement indicators.

Table 2: Key performance indicators (KPIs) of a Production line

KPIs	Description
Factory efficiency	It is the overall efficiency of active production lines
Process performance	<ul style="list-style-type: none"> • Cycle time • Throughput • Bottlenecks • Rejection rates
Operator performance	<ul style="list-style-type: none"> • Workers skills matrix • Number of workers per line • Units per worker • Turn-over and absenteeism
Employees turn-over and workers absenteeism	It is the rate of workers shifts and missing from their jobs by different cases
Man-to-machine ratio	The assigning of machines to the workers in the production line
Cut-to-ship ratio	This is a ratio of total cut quantity and total shipped quantity of an order
Average style change-over time	The time-space between changing of product styles
Percentage defective level (DHU%)	It is defects produced in % in a specific number of inspections

Reworks	It is an extra processing time that can increase overhead costs
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2.5 Gaps and summary of the literature

So far, it has been discussed different related literature worked on production line efficiency and workers' performance improvement in different manufacturing industries including textile and apparel industries. However, most of the studies covered under this paper are discussed to improve a specific part of a production line efficiency by applying a specific method or technique. For instance, line balancing and simulation techniques are frequently used by several researchers to improve production resource usages. On the other hand, the application of time study and wastes of lean is used as an alternative for production process enhancement. But, in a lean six sigma (LSS) methodology continuous improvement in all aspects of production processes can be achieved through the applications of its powerful tools and techniques.

Table 3: Summary of literature

Author	Topic	Methodology (used tools, techniques, and models)	Solved problems	Limitations/unsolved/gaps
Adikorley, et al., 2017	Lean Six Sigma applications in the textile industry: a case study	A qualitative approach of descriptive study on LSS	Change over time reduction and metal contamination	Is a specific case study/ not generalized
Ahmed & Chowdhury, 2018	Increase the Efficiency and Productivity of Sewing Section through Low Performing Operators Improvement	Eight Wastes of Lean Methodology	Increased the efficiency and productivity of a sewing section	considered only low performer to increase overall efficiency
Alhuraish, et al., 2017	A comparative exploration of lean manufacturing and six-sigma in terms of their critical success factors	comparative study on lean and six-sigma importance	Breakthrough how organizations identify their CSF on capabilities and resources utilizations	not clearly solved a specific company efficiency problem
G.Muthukumaran, 2013	Impact on the integration of Lean Manufacturing and Six Sigma in various applications - a review	Reviews various applications of LSS tools and concepts	Suggests an LSS for a better industry process and quality control	it is just a review study on the concepts of LSS
Jilcha, et al., 2015	Workers and Machine Performance Modeling in Manufacturing System	Arena modeling and simulation software has	Improvements and suggestions made on	do not under estimate the cons of arena

	Using Arena Simulation	been used for performance analysis	workers performance and bottlenecks area	application int the manufacturing
Mousa, 2013	Lean, six sigma and lean six sigma Overview	Various applications of lean and six-sigma methodologies implied	The integrated uses of LSS can create rapid transformational improvement at a lower cost.	it is a review on LSS applications, and not justify a case of a problem
Olanrewaju, et al., 2019	Lean Six Sigma Methodology and Its Application in the Manufacturing Industry- A Review	The study has assessed the integration of lean and six-sigma methodology concepts	A literature review and analysis are conducted over the ways and benefits of LSS integrations on mfg.	analysis LSS integration concepts does not identify manufacturing problems for and solution
Pepper & Spedding, 2010	The evolution of lean Six Sigma	Desk research and a literature review has conducted on each methodology	Provide a systematic approach and conceptual model for the successful integrations of LSS	it is providing just a framework to integrate LSS, not delivering a clear research outcome
Rodrigues Nogueira et al., 2017	Lean Six Sigma Implementation in Textile Industry	Applied lean tools and Six-sigma DMAIC methodology	Propose structured LSS integration frameworks to enhance bottom-line defect occurring and customer loyalty	the study has assessed to minimize only defects, workers performance and

				efficiency is not described
Ruben, et al., 2017	Lean Six Sigma with environmental focus: review and framework	A qualitative type of reviews of researches and literature studies	An LSS framework developed incorporating cost, wastes, environmental impacts	it is highlighting several LSS related works
Sibaliya & Vidosav, 2014	Integrating Lean with/within Six Sigma	Used lean principles and tools into an existing Six Sigma program with various approaches	Discussed the synergetic advantages of LSS integrations on process-improvement projects	the study discussed only LSS integration process and no solved case problem shown

CHAPTER THREE

3. Research Design and Methodology

3.1 Research Design approach

According to (Kothari, 2004), a research design is a road-map for the preparations and executions of an overall research project. Quantitative research is an approach for testing objective theories by examining the relationship among variables. A statistical procedure is made to interpret and analyze the numbered collected data. The final written report has a set structure consisting of introduction, literature, and theory, methods, results, and discussion. Therefore, a research framework has been drafted which can clearly show the steps from research problem definitions to the final parts of the conclusion and recommendation. In the figure below, the general flows of research operations and activities are organized and described successively.

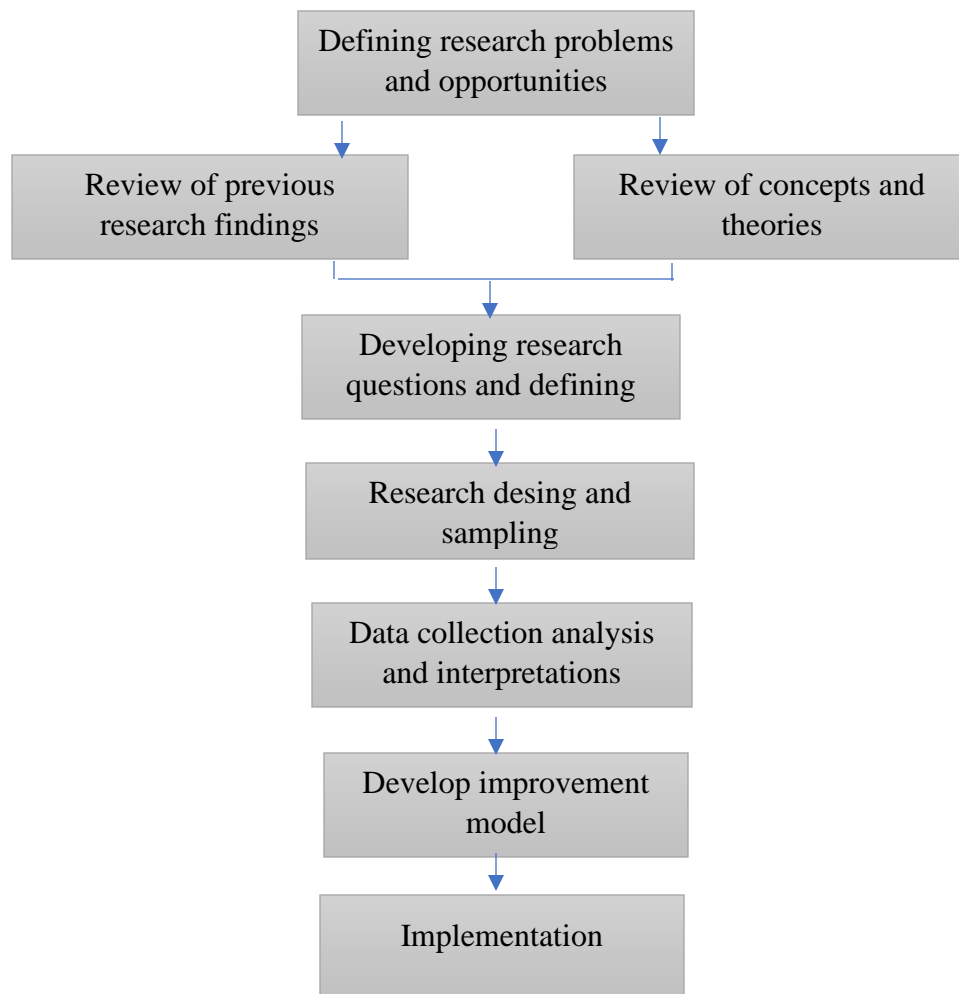


Figure 4: Research design Framework

3.2 Research Methodology

This research has followed several methods and techniques of fact gathering, data collections, and analysis tools. The appropriateness and selections of various methods and techniques are based on the type and characteristics of the nature of problems dealing with. Also, the selections of appropriate sampling techniques and the sample size are part of the methodology.

3.2.1 Means of data collection

Data collection is an important journey of research work for gathering and measuring information from the working environment (i.e. variables) which is/are going to be studied and addressed by the researcher. As a result, to answer the above-stated research questions, this study encompasses primary and secondary means of data collection techniques. Original and raw data can be easily fetched through a primary data collection source. However, commonly used materials and references are discovered by secondary data collection sources.

3.2.1.1 Primary data collection

In the primary data collection means, different sources will be used for facilitating the study process. These types of data are very essential to get information from the primary sources and could help to perform statistical surveys. In general, Questionnaires, interviews, and observations are the key sources for data gathering.

3.2.1.2 Secondary data collection

Despite its validity, secondary data collection sources are very important when the environment is rare for information. For this study, the following qualitative and quantitative data sources will be included.

- ❖ Company reports, brochures, and records- information regards to the case company background, business status, and facts will be highlighted.
- ❖ Books- published books whose topics are related to the objective of this research will be reviewed.
- ❖ Literature reviews (articles, books, etc.)- conducting a systematic literature review can be the breakthrough to discover scientific knowledge on specific issues. As a result, to tackle the problem which is going to solve under this study, several kinds of literature are

overviewed with their strengths and weaknesses or gaps. Top latest and arguing papers are selected for further discussions and analyses from a well-known journal publishing website including a recently published thesis paper in Addis Ababa University is also part of this research study.

- ❖ Data archives- are enriched places for shelved documents last year of achievements and progress of the company.
- ❖ Websites- historical backgrounds, the positions of the company, and other related information will be easily obtained.

3.2.2 Means of data analysis

Data analysis tools and techniques are very essential inputs for this study. Particularly, after the raw data is/are captured and collected, further analysis for a meaningful understanding is important.

- ❖ Analysis software- a set of data are collected, analyzed, and interpreted using a free software package of POM for windows, and MS excel.
- ❖ Analysis tools- a useful tool for diagnosis of a root cause for a certain problem like cause and effect, Pareto analysis are used.
- ❖ Diagrams and flow process- mini software like Smart draw and Visio are very help full to show charts, operations, and production flow processes.
- ❖ Recording tools- for real-time records of operations, data recording sheets, and stopwatches are involved during the study.

3.2.3 Sampling techniques

Activity sampling is a technique in which several consecutive observations are made through-out a single or groups of workers, machines, or processes. For this study, sampling is the most significant part and will be taken from production lines (machines) and workers' population. Again (Kothari, 2004), performing a census study in a large population will involve a high amount of resource usages. In general, sampling can be classified into probability sampling (random) and non-probability sampling. Typically, in the textile and apparel manufacturing industries, there is a large number of the worker involved in different operations. Therefore, a non-probability sampling technique is used from the given sewing lines workers. Determining the appropriate sample size

is very important for testing a hypothesis or establishing an association between the populations that are going to be studied (Kothari, 2004).

3.2.3.1 Sample size selection

The study is being conducted on the production line specifically to the sewing section operations. However, the sewing lines takes about 44% of the total workers involved in the company (approaching 200 workers). As a result, for the start-up of this study an appropriate sample size has been selected using a purposive (non-probability sampling technique). This type of sampling would help to select candidates to form the given population according to their specific operations, knowledge, and working experiences. A simplified formula has been used below to calculate the required level of sample sizes form the sewing section operations.

$$n = \frac{N}{(1 + N(e)^2)}$$

Where, n is th required sample size, N total populations, and e can be a marigin of errors.

Table 4: Required sample size calculation

Population (N)	Marigin of errors (e%)	Requied sample size (n)
50	5	45
100	10	50
150	15	34
200	20	22

Therefore, for a confidence level of 95%, and the population size of 200, the appropriate sample size selected is 22 workers.

CHAPTER FOUR

4. Data presentation, analysis, and interpretations

4.1 Introduction to the case company

In Ethiopia, industrial parks are the destinations for textile, garment, and apparel manufacturing industries. Among these, Bole-Lemi industrial park (already operational) is considered as the first Ethiopian IP which was established by the IPDC in 2014 around Addis Ababa, the capital of Ethiopia. Inside the park, there are different international companies, almost all are producing textile, apparel, and garment products. Specifically, this study is going to be held at the Evertop Sport-wear manufacturing PLC (IPDC shade number 11). The varieties of products, complexity, and the number of production lines, and labor forces are the first reasons for the selection of this shade. The Evertop sports-wear company is known for manufacturing different types of sporting clothes in different sizes and shapes for the local and export markets. Currently, the company has 9 active production lines and operates between 450-500 full-time employees.



Figure 5: Bole lemi industrial park (google maps, ©2019)

4.2 Production departments of the case company

The Evertop sportswear manufacturing company has two major products namely classic and fleece types of cloths. The study has selected a classic type of sports to wear product due to its operational complexity and more resource usages. This product is assembled through passing more than 22 sequential sewing operations performed by all lined-up workers. In general, the company has four major production departments as described below.

- ❖ Pattern making department- this operation is performed through cutting and preparation of different parts of the product such as front and back sections, sleeves, pocket, and trim, etc.
- ❖ Sewing section department- of course known as the assembly line which consists of various stitching and attachments of different parts of the product together. The workflow process chart for this section is presented below and it is the main consideration area of the study.
- ❖ Printing department- is also known as the embroidery section includes logo design and color printing
- ❖ Finishing department- is the last operation involved with packing and labeling of the product concerning its characteristics.

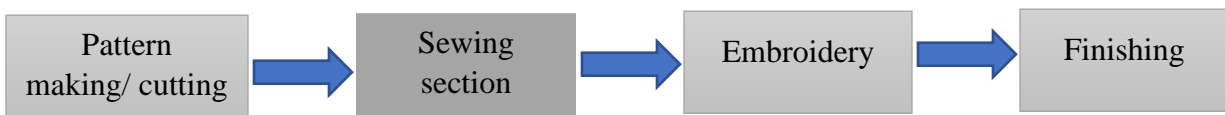


Figure 6: Company's production phases

4.2.1 Sewing (assembly) department operations process

The sewing section can be taken as a money-making area of the company. Because, several pieces of product parts are ready to assemble and produce a single product type, i.e. classic sportswear. However, sewing operation phases are consumed most of the time because of several product parts attachments (operations) and reworks. Sewing or assembly operation is not an easy task, firstly, when the fabric is entered to sewing process, it has to be rechecked by each department related to line arrangement, machine preparation, product component preparation such as pieces of fabric, threads, embroidery, etc., and all at once the result of sewing line layout and daily production target made by the industrial engineering department based on data records taken and count using time study techniques.

As it was discussed above, all parts attachments and assembly operations are described by the 22 distinctive names. For a clear understanding of the whole sewing or assembly operations, the following figure puts together in a sequential and abbreviated name of different part attachments.

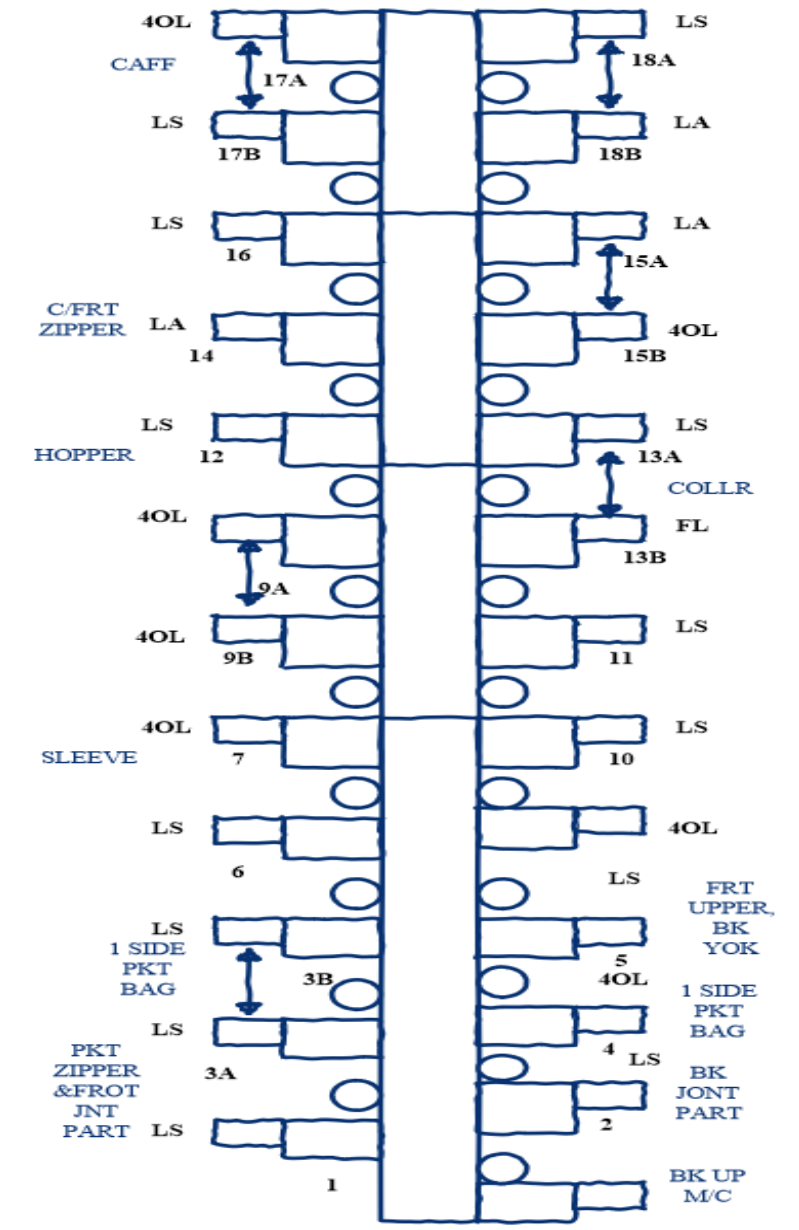


Figure 7: Sewing operations flow process chart (Sourced from case company)

The pictorial representation of assembly operations is also indicating arrangements of machine, specific operation, and assigned worker along the whole line in a task-oriented sequential flow. According to the survey study, more than 22 active workers have participated in a single line of assembly operations. Sometimes, there is also a chance of performing more than one operation jointly by a single operator based on the complexity level of the product and workers' individual performance.



Figure 8: Workers under sewing operations duty (Sourced from case company)

4.3 Analysis of questionnaires and responses

The author has been prepared and distributed all necessary questionnaires for different respondents working in different hierarchical positions. The production managers, supervisors, and sewing line operators participated in the responses of open and closed types of questionnaires. Besides that, a survey study is also conducted to analyze the actual conditions of the case company. A summary of prepared questionnaire formats and their response rates are placed in the appendix part of this paper.

Table 5: Questionnaires response rates

Instrument	Total prepared/distributed	Actual respond/replied	Succeed level (%)
Interviews (open)	12	12	100%
Questionnaires (survey)	18	13	72%
Instrumental records	10	6	60%
Total	40	31	77.5%

Performing instrumental records on the sewing line operations were so difficult and the success level was lower than other used instruments of data collection sources. However, regards to the overall response rate, the success level was about 76% of the total prepared and distributed

questionnaires, as a result, the study has got enough response rate to proceed and achieve its pre-established objectives.

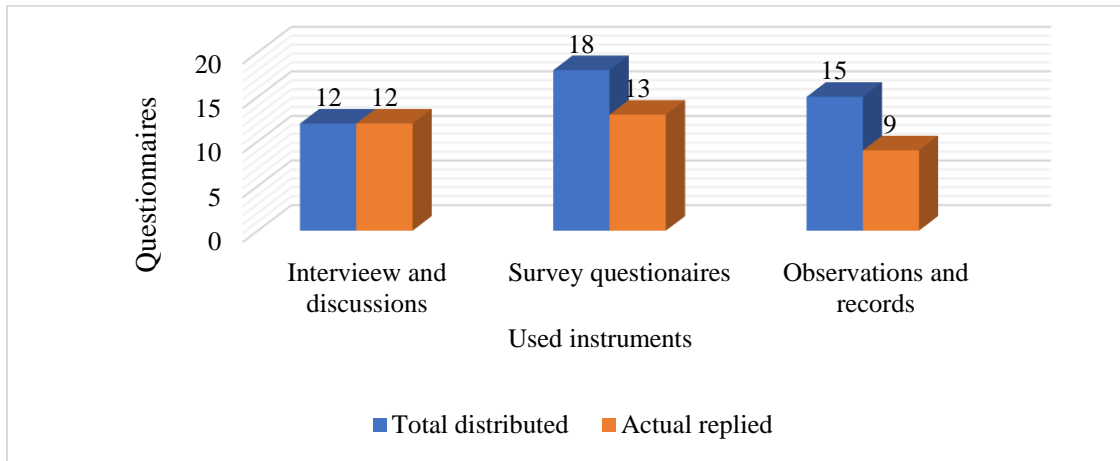


Figure 9: Response rates of questionnaires

4.4 Line efficiency and workers performance analysis

4.4.1 Line efficiency analysis

Measuring line efficiency based on workers' performances can help to re-adjust machines and resource distributions. It is also a signaling point to detect wastes or defects and identify the lowest performer (operator) in the operation line. The average pieces achieved per week per worker was recorded from line 6 sewing operations and summarized in the appendix of this paper. However, the whole cumulated data for these sewing lines are summarized per month (For June) production session. Based on the data provided below, the actual workers' performances and line efficiency were calculated.

Some necessary calculations,

- ❖ *Average pieces achieved per day = pieces archived per hr.*8.75 working hrs.*
- ❖ *Average pieces achieved per week = average pieces achieved per day* 6 working days*
- ❖ *Operators performance = Average Pcs achieved (produced) / Graph capacity*
- ❖ *Line efficiency = (Total pieces produced by the line *SMV*100) / (Number of operators attended*working hrs.*60).*

According to the data summarized in the following table, the weekly analysis of workers' performance level and overall line efficiency was calculated.

Table 6: Weekly line efficiency and workers performance

Week	Total pieces produced	Graph capacity	Line efficiency (%)	Performance (%)
1	893	1100-1300	53.7	68.6
2	1155	1100-1300	69.4	88.8
3	945	1100-1300	56.8	72.6
4	1103	1100-1300	66.3	84.8

Week 1, line efficiency = $\frac{893*41.68}{22*8.75*60*6} = 53.7\%$, Line performance is 68.6%

Week 2, line efficiency = $\frac{1155*41.68}{22*8.75*60*6} = 69.4\%$, Line performance is 88.8%

Week 3, line efficiency = $\frac{945*41.68}{22*8.75*60*6} = 56.8\%$, Line performance is 72.6%

Week 4, line efficiency = $\frac{1103*41.68}{22*8.75*60*6} = 66.3\%$, Line performance is 84.8%

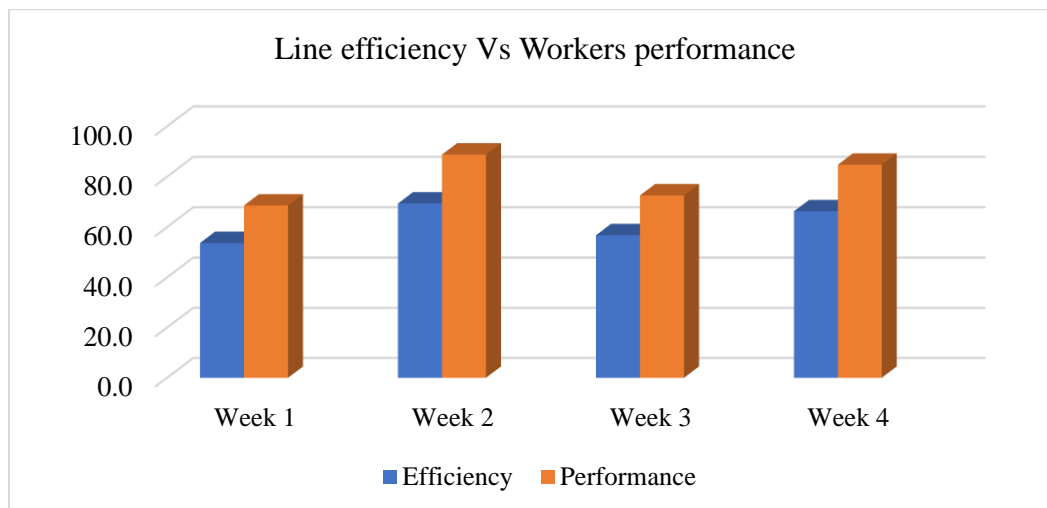


Figure 10: Line efficiency Vs Workers performance

As it is summarized in the above table, both line efficiency and workers' performances frequently deviate from the company's targets in weekly records. The study has concluded that several factors would make significant contributions to lower efficiency registered. Following that, details of individual operator performance were analyzed and most root causes for lower pieces production rates was investigated

Table 7: Sewing line efficiency and worker performance analysis (for June)

Operator involved	Sewing machine	Type of operation	Pieces achieved / line//week				Average Pieces achieved / month	Average graph capacity/month	SMV	Operators performance/month (%)
			L1	L2	L3	L4				
1897	CM	FR. SIDE JNT TACK	682.5	840	1102.5	1207.5	3832.5	9450	3.0	40.5
952	5OL	FR. SIDE PART JNT	682.5	735	945	945	3307.5	5250	1.5	63
1657	LST	FR. SIDE PART T/S	630	682.5	787.5	840	2940	5250	2.6	56
1330	LST	PKT ZIPPER JNT	630	630	892.5	945	3097.5	5670	3.5	54.6
1096	LST	PKT BAG 1&2 JNT	630	787.5	735	1050	3202.5	5250	1.2	61
1809	4OL+LST	PKT BAG1&2 CLOSE	630	787.5	682.5	1155	3255	5250	1.35	62
1340	5OL	BK. SIDE JNT	630	682.5	630	1102.5	3045	5670	1.5	53.7
1896	LST	BK. SIDE T/S	682.5	682.5	735	997.5	3097.5	5250	2	59
1038	5OL	SLV JNT	682.5	630	840	840	2992.5	5250	1.61	57
1656	LST	SLV T/S	682.5	735	892.5	945	3255	5460	1.5	59
1760	4OL	SIDE SEAM	735	735	945	1207.5	3622.5	5670	0.5	63.8
1745	HM	BTTM HOLE MAKING	52.5	787.5	787.5	997.5	2625	6300	1.5	41.6
1879	LST	BTTM TACK	1102.5	945	892.5	1260	4200	3360	2	125
1800	LST	BTTM TACK	525	787.5	1155	1365	3832.5	6300	1.4	60.8

1889	FL	BTTM HEMMING & CUFF	840	892.5	945	997.5	3675	5040	1.4	72.9
1294	LST	STRING, STOPER, BID INSERTION	892.5	840	840	840	3412.5	4410	1.52	77.3
1754	4OL+LST	CLLR JNT	892.5	997.5	997.5	945	3832.5	5250	3	73
1881	LST	CLLR 9 PART	892.5	945	892.5	1365	4095	6720	2	60.9
992	LST	C.F ZIPPER	525	682.5	787.5	892.5	2887.5	5670	2.5	50.9
1122	LST	TAPE BINDINGT	892.5	997.5	997.5	997.5	3885	6300	2.5	61.6
1782	LST	C.F T/S	892.5	1155	945	1102.5	4095	6090	2	67.2
1897	LST	CLLR T/S	0	945	892.5	1207.5	3045	6090	1.6	50
Total			14805	17902.5	19320	23205	75232.5	124950	41.68	

4.4.2 Workers performance analysis

The company is measured its workers' performance through the number of pieces achieved by the graph capacity of the production line. The level of performance for each operator is varied as the type and nature of operations changed. Therefore, identifying low-performing operators is the key to enhancing overall line efficiency. After calculating the performance level of all workers across the sewing operations line, the least performers were identified and investigated for further analysis. On the above table, 45.4% (10 workers) has achieved below 60% of the individual performance level expected by the company. Several reasons would take part in low performing and line inefficiency.

$$\diamond \text{ Workers performance} = \text{Average Pcs achieved (produced)} / \text{Graph capacity or target} * 100$$

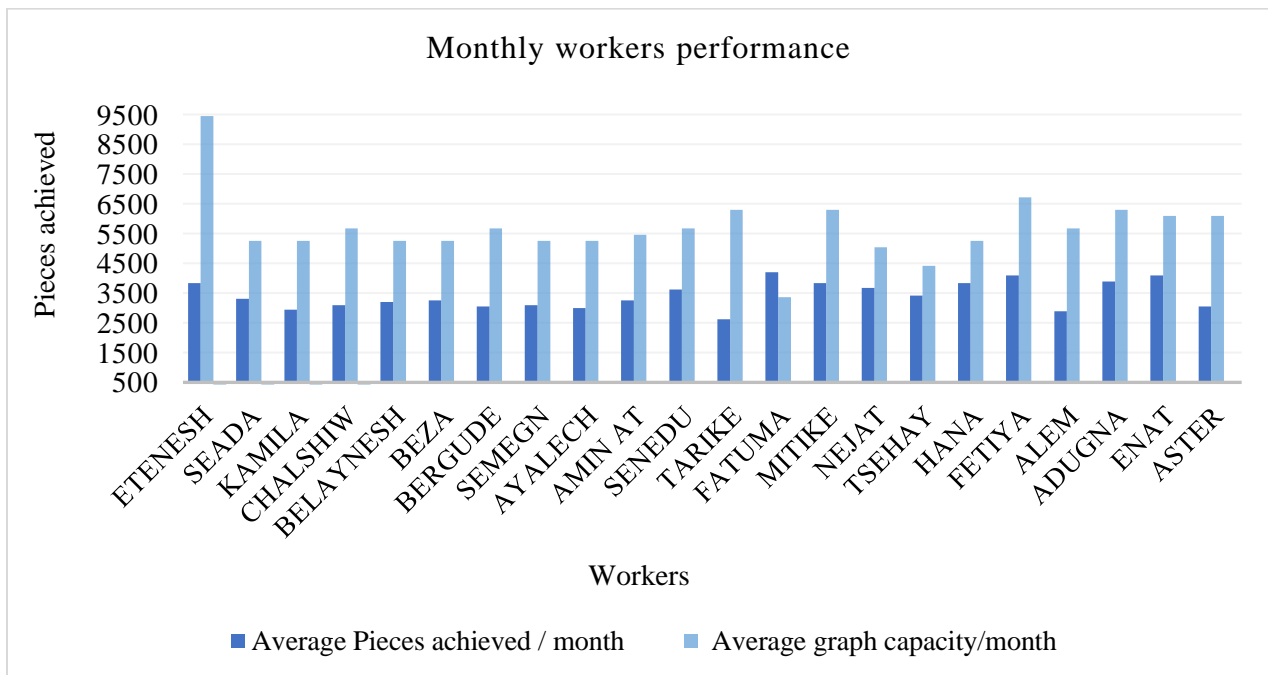


Figure 11: Workers' performance chart

Worker ID	Operations	Machine	SMV	Pieces achieved	Graph capacity	Performance	Remark
1897	FR. SIDE JNT TACK	CM		3832.5	9450	40.5	Lower
1657	FR. SIDE PART T/S	LST		2940	5250	56	Lower
1330	PKT ZIPPER JNT	LST		3097.5	5670	54.6	Lower

1340	BK. SIDE JNT	5OL		3045	5670	53.7	Lower
1896	BK. SIDE T/S	LST		3097.5	5250	59	Lower
1038	SLV JNT	5OL		2992.5	5250	57	Lower
1656	SLV T/S	LST		3255	5460	59	Lower
-	BTTM HOLE MAKING	HM		2625	6300	41.6	Lower
992	C.F ZIPPER	LST		2887.5	5670	50.9	Lower
1247	CLLR T/S	LST		3045	6090	50	Lower

According to the data analyzed below, several sewing operation challenges are studied that cause poor workers' performance and overall line inefficiency. However, in this study, sewing operation wastes are contributed to more than half of all listed challenges below. Most of these wastes are highly associated with the seven or eight lean manufacturing wastes.

Table 8: Major identified sewing operation challenges

No.	Major sewing operations challenges	What cause/happened	Percentage contributed
1	Production wastes	Involved in all the seven production wastes	55%
2	Skill/training gaps	Jumping essential operations, experience problem	20%
3	Product complexity	Changes in style and operations sophistications	10%
4	Control/ supervising	Lack of process control and follow-ups	7%
5	Workers absenteeism	Operators personal problems	5%
6	Workstation/ layout	Ergonomic and other work-related challenges	3%

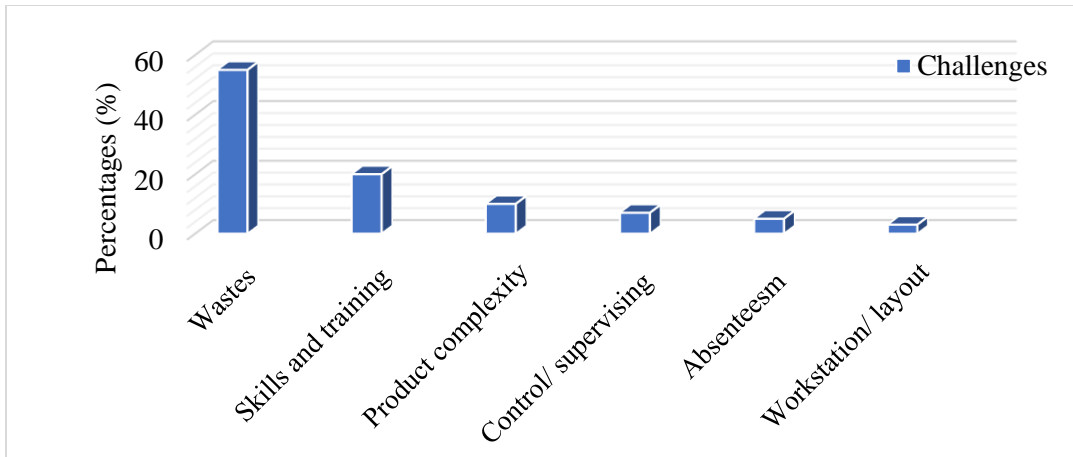


Figure 12: Sewing operation challenges

4.5 Lean wastes of sewing operations

Identifying and controlling the types of production wastes in the sewing operation is very important to increase the overall performance and efficiency of the line. Wastes are non-value adding activities that are created intentionally inside the company’s workers. All sewing operations are examined under the eight types of lean wastes. However, some are contributing an insignificant number of contributions to the production operation processes. Besides, in the analysis below, percentages of wastes for waiting and defects are covering more than half of the rest.

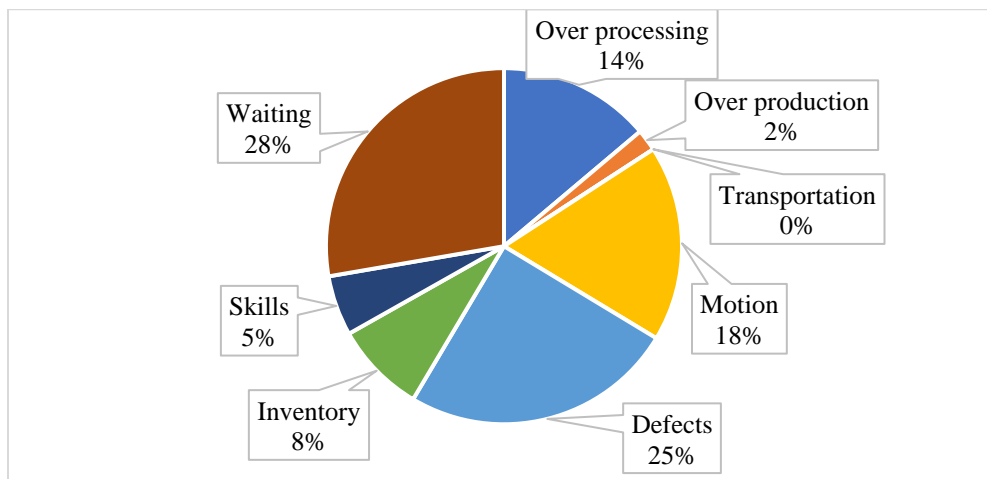


Figure 13: Percentages of Lean wastes of sewing operations

Table 9: Lean wastes of sewing operations

W.name	Operation	Type of wastes associated	Why/ How
1897	FR. SIDE JNT TACK	Waiting Motion	Front side parts are transported from the cutting section, and the operator makes some motions to collect them
952	FR. SIDE PART JNT	Waiting Over-processing	The operator will wait for part receiving, joining operation takes some time
1657	FR. SIDE PART T/S	Motion Defects	Operator move to get joined part, operational mistakes occurred
1330	PKT ZIPPER JNT	Defects Motion	Wavy zipping defect occurred; the operator move for correction/reworks
1096	PKT BAG 1&2 JNT	Inventory Waiting Skills	Several pockets are left on the table for operations, waiting for joined part for pocketing, operator skill gap (speed)
1809	PKT BAG1&2 CLOSE	Waiting	The operator is waiting to receive the part,
1340	BK. SIDE JNT	Motion waiting	The back parts are delivered from the cutting section (waiting occurred), the operator moves back to get it
1896	BK. SIDE T/S	Defects Over-production	Stitching problems have occurred Many back-side T/S operations are performed
1038	SLV JNT	Motion Skills	Operator move for collecting joining stitch, poor skill of production speed
1656	SLV T/S	Defects	Missed operations and unevenness
1760	SIDE SEAM	Waiting	The operator took some time for correction

1745	BTTM HOLE MAKING	Waiting Defects	Waiting to receive seaming job from an operator, missing the right place to make the hole
1879	BTTM TACK	Over-processing	Extra non-value-adding operations took place
1800	BTTM TACK	Waiting	The operator waited to get the above part
1889	BTTM HEMMING & CUFF	Motion Defects	Slow hand movement, excessive motion taken
1294	STRING, STOPPER, BID INSERTION	Over-processing Defects	The operator took time to make insertion of materials
1754	CLLR JNT	Motion Waiting	The collar is coming from other section (waiting), operator move to receive
1881	CLLR 9 PART	Waiting	Operator wait while collecting collars
992	C.F ZIPPER	Inventory Waiting	Many zippers are ready for operations, an operator is waiting to get zipping parts
1122	TAPE BINDING	Defects	Tapping operation defects have occurred
1782	C.F T/S	Over-processing Defects	Extra operations are performed by the operator
1897	CLLR T/S	Over-processing Inventory	Checking of collar joints and taping quality takes more processing time More products are placed on the workstation/table of the operator

4.5.1 The 5S's (A way of lean waste elimination method)

In lean manufacturing, the 5S's of lean wastes elimination method is the most powerful tool to remove wastes associated with and improve production operations performances in major five sequential steps. However, some types of wastes such as the production of defects are highly inherited from the workers' daily operations and it is very difficult to remove totally. In the sewing section, wastes are highly associated with workers, machines, and methods. Therefore, successful implementation and control of 5S's wastes are very important activities in the production process for improving sewing operations.



Figure 14: A 5Ss wastes eliminating method

- ❖ Sort- Seiri' means 'sorting'. That is, to sort and discard; sorting things into necessary and unnecessary item
- ❖ Straighten- This stage comprises in arranging right materials at right place for access and disposal quickly.

- ❖ Shine- Seiso’ means ‘shine / super clean’. That is, to keep work areas clean.
- ❖ Standardize- The stage Seiketsu may be employed to eliminate underutilisation of facilities. To establish standard so that areas stay cleaned up in order to ensure smooth work-flow in the work-place
- ❖ Sustain- ‘Shitsuke’ Means‘ToSustain’. That is, to establish procedures for safe working environment

Table 10: Types of wastes and corrective action

SN	Types of wastes	Action taken
1	Waiting	Redesign workflow and balancing operations
2	Defects	Keeping the quality of each operation and avoid the sources of defect production
3	Motion	Appropriate workstation and layout design
4	Over-processing	Minimize work complexity and resource distributions
5	Inventory	Developing an appropriate cycle time and SMV
6	Skills	Frequent training and education for workers
7	Overproduction	Identify and minimize bottlenecks & starvations lines

4.6 DMAIC analysis of defects and reworks

Perhaps, one of the most interesting application tools of six sigma, i.e. DMAIC (define, measure, analyses, and control) which can detect and manage various defects in the production process of a company. Different six sigma tools can be applied in several analysis phases. In this case, Pareto analysis is used to identify the major types of sewing operation defects, and the root causes of those defects were detected by cause and effect analysis (fish bond diagram).

Table 11: The DMAIC methodology descriptions

DMAIC	Descriptions	Procedural tools applied
D	Defining the problems and projects to be improved to get the desired sigma level	Data collection, VSM, flow-process chart, SIPOC
M	Measuring the actual performance of the operations or process capability	Defect per million opportunities analysis (DPMO)

A	Source of problem identification	Cause and effect analysis, process mapping Pareto chart
I	Forwarded and implement the alternative solution	
C	Control by the	5S and standard operating procedure (SOP)

Define phase- The sewing section can be taken as a critical section for the company. Dozens of operations are cumulated to make a single product. Meanwhile, there are also operational steps missing and yields production of a defective product which can incur the company for extra resource usages and line inefficiencies. Of course, there are several reasons to produce defects. Below, major defects are identified by the company and have been given big attention in their day-to-day quality control activities. The major sources for defects can be machine setting and arrangement problems, workers skill gaps and personal discomforts, lack of supervision and control over the process, the quality of raw material being used, and other related factors sum-up together for the overall production process problems. The overall sewing operation flow process chart is described below.

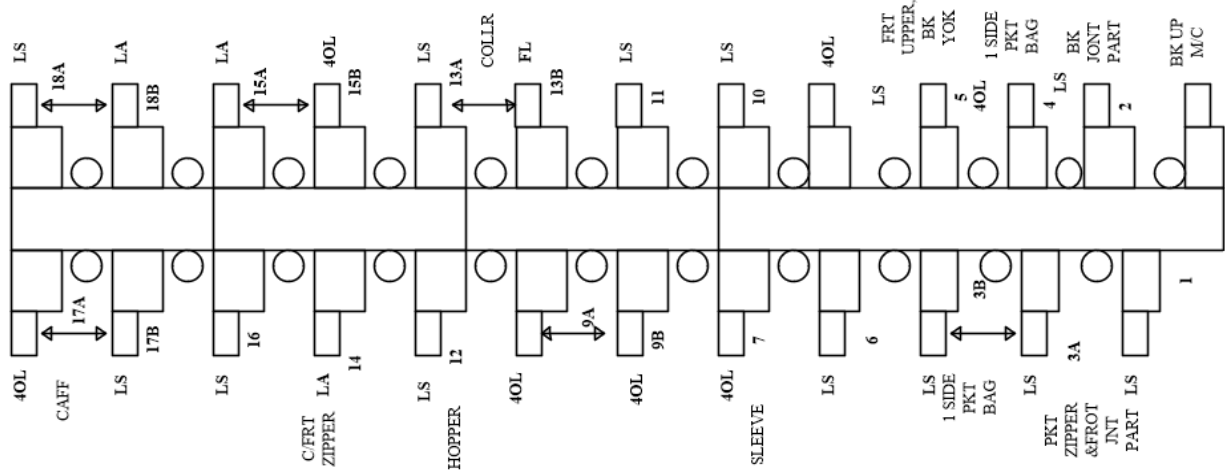


Figure 15: Sewing operation flow process chart

Measuring phase- It has been studied the number of achieved pieces in the selected sewing section lines for a month. Based on that, the defect per million opportunities (DPMO) and the sewing

operations sigma level can be analyzed. Besides, the frequency of each defect type that occurred on the product while sewing operations performed is inspected and summarized.

Table 12: DPMO analysis

Week	Average pieces produced (June session)	Confirmed (no defect)	Non-conformed (with defect)	Rework rate (%)
1	893	823	70	5.37514
2	1155	1099	56	4.848485
3	945	918	27	2.857143
4	1103	1067	36	3.263826
Total	4096	3907	189	4.077148

$$DPMO = (\text{Number of non-conforming items} / \text{Number of checked items}) * 10^6$$

$$DPMO = (189 / 4096) * 10^6$$

$$DPMO = 46,143$$

$$\text{Proportion of non-conformings} = (46,143 / 1,000,000) = 0.046$$

$$\text{Proportion of conformings} = 1 - 0.046 = 0.954, \text{ which is } 95.4\% \text{ are defect free.}$$

The number of standard deviations corresponding to 0.9346 proportion of conforming units is Z 1.70. Similarly, Cp can be computed from the obtained number of standard deviations;

$$Cp = Z/3 \quad Cp = 1.70/3 = 0.566$$

Therefore, as the computed above Cp value is less than 1, it can be concluded that the process is not capable

DPMO	Yield	Z value	Sigma level	Cp (z/3)	Process condition
46,143	95.4	1.70	3.2	0.566	Incapable

Analysis phase: Pareto Chart is used to graphically summarize and display the contribution of each type of defect. The lengths of the bars represent occurrence and are organized with the longest bars on the left and the shortest to the right. In this way, the chart visually shows which defects are

more significant. By using the Pareto Chart major types of defects were identified which are shown as follows.

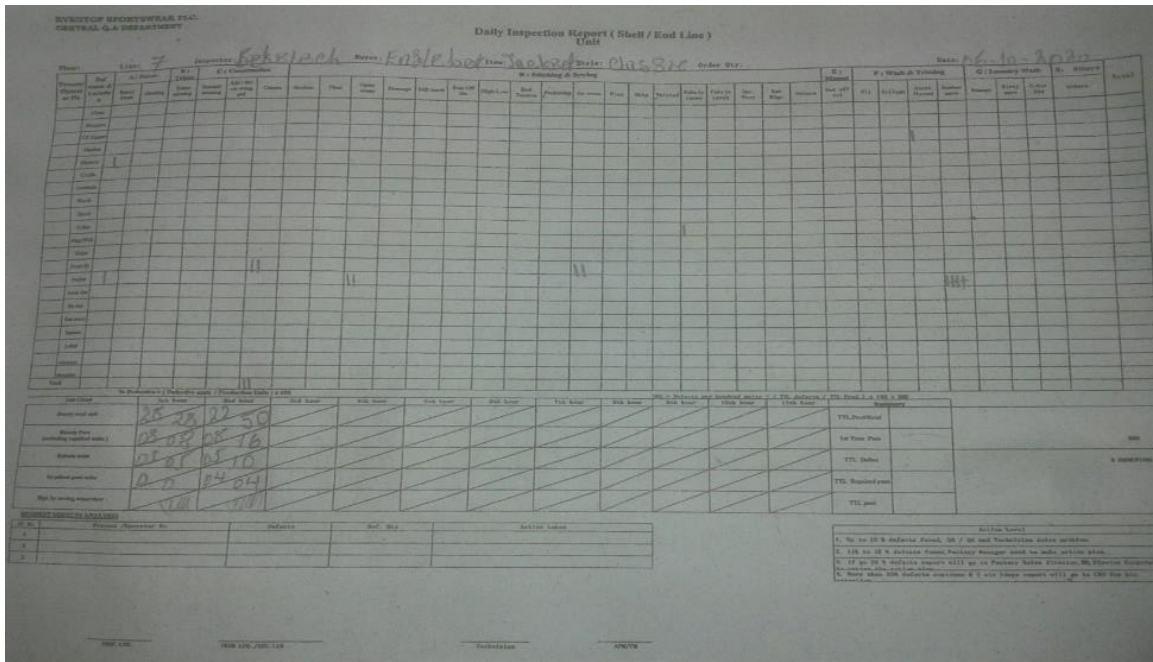


Figure 16: Company's defect inspection checklist

Table 13: Category of sewing line defects

Defect category	Defect name	Occurrences (frequency)	Percentage (total)	Cumulative percentage
Fabric type	Fabric fault	120	15.7	15.7
	Shading	110	14.4	30.1
Trimming	Trim missing	105	13.8	43.9
	bartock missing	98	12.8	56.7
Construction	Loose stitch	75	9.8	66.5
	Wavy stitch	61	8	74.5
	Label missing	53	6.9	81.4
	Size variation	58	7.6	89
Others	Needle mark	36	4.7	93.7
	Damage/ puck	25	3.2	96.9

	Broken/ rupture	19	2.5	99.4
Total		760		

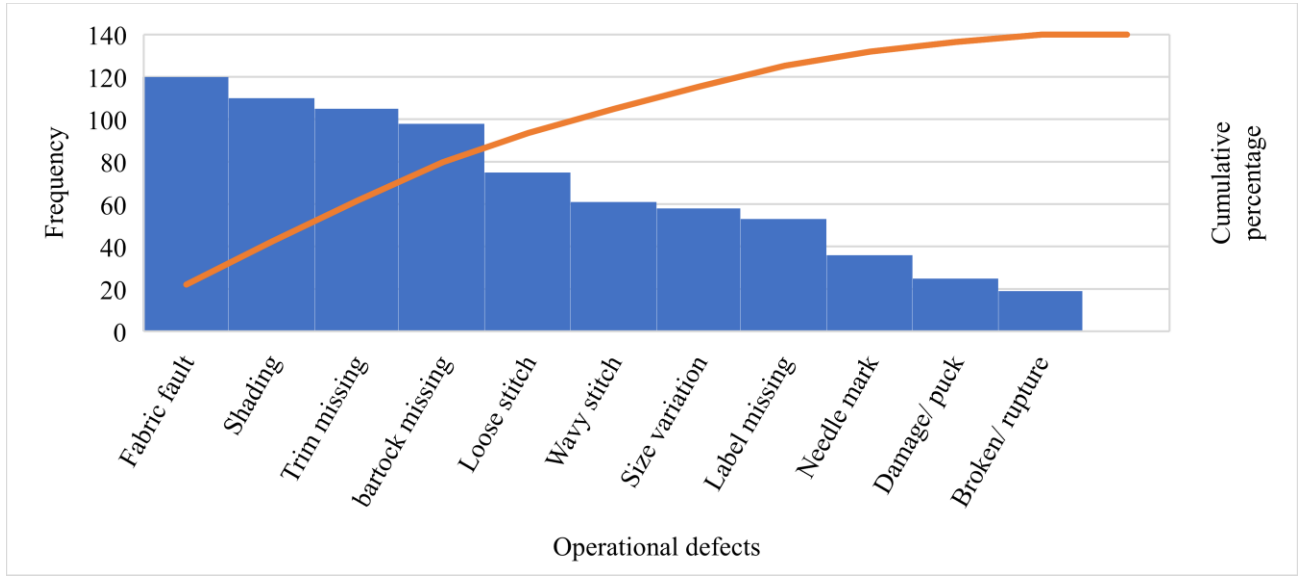


Figure 17: Pareto analysis of defects

4.6.1 Cause and effect analysis of defects and reworks

Fish bond diagram, one of the most applicable tools for signaling the cause and effect relationships in the production process. The main causes for defects and rework that occurred in the sewing operations are highlighted by the level of their influences over the production process.

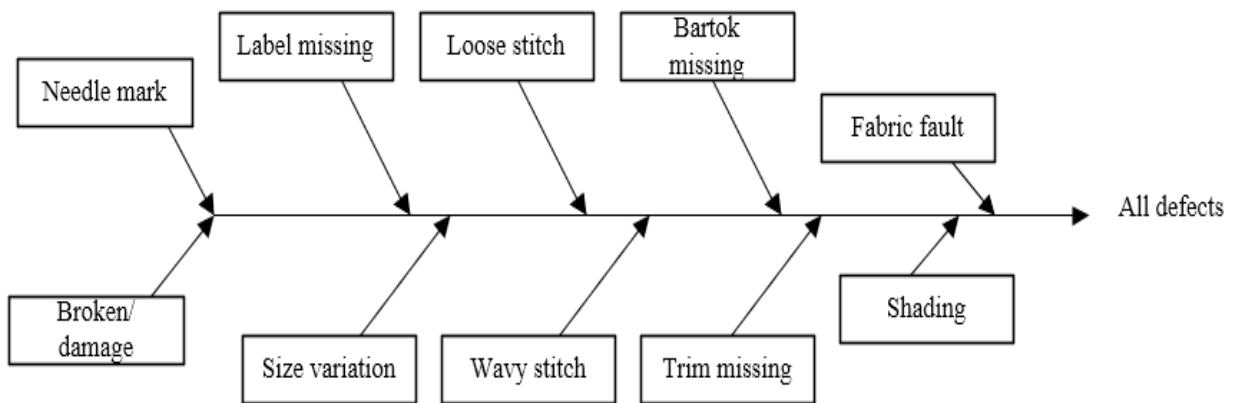


Figure 18: Analysis of all sewing line defects

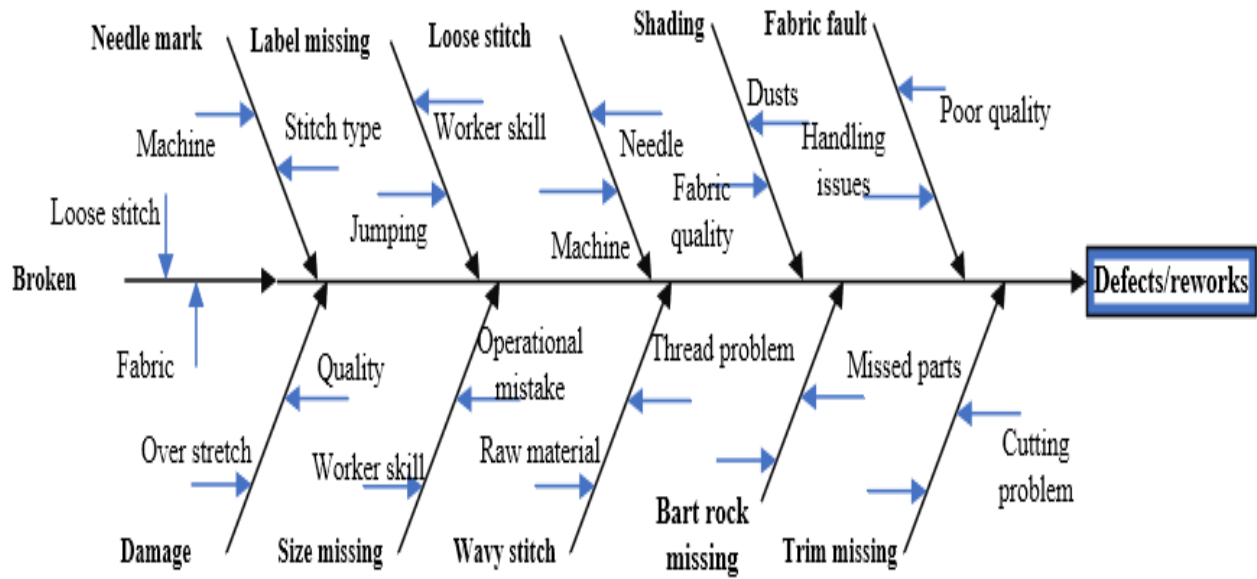


Figure 19: Cause and effect analysis of defects

4.6.2 Controlling causes of defects (the why-why analysis)

In the above fish bond diagram, several defects and reworks are identified and sourced from various root causes. Most of these causes are categorized under operational mistakes (complexity, skills, handling, etc.) in the controlling phase of DMAIC methodology and alternative solutions and suggestions are forwarded. As a result, by identifying each type of defect the following general controlling and corrective actions are placed.

Table 14: Types of defects and alternative corrections

Defects name	Root causes	Alternative solutions/corrections
Fabric fault	Poor quality Handling issues Machine	Appropriate handling, adjust machine setting, selecting the right quality raw material
Shading	Operational dust Wavy stitches	Choose the right fabric quality and create a clean and free workplace
Trim missing	Cutting mistakes Trim jumps Poor methods	Developed an appropriate cutting method

Bartok missing	Parts missing	Prepare and selecting the right part for seaming and joining
Loose stitch	Needle problem Machine setting	Adjust the right needle, and machine settings
Wavy stitch	Thread problem Raw material	Adjust threading machine, raw material selection
Label missing	Operational jumping Skill	Follow the right procedures, develop operational skill
Size variation	Operational mistakes	Checking and rework
Needle mark	Stitch type Machine problem	Correct the stitching type and operation
Damage/ puck	Over stretch Fabric quality	Smooth handling and moving
Broken/ rupture	Loose stitch Fabric type	Check and rework stitching

4.7 Proposing LSS integration model

A model framework has been developed in the integrations of basic concepts of lean and six sigmas', the model has also considered qualitatively (Lean) and quantitatively (six sigma) problem analysis approaches in the production line/ sewing operations. However, these two approaches will be twisted and integrated by the DMAIC methodology of problem analysis (define the problem, measure problem, analyses, and control). The model is applicable other than sewing operation such as cutting, and embroidery production phases of the company. The complexity and number of operations will determine the level of LSS integration scope and uses. As it has been stated in the problem statement (chapter one) of this paper, the study will discover major issues of this production line (for the sewing operation) to make an analysis and concludes for similar others.

The company business condntions- in this stage, top managements will evaluate their actual business conditions regards to overall performances and efficiency. This can be a road-map for overall improvements.

Assessing production lines efficiency- the step which can help to dig-out constraints for lines efficiency problems. Under this every operational challenges inherited to the process are identified as internal and external problems. Most internal production problems are comes from machine and workers, while external may include managements and environments.

The DMAIC step

It is a data-driven problem-solving technique designed to identify and address inefficiencies in a process, which improves its outcomes and makes these improvements more predictable. Lean and Six Sigma complement each other. Lean accelerates Six Sigma, delivering greater results than what would typically be achieved by Lean or Six Sigma individually. As a result, these DMAIC is used as a tightening tool for lean and six sigma approaches. Several tools and techniques are inscribed under each phases for improving the overall operations.

Table 15: DMAIC implementations

Phases	Applicable lean and six sigma tool
Define	Define the problems through VSM, SIPOC, etc.
Measure	Identification and measuring the baseline performance through lean metrics.
Analysis	Analytical descriptions using an appropriate charts and maps with an appropriate data.
Improve	Showing the changes with a quick oprimization and standardizing the process.
Controls	Design a control plan using mistake-proofing approach and corrective actions plan.

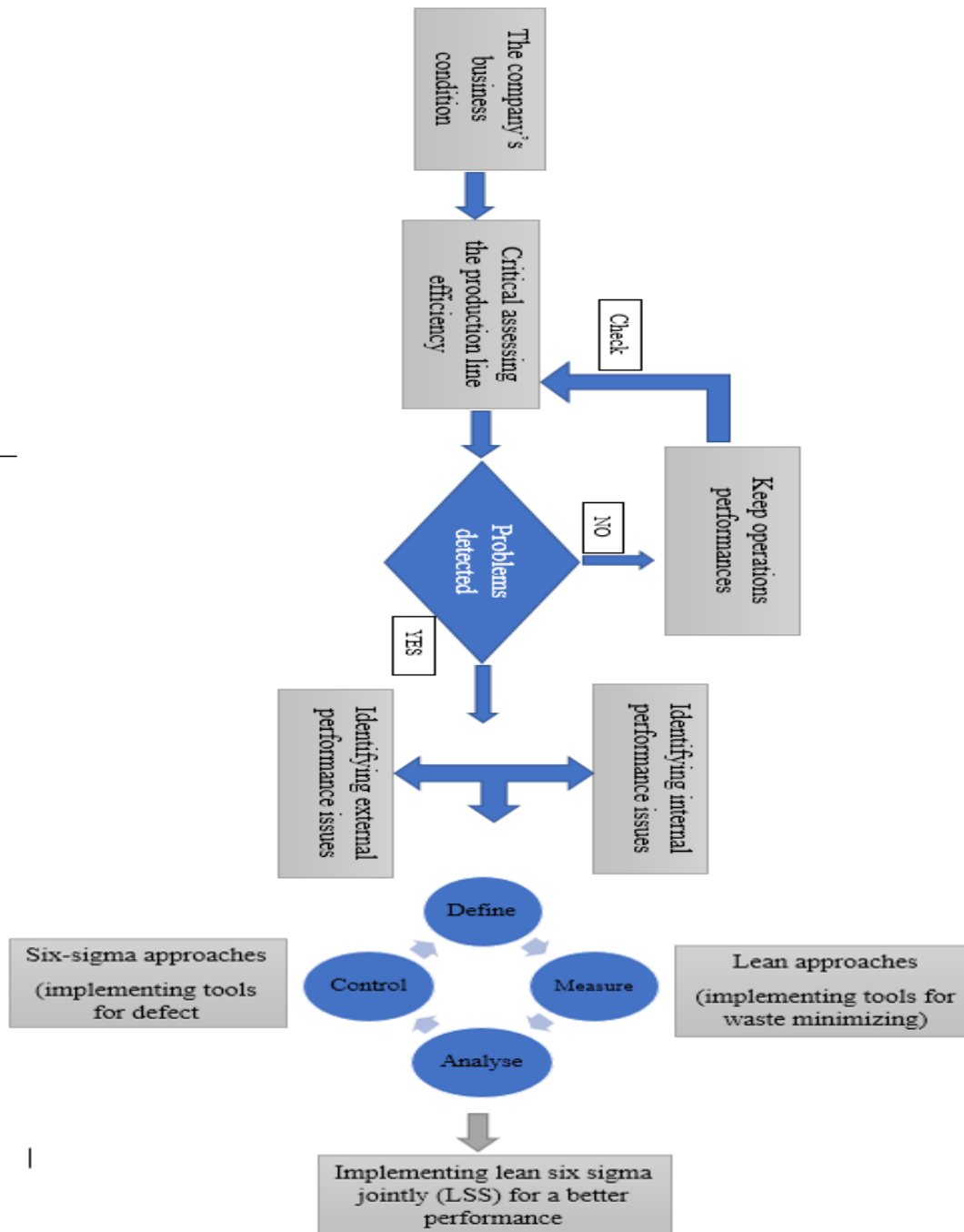


Figure 20: Proposed LSS model

CHAPTER FIVE

5. Conclusion and recommendation

5.1 Conclusion

Production lines are sources for money-generating to the company business, and these lines are consisting of more than half of a company's resources. In the textile, garment, and apparel industry, the overall productivity of the company is measured through how production lines are effectively and efficiently integrated along with the optimum workers' performances. As a result, different methods and techniques have been implemented in the companies' production process. In this study, the wide applications of integrated use of lean and six sigma methodology have been discussed and brought a successful change, particularly in the sewing section of the case company. Lean can quantitatively detect production issues as well as six sigma's statistical analysis of operational obstacles that can bring a dramatic effect on the overall production process of the company. Several problems such as production-related wastes, defects, and process variations can be easily detected and every necessary action is taken and significant improvement is made on the sewing section operations. The overall sewing section productivity, efficiency, and workers performance improvement can be achieved through and the company can survive from the production of defects and unnecessary cost of reworks.

5.2 Recommendation

The complexity in manufacturing and production processes compel industries to apply and integrate several manufacturing techniques and principles. Especially, the textile and apparel industry has been used lean manufacturing and six sigma methodology independently. However, integrate usages of these giant approaches will discover many hidden business process problems and production-related inefficiency. The company covered under this study is highly adopted lean manufacturing techniques and principles such as time study, wastes minimizations, etc. But the company is still challenging several production defects and reworks typically in the sewing sections. As a result, it is highly recommended to apply the six sigma methodology to control and minimize defects and reworks. The company is also strongly recommended to give training and educations before the implementation of lean six sigma methodologies.

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Appendixes

Addis Ababa University

Addis Ababa Institute of Technology

A survey data collection work-sheets

The objectives of this data collection sheets are used for further analysis of the current actual conditions of your company. As a result, all necessary data and information will be ethically considered and used for academically purposes of this research. The respondents are expected to feel free and confidential for the information provided under each questionnaire. The data collection sheets consisted of interviews (open type of questionnaires) and discussions, open tables to be filled by, and actual records of production line efficiency and workers performance level.

Appendix I

The following open type questionnaires (structured interviews) are presented to the GM, production managers, supervisors, to preliminary assesses the current condition of the case company.

1. *How many active production lines do you have currently?*

2. *Which line/s took more cycle time and labor?*

3. *What is your company current overall line efficiency in %, and what your theoretical target?*

4. *What are your current average production rates per day?*

5. *How many varieties of products (types of sportswear) do you have produced? And can you name and list in terms of their complexity? And do you have local markets?*

6. *What types of products (sport wear) took more labor, time, and resources?*

7. *How many active workers and shifts in working hours do you have?*

8. *What is the current overall productivity (%) of the company, what is your theoretical target?*

9. *What is your company SMV for different sport-wear products?*

10. *How do you measure workers' performance and production line efficiency of your company?*

11. *What type of defects are there in the production lines of the company?*

12. *Have you been implemented/ used lean and six sigma methodologies before?*

Appendix II

In the following consecutive tables, an overall situation of the company’s production lines (particularly, the sewing section) efficiency and level of workers performance is going to be assessed. As a result, sewing line supervisors and line operators are expected to fill the required data under the table.

A summary of data recording tables

Table 1: help to assess/identify different impacts of sewing line efficiency and worker performance

Table 2: prepared for recording and organizing various production wastes generated by workers

Table 3: all sewing operational defects are identified and recorded

Table 4, 5, 6, & 7: are tables for recording weekly base workers performance

Table 1: Identified impacts of line efficiency and workers performance

Challenges/ issues	Level of impacts on production line efficiency and workers performance			
	Very high	High	Medium	Low
Wastes				
Skills and training				
Product/operation complexity				
Poor line control/supervising				
Operators absenteeism				
Workstation/ layout				
Employees discomforts				
Peer conflict				
Machine stoppages				
Power interruptions				
Other (if any)				
Total scored				

Production or operational wastes are expected as the main challenges to poor operators' performances and line inefficiency. Here below, operators are assessed by all the types of wastes associated with the specific operations performed. Therefore, respondents can mark 'X' if a specific type of waste are registered by any operator along with.

Table 2: Operational wastes recording sheet

W.name	Operations	Types of wastes associated with							
		Trans	Motion	Inventory	Waiting	O.produn	O.procsing	Defects	Skills
ETENESH	FR. SIDE JNT TACK								
SEADA	FR. SIDE PART JNT								
KAMILA	FR. SIDE PART T/S								
CHALSHIW	PKT ZIPPER JNT								
BELAYNESH	PKT BAG 1&2 JNT								
BEZA	PKT BAG1&2 CLOSE								
BERGUDE	BK. SIDE JNT								
SEMEGN	BK. SIDE T/S								
AYALECH	SLV JNT								
AMIN AT	SLV T/S								
SENEDU	SIDE SEAM								
TARIKE	BTTM HOLE MAKING								
FATUMA	BTTM TACK								

MITIKE	BTTM TACK								
NEJAT	BTTM HEMMING & CUFF								
TSEHAY	STRING, STOPER, BID INSERTION								
HANA	CLLR JNT								
FETIYA	CLLR 9 PART								
ALEM	C.F ZIPPER								
ADUGNA	TAPE BINDINGT								
ENAT	C.F T/S								
ASTER	CLLR T/S								
Total wastes scored									

Again, the chance of defect and rework production can significantly decrease the line efficiency and capacity of pieces production by operators. The major types of defects are identified and categorized by the company's sewing line department. For the production sessions of June, defects are recorded for each sewing operations per operator in the following prepared table.

Table 3: Data recording sheet for defects (for June)

Operator involved	Operations	Machine	Defect records (in category)				Total	Remark
			Fabric	Trimming	Construction	Others		
ETENESH	FR. SIDE JNT TACK	CM	16	19	15	3	53	

SEADA	FR. SIDE PART JNT	5OL	9	13	20	3	45	
KAMILA	FR. SIDE PART T/S	LST	13	15	10	4	42	
CHALSHIW	PKT ZIPPER JNT	LST	11	10	19	5	45	
BELAYNESH	PKT BAG 1&2 JNT	LST	12	10	31	4	57	
BEZA	PKT BAG1&2 CLOSE	4OL+LST	8	0	7	8	23	
BERGUDE	BK. SIDE JNT	5OL	13	11	13	5	42	
SEMEGN	BK. SIDE T/S	LST	12	8	0	2	22	
AYALECH	SLV JNT	5OL	10	8	0	4	22	
AMIN AT	SLV T/S	LST	12	10	10	5	37	
SENEDEU	SIDE SEAM	4OL	13	9	12	2	36	
TARIKE	BTTM HOLE MAKING	HM	13	11	9	2	35	
FATUMA	BTTM TACK	LST	18	0	11	4	33	
MITIKE	BTTM TACK	LST	16	16	11	5	48	
NEJAT	BTTM HEMMING & CUFF	FL	6	9	22	3	40	
TSEHAY	STRING, STOPER, BID INSERTION	LST	12	8	13	4	37	
HANA	CLLR JNT	4OL+LST	5	10	9	4	28	
FETIYA	CLLR 9 PART	LST	9	10	10	3	32	
ALEM	C.F ZIPPER	LST	9	8	5	2	24	
ADUGNA	TAPE BINDINGT	LST	5	11	4	0	20	
ENAT	C.F T/S	LST	8	0	8	5	21	
ASTER	CLLR T/S	LST	0	7	8	3	18	
Total defects			230	203	230	80	760	

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A sample of data on the sewing operations has been recorded for about a month. For this, classic sport-wear product of the company is selected for this study. There are 22 consecutive sewing operations performed by nearly 22 lined-up sewing section workers. The company is analyzing its workers performance in a weekly bases, as a result average pieces achieved per hour per worker are summarized in the following tables.

Table 4: Sewing section line workers profile data (June, Week 1)

SN.	W.name	Machine	Operation	SMV	Avg. achieved Pcs/hr.	Capacity/hr.	Avg Pcs/day	Capacity/day	Variance (%)	Workers performance (%)
1	ETENESH	CM	FR. SIDE JNT TACK		13	45	113.75	393.75	-71.1	28.9
2	SEADA	5OL	FR. SIDE PART JNT		13	25	113.75	218.75	-48	52
3	KAMILA	LST	FR. SIDE PART T/S		12	25	105	218.75	-52	48
4	CHALSHIW	LST	PKT ZIPPER JNT		12	27	105	236.25	-55.5	44.5
5	BELAYNESH	LST	PKT BAG 1&2 JNT		12	25	105	218.75	-52	48
6	BEZA	4OL+LST	PKT BAG1&2 CLOSE		12	25	105	218.75	-52	48
7	BERGUDE	5OL	BK. SIDE JNT		12	27	105	236.25	-55.5	44.5
8	SEMEGN	LST	BK. SIDE T/S		13	25	113.75	218.75	-48	52
9	AYALECH	5OL	SLV JNT		13	25	113.75	218.75	-48	52
10	AMIN AT	LST	SLV T/S		13	26	113.75	227.5	-50	50
11	SENEDU	4OL	SIDE SEAM		14	27	122.5	236.25	-48.1	51.9
12	TARIKE	HM	BTTM HOLE MAKING		15	30	8.75	262.5	-96.6	70
13	FATUMA	LST	BTTM TACK		21	16	183.75	140	31.2	62
14	MITIKE	LST	BTTM TACK		10	30	87.5	262.5	-66.6	52

15	NEJAT	FL	BTTM HEMMING & CUFF		16	24	140	210	-33.3	70
16	TSEHAY	LST	STRING, STOPER, BID INSERTION		17	21	148.75	183.75	-19.0	79
17	HANA	4OL+LST	CLLR JNT		17	25	148.75	218.75	-32	69
18	FETIYA	LST	CLLR 9 PART		17	32	148.75	280	-46.8	33
19	ALEM	LST	C.F ZIPPER		10	27	87.5	236.25	-62.9	62
20	ADUGNA	LST	TAPE BINDINGT		17	30	148.75	262.5	-43.3	56
21	ENAT	LST	C.F T/S		17	29	148.75	253.75	-41.3	48
22	ASTER	LST	CLLR T/S		0	29	0	253.75	-100	58

Table 5: Sewing section line 4 workers profile data (June, Week 2)

SN.	W.name	Machine	Operation	SMV	Avg. achieved Pcs/hr.	Capacity/hr.	Avg Pcs/day	Capacity/day	Variance (%)	Workers performance (%)
1	ETENESH	CM	FR. SIDE JNT TACK		16	45	140	393.75	-64.4	35.6
2	SEADA	5OL	FR. SIDE PART JNT		14	25	122.5	218.75	-44	56
3	KAMILA	LST	FR. SIDE PART T/S		13	25	113.75	218.75	-48	52
4	CHALSHIW	LST	PKT ZIPPER JNT		12	27	105	236.25	-55.5	44.5
5	BELAYNESH	LST	PKT BAG 1&2 JNT		15	25	131.25	218.75	-40	60

6	BEZA	4OL+LST	PKT BAG1&2 CLOSE		15	25	131.25	218.75	-40	60
7	BERGUDE	5OL	BK. SIDE JNT		13	27	113.75	236.25	-51.8	48.2
8	SEMEGN	LST	BK. SIDE T/S		13	25	113.75	218.75	-48	52
9	AYALECH	5OL	SLV JNT		12	25	105	218.75	-52	48
10	AMIN AT	LST	SLV T/S		14	26	122.5	227.5	-46.1	53.9
11	SENEDE	4OL	SIDE SEAM		14	27	122.5	236.25	-48.1	51.9
12	TARIKE	HM	BTTM HOLE MAKING		15	30	131.25	262.5	-50	50
13	FATUMA	LST	BTTM TACK		18	16	157.5	140	12.5	87.5
14	MITIKE	LST	BTTM TACK		15	30	131.25	262.5	-50	50
15	NEJAT	FL	BTTM HEMMING & CUFF		17	24	148.75	210	-29.1	70.9
16	TSEHAY	LST	STRING, STOPER, BID INSERTION		16	21	140	183.75	-23.8	76.2
17	HANA	4OL+LST	CLLR JNT		19	25	166.25	218.75	-24	76
18	FETIYA	LST	CLLR 9 PART		18	32	157.5	280	-43.7	56.3
19	ALEM	LST	C.F ZIPPER		13	27	113.75	236	-51.8	48.2
20	ADUGNA	LST	TAPE BINDINGT		19	30	166.25	263	-36.6	63.4
21	ENAT	LST	C.F T/S		22	29	192.5	254	-24.1	75.9
22	ASTER	LST	CLLR T/S		18	29	157.5	254	-37.9	52.1

Table 6: Sewing section line 4 workers profile data (June, Week 3)

SN.	W.name	Machine	Operation	SMV	Avg. achieved Pcs/hr.	Capacity/hr.	Avg Pcs/day	Capacity/day	Variance (%)	Workers performance (%)
1	ETENESH	CM	FR. SIDE JNT TACK		21	45	183.75	394	-53.3	46.7
2	SEADA	5OL	FR. SIDE PART JNT		18	25	157.5	219	-28.0	72
3	KAMILA	LST	FR. SIDE PART T/S		15	25	131.25	219	-40.0	60
4	CHALSHIW	LST	PKT ZIPPER JNT		17	27	148.75	236	-36.9	63.1
5	BELAYNESH	LST	PKT BAG 1&2 JNT		14	25	122.5	219	-44.0	66
6	BEZA	4OL+LST	PKT BAG1&2 CLOSE		13	25	113.75	219	-48.0	52
7	BERGUDE	5OL	BK. SIDE JNT		12	27	105	236	-55.5	44.5
8	SEMEGN	LST	BK. SIDE T/S		14	25	122.5	219	-44.0	56
9	AYALECH	5OL	SLV JNT		16	25	140	219	-36.0	54
10	AMIN AT	LST	SLV T/S		17	26	148.75	228	-34.7	65.3
11	SENEDEU	4OL	SIDE SEAM		18	27	157.5	236	-33.2	66.8
12	TARIKE	HM	BTTM HOLE MAKING		15	30	131.25	263	-50.0	50
13	FATUMA	LST	BTTM TACK		17	16	148.75	140	6.25	93.75
14	MITIKE	LST	BTTM TACK		22	30	192.5	263	-26.8	63.2
15	NEJAT	FL	BTTM HEMMING & CUFF		18	24	157.5	210	-25	75
16	TSEHAY	LST	STRING, STOPER,		16	21	140	184	-23.9	76.1

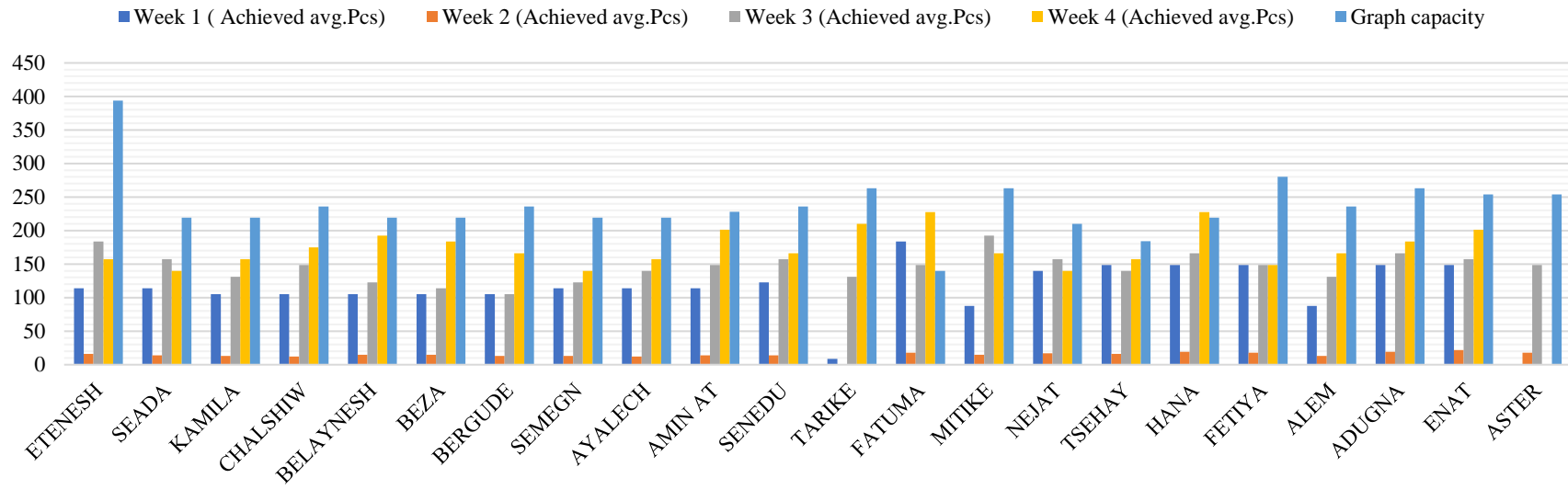
			BID INSERTION							
17	HANA	4OL+LST	CLLR JNT		19	25	166.25	219	-24.0	76
18	FETIYA	LST	CLLR 9 PART		17	32	148.75	280	-46.8	53.2
19	ALEM	LST	C.F ZIPPER		15	27	131.25	236	-44.3	55.7
20	ADUGNA	LST	TAPE BINDINGT		19	30	166.25	263	-36.7	63.3
21	ENAT	LST	C.F T/S		18	29	157.5	254	-37.9	62.1
22	ASTER	LST	CLLR T/S		17	29	148.75	254	-41.4	58.6

Table 7: Sewing section line 4 workers profile data (June, Week 4)

SN.	W.name	Machine	Operation	SMV	Avg. achieved Pcs/hr.	Capacity/hr.	Avg Pcs/day	Capacity/day	Variance (%)	Workers performance (%)
1	ETENESH	CM	FR. SIDE JNT TACK		23	45	201.25	394	-48.9	51.1
2	SEADA	5OL	FR. SIDE PART JNT		18	25	157.5	219	-28.0	72
3	KAMILA	LST	FR. SIDE PART T/S		16	25	140	219	-36.0	64
4	CHALSHIW	LST	PKT ZIPPER JNT		18	27	157.5	236	-33.2	66.8
5	BELAYNESH	LST	PKT BAG 1&2 JNT		20	25	175	219	-20.0	80
6	BEZA	4OL+LST	PKT BAG1&2 CLOSE		22	25	192.5	219	-12.1	87.9
7	BERGUDE	5OL	BK. SIDE JNT		21	27	183.75	236	-22.1	77.9
8	SEMEGN	LST	BK. SIDE T/S		19	25	166.25	219	-24.0	76
9	AYALECH	5OL	SLV JNT		16	25	140	219	-36.0	64
10	AMIN AT	LST	SLV T/S		18	26	157.5	228	-30.9	69.1

11	SENE DU	4OL	SIDE SEAM		23	27	201.25	236	-14.7	85.3
12	TARIKE	HM	BTTM HOLE MAKING		19	30	166.25	263	-36.7	63.3
13	FATUMA	LST	BTTM TACK		24	16	210	140	50	150
14	MITIKE	LST	BTTM TACK		26	30	227.5	263	-13.4	86.6
15	NEJAT	FL	BTTM HEMMING & CUFF		19	24	166.25	210	-20.8	79.2
16	TSEHAY	LST	STRING, STOPER, BID INSERTION		16	21	140	184	-23.9	76.1
17	HANA	4OL+LST	CLLR JNT		18	25	157.5	219	-28.0	72
18	FETIYA	LST	CLLR 9 PART		26	32	227.5	280	-18.7	81.3
19	ALEM	LST	C.F ZIPPER		17	27	148.75	236	-36.9	63.1
20	ADUGNA	LST	TAPE BINDINGT		19	30	166.25	263	-36.7	63.3
21	ENAT	LST	C.F T/S		21	29	183.75	254	-27.6	72.4
22	ASTER	LST	CLLR T/S		23	29	201.25	254	-20.7	79.3

Workers average performance Vs Graph capacity (June)



Answer for questionnaires

Appendix I

Answers for open type structured interviews by the production manager and line supervisors:

1. How many active production lines do you have currently?

Ans: currently we have 9 active production lines. However, in the future the company has a goal to increase its number to 12 lines.

2. Which line/s took more cycle time and labor?

Ans: according to the type of operations and specific product type, different lines will take different resource usages. For instance, those production lines producing classic type of sport-wear took more labors and longer cycle time of operations.

3. What is your company current overall line efficiency, and what is your theoretical target?

Ans: currently, the overall line efficiency is about 62% and with full resource integration and workers performance improvements, the company has a plan to reach its overall efficiency up to 75% in the coming production year.

4. What are your current average production rates per day?

Ans: since we have two major product types namely classic and fleece sport-wear. By this time, we have a capacity to produce up to 100 classic and 1300 fleece types of sport-wear. Practically, our production crews are producing under this target for different reasons.

5. How many varieties of products (types of sportswear) do you have produced? And can you name and list in terms of their complexity?

Ans: As I have discussed so far, we have two types of sport-wear products (classic and fleece). Interm of operational complexity the former one takes more resources and several sequential operations.

6. Which types of products (sport wear) took more labor, time, and resources?

Ans: the classic one is more labor intensive and time consuming. The product has more than 22 assembly (sewing) operations for a single piece output.

7. How many active workers and shifts in working hours do you have?

Ans: there are between 450 to 500 workers working in a single shift (8.75 hrs. per day for 6 days in a week). However, 43% of the total workers are involved under sewing line operations.

8. What is the current overall productivity (%) of the company, what is your theoretical target?

Ans: we are measuring our company's productivity through various techniques; however, labor productivity and level of production resource usages are the two major approaches. As a result, the company's productivity is frequently changed based on the daily production capacity and over all resource integrations. Currently the overall productivity is about 72% in total, but we are still working restlessly to increase by 10% in the upcoming production sessions.

9. Wastes are the most frequently challenging non-value adding activities performed by production line workers, if exists please mention all type of wastes associated to the sewing line operations.

Ans: obviously we are fighting non-value adding activities which are the source for production of wastes in different operations. Wastes are directly affecting workers performance level in different ways. We have identified all types of wastes (the seven wastes) for each operation and some mechanisms were developed to tackle-down their sources.

10. How do you measure workers' performance and production line efficiency of your company?

Ans: each production line efficiency is directly related to the number of operations, number of operators, and level of resources consumed or used. However, performing capacity of individual workers is crucial to this company. As a result, workers are assessed through all value adding activities along with the line specified to the standard minute values (SMV) and performance indices. Similarly, we are using some mathematical relationships (calculations) to analyses our production line efficiency.

$$\text{Line efficiency (\%)} = \frac{\text{Total pieces produced} \times \text{SMV} \times 100}{\text{Total number of operators} \times \text{Working hours}}$$

$$\text{Total pieces produced} = \frac{\text{Working hours} \times 60 \text{ minutes} \times \text{number of operators}}{\text{SMV}}$$

11. Do you have production defects and reworks? If there exists what type of defects are there in the production lines of the company?

Ans: yes! as a company we have a range of defect production rates between 5-6%. However, sewing production lines takes most portion of it because of several assembly and attachment operations involved. Majorly, these defects can be immediately corrected (reworked) or become scraps. There are identified categories of defects these are sourced from fabric defects, trimming defects, and constructional defects.

12. Have you been implemented/ used lean and six sigma methodologies before?

Ans: we are adopting some lean techniques such as time study, VSM, and 5Ss to analyse and interpret the production line conditions. However, in terms of six sigma or lean six sigma, we do not have a practical application and not yet implemented here. In the future, the company has a plan for training and experience sharing of some new upgrading production principles and methodologies like six sigmas for a better improvement.