Integration of Lean, Green and Six Sigma principles to Reduce Materials Waste: A Case of Adama Agricultural Machinery Industry

A thesis submitted by

Murtesa Dabesa Gurmesa

(GSR/0111/09)

For the Partial fulfillment of the

Requirement for the award of degree

of

Master of Science

In Manufacturing Engineering

Advisor:

Dr. Guteta Kabeta

Mechanical Design & Manufacturing Engineering Program

School of Mechanical, Chemical and Materials Engineering

Adama Science and Technology University

Adama, Ethiopia

June 2018

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIAL ENGINEERING

DEPARTMENT OF MECHANICAL DESIGN AND MANUFACTURING ENGINEERING

Integration of Lean, Green and Six Sigma principles to Reduce Materials Waste: A Case of Adama Agricultural Machinery Industry

By

MURTESA DABESA GURMESA

Approved by Board Examines

		Signature	Date
I.	Chair, Department Graduate committee	Signature	Date
	______________________	__________	__________
II.	Internal Examiner	Signature	Date
	______________________	__________	__________
III.	External Examiner	Signature	Date
	______________________	__________	__________
IV.	Advisor	Signature	Date
	Dr. Guteta Kabeta	__________	________

DECLARATION

I hereby declare that the work which is being presented in thesis entitled "**Integration of Lean, Green and Six Sigma principles to Reduce Materials Waste: A Case of Adama Agricultural Machinery Industry**." In partial fulfillment of the requirement for the award of the degree of Masters of Science in Manufacturing Engineering is my own work carried out September to June 2018 under the supervision of **Dr. Guteta Kabeta,** program of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University, Adama, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis has been duly acknowledge.

Murtesa Dabesa Gurmesa

Candidate	Signature	Date

This is to certify that the above declaration made by the candidate is corrected to the best of my knowledge and belief. This thesis has been submitted for examination with our approval.

Dr. Guteta Kabeta

Advisor	Signature	Date

ACKNOWLEDGEMENTS

First of all, I would like to praise the Almighty God, who made me a valuable man from nothing and who is a reason for my existence in healthy life.

Conducting of this thesis work, from start to end could not be fruitful without the generous assistance of individuals, who needs to be acknowledged. In particular, I express my deepest gratitude to my advisor, **Dr. Guteta Kabeta**, for his encouragement, valuable advice and comment throughout the study from beginning to end. I would like to give my gratitude to **Mr. Hailu Bayecha,** Adama Science and Technology, University academic staff, for his slice comments on this paper.

In addition, I would like to thank**, Mr. Robera Miesso, Mr. Mengistu Mekonnen, Mr. Semere Mehari** and all workers and staff members of AAMI for their willingness to support and provide me information required for the completion of this thesis work.

Finally, I would like to thank, all my friends and relatives who were beside me with their advice and countless support. Specially, I would like to express my heartful gratitude to my lovely parents who are always beside me with their support and prayer.

TABLE OF CONTENTS

ABSTRACT

When implemented individually, Lean, Green and six sigma initiatives are very successful in materials waste reduction. However, many reviewed literatures reveal that, the integration and simultaneous implementation of these paradigms improves the performances of organizations more. Green, Lean and Six Sigma are three strategies that are compatible and complementary; thus, each strategy has the capacity to reduce the shortcomings of the others. For instance, lean manufacturing deals with elimination of process wastes and non-value adding activities but, does not cover all environmental aspects which needs the addition of green manufacturing. Also, evidences indicate that the integration of the two strategies may have inherited the same limitations as the individual Green and Lean approaches, but these may be overcame through the integration of Six Sigma. The purpose of this study was to present a model that converges lean, green and six sigma principles as a tool to reduce solid materials waste. A case study was conducted on Adama agricultural machinery industry and qualitative research approach was employed to study the gap between theoretical concepts and real company case. Survey of related works, informal interviews, physical observations, and focus group discussions were used to collect data. Waste materials currently exist in the company were documented and categorized as surplus, obsolete and scrap. The root causes of each waste category were identified, prioritized and correction actions were recommended. The results from FMEA indicates that, RPN of 80, 63 and 18 were obtained for surplus, obsolete and scrap materials waste respectively. Surplus waste category is most severe and needs immediate action. Finally, a model that converges the lean, green and six sigma principles was developed as a tool of materials waste reduction. The model requires motivation and awareness of employees on LGSS principles before implementation and needs to be sustained if implemented once. Since the company did not adopted none of paradigms it may take a long time to implement the model at a maturity level. However, it will be possible through the application of critical success factors. This model may bring a tangible improvements to a waste minimization program and it can be a part of options for AAMI as well as other organizations seeking to achieve sustainability, if they will implement it.

Key words: Lean, Green, six sigma, materials waste reduction.

LISTS OF TABLES

LISTS OF FIGURES

NOMENCLATURES

AAMI	Adama Agricultural Machinery Industry
AIAG	Automotive Industry Action Group
CED	Cause and effect diagram
CIP	continuous improvements of performance
CTQ	Critical to quality
DMAIC	Define, Measure, Analyze, Improve and Control
DMADV	Define, Measure, Analyze, Design and Verify
DOE	Design of experiments
DOWNTIME	Defect, Overproduction, Waiting, Non-utilized Talent, Transportation, Inventory, Motion and Excessive Processing
DPMO	Defects per million opportunities
EPA	Effective point advice
FMEA	Failure modes and effects analysis
GOE	Government of Ethiopia
JIT	Just in time
LGSS	Lean, Green and Six Sigma
METEC	Metal and Engineering corporation
MRP	Materials requirement planning
NTAP	Nazareth Tractor Assembly Plant
NNVA	Necessary non-value adding activity
NVA	Non value-adding activity
OTS	One touch setup
QRM	Quick response manufacturing
RPN	Risk priority number
SIPOC	Suppliers inputs process outputs customers
SMED	Single minute exchange of die
TPM	Total productive maintenance
TPS	Toyota production system
VA	Value adding activity
VSM	Value stream map
WIP	Work in process
WRT	Waste reduction technique
3R	Reduction, Reuse and Recovery

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Human interest is increasing from day to day in order to get quality, sustainable and quickly delivered, products in this world. To satisfy and fulfill these human demand, many methodologies and philosophies such as Lean, Six sigma, Green, Agile, Quick response manufacturing (QRM) and Rethinking manufacturing were developed by Academicians and practitioners; like manufacturing companies and service sectors few decades ago. These methodologies are very powerful to bring a continuous improvements of performance (CIP) towards the customer demand in all production companies and service sectors.

Lean manufacturing is the systematic scenario to satisfy the human demand using a minimum resource and manufacturing cost, by reducing or eliminating wastes and non-value adding activities. Lean philosophy has also been successfully applied to administrative and engineering activities as well. According to (Shah, 2007), Lean manufacturing is an integrated socio-technical system, whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability. Waste is broadly defined as anything that adds cost to the product without adding value to it. In Lean manufacturing there are eight identified wastes or mudas abbreviated as DOWNTIME, (defect, overproduction, waiting, non-utilized talent, transportation, inventory, motion, and excessive processing).

The other methodology is Green manufacturing which concerns with the social and environmental aspects. It plays a great role in reduction of material wastes through its 3R hierarchy's (reduction, reuse and recovery). In an environmental improvement plan, several issues can be taken into account: carbon dioxide (CO_2) emissions, emissions of volatile organic compounds (VOC), waste generation, and water use (Yu, 2009).

On other hand six sigma methodology improves the quality of products and services by minimizing defects and wastes to satisfy the customers demand. This methodology identifies the root cause of defects and wastes to bring the continuous improvement of performance (CIP) in production and service providing.

It is considered that Six Sigma methodology is the best way for improving quality / reducing waste by helping organizations produce products and services better, faster, and cheaper (Pyzdek, 2010).

The same Authors believe that, Six Sigma is a "rigorous, focused, and highly effective implementation of proven quality principles and techniques; Six Sigma aims for virtually error-free business". Six Sigma methodology has two approaches: DMAIC (D-Define, M-Measure, A-Analyze, I-Improve, C- Control), which is applicable to an existing product or process to be improved, and DMADV (D-Define, M-Measure, A-Analyze, D-Design, V-Verify), which is applicable to new products or processes, to be designed and / or implemented in a manner that will provide a Six Sigma performance (Adrian, 2016). However, implementing these methodologies as a single cannot make the production companies and service sectors efficient and effective to satisfy the customer demand in all dimension including reduction and elimination of material wastes. Thus, the integration and combination of two or more of these philosophies is needed. Many literatures reveal that, the matrix between the methodologies is crucial. Manufacturers can simultaneously adopt these twin strategies of 'Lean and Green' and create an environmental stance that is a driver for reduced costs and risks, increased revenues, and improved brand image; phrases such as "lean and green" are increasingly commonplace (Corbett, 2006). Combining green management with lean manufacturing is proving pertinent (Yang, 2011). Lean Six Sigma is defined as a business strategy and methodology that increases process performance, and develops customer satisfaction, leadership, and bottom line results by improving quality, delivery speed and costs. The success of Lean Six Sigma as one of the best known hybrid continuous improvement methodologies has led many organizations across the globe to adopt it in order to address their operations and become more competitive (Anass Cherrafi, 2016).

1.2. Background of Adama Agricultural Machinery Industry (AAMI)

It was established as the Nazareth Tractor Assembly Plant (NTAP) in 1984 through a technical and economic cooperation agreement between the Government of Ethiopia (GOE) and the former Union of Soviet Socialist Republic. NTAP was renamed as the Adama Agricultural Machinery Industry (AAMI) in 1992. It was transferred to the Metal and Engineering Corporation (METEC) in 2010. AAMI is located 90 km East from Addis Ababa in the town of Adama in the Oromia Regional State. AAMI's four factory sites are located on 114,388 square meters lot.

AAMI has playing a significant role for the country transformation from backward agricultural system to better and mechanized level of agriculture.

Since the last two decades, AAMI has been closely working with government organizations, investors in agricultural firms and construction sectors, public enterprises, charity organizations, farm unions, municipality and civic organizations. It is providing the following products and services for the above mentioned firms.

Products

- Assembly of different size and brands of tractors;
- Manufacturing of various construction equipment such as trailers, loaders, water tankers etc.;
- Assembly of various tractor combines including disc ploughs and harrows;
- Assembly of water pumps that have various ranges.

Services

- Maintenance and service of tractors , implements, pumps, irrigation equipment both at client sites as well as on company premises;
- Sales of tractor, tractor implement, water pumps & irrigation equipment spare parts;
- Training operators of tractor & tractor implements.

Applications/Uses of Products and or services

Products are primarily used by the government, farm unions, and state-owned enterprises for agriculture, water irrigation, construction, and transportation projects.

1.3. Statement of the problem

Most of manufacturing companies in our country pay less attention for environmental sustainability as well as customer satisfaction, by producing quality products instead, they focus on how to increase their profit and productivity. As a result, they cannot be competent with international production companies which are working in response to their customers' demand and environmental sustainability rather than, seeking for profit only.

In waste reduction and elimination process each methodology i.e. Lean, Green and Six sigma plays a great role. However, still shortcomings and gaps are existing in effectiveness and efficiency of their performance when they are implemented as a single. For instance, (Dues, 2013) States that, not all Lean processes, procedures and waste reduction efforts are positively related to environmental performance or pollution reduction and Lean practices alone will never be enough to address all environmental issues.

For companies that are new for lean manufacturing implementation, lean practices alone will not be effective to eliminate previously existing waste materials. Lean focuses only on elimination of process wastes and non-value adding activities rather than elimination of previously existing waste materials. So that, green methodology is needed to remove the waste materials exist before implementation of lean. Thus, integrating these methodologies is needed because, one can fill the shortcomings and gaps of another in waste reduction and creating sustainable environment. Evidence indicates that integration of the two strategies may have inherited the same limitations as the individual Green and Lean approaches, but these may be overcame through the integration with Six Sigma (Garza-Reyes J. A., 2015). Lean is characterized by its ability to identify and eliminate waste, but it does not take into consideration environmental impacts hence, Green strategy should be implemented to fill this gap. Later, studies have proposed to integrate Green and Lean in order to reduce environmental wastes, but their integration has not helped organizations to achieve peak sustainability performance. Six Sigma has the capacity to address this gap (Banawi, 2014) and it offers a rigorous and disciplined structure for executing problem solving and improvement initiatives (Garza-Reyes J. A., 2015). Hence, this work proposes the integration of the three methodologies to minimize materials waste in Adama agricultural machinery industry (AAMI), which was observed as one of the crucial problems of the company during an industrial visit program.

1.4. Objectives of the study

1.4.1. General objective

The general objective of this study is to develop an integrated Lean, Green and Six sigma model for materials waste reduction in case of Adama Agricultural Machinery Industry (AAMI).

1.4.2. Specific objectives

The specific objectives of this study are to:

- Document and Categorize the waste materials exist in AAMI;
- Identify and analyze the root causes of each waste category;
- Generate options of waste reduction;
- Develop a model that combine lean, green and six sigma best practices for waste reduction.

1.5. Significance of the study

This study is significant to the manufacturing facilities from low to high production capacity, the business sectors, the entire manufacturing industries, and future researchers.

The study proposes the government service sectors, industry owners and stakeholders to create sustainable environment and be productive through implementation of integrated Lean, Green and Six sigma methodologies. Also it proposes the company under the case study i.e. Adama agricultural machineries industry (AAMI) to apply the methodologies to solve its internal and external problems and to be productive in all dimensions.

Future researchers will get a benefit from this study as they will be able to use the provided information as a reference for further developing research pertaining to the utilization of Lean, Green and Six Sigma to improve production and business processes.

1.6. Delimitation of the study

The primary delimitation of this study is that, the focus of the case study is on a single company i.e. Adama agricultural machinery industry (AAMI). Due to this reason, a single case study research strategy is employed. The focus of the study lies only on the waste minimization of solid materials which was observed as one of the main problems of the company.

1.7. Limitation of the study

The limitations of this study may include: it is assumed that, the information provided by participants is believed to be honest; the participants answered the questions to the best of his/her ability and may not ask questions about anything that is unclear before providing a response. The respondent's awareness, mindset, ability or educational background around the issue under investigation are not taken into account during the interview.

1.8. Research Questions

Under this study the following questions are able to be raised:

- What are the waste materials exist in AAMI?
- How they can be categorized?
- What are root causes of each materials waste category?
- How the root causes will be analyzed?
- What are the appropriate solutions needed to reduce materials waste?

1.9. Research Organization

This paper is organized in to five parts. Part one introduces background, problem statement, objectives, significance, limitation and delimitation of the study. Part two contains the literature review and states the research gap. Next, in part three the qualitative methodology to accomplish this study is detailed. Results and discussions are presented in part four. Finally, the fifth part concludes the results of the study, provides the recommendation ideas and suggests future research activities in this area.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

This section briefly reviews, the existing state of arts which are related with waste management, Lean manufacturing or Lean production, Green manufacturing, and six sigma concepts. In addition, this chapter describes the integration and matrix between Lean and Green, Lean and six sigma and their effects in material waste management, in service sectors, in maintenance management, in manufacturing industries, etc. The efficiency and effectiveness of all methodologies when they are applied individually, as well as, in an integrated manner are discussed from perspective of existing knowledge. Four articles, two papers from the combination of Lean/Green and the remained two papers from combination of Lean/six sigma methods are surveyed deeply. Finally, the research gap is identified.

2.2. Waste management

As early as (Allen, 1994), defined the five echelons of a waste hierarchy. First, disposal (usually landfill or incineration) is the least attractive waste management option. The second level is the recovery of value or energy from waste materials. This includes material recycling, composting and the recovery of energy from waste. Third, reuse involves putting objects back into use so they do not enter the waste stream. Reduction is the main priority for sustainable waste management: the reduction or minimization of waste at the source. The final aim is the total elimination of waste by radical process changes (usually an unrealistic expectation). This hierarchy of action is commonly called “3R” (Reduction, Reuse, and Recovery).

A three-step sequential approach is described by (Musee, 2007), waste source identification and quantification, qualitative evaluation of waste causes and finally feasible derivation of alternatives for waste minimization.

(Darlington, 2009), have proposed a waste analysis methodology tailored to the specific requirements of food manufacturing, which consists of: waste inventory analysis to highlight and monitor the sources of waste throughout the production processes, cost and environmental impact analysis to perform a cost analysis and to prioritize the importance of cost management, Reduce–recycle– disposal analysis to highlight a detailed step-by-step solution for reducing, reusing and recycling and safe disposal of the waste.

2.2.1. Types of material waste

According to (Kumar, 2006), the industrial waste and scrap consists of spoiled raw-materials, rejected components, defective parts, waste from production departments etc. involves some commercial values.

They should be disposed of periodically and proper credit of the amount should be taken in the books of accounts. Hence, waste management places an important role in managing operations. Material Wastes can be categorized into obsolete, surplus and scrap items.

1. Obsolete items: These are those materials and equipments which have economic worth but, are no longer useful for the Company's operation owing to many reason such as, changes in product line, process, materials, and so on.

2. Surplus items: These are those materials and equipments which have no immediate use but have accumulated due to faulty planning, forecasting and purchasing. However, they have a usage value in future.

3. Scrap: It is defined as process wastage, such as, turnings, borings, sprues and flashes. They may have an end-use within the plant having commercial values. Hence, should be disposed of periodically.

2.2.2. Reasons for waste materials Generation and Accumulation

Following are the reasons for the generation and accumulation of obsolete, surplus and scrap items (Kumar, 2006):

1. Changes in product design: This may lead to some items getting invalid so far as the final product is concerned. Hence, the entire stock of such items as surplus obsolete.

2. Rationalization: Sometimes raw materials are renationalized so as to minimize variety and simplify procurement. The rationalization process renders some items as surplus or obsolete.

3. Cannibalization: When a machine breakdown occurs, sometimes it is rectified using parts of an identical machine which is not functioning due to various reasons. This process of 'cannibalization' is not uncommon in many project-based industries. When continued unchecked, this results in obsolete and scrap items.

4. Faulty planning and forecasting: The marketing department may have projected a sales forecast which might be on the higher side.

Any material planning has to be based on sales forecasts and this could result in surplus items. Wrong indenting by the user departments also leads to accumulation.

5. Faulty purchase practices: Sub-optimizing decisions like buying in bulk to take care of discounts and transportation economy without taking into account factors such as, shelf life, storage space requirements and technological changes once again lead to the accumulation of surplus and obsolete stocks.

6. Other Causes: Many items are held as insurable spares for many years without any consumption. Faulty store-keeping methods, without adequate preservation, lead to spoilage. Inferior materials handling, improper codification and poor manufacturing methods also result in obsolete, surplus and scrap items. Poor maintenance of machine tools may result in excessive tools wear and greater process scrap (Kumar, 2006).

2.2.3. Identification and control of material waste

Many organizations have introduced formal documentation in introducing changes in design or product. It is called the 'Effective Point Advice.' This is popularly known as EPA. Here, the proposed changes, details of new materials and products required, details of materials and the products which will be invalid/obsolete when the change occurs and the approximate date when the change is expected to be introduced are detailed and circulated to concerned departments. EPA thereby helps in tapering off the stocks of 'invalid' items, cancellation of orders for such items, placing orders for buying and/or manufacturing new items and related activities. EPA systems help in better coordination for profitable introduction of changes with minimum 'side effects' such as the accumulation of obsolete items. It is possible to salvage scrap for usage within the firm in some cases. Press parts are normally made from sheets and plates. The off-cuts generated during such process can be profitably utilized in making smaller press components such as washers. Rationalizing the supply size, changes in process such as reversing the dies may result in minimization of scrap. Big organizations have a full-fledged scrap salvaging department. These departments segregate the scrap into categories, like turnings, borings, plate cuttings, end pieces of billets, punching etc. Color coding the scrap is also done to avoid the mixing of different categories of scrap. It is also advantageous to the end-users in each category and supply of scrap at the appropriate time for production (Kumar, 2006).

Often informing the production department at the right time about the volume of scrap generated enables prevention of excessive scrap through timely changes in production methods, tooling and materials.

2.2.4. Disposal of Scrap

Disposal of scrap when handled in an imaginative manner can result in handsome returns to the organization. An effective disposal requires a compact disposal organization reporting to the materials manager, continuous market survey on the prices of various categories of scrap generated in the plant and constant touch with the industries which generate similar scrap and with the end-users. Disposal action follows when the scrap cannot be utilized within the organization. In practice, it has been found that it is profitable to dispose the scrap directly to end-users rather than to middlemen who normally form a cartel of their own which leads to lower returns (Kumar, 2006). Before disposal action it is essential that the scrap is segregated according to metal, size, etc.

Auction and Tender methods are frequently used for disposal of scrap. Parties in both the cases are normally required to inspect the scrap in the scrap yard and deposit earnest money. Very often the company insists on a basic price depending upon the category of scrap. The disposal section works, in this aspect, in close coordination with the finance department. Many companies have found to their displeasure scrapped components appearing in the market and competing with their parts as 'original equipment'. This is the price which organizations pay for not dismantling and disfiguring the scrap before disposal (Kumar, 2006).

2.3. Lean manufacturing

Lean manufacturing is one of the initiatives that many major manufacturing plants in Asia, especially in Malaysia have been trying to adopt in order to remain competitive in an increasingly competitive global market. The focus of the approach is on cost reduction through eliminating non value added activities via applying a management philosophy which focused on identifying and eliminating waste from each step in the production chain respective of energy, time, motion and resources alike throughout a product's value stream, known as lean. Since the birth of Toyota Production System, many of the tools and techniques of lean manufacturing (e.g., just-in-time (JIT), cellular manufacturing, total productive maintenance, single-minute exchange of dies, production smoothing) have been extensively used.

This activity is more towards to Toyota Production System (TPS), a systematic approach to identify and eliminate waste activities through continuous improvement. All these effort is objectively to keep cost down and stay ahead in the race (Rahani, 2012).

For more than two decades, lean philosophy has been the business strategy which guarantees competitiveness and eco-friendliness by concentrating on the elimination of non-value added activities (Mourtzis, 2016). Lean Production is a model of organization focused on the customer and delivery of on time quality products, materials and information without any wastes, i.e., activities that add no value to the products. LP do this with the involvement of all people in the company in a way that not injuries the environment.

Lean Production means "doing more with less" where less implies less space occupied, less transports, less inventories, and most important, less human effort and less natural resources (Laura, 2013). The same Authors stated that, to satisfy the clients, companies consume energy, water and raw materials (natural resources). At the same time, they must be careful not to be a larger than life consumption because not only it is expensive but also natural resources are limited. So, it is necessary to optimize the processes and prevent wastes of resources in a reasonable "doing more with less". The relationship between Lean Production and sustainable development is evident, sharing the same key idea of "creating or doing more with less".

According to (Salah, 2010), there are two approaches to lean manufacturing. The first of these two approaches is the identification and steady elimination of the underlying cause of waste (i.e. Muda) through a set of tools. Examples of these lean tools are 5S, Value Stream Mapping, Kaizen that is continuous improvement teams and events, SMED, Senpai and Kohai that is mentoring process to think up and down the organizational structure, Poke-yoke that is error-proofing, and automation that is to automate and to give the machines enough intelligence to recognize when they are working abnormally and flag this for human attention. In the second approach to lean manufacturing the emphasis is placed on improving the flow or smoothness of work, thereby steadily eliminating Mura (i.e. unevenness) through the system and not upon 'waste reduction' per se. It is based on the fact that if production flows perfectly, there will be no inventory.

2.3.1. Lean manufacturing and Toyota production system (TPS)

As it was stated on (Lonnie, 2010), Lean Manufacturing, also known as the Toyota Production System (TPS), is part of a business system, so there clearly are business aspects to it.

The TPS is often used interchangeably with the terms Lean Manufacturing and Lean Production. Regarding the technical issues of TPS and Lean he frequently use these terms interchangeably.

It is called Lean because, in the end, the process can run:

- Using less material
- Requiring less investment
- Using less inventory
- Consuming less space and
- Using less people

Taking all together, we can define "the TPS is a production system which is a quantity control system, based on a foundation of quality, whose goal is cost reductions, by means of absolute elimination of waste."

The Author found that, all of these definitions miss part of the essence of Lean Manufacturing. He did not think Ohno defined it more carefully oftentimes as we do not feel the need to define those things that are very near and very obvious to us. He believe others may not define it better because they simply miss the point, while others may understand it but not be able to articulate it. His definition of the TPS is a manufacturing system that:

1. Has a focus on quantity control to reduce cost by eliminating waste;
2. Is built on a strong foundation of process and product quality;
3. Is fully integrated;
4. Is continually evolving and
5. Is perpetuated by a strong healthy culture that is managed *consciously*,

Continuously, and *consistently* (Lonnie, 2010).

The author revealed that, the term Lean Manufacturing has since become synonymous with the Toyota Production System, but there are at least two differences. The first difference is subtle and is lost on many people. It has to do with the starting point of the journey into Lean. Recall that quantity control is the defining characteristic of Lean. When Ohno started in 1955, he had in place an extremely sound quality control system. His foundation of quality control was more than sound, it was very mature.

So they must simultaneously work themselves out of a serious quality problem while trying to implement quantity control measures. Consequently, to implement a Lean initiative today, companies must embark on a renewed effort in quality control.

Hence, Lean efforts today have become synonymous with not only quantity control but also quality control, which was never an issue with Ohno. The second difference is more obvious.

Many businesses will achieve large gains in profits, be able to reduce lead times, become more flexible and responsive, and generally become a better business easily. Quite frankly, this is not too hard. What it takes is sound leadership, a decent plan, a motivating environment, a few problem solvers with a willingness to implement change, and good old-fashioned hard work (Lonnie, 2010).

2.3.2. The seven Mudas

Pure waste in production is commonly divided into seven (or eight) subcategories, including defects, over-production, transportation, waiting, inventory, motion and processing (and underutilization of people). Depending on manufacturing process, its efficiency may be as high as 80-90 % (Torgeir, 2016).

2.3.2.1. Defects

As (Arunagiri, 2014) outlined, usually defects will add additional rework, inspection, design changes, process changes, and machine downtime analyze problems. The original cost must be absorbed, and unnecessary rework or replacement costs need to be captured. Poor quality and the resulting defects are a major source of cost for many companies. This is also a cost that is often under reported as there are direct and indirect effects of defects. A defect is any error in a process that makes a product or service less valuable to a customer, or that requires additional processing to correct the defect.

2.3.2.2. Over production

Parts are being produced without any new order or demand from the customer. Producing more material than the customer demand or produce it before it is needed is termed as over production.

Overproduction means making more than that is required by the next process, making earlier than that is required by the next process, or making faster than required by the next process (Arunagiri, 2014).

2.3.2.3. Transportation

Transportation is defined as delivered to and from outside the factory warehouse facility. The transportation of finished goods normally is generated by the poor plant process, or necessary plant process layouts. The majority of transportation costs is generated by moving raw materials to a factory and moving finished goods to a customer.

The cause of this transportation is the centralized production of a product, and the design of the supply chain supporting production.

In most industries, large scale centralized production is the norm. The result is a product that may be produced hundreds or thousands of miles away from where it is needed. The supply chain has a big effect on transportation. Sourcing raw materials locally can reduce transportation costs. When making sourcing decisions, the transportation costs are typically included in the total cost of the material being acquired. Inside a facility, transportation is caused by wait time and inventory (Arunagiri, 2014).

2.3.2.4. Waiting/Delay

Some common wait time is caused by processing delays, machine or system downtime, response time and signature required for approval wait time. The reason for the delay and waiting for materials is questionable and the next machines to be ready or extra help to complete the job. Delay usually caused by the loading and unloading the work piece in the machines. The operator's time allocation is more than that of the actual processing time. This excess time allocation for the operators to do the job increases the overall wait time and delay in the process (Arunagiri, 2014).

2.3.2.5. Inventory

Excess inventory is called storing excess products with no orders in the warehouse and having excess WIP. This will impede and tie up the cash flow and it may end up creating a negative cash flow. Causes of Inventory Overproduction, another of the 7 Wastes, are a primary cause of inventory.

Processes and incentives that encourage producing too much product will lead to higher inventory levels. It protects against unexpected events such as a material shortage, machine breakdown or natural disaster.

Poorly controlled processes lead to lot sizes, inaccurate forecasts, poor communication with suppliers and customers, and errant management decisions. All of these limitations will result in higher inventory levels.

The most obvious effect of inventory is the capital required to carry the inventory. The cost of inventory is significant, and that cost generates no return (Arunagiri, 2014).

As it was stated on (Hobbs, 2004), the disadvantages of high inventory levels also impact overhead costs. These inventories require space on the shop floor, in warehouses, and in distribution centers. This space is not free and adds to the overhead cost of doing business. Inventory must be counted, moved, and taxed.

Funds consumed by inventories are unavailable for alternative investments, so opportunity is lost. The financial implications of high inventories are simple to determine: *"Inventory = Cash!"*.

2.3.2.6. Unnecessary motion

Unnecessary movements in the manufacturing environment will result in processing delays. Other unutilized talents are employee lost time, unused skills, employee ideas, and recommendations in simplifying the process (Arunagiri, 2014). Waste of motion study for economy and consistency. Economy improves productivity and consistency improves quality. First improve the motions, then mechanize or automate (Kumar, 2006).

2.3.2.7. Over processing

Storing work-in-process (WIP) products in further location adds unneeded processing steps to complete the project. Simplifying processes are critical to the lean methodology, and it is at the core of eliminating processing waste. Each activity in the production process should be assessed in detail. The activity must add value to the customer, and must be an activity that cannot be accomplished automatically. In turn the activity should be eliminated or consolidated with other processes. As with the other wastes, it is important to examine every activity or process through the lens of lean (Arunagiri, 2014).

2.3.3. Pillars of lean manufacturing

Ohno describes the TPS as consisting of many techniques that are designed to reduce the cost of manufacturing. His method of reducing cost is to remove waste. This waste elimination system, the TPS, is built on two pillars (Lonnie, 2010) they are just in time (JIT) and Jidoka.

2.3.3.1. Just In Time

The first pillar is Just in Time (JIT). This is the technique of supplying exactly the right quantity, at exactly the right time, and at exactly the correct location. It is a quantity control. It literally is at the technical heart of TPS. Most people envision this pillar as inventory control, and this is a part of it. However, JIT is much more than a simple inventory control system. What's surprising to a large number of practitioners is that at the heart of quantity control at the heart of JIT is a deep understanding and control of variation.

2.3.3.2. Jidoka

The second pillar is jidoka. This is a series of cultural and technical issues regarding the use of machines and manpower together, utilizing people for the unique tasks they are able to perform and allowing the machines to self-regulate the quality. Technically, jidoka uses tactics such as poka-yoke, (methods of fool proofing the process), andons (visual displays such as lights to indicate process status especially process abnormalities), and 100 percent inspection by machines. It is the concept that no bad parts are allowed to progress down the production line. This not only is needed to protect the customer and reduce scrap costs, it is a continuous improvement tool and is a key element in making kanban work.

2.3.4. Tools of lean manufacturing

Lean Tools are dependent on lean theory and principles, and can be applied to every enterprise worldwide with appropriate modifications (Mourtzis, 2016). Nearly all the 20 Lean tools require an understanding of, and reduction of, variation to work (Lonnie, 2010). Once enterprises pinpoint the major sources of waste, lean tools, for instance “5S”, just-in-time production, Gemba, poka yoke, kaizen, value stream mapping, single minute exchange of dies (SMED)/one touch setups (OTS), lead time reduction, minimum lot size, 5whys, total productive maintenance (TPM), kanban, cells, etc., will guide organizations through corrective activities to eliminate waste and continuous improvement (Lonnie, 2010).

2.3.4.1. Kanban System

As it was stated on (Hobbs, 2004), the kanban methodology is a material presentation method designed to simplify material handling and inventory management. Instead of materials being placed in "kits" or allocated to a shop order and launched into manufacturing based on a production schedule, materials are instead replenished with a kanban or "signal." In a kanban system, a relationship that identifies where materials are used and where they are refilled must be established. These relationships are known as a pull sequence. A series of sequences linked together describing all restocking points is called a pull chain. When material has been consumed through the building of a product, a "kanban" signal is created. The empty kanban "signals" the need to refill or replace the materials used. This signal can be a card or the empty Container itself. A goal of any kanban system is to keep inventory moving through the manufacturing process at a rapid pace. This velocity improves the turn rate usage of the inventory investment and reduces the working capital requirements of the business.

As a delivery frequency is established for each pull sequence for each part or component, the amount of inventory investment will be in direct proportion to the frequency of its replenishment. The longer the replenishment times, the greater the inventory investment. Kanban systems establish an optimum strategy for balancing inventory investment and material-handling costs. A kanban system that places materials directly on the Lean line at the workstation where parts are consumed directly into the product offers several advantages to the Lean manufacturer.

All material in manufacturing is available for use on any product. Because components are not assigned to a specific shop order and are already on the line, any product demanded by the customer can be manufactured immediately, in its work content time down the Lean line. The Kanban system is one of the manufacturing strategies for lean production with minimal inventory and reduced costs. However, the Kanban system is not being implemented widely by manufacturing companies in Malaysia (AbdulRahman, 2013).

2.3.4.2. Value Stream Mapping (VSM)

Value Stream is defined as "the set of all the specific actions required to bring a specific product through the three critical management tasks of any business: Problem Solving, Information Management and Physical Transformation". Value Stream Mapping (VSM) is the process of mapping the material and information flows required to coordinate the activities performed by manufacturers, suppliers and distributors to deliver products to customers (Sundar, 2014). First, VSM is a tool to assist you in the battle to reduce waste. Don't get too hung up on the rules.

The general ideas will guide you nicely, but if there are some relevant data you think would be helpful but you haven't seen it on some primer on value stream mapping, don't hesitate to use it. The objective is waste reduction don't lose sight of that (Lonnie, 2010).

The VSM method strictly divides all processes into two groups: value adding (VA) and non-value adding (NVA). The outcome of a VSM is chart presenting value flow across whole company, where is subsequently possible to identify a place of heaping inventory, find out a total manufacturing lead-time or realize how many percent of this time are VA in other words how long are inventory items inactive and stored in warehouse shelves (Rohac, 2015).

A value stream map (VSM) is a special kind of flow chart that uses special symbols known as "the language of lean". It is used to depict and improve the flow of inventory and information in manufacturing companies.

It clearly shows where delay is caused which gives opportunities to optimize the flow and hence reducing the wastes. VSM provides optimum value to the customer through a complete value creation processes with minimum waste.

2.3.4.3. Single minute exchange of dies (SMED)

SMED technology is a science developed by Shigeo Shingo and is designed to reduce changeover times. The problem is simple; any machine that has long changeover times must have an excess capacity to account for the downtime of the changeover. Furthermore, to supply the rest of the downstream process during the changeover, a large batch must be stored up. Any effort to reduce the changeover times also reduces these two forms of waste: excess capitalization and overproduction. ("Single minute" means a single digit number of minutes that is less than 10.)

In actuality, the objective is to reduce the changeover time as much as possible. In some refined cases, the changeover is handled by having multiple fixtures on the same basic machine, and by simply throwing a switch the changeover is made. This is called One Touch Setups (OTS), or sometimes One Touch Exchange of Dies (OTED) (Lonnie, 2010).

Based on time/video study Shingo separated the changeover (C/O) time into internal and external upset time. the activities performed by stopping the machine are called internal set-up time and the other hand the activity are performed without stopping the machine, these activity are called external set-up time. Yamazumi chart is used to analyze the internal (on-line activity) and external (off-line) set-up time.

Based on these analysis possible internal set-up time are converted to external set-up and internal set-up time are streamlined by introducing multi operator working parallel during On-line activity and one touch set-up adjustments to convert the C/O time to single minute (Sundar, 2014).

2.3.4.4. Lead time reduction

Reducing the lead time is not only a result of reducing variation, it is a variation reduction technique of extreme power. Reducing the lead time directly allows inventory reductions in the process. This reduces exposure to environmental factors and possible damage and deterioration. Short lead times and lead-time reduction is such a basic tool in Lean that you will find it to be a strong measure of Leanness.

In addition, if a company has short lead times, several other inferences can be drawn about that company.

Almost without exception, you will find that they have (Lonnie, 2010):

- Good inventory management;
- Good quality;
- Good delivery performance;
- Good machine availability;
- Good problem solving;
- Low levels of variation and
- Stable processes.

2.3.4.5. Kaizen/continuous improvements

Continuous Improvement (CI) is a philosophy that Deming described simply as "Improvement initiatives that increase successes and reduce failures" Continuous Improvement is the management driven element which effort the cultural change in the workplace.

Once process stability is established, CI element tools are required to determine the root cause of inefficiencies and apply effective countermeasures to reduce those inefficiencies. Establish and design a process with zero inventories exposes waste such as the idle time, waiting time, inventory and resource problem. In order to eliminate this waste, management need to develop the stable personnel with organization knowledge base (Sundar, 2014).

Kaizen is the concept of improving a process by a series of small continuous steps. Often times these improvements are small and hard to measure, however the accumulated effect is significant. Over the years, kaizen has evolved to mean improvement. CIP stands for Continuous Improvement Process or Philosophy. Many can talk about it, but few can show a process flow chart for their CIP, and even fewer can adequately measure it (Lonnie, 2010). Kaizen tools applied to service activities must not be mainly focused on internal processes, but on customer focused perspective by including the customer in Kaizen system's view (Andrés López, 2015).

2.3.4.6. "5S"

5S is a set of techniques, all beginning with the letter "S." They are used to improve workplace practices that facilitate visual control and Lean implementation. The 5Ss in Japanese and English are (Lonnie, 2010):

- Seiri…Separate (Remove items not used to manufacture products on a regular basis).
- Seiton…Set to order (Identify and arrange items that belong in the area a place for Everything and everything in its place).
- Seiso…Shine (Maintain order, sweep, and clean).

- Seiketsu…Standardize (Practice management discipline).
- Shitsuke…Sustain (It is management's responsibility to reinforce and demonstrate Leadership).

To improve quality perceived by the customers, 5S methodology in service activities must emphasize its implementation in areas with contact with customers. For a successful 5S application in a service organization a cross-functional team of operators should consider both general housekeeping (all office activities) and IT (Sundar, 2014).

2.3.4.7. Minimum lot size (minimum batch)

A batch is a set of parts of the same part family. While part families are supposed to be given in advance, lot sizing is a part of the decision making process. Conventional manufacturing systems are run based on buffer production system.

The built-in buffer system was introduced to overcome the material flow interruption in case of for equipment break down, machine C/O, absenteeism which lead to high quality problem and lead time.

In order to smoothen the material flow and to overcome the quality and lead time issues, buffer quantity should be optimized (Sundar, 2014).

Minimum lot size is a means to reduce lead times. By reducing production lot size and transfer lot sizes, the process proceeds much faster. Two benefits are achieved. First, we reduce the lead time for the first piece through the process. This benefit is usually felt in quality responsiveness. If the first piece lead time is reduced, and there is a problem with the product, this information is fed back to the problematic station more quickly. The problem can be resolved more quickly, and if rework is required, fewer items will need to be reworked.

The second benefit is that the overall product will be completed more quickly, reducing production lead time for the lot. Minimum lot size, with the ultimate being "one-piece flow," is the key to plant flexibility and product supply responsiveness (Lonnie, 2010).

2.3.4.8. Poka yoke (mistake proofing)

Poka-yokes are powerful tools and should be fully exploited before other procedural changes are implemented. Poka-yoke is a series of techniques, limited only by the engineer's imagination. The purpose of poka-yokes is to achieve error proofing of a process activity and thereby make the process more robust. Poka-yokes are also used in the inspection process to achieve 100 percent inspection.

There are two types of inspection poka-yokes: those that control that is, shut down the process or isolate the product upon finding a defect; and those that warn the operator via an andon (Lonnie, 2010).

2.3.4.9. Total productive maintenance (TPM)

TPM are the initials for Total Productive (not preventive) Maintenance. It is a revolutionary approach to the management of machinery.

It consists of activities that are designed to prevent breakdowns, minimize equipment adjustments which cause lost production, and make the machinery safer, more easily operated, and run in a cost-effective manner. In most plants, wishing to implement a Lean Initiative, we find that equipment availability is a large source of the process losses. Frequently, the largest of the three losses in the OEE metric.

TPM is therefore a powerful tool to improve overall performance of the plant. It is generally defined as having five pillars, which are (Lonnie, 2010):

- Improvement activities, designed to reduce the six equipment-related losses of:
  - ✓ Breakdown losses
  - ✓ Setup and adjustment losses
  - ✓ Minor stoppage losses
  - ✓ Speed losses
  - ✓ Quality defects and rework
  - ✓ Startup yield losses
- Autonomous maintenance, which is an effort to have many routine activities performed by the operator rather than the maintenance department.
- A planned maintenance system, which is based on failure history. This is not timed maintenance. Instead, it is based on historical evidence.
- Training of operators and maintenance personnel to improve operations and maintenance skills.
- A system for early equipment maintenance to avoid the loss that occurs upon new equipment startup.

2.4. Green manufacturing

According to (Fercoq L. L., 2013.), more recently, environmental and social concerns have increasingly become critical issues within our societies and economies.

Since the end of the Eighties, the sustainable development concept (WCED 1987) defined as "Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs", has aroused growing interest. The recognition of the debilitating effects of environmental pollutions has put the industries and communities on alert to the impending doom if appropriate action is not taken in time.

A sustainable enterprise is the one that contributes to sustainable development by simultaneously delivering economic, social, and environmental benefits or what has been termed "the triple bottom line" (Norman, 2004).

Steve Hope, general manager of Toyota Motor Europe, stated that the whole company should be "green, clean and lean". Accordingly, Toyota was the first company to achieve "zero waste to landfill" in the worldwide automotive industry (Farish, 2009).

Nevertheless, some contradictory results have been highlighted: the Green Supply Chain prescribes a reduction in delivery frequency in order to reduce carbon dioxide emissions, resulting in a potentially negative impact on operational supply chain performance (Carvalho, 2011.).

Several issues can be dealt with in an environmental improvement plan: carbon dioxide (CO2) or volatile organic compounds (VOC) emissions, waste generation and water use (Yu, 2009). (Bicheno, 2000), identifies wasted materials as one of the "new" wastes. Environmental impacts can be considered as a result of "green wastes" (Verrier, 2014).

The term green manufacturing was coined to reflect the new manufacturing paradigm that employs various green strategies and techniques to become more eco-efficient. These strategies include creating products/systems that consumes less material and energy, substituting input materials (e.g. non-toxic for toxic, renewable for non-renewable), reducing unwanted outputs and converting outputs to inputs (recycling). This manufacturing concept is not just restricted to addressing the social and environmental impact of a pollution-centric process. Green manufacturing addresses process redundancy, ergonomics and cost implications due to faulty methods of producing goods. Faster and cheaper are no longer the only two criteria in manufacturing a product or evaluating an existing process line.

Several other factors such as materials used in manufacture, generation of waste, effluents and their treatment (or possible elimination), life of the product and finally, treatment of the product after its useful life are all important considerations (Jasiulewicz, 2014).

2.5. Six sigma concept

The desire to achieve business excellence in the Automotive Industry assumes the management commitment to develop and deliver perfect solutions, products or services, to promote the "Zero Defects" and first time right production philosophy, the integration of environmental protection in all its activities (design and production), as well as training, motivating and involving all staff in the effort towards excellence (Adrian, 2016). In this context, it is considered that Six Sigma methodology is the best way for improving quality / reducing waste by helping organizations produce products and services better, faster, and cheaper (Pyzdek, 2010). (Pyzdek, 2010), believe that Six Sigma is a "rigorous, focused, and highly effective implementation of proven quality principles and techniques.

Six Sigma methodology has two approaches: DMAIC (D-Define, M-Measure, A-Analyze, I-Improve, C-Control), which is applicable to an existing product or process to be improved, and DMADV (D-Define, M-Measure, A-Analyze, D-Design, V-Verify) which is applicable to new products or processes, to be designed and /or implemented in a manner that will provide a Six Sigma performance (Adrian, 2016).

Six-sigma can be defined as the measure of quality that strives for near perfection. It uses a disciplined approach for eliminating defects from any process. The main goal of six sigma is to increase the profit of an organization by reducing variability, defects and wastes that undermine customer loyalty. The principle philosophy of six-sigma is to reduce variability and to take customer-focused data-driven decision. It uses statistical analysis to measure and improve a company's operational performance. Six-sigma is strongly associated with the process improvement methodology that provides the organization structure to support continuous improvement (Harmon, 2007), (as it was referred by another researchers).

The statistical representation of six-sigma helps us in determining how the process is performing. In order to achieve six-sigma standards we must not have more than 3.4 defects per million opportunities (DPMO). Many industries are bound to have six-sigma standards, for example an airline industry cannot have more defects.

It is very difficult to attain this standard in many industries but still it can be used as a measurement to reduce the defect and narrow down the variability. Most six-sigma projects use a process improvement approach that is referred to as DMAIC (Harmon, 2007).

The steps define customer requirements for the process, measure existing performance and compare with customer requirement, analyze existing process, improve the process design and implement, control the result and maintain the new performance (Pepper, 2009) (as it was referred by other researchers).

2.6. Lean-Green Integration

At the company level, combining Green management with Lean Manufacturing is also proving to be a suitable choice (Yang, 2011). Lean and Green manufacturing can provide the competitive advantage and profitability that many manufacturers are looking for. In their recent examination of the relationships between Lean, Green, and sustainability, (Dhingra, 2014), observed that the previously held notion that Lean leads to Green, but not necessarily vice versa, is reiterated and confirmed.

And concerning formal management systems (Kurdve, 2014), recommend the integration of the production system and formal environmental management systems (ISO 14001. The latter two are very common in any industry, and waste generation is the area that is closest to the Lean Manufacturing concept, as it is focused on the reduction of any type of excess.

Lean practitioners traditionally have focused on what they refer to as the seven forms of waste: over-production, defects, unnecessary inventory, inappropriate processing, excessive transportation, waiting, and unnecessary motion (Pepper, 2009).

(Fercoq L. C., 2016), believe that, Lean not only serves as a catalyst, but also is synergistic with the Green strategy. This means that Lean is beneficial for Green practices and the implementation of Green practices in turn has a positive influence on existing business practices (Dues, 2013). (Martínez, 2014), showed that Lean and Green are complementary and are governed by three main principles: waste reduction, a process-centered focus, and high levels of involvement and participation by people. In addition, according to a recent state-of-the-art review of the research on Lean/Green (Garza-Reyes J. A., 2015), there are some interesting research questions that could be answered by the development of a quantitative study on Lean/Green management (compatibility, integration, performance assessment method, and impact on organizational performance).

Many articles revealed that, the simultaneous implementation of Lean and Green methodologies has a power to improve the productivity, efficiency and effectiveness of the manufacturing companies and service sectors. Due to integration of these paradigms, the quality of produced products and provided services is increased and also the customer demand is fulfilled.

Among those articles which support the concept of simultaneous implementation of Lean and Green methodologies, two of them are selected to review their objectives, methods and key findings. The first one is the work of (Jasiulewicz, 2014) on integrating Lean and Green paradigms in maintenance management. The main objective of this study was, to identify the common elements of the paradigms introduced for better understanding of synergy between them and overall improvement of maintenance efficiency. According to this study, the goal of integration of Lean and Green paradigms in maintenance is mostly harmonization and coordination of many aspects of activities, combination processes, procedures, practices and creating a system which enables meeting goals predefined in a maintenance strategy in a more efficient way. The result of the study is summarized in the table below.

Table 2.1 The impact of Lean, Green and TPM on maintenance performance (Jasiulewicz, 2014)

Productivity and Quality	**Impact of TPM**
	reduce need for intervention, reduce breakdowns, potential to reduce tolerance, control of technology, reduce start-up loss
	Impact of lean thinking
	reduce non-value-adding activities increase added value per labor hour, highlight quality defects early
	Impact of green thinking
	reduce wasted energy from heating, cooling, and lighting during production downtime
Cost	**Impact of TPM**
	reduce material, spares
	Impact of lean thinking
	lower inventories
	Impact of green thinking

	Decrease of environmental fees (e.g. by waste segregation, decrease of amount of media use)
Safety and Morale	**Impact of TPM**
	Less unplanned events, less intervention controlled wear, better understanding of technology, more time to manage
	Impact of lean thinking
	less movement, less clutter, abnormal conditions become visible easily, less clutter closer to the internal customer, higher appreciation of what constitutes internal customer value
	Impact of green thinking
	reduce risks to the health of workers, increase of workers' consciousness (e.g. by training programs)
Environment	**Impact of TPM**
	closer control of equipment, less unplanned events /human error
	Impact of lean thinking
	no 'over-production' Systems geared to needs not theoretical batching rules
	Impact of green thinking
	reduce risks to the environment, reduction of nonrenewable resources use, product lifecycle management

The Author concluded that, including tools and techniques applied in Lean and Green approaches to maintenance actions and processes is supposed to increase their efficiency and create a basis for development of the area towards sustainable developments.

The second one is, the research conducted by (Fercoq L. C., 2016), on Lean/Green integration focused on waste reduction techniques. The purpose of this study was to present a quantitative study on Lean and Green integration with a focus on solid waste management in manufacturing. It was built on the recent works and point out that Lean and Green overlap especially in waste reduction techniques (WRT) which constitute the focus of the study.

The study was performed using the Design of Experiments (DOE) tool to measure the influence on waste management, the 3R hierarchy (reduction/reuse/recovery) and the combination of these two methods.

The key findings of this study was presented as follows. First, the individual contributions of the Lean and Green methodologies on solid waste performance in manufacturing with in an integrated Lean/Green approach was identified.

Second, the 3R hierarchy and the seven deadly wastes (mudas) of Lean management improves the performance of waste minimization program in manufacturing.

Third, integrating the two methods through the use of a Lean/Green matrix strengthens the performance of a waste progress plan; the impact on waste minimization plan can be doubled.

2.7. Lean-six sigma Integration

Lean six sigma method has been broadly accepted by the manufacturing industries to improve its production performance (Indrawati, 2015). The functions of this method are to identify and minimize waste or non-value added activities through continuous improvement (Brue, 2002).

(Indrawati, 2015) Believe that, lean six sigma has a positive impact on quality improvement, financial advantages, and benefits for the customers as well as employees and production improvement strategies using lean six sigma are needed to improve production performance and minimize production waste. The fusion of the two continuous improvement methodologies was a way for organizations to increase their potential improvement (Bhuiyan, 2005). Lean Six Sigma is defined as a business strategy and methodology that increases process performance, and develops customer satisfaction, leadership, and bottom line results by improving quality, speed and costs (Snee, 2010).

It achieves this by applying the tools and techniques from both lean and Six Sigma (Anass Cherrafi, 2016). Thus, a company will typically identify which of its processes needs improvement and which methodology is compatible with this need. The company will also have to determine how and when to implement six sigma and/or lean manufacturing. Without doing this the company may not achieve the benefits that lean manufacturing and/or six sigma can yield (Ibrahim, 2017).

The integration of lean and six-sigma philosophies, known as lean sigma, is a business improvement methodology which combines both lean principles and six-sigma. Lean focuses on speed by eliminating waste from the environment whereas six-sigma helps in attaining higher quality product or services. Combining these two can fetch us a high quality product at shorter duration of time (Pepper, 2009).

Lean alone: Lean methods are very effective at eliminating process waste and accelerating velocity. Yet organizations that apply Lean methods only, even with all of its potency for streamlined process improvement, often fail to sustain their gains, or fail to practice the internal habits that drive bottom line returns and strategic alignment with overarching goals.

A goal of Lean is to improve process speed and improve capacity. However, process variation can have enormous adverse impacts on speed and required capacity. Lean depends on low process variability but lacks an effective analysis approach. Six Sigma is well known as a highly effective means to uncover and eliminate the root causes of unknown process variability (George, 2010).

Six Sigma alone: Six Sigma's superior root cause analysis tools and prescribed infrastructure give companies the power to eliminate variation and drive priority improvements across the business. But if they applied Six Sigma only, benefiting from its fact based, customer centric statistical decision making and root cause identification, companies often struggle to create transformed processes with lower cost solutions. There is no explicit approach to remove waste and improve speed (other than defect elimination). A pure Six Sigma model may lack rapid improvement events such as Kaizen, which can accelerate results and project completion rates. According to one self-reported survey, nearly 40 percent of Six Sigma practitioners claimed their own projects as failed or incomplete (iSixSigma magazine survey, November/December, 2008, v4, no.4). Most of these companies also struggle to achieve a payback early enough to compensate for the upfront fees of Six Sigma training requirements. Without Lean efficiencies and rapid improvement, Six Sigma suffers delayed payback and sub optimized solutions (George, 2010).

The idea of implementing an integrated Lean manufacturing and Six sigma methodologies is emerging. The current state of arts revealed that, combining both concepts dramatically improves the quality of products, businesses, productivity, and environmental safety. Among many studies that support the integrated implementation of Lean manufacturing and Six sigma paradigms; two papers are selected and their contents are reviewed and highlighted as follows.

The first is a research conducted on "manufacturing continuous improvement using lean six sigma: an iron ores industry case application" by (Indrawati, 2015).

The intention of the study was to improve product quality through data collection of product defect, data analysis using failure mode and effect analysis (FMEA) and give some corrective action to reduce the level of product defect.

The study was conducted using DMAIC (define, measure, analyze, improve, control) method and based on this method, the following results were obtained.

2. From production activity, non-value added (NVA) activity consists of 33.6% and necessary non-value added (NNVA) activity consists of 14.20%. The production of drying iron ore is not optimal due to production efficiency only at the level of 52%.
3. The most common and influential waste are inappropriate processing and defect. The process capability is at the level of 2.96 sigma.
4. The proposed improvement program is develop to overcome the problems that consist of redesigning chute dust collector, weighing standard operation procedures, BC 05 erection, vibrometer installation and nitrogen plant installation.

The second is the research done on a comparative exploration of Lean manufacturing and Six sigma in terms of their critical success factors by (Ibrahim, 2017).

The purpose of the study was to identify the differences and similarities between Lean manufacturing and Six sigma in terms of the importance of critical success factors.

In this study, experts which have an understanding of Lean manufacturing and Six sigma participated. Data is collected via on line survey to compare the importance of the same specific critical success factors in the implementation of Lean manufacturing and Six sigma methods.

Based on the feedback and advice from two experts participated from Lean manufacturing and Six sigma, an additional question was added to the survey i.e. what are the reasons for implementing Lean manufacturing and Six sigma simultaneously?

At the conclusion of the pilot study, the survey was distributed on line. The survey participants were asked to choose from the following indicators: 1= unimportant; 2= slightly important; 3= important; 4= very important; 5= critical. An ordinal scale was used for measuring the dependent variable.

Based on the conducted survey, the researchers able to reach on the following results. The experts were experienced and understood the advantages of implementing lean manufacturing and six sigma. They were required to answer questions regarding the reasons for implementing Lean manufacturing and Six sigma simultaneously.

The majority (36.1%) of the experts opined that implementing both methodologies simultaneously yielded a rapid improvement in processes.

A further 19.4% of the experts felt that the simultaneous implementation of six sigma and lean manufacturing increased customer satisfaction.

Another 19.4% stated that there was a lack of improvement when Lean manufacturing and Six sigma were implemented separately. Only one company, representing 2.7% of the total, indicated an improvement in sales. Other improvements following the simultaneous implementation of six sigma and Lean manufacturing, noted by 22.2% of the experts, were improved safety, sustainability, and time savings. One expert observed rapid improvements, but still suggested separate implementation because their firm had conducted sequential implementation using tools inclusive of the 5S, Kaizen, Poka Yoke, Small Group Projects, and Quality Circle procedures, which was then followed by the implementation of lean manufacturing and then six sigma methodology.

2.8. Integration of Lean, Green and six sigma principles

Many studies have proposed to integrate Green and Lean in order to reduce environmental wastes, but their integration has not helped organizations to achieve peak sustainability performance. Six Sigma has the capacity to address this gap. It offers a rigorous and disciplined structure for executing problem solving and improvement initiatives. In this context, the use of DMAIC (define-measure-analyze-improve) model can provide Green Lean with a more specific and holistic project-based orientation to the implementation of Green Lean initiatives (Banawi, 2014), (Garza-Reyes J. A., 2015). According to (Garza-Reyes J. A., 2015) the systematic, data and statistical driven characteristic of Six Sigma can complement the Green Lean approach and contribute in overcoming the limitations and challenges of this concept.

As lean tends to emphasize waste reduction, it provides a better atmosphere to deploy green philosophies, initiatives and tools. In this scenario, the similarity between the two seems logical, waste reduction. However, green goes beyond waste reduction as it is also concerned with process efficiency, reduction of material consumption and recycling, and similarly as all the quality improvement approaches, one of its ultimate objectives is to improve customer's satisfaction (Garza-Reyes G. M., 2014). Waste reduction concepts are different for lean and green. For lean methodology waste is any non-value adding activity to the products but, which adds costs. From green perspective, waste unsustainable utilization of resources (water, Energy, raw materials etc.).

Also, there are limitations in individual lean, green and six sigma approaches which were identified by evidences. For instance (Garza-Reyes G. M., 2014) states that, "Limitations of the pure lean approach include the fact that (1) none of its methods or tools control and monitor a process using statistical data, (2) they do not scrutinize variations in processes, which are utilized for making decisions, and (3) there are no practices associated with the use of quality and advanced statistical/mathematical tools to identify further problems still remaining in processes after waste has been eliminated". Lean methodology also, lacks a data driven approach to process improvement. An integrated green lean approach will not only confront the limitations of lean but also the limitations and challenges of the green approach (Nunes, 2010), (Garza-Reyes G. M., 2014).

The individual limitations and challenges of lean and green, also inherited by the integrated green lean approach, and the lack of methods or tools from the "other" concept (i.e. lean or green) to overcome these, calls for the integration of additional methods and tools capable of contributing to the reduction or elimination of these challenges and limitations. These "other" methods and tools can come from Six Sigma (Garza-Reyes G. M., 2014).

2.9. Research Gap

Many researchers introduced the simultaneous implementation of two or more of the methodologies such as Lean/Green integration, Lean/six sigma integration, Lean/six sigma/green etc. According to the reviewed articles, simultaneous implementation and integration of these methodologies dramatically improve the performance of businesses, service and manufacturing sectors.

However, none of the researchers tried to conduct a study and apply the integrated implementation of Lean, Green and six sigma methodologies to reduce solid material waste. Thus, this study is conducted to fill the research gap, to introduce and to apply the integrated implementation of these methodologies in material waste reduction and elimination. As a result, it is possible to create safe, clean, green, profitable, productive and conducive environment.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Definition and Purpose of the Case Study

According to (Yin, 2014), Case study research is the preferred strategy on inquiry when the questions associated to the research are “how” and “why” questions. The more that your questions seek to explain some present circumstance, the more that case study research will be relevant. The case study’s design serves a blueprint for the research and provides information in regards to what questions should be studied, what data is relevant, what data should be collected, and how results should be analyzed (Ellis, 2016).

As it was stated by (Gray, 2014), before a case study design is chosen, a researcher must determine whether the study will follow an inductive or deductive reasoning approach. Through the inductive approach, plans are made for data collection, after which the data are analyzed to see if any patterns emerge that suggest relationships between variables. This approach is used when cases do not start from a theoretical position, and observations from inductive approaches can be used to construct generalizations and theories. A deductive approach is used when the case study begins with a theoretical position and is confirmatory in nature. (Gray, 2014) .

This study is based on a case study research strategy and conducted on Adama agricultural machinery industry (AAMI) to study the current state of issues regarding to materials waste, to identify problems regarding to material waste management and provide alternative solutions for the identified problems using theories of Lean, Green and six sigma methodologies. Therefore, it follows the deductive reasoning approach, which relates the theoretical approaches of lean, green and six sigma principles to the real company case.

3.2. Methodology

The procedures used to complete this thesis work are presented as follows: Frist, data are collected using different sources and techniques. The past works related to lean, green and six sigma paradigms are reviewed and analyzed from different scientific articles. Other data are collected from the company. The data collection process from company has two phases, one is identifying and documenting the waste materials exist, the other is identifying the reasons for these materials waste. Second, the collected data are measured.

Finally, data are analyzed, the root causes of problems (materials waste) are identified, solution ideas are recommended and the model that converges the lean, green and six sigma principles is developed as a tool for materials waste reduction and the guidelines to implement the model are provided.

3.2.1. Data Sources and Collection Methods

Research uses data as the raw material in order to come to conclusions about some issues. It depends on the issue being investigated what data needs to be collected. Data come in two main forms, depending on its closeness to the event recorded. Data that has been observed, experienced or recorded close to the event are the nearest one can get to the truth, and are called primary data. Written sources that interpret or record primary data are called secondary sources, which tend to be less reliable (Waliman, 2011). Sources of primary data collection include surveys, questionnaires, interviews, and observations. Secondary data is published data and data that was collected in the past by someone other than the researcher. Sources of secondary data collection include published electronic sources, books, journals, periodicals, magazines, and newspapers (Ellis, 2016).

In this research both primary and secondary data are used to identify the waste materials exist and their root causes as well as, to make things suitable for generation of alternative solutions. The primary data are collected through direct observation, informal interviews, and focus group discussions methods. (Yin, 2014) States, "Case study evidence may come from six sources: documents, archival records, interviews, direct observations, participant-observations, and physical artifacts (Ellis, 2016).

Direct observation and informal interviews are used during waste material identification and documentation process, by physically presenting at the company. All waste materials from huge tractors to smaller metal scraps are documented by direct observation and, when additional information regarding to the subject matter is needed, informal interview with workers, operators and other stake holders is taken place. The list of these waste materials is documented on a check sheet prepared for this purpose.

Focus group discussion is needed to identify the root causes of each material waste type. In this session, four groups each contains six respondents [A focus group is a discussion group composed of a few chosen people (approximately five to nine) to talk about a selected subject (Issa Bass, 2009)] are assigned.

In each group, respondents are selected randomly from different departments, they include; Operators, Marketing personnel, Designers, Engineers and managers. Brainstorming session is conducted at different time for each group. Focus group discussion is used because, it is an easy way to generate more ideas as well as to control and understand the respondents' feelings. It is believed that, more reliable data are gathered through focus group discussions than questionnaires. As it was stated by (Margaret, Melissa B., 2009), in seeking a very complete response, interviews and focus groups are most likely to provide the depth of information that might be useful. Focus groups and interviews are also the best methods to resolve seemingly conflicting information, because the researcher has the direct opportunity to ask about the apparent conflict.

Totally ten questions are asked (Appendix I) and all respondents in each group are opined their ideas and feelings on the subject under study. The responses gathered from the focus groups are organized for analysis (discussed in chapter four).

The secondary data are collected from different websites, books, scientific journals, scientific articles, preceding reports, conference papers, and E-libraries which have related contents with the subject on hand (lean, green and six sigma principles). And also documents and archival records of the company are used to gather information about the company such as, background, services, products, suppliers, processes etc.

3.2.2. Data Measurement and Analysis

Data can be measured in different ways depending on their nature. These are commonly referred to as levels of measurement nominal, ordinal, interval and ratio. Nominal measurement is very basic, it divides the data into separate categories that can then be compared with each other. Nominal data can be analyzed using only simple graphic and statistical techniques.

Ordinal measurement puts the data into order with regard to a particular property that they all share, such as size, income, strength, etc. Precise measurement of the property is not required, only the perception of whether one is more or less than the other. In the interval form of measurement, the data must be able to be measured precisely on a regular scale of some sort, without there being a meaningful zero.

The ratio level of measurement is the most complete level of measurement, having a true zero: the point where the value is truly equal to nought (Waliman, 2011).

In this study, data are measured using nominal measurement method. In this case, the all documented waste materials are categorized into three groups (discussed in chapter four).

The data are analyzed using cause and effect diagram (CED) and failure modes and effects diagram (FMEA). Under this portion the root causes of each materials waste category are analyzed using CED and the waste categories are prioritized using FMEA. CED and FMEA are developed using mini tab V.17 and Sigmaxl V.8 Softwares respectively. After the root causes of materials waste and their effects (impacts) are identified, the solution ideas are provided to mitigate the currently existing waste materials.

3.3. Research Approach

(Creswell, 2014) Informs us that “research approaches are plans and the procedures for research that span the steps from broad assumptions to detailed methods of data collection, analysis, and interpretation”. There are three approaches to research: quantitative, qualitative, and mixed methods. A qualitative approach uses verbiage to interpret findings, but a quantitative approach uses numerical data to interpret and report findings. A mixed method approach combines quantitative and qualitative approaches (Ellis, 2016).

Quantitative data can be measured, more or less accurately because it contains some form of magnitude, usually expressed in numbers. Observation notes, interview transcripts, literary texts, minutes of meetings, historical records, memos and recollections, documentary films, are all typical examples of qualitative data. Also qualitative data rely on human interpretation and evaluation and cannot be dispassionately measured in a standard way (Waliman, 2011).

The data used in this study are qualitative in nature, generally expressed and described in words rather than in numerical approaches. It is difficult to quantitatively measure or to count and get the real quantity of materials waste at the company, because huge amount of materials are accumulated and disposed as scraps. Also, it is not allowed to count or to get the quantity of materials due to confidentiality. So that, the qualitative research approach is employed.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Introduction

In this chapter two main parts of discussion are presented. The first one is the discussion on the case study conducted on Adama agricultural machinery industry (AAMI) and the second is discussion on the model proposed to reduce materials waste. In the case study, current problems on going in the company (materials waste) are discussed, the root causes of these problems are identified and the control actions (solutions) are presented. A model composed of lean, green and six sigma principles, is developed to solve the identified problems from their root. Applicability of the model in case of real company is discussed, the critical success factors required implement the model and the recommended tools of LGSS are presented.

4.2. Case study

4.2.1. Definition of the current problems

According to lean manufacturing philosophy, waste is defined as anything that adds no value for the customers and other stakeholders instead, it adds cost and time. From this perspective, it is possible to declare materials that currently do not add any value for the company and customers but, adding the costs of storage and movement from store to workshops and vice versa, until they are sold or delivered to their end users or removed by for another purposes.

It is believed that, Adama Agricultural Machinery Industry (AAMI) is playing a great role in transformation of Ethiopian agriculture from traditional to mechanized system.

However, its material management is not to the standard of modern manufacturing system. Very large amount of materials (which are difficult to count and reach on their quantity), are accumulated, stored and disposed. They include; raw materials, finished/end products, used materials, damaged materials (raw materials and end products) and scrap materials.

The following five problem statements are developed based on some data obtained by direct observation that show an ongoing situation.

1. Accumulation of materials is adding costs of storage and movement (between shop and store) and tied up the working capital.
2. The materials are damaging and losing due to mechanical, chemical and environmental factors. Mechanically, raw materials and end products can be broken or cracked due to unnecessary motion from store to workshop and vice versa.

3. Chemically, due to large storage time, parts and spare parts of raw materials and end products can be attacked by wear and corrosion. Environmentally, due to improper storage, materials are exposed to extreme weather conditions, dust contamination and leakage.
4. Due to low quality of products the customers lose interests to buy the products, instead they start searching for other companies which can satisfy their specifications and expectations.
5. The disposed materials have negative impacts on the environment because, some toxic materials may exist.
6. Due to accumulation and storage of these materials large amount of space is occupied.

(a) (b)

Figure 4.1 Samples of finished products (photo taken from AAMI).

(a) (b)

Figure 4.2 Samples of Raw materials (photo taken from AAMI).

(a) (b)

Figure 4.3 Samples of Scrap materials disposed (photo taken from AAMI).

(a) (b)

Figure 4.4 Samples of damaged products (photo taken from AAMI).

4.2.2. Goal statement

The following goal statements are developed as a direct reflection of problem statements.

1. Reducing material losses.
2. Reducing the damage of end products and raw materials.
3. Satisfying and properly responding the customers' needs and expectations.
4. Reducing environmental hazards.
5. Reducing unnecessary space occupation and managing the stock properly.
6. Reducing costs incurred by materials waste.

The goal statement provides the counter measures that should be taken to fill the gap between current situations and the requirements or critical to quality (CTQ). CTQ analysis is used to determine what needs to meet the actual customers' requirements. CTQ tree is one of the tools used in define phase of six sigma projects to relate the current needs with the CTQ.

In this study, the specifications of Lean, Green and Six sigma methodologies are used as critical to quality and the CTQ tree is developed as shown below.

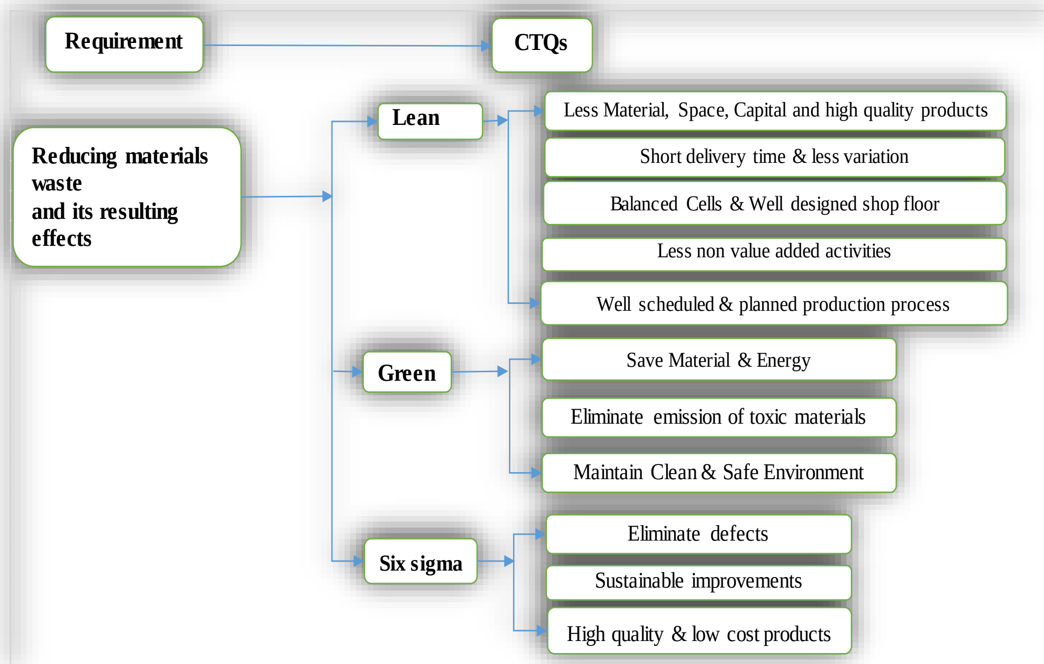

Figure 4.5 CTQ tree (Source: Author).

Figure. 4.5. Illustrates the transition of requirements/goals of this study to the Lean, Green and six sigma requirements. The requirements of this study are reducing materials waste and its' all negative effects. The most critical requirements are attaining at the norms and requirements of Lean, Green and six sigma.

4.2.3. SIPOC Diagram

SIPOC Diagram describes the transformation process of inputs form suppliers to output for customers & gives a high level understanding of the process, the process steps (sub processes) and their correlation to each other.

The five key components of a SIPOC diagram are:

1. Suppliers:- The providers of raw materials, services, and information used in the process to generate the values/products sold to customers.

2. Inputs:- The actual services, raw materials, and information used to create the values/products sold to customers.

3. Process:- The sequence of events used within the organization to transform the raw materials and serviced into value.

4. Outputs:- The value/product created by the organization to satisfy customers' demands.

5. Customers**:-** The users of the value/product created by the organization.

The SIPOC diagram for AAMI is developed; it illustrates the manufacturing processes of different power capacity Tractors and different discharge capacity pumps as shown below. Figure. 4.6. Illustrates the current flow of materials from suppliers to the customers through AAMI. The suppliers include; Awash Auto Batteries Plc., Hebex GMBH, Industrija Motora Rakovic U, Minsk Tractor Works Spare Parts and Nardi S.P.A. The inputs are all parts, spare parts and accessories of tractors and water pumps. The processes are; accepting the inputs from the shipment, stocking for certain time period, assembling, inspecting, and stocking the finished products until new orders come. Finally, the products are reconditioned and reach at the customers' hand. The out puts of AAMI are different size and power capacity tractors with their all implements as well as, different types and discharge capacity water pumps. The customers buying and using the products of AAMI include: Amhara Seed Enterprise, Ethiopian Road Authority, Ayou Ziginin Farm, Coffee Plantation, Ethio Agri-Ceft, Ethiopian Agriculture Research Institute, Ministry of agriculture, Ethiopian Seed Enterprise, Seka Agro Processing, Sugar Corporation and Universal Road Authority.

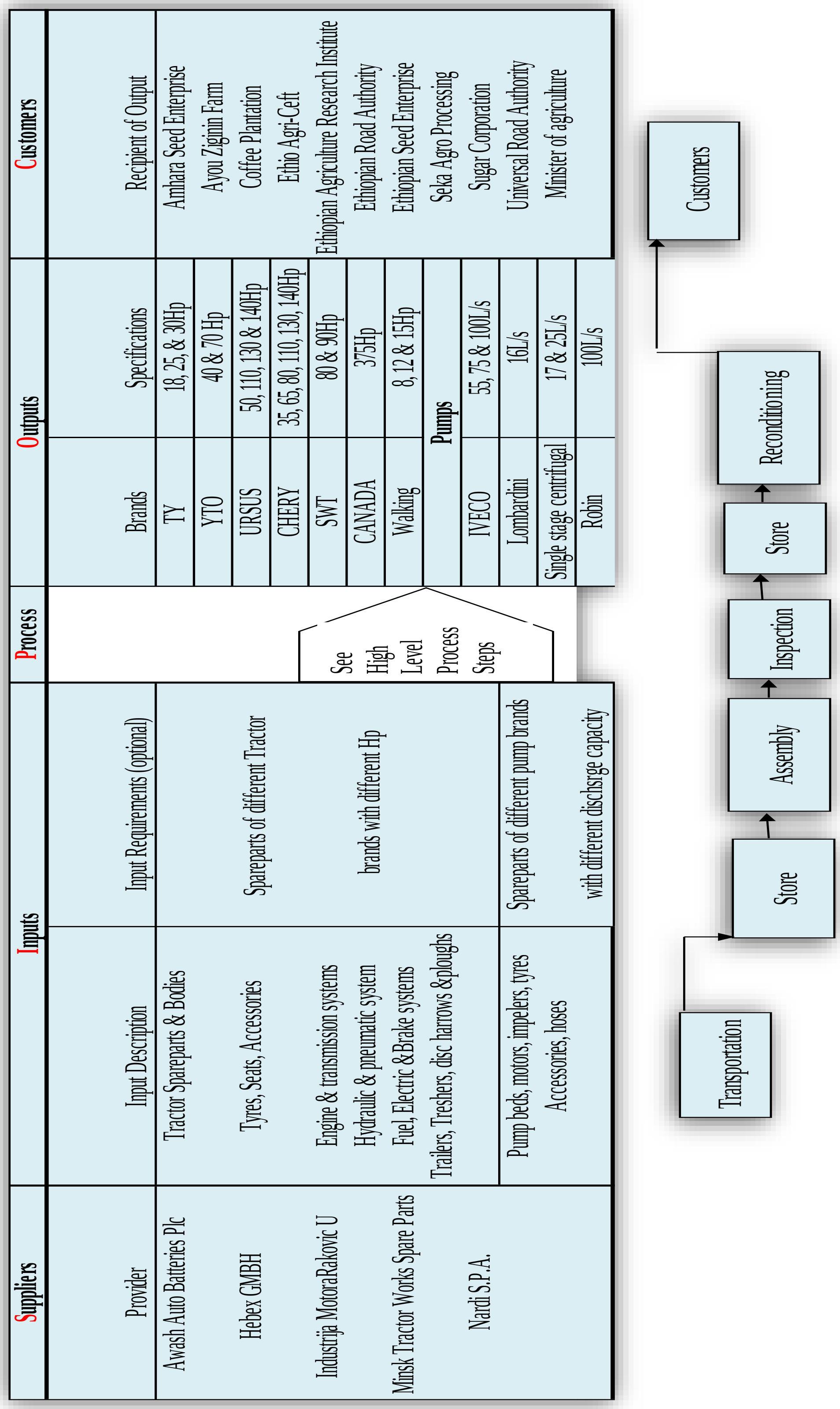

Figure 4.6 SIPOC Diagram developed to describe the materials flow (Source: Author).

4.2.4. Process Mapping

Process map illustrates the detail of materials flow in the manufacturing process, source of process inefficiencies and the functional relationship between the process and data to be collected. The detailed process map is a more in-depth version of the process map developed during the Define Phase. The detail process map of the current tractor assembly for AAMI is developed as shown below on figure. 4.7.

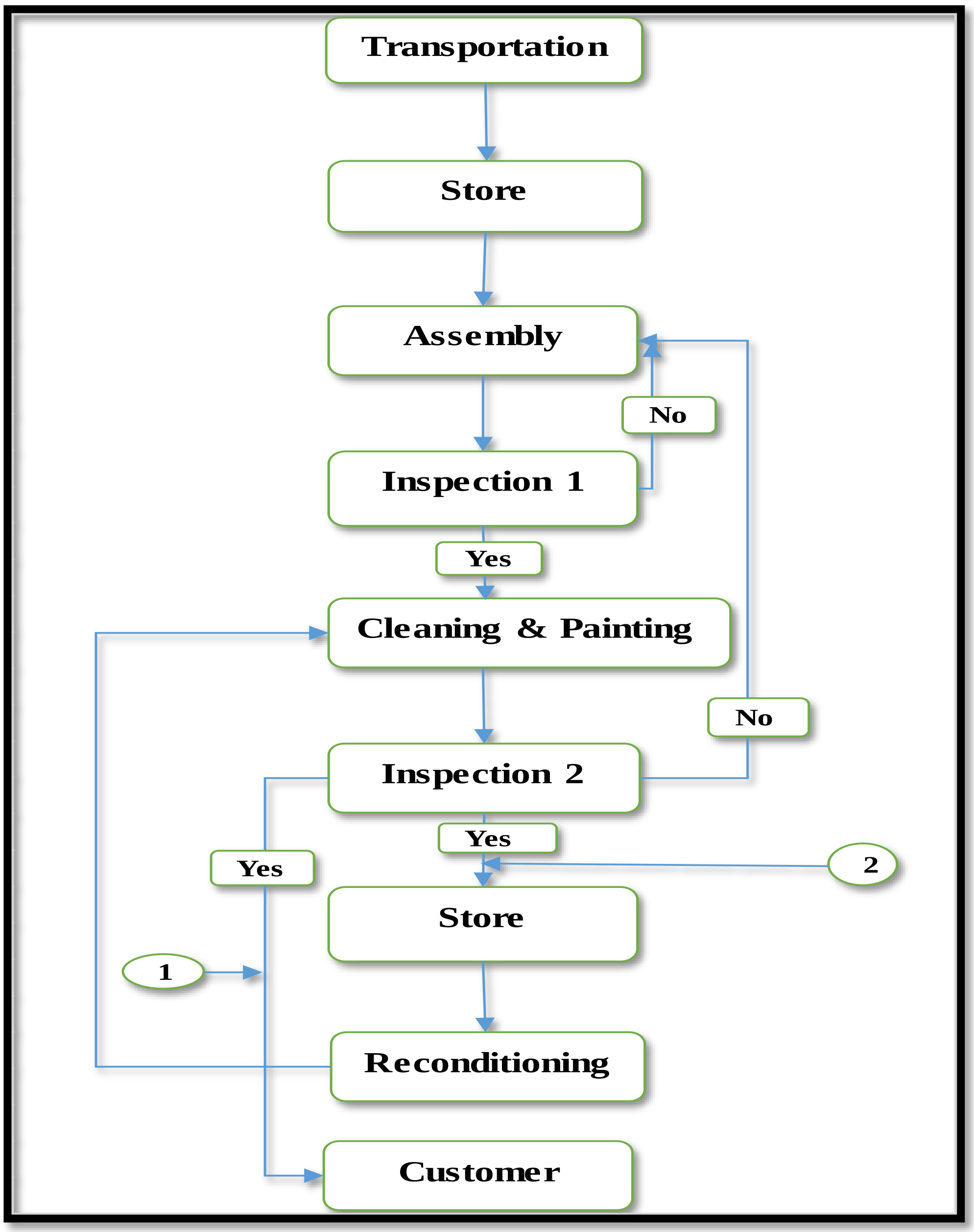

Figure 4.7 Process map of Tractor manufacturing.

The above figure briefly illustrates the sequence of materials flow from shipment to the customers for the assembly of different types and power capacity tractors. The process map, already prepared by the company is not allowed for external use because of confidentiality, so that, the above process map is developed by the researcher using certain data gathered through direct observation and informal interview.

First the raw materials (tractor parts) are transported to the store and stay there until, the material (product) previously on process leaves the space or until new orders come. Then, it moved to assembly shops; after assembling of tractor parts and installation of different accessories, the assembled tractor is moved to the first inspection room and the functionality of all parts is checked. If any problem is detected, then it moved back to assembly room to be reassembled. If there is no problem detected and all parts are functioning well, it moved to the next step for cleaning and painting.

After cleaning and painting process the product is brought to the second inspection room. If a problem is detected during the second inspection time, again it moved back to the assembly step to be reassemble and rechecked. But, if there is no detected problem, the product passes through either of the two lines labeled by (1) and (2) (refer figure. 4.7). If an order come when the product is leaving the second inspection step, or if the process is already started by accepting an order, it directly delivered to the customer (buyer) by passing through line(1). But, if no order is available just when the product leave second inspection step, or if the process is proceeding without order or if the customer changes his/her idea after the production is started, then the product is moved to the store until next orders come. When new orders come after certain time, the product go to the reconditioning shop. During reconditioning process the product is rechecked, the damaged parts are replaced by new parts and finally, reached at the customer's hand after cleaning, painting and inspection processes.

4.2.5. Data Collection and Measurement

In this section, the detail of all idle materials from larger tractors to very small metal scraps are documented on a check sheet prepared for this purpose (Appendix II). Direct observation and informal interview methods are applied to develop this task.

Since categorization is one technique of data measurement, waste materials documented previously are categorized into groups based on their current functions and status.

As it was stated on (Kumar, 2006) book, “Material Wastes can be categorized into obsolete, surplus and scrap items.” Therefore, the documented waste materials are divided under the three categories. Before categorizing these materials, it is necessary to define and clarify what these terms mean i.e. surplus, obsolete and scrap items.

Surplus materials:- (Kumar, 2006) defined surplus items as, “materials and equipment which have no immediate use but have accumulated due to faulty planning, forecasting and purchasing. However, they have a usage value in future.” These items can be raw materials or spare parts which are waiting to be processed or finished products waiting to be sold in the future. Currently they do not add any value for the company and customer, instead they add storage cost to the company.

(a)

(b)

(c)

(d)

Figure 4.8 Surplus materials (photo taken from AAMI).

Obsolete materials:- (Kumar, 2006) defined obsolete items as “materials and equipment which have economic worth but are no longer useful for the Company’s operation owing to many reason such as, changes in product line, process, materials, and so on.” Production and processing methods, as well as designs and materials are changed and modified from time to time as technological advancements increase based human interests.

Products that produced before occurrence of these changes are considered as obsolete items. Because they do not needed by the customers more. After certain period of time, surplus materials become obsolete.

Sometimes products become defective or damaged or inefficient and then could not meet the customers' specifications, then they are declared as an obsolete materials. Also sometimes wrong spares and raw materials are purchased and rejected, these items are also declared as obsolete.

(a) (b)

(c) (d)

Figure 4.9 Obsolete materials (photo taken from AAMI).

Scrap materials:- (Kumar, 2006) defined scrap items as "process wastage, such as, turnings, borings, sprues and flashes. They may have an end-use within the plant having commercial values."

Scrap materials may include;

- ✓ The residue of raw materials or pieces cut out during manufacturing processes,
- ✓ Worn out raw materials, spare parts and products during manufacturing process, material movement and transportation,
- ✓ Rejected components,

- ✓ Non-returnable containers,
- ✓ Pallets and different packing cases,
- ✓ Deteriorated obsolete items because of wear and corrosion attacks for a long time.

(a)

(c)

(b)

(d)

Figure 4.10 Scrap materials (photo taken from AAMI).

The all documented materials categorized as shown on table below.

Table 4.1 Illustrates Category of Waste materials.

Surplus materials	Obsolete materials	Scrap materials
Tractors(new)	Tractors(old)	Wheels
Tractor tires(new)	Tractor tires(old)	Worn out Tractor Engines
Disk arrows(new)	Disk arrows(old)	Metal scraps/fragments
Ploughs(new)	Ploughs(old)	Crank shafts
Tractor engine(new)	Tractor Engines(old)	Oil tanks
Tractor body(new)	Tractor body(old)	Pistons
Pumps(new)	Pumps(old)	Gears
Walking(new)	Walkings(old)	Engine blocks
Trailers(new)	Worn out trailers	Axles
Structural steels	Water tanks	Cylinders
Pump beds	Non-functional vehicles	Thrashers
Pump tires	Damaged & defective tractors	Gear boxes
Pump motors		Cylinder heads
Thrashers		Wooden packs/boxes
		Angle irons
		Structural steels
		Shafts
		Tractor seats
		Bolts
		Bearings
		Barrels

4.2.6. Root Cause Analysis

The root causes of each waste category are identified through focus group brainstorming. The responses of participants against the asked questions (Appendix I), are presented on Appendices III, IV, V and VI.

To generalize the responses of participants, raw materials are stored because of:

- Fear of market inflation and raw materials shortage;
- To use some discount opportunities;
- Assuming to reduce lead times;
- To produce large batch size;
- Lack of market network;
- Lack of well-organized planning and forecasting;

- Knowledge gap;
- Assuming to control production interruption and to access materials easily;
- Purchasing parts without understanding the current customers demand;
- Bottlenecking and
- Lack of research and technological advancements.

Finished products are stored/accumulated because of:

- Lack of market networks and advertisements;
- Customers' requirement of better products;
- Overproduction and production without understanding the current demands;
- Knowledge gap on planning, forecasting and marketing;
- Assuming to prevent parts damage;
- Assuming to deliver ready made products;
- Imported parts are produced without considering the country's climate, soil type and altitude;
- Lack of communications;
- Customers' lack of awareness and financial capacity to buy the products.

These participants' opinions (appendix III and IV) are considered to be the root causes of surplus materials waste. Finally, these responses are merged and organized under market, material, personnel, plan, method and environment labels and displayed by cause and effect diagram as shown on figure. 4.11.

The root causes of obsolete materials generation and accumulation are:

- Shortage of spare parts;
- Damage of materials during movement and in the stock;
- Introduction of new materials, designs and products;
- Wear and corrosion attack of surplus materials;
- Completion contract terms with raw material suppliers;
- Defect and under qualification of finished products;
- Purchasing of wrong materials;
- Long time storage of surplus materials;
- Lack of organized materials management;
- Customers demand to new and better products;

- Lack of safety for materials;
- Planning, forecasting and marketing problems.

The root causes of obsolete materials waste are organized under market, material, personnel, plan, method and environment labels and displayed by cause and effect diagram as shown on figure. 4.12.

The reasons why scrap materials are accumulated and disposed are:

- Breaking and complete failure of parts and equipment;
- Defects and under qualification of parts;
- Lack of attention and measurement error;
- Wear and corrosion attack;
- Chips of machining, drilling and cutting;
- Deterioration of obsolete materials;
- Wrong and mismatched parts;
- Maintenance and replacement of damaged parts;
- Knowledge gap and lack of interest to handle materials properly;
- Lack of training and experience sharing practices with other companies.

The root causes of scrap materials waste are organized under Measurement, Materials, Personnel, Method and Environment labels of cause and effect diagram as displayed on figure. 4.13.

Data obtain from direct observation and brainstorming session indicates that, due to long accumulation period, surplus materials deteriorated to obsolete and obsolete materials deteriorated to scrap as wear and corrosion attacking of materials is lasting for long time.

4.2.6.1. Cause and Effect Diagram

The root causes of each waste category listed during brainstorming session are organized and displayed using a Lean-six sigma tool called cause and effect diagram.

A cause and effect diagram, often called a "fishbone" diagram, can help in brainstorming to identify possible causes of a problem (materials waste) and in sorting ideas into useful categories or labels as, man, machine, method, measurement, mother environment and others.

Root causes of Surplus materials waste

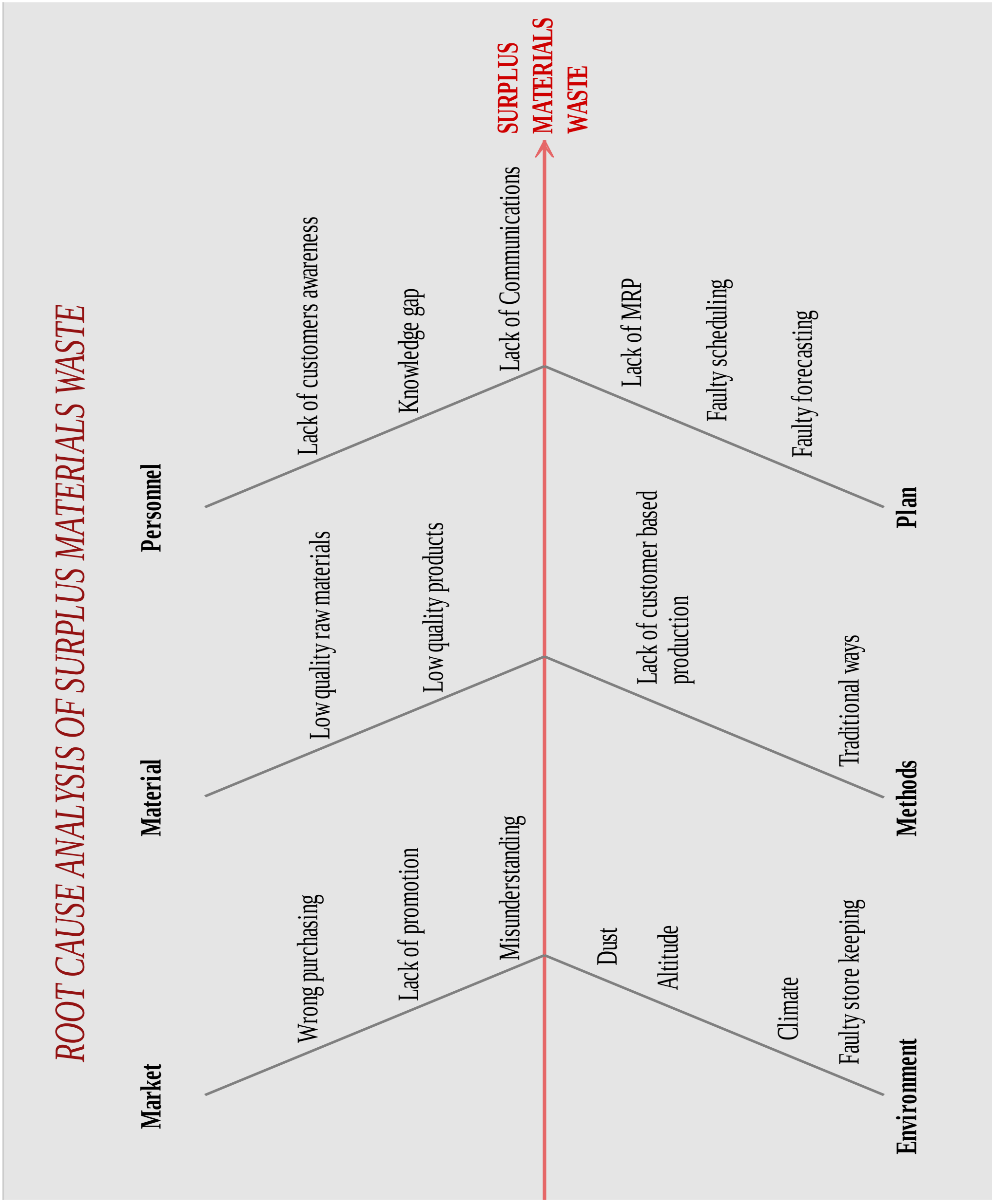

Figure 4.11 Cause and Effect diagram developed for surplus materials waste.

Figure. 4.11. Illustrates the root causes of surplus (raw materials and finished products) materials waste. This shows that, problems related with market, materials, personnel, environment, planning and production methods are the causes of surplus materials waste. This cause and effect diagram is developed based on responses of focus groups respondents. Minitab V.17 is the tool used to design the cause and effect diagram.

Root Causes of Obsolete Materials Waste

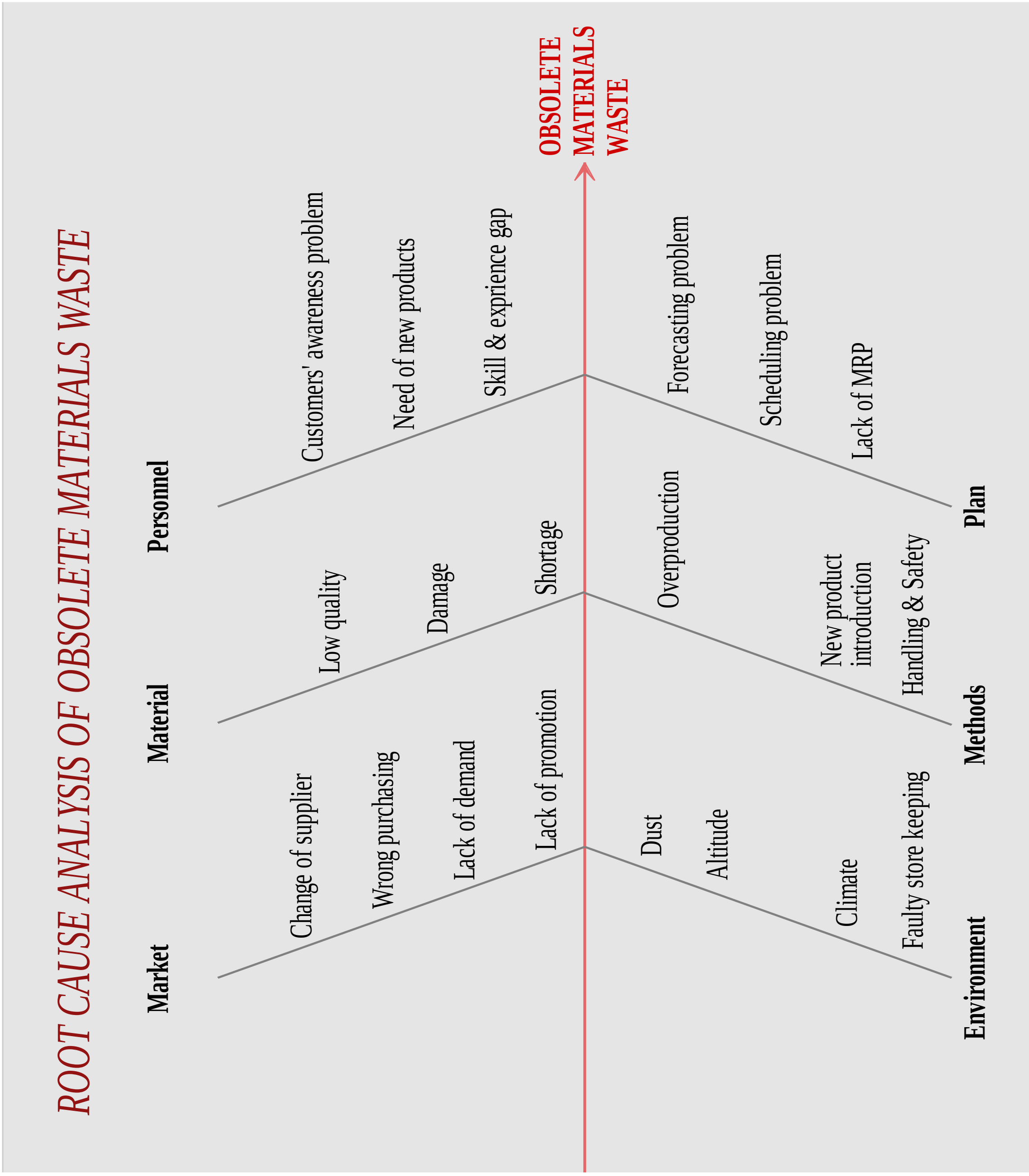

Figure 4.12 Cause and Effect diagram developed for obsolete waste materials.

Figure. 4.12. Illustrates the root causes of obsolete materials waste. This cause and effect diagram is developed based on responses of focus groups respondents. It implies that, problems related with market, materials, personnel, environment, planning and production methods are the causes of obsolete materials waste. Minitab V.17 is the tool used to design the cause and effect diagram.

Root Causes of Scrap Materials Waste

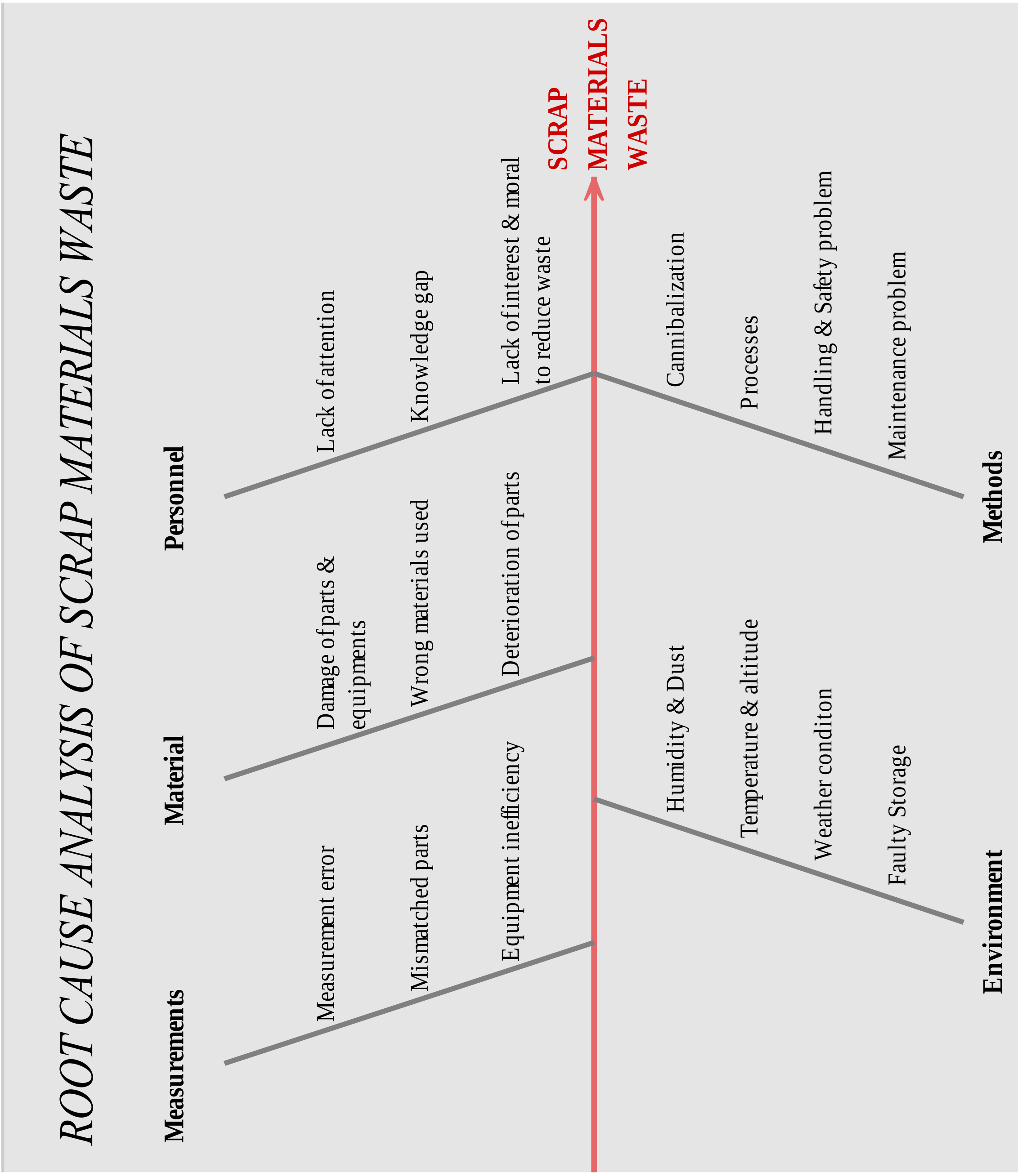

Figure 4.13 Cause and Effect diagram developed for scrap materials waste.

Figure. 4.13. Illustrates the root causes of scrap materials waste. Accordingly, the problems related with measurement, methods, man, environment, and materials are the causes of scrap materials waste. This cause and effect diagram is developed based on responses of focus groups respondents. Minitab V.17 is the tool used to design the cause and effect diagram.

4.2.6.2. Failure modes and Effects Analysis

(Issa Bass, 2009) described failure modes and effects analysis (FMEA) as "A graphical presentation of an FMEA is generally a representation of two combined matrices: on one side is the failure mode and effect part, which consists of developing a list of all the causes of the potential failures and their effects on the overall process or product, and on the other side is the action plan, which determines what needs to be done to prevent the failures from materializing. FMEA have the following components;

1. Potential failure mode:- Potential failure mode describes the way in which the corresponding item listed in the process step or product function could possibly fail to satisfy its intended purpose.
2. Potential effect of the failure:- Potential effect of the failure describes the impact of the failure on the functionality of the product or process (Issa Bass, 2009).
3. Potential causes of the failure:- This describes the flaws of the design that may lead to a potential failure
4. Severity:- The severity measures how critical or serious a potential failure can be on the product or process. If the failure is so serious that it can stop production, it is graded 10 and if it is very easy to correct, it is graded 1.
5. Detection:- Detection is a measure of the ability to detect preemptively the failures. If the potential failure is easy to detect, the grade should be low (1 for very easy to detect and 10 for very hard).
6. Occurrence:- The occurrence measures how often the failure is likely to happen. The likelihood of an occurrence is expressed in ranking from 1 to 10 (1 for rare and 10 for often).
7. Current control:- Current controls are known preventive controls that are currently being used in similar processes or products.
8. Risk priority number:- The risk priority number (RPN) helps to rank the failures and establish their precedence for problem resolution considerations. The RPN is the product of the severity, detection, and occurrence levels. The higher the RPN, the more attention that particular step of the process or that characteristic of the product should get.
9. Recommended actions:- The recommended preventive actions are generally suggested by the FMEA team during a brainstorming session (Issa Bass, 2009).

To prioritize the materials waste failure modes and effects analysis (FMEA) is used. Waste prioritization is used to rank wastes according to their severity and then generate alternative options to mitigate the impacts of these waste types. Thus, FMEA is a best tool to perform this task. FMEA on figure 4.14 below displays the detail of potential modes, potential effects, potential causes, severity, occurrence, detection, RPN, current control and recommended actions for surplus, obsolete and scrap materials waste.

The FMEA below indicates failure modes or the ways in which these waste categories are failed to meet the requirements. Accordingly, surplus waste materials can be failed in modes of Inventory, Overproduction, Transportation, Unnecessary motions, Over-processing and Waiting. Raw materials are purchased without identifying customers' demand and products are produced without order, this results excess inventory and overproduction. Due to unplanned production system, there will be transportation and unnecessary motions between store and workshops. Raw materials move from store to workshops then, products move from workshops to store in the absence of orders from customers. Such movements add no value for customers and company, even, it incur cost on the company. Due to unplanned production, there is rework and reconditioning which do not add value for customers and company. The produced products are stored and waiting for customers order to be sold, and also raw materials are stored and waiting until the previously in line materials leave positions, to enter the processing line. This also incurs the inventory cost and shorten the materials life.

Obsolete materials can be failed in modes of Inventory and defects. This waste category is accumulated and occupied more space which leads to inventory cost. On other hand, it do not meet the customers' requirements so that, they can be considered as defective materials.

Scrap materials can be failed in inventory, defects and environmental effect modes. This waste category occupied more space which leads to inventory cost and do not meet customers' needs as a result, it can be considered as defective materials. Also they may contain toxic materials which can affect the environment.

The responses of focus group participants described on Appendices III, IV, V and VI are used as potential causes of failure (material waste) in FMEA below.

Waste Category	Potential Failure/Waste Mode	Potential Effects of Failure/Waste	Severity (1-10)	Potential Cause(s) of Failure	Occurrence (1-10)	Current Controls	Detection (1-10)	Risk Priority Number (RPN)	Recommended Action
Surplus	Inventory Overproduction Transportation Unnecessary Motion Over-processing Waiting	Occupy more space Tie up the working capital Reduce quality of products Add storage cost Add movement cost Product damage Reduce product life Customer dissatisfaction Loss of customer interest from the products Interruption of sells Interruption of production	8	No organized MRP Faulty planning Faulty forecasting (incase ideology) Purchasing raw materials without identifying the current demand Producing large batch size Unreliable production methods Unstable schedules Unbalanced cells Inaccurate information about current demand Production without order Lack of market promotion & network	10	Tried to sell products with minimum price.	1	80	Promoting the products using public media; Producing & purchasing what customers want only (avoid incase mentality); Creating awareness & means of communication with customers; Producing with plan & schedule; Selling idle materials by discount price; Working on quality rather than quantity; Giving trainings & short term courses on planning, forecasting & marketing for respective departments personnel; Using kyzien principles.
Obsolete	Inventory Defect	Occupy more space Add storage cost Tie up working capital Add movement cost Material loss	7	Wrong material & design selection Damage of surplus items Wrong purchase practise Wrong material management Cannibalization & lack of spare Wrong store keeping Underqualification of products Change of raw materials supplier Long time storage of surplus Introduction of new material & design	9	No action taken	1	63	Purchasing right materials; Keeping & handling materials in a safe way; Salvaging; Providing for educational institutions; Always understanding what customers really want.
Scrap	Inventory Defect Environmental effects	Occupy more space Add storage cost Add disposal/transportation cost Material loss Environmental hazards	6	Breakdown of parts on motion Trashes of machining, offcuttings, etc Maintenance & measurement errors Cannibalization Deterioration of Obsolete items Wear and corrosion Used pallets Used office materials/equipments Wrong purchased spare parts	3	Selling the scraps to metal processing organizations	1	18	Salvaging; Selling for byproduct users; Providing or Selling for surrounding society for energy purposes; Reuse for the company purpose; Working on reduction of materials damage & keeping safety; Careful processing & measurements. (Reduce, Recover, Reuse, Recycle).

Figure 4.14 FMEA developed to describe surplus, obsolete and scrap waste materials (Source: Author).

The potential effects of surplus waste materials include:

- Occupy more space;
- Tie up the working capital;
- Reduce quality of products;
- Add storage cost;
- Add movement cost;
- Product damage;
- Reduce product life;
- Customer dissatisfaction;
- Loss of customer interest from the products;
- Interruption of sells;
- Interruption of production.

The potential effects of obsolete materials waste include:

- Occupy more space;
- Add storage cost;
- Tie up working capital;
- Add movement cost;
- Materials loss.

The potential effects of scrap materials waste include:

- Occupy more space;
- Add storage cost;
- Add disposal/transportation cost;
- Materials loss;
- Environmental hazards.

The current action taken to control surplus materials waste is, the company tried to sell the products with minimum cost. For obsolete waste materials reduction currently, no action is taken. For scrap waste materials, scraps are selling to metal processing organizations.

Severity, Occurrence and Detection scores are given based on the guidelines of Automotive Industry Action Group AIAG (PFMEA 4^{th} edition.) and six sigma, taken from Sigmaxl V.8 software (Appendix VII, VIII & IX). Accordingly, for Surplus waste; Severity=8, Occurrence=10 and Detection=1 is given. To justify the above scores, the potential effects of Surplus waste materials are very serious and can stop the production process. From 10 produced products at least 1 product enter the store and from 10 purchased raw materials almost all of them enter the store. This problem is obvious and do not need another means of detection. For Obsolete waste materials; Severity=7, Occurrence=9 and Detection=1 are given.

For Scrap waste materials; Severity=6, Occurrence= and Detection=1 are given.

The RPN results are; 80, 63 and 18 for Surplus, Obsolete and Scrap waste materials respectively.

From this, Surplus waste materials have highest RPN which indicates, this waste category is the most severe and need an immediate action to fix. Figure 4.15 below, illustrates the RPN of waste categories.

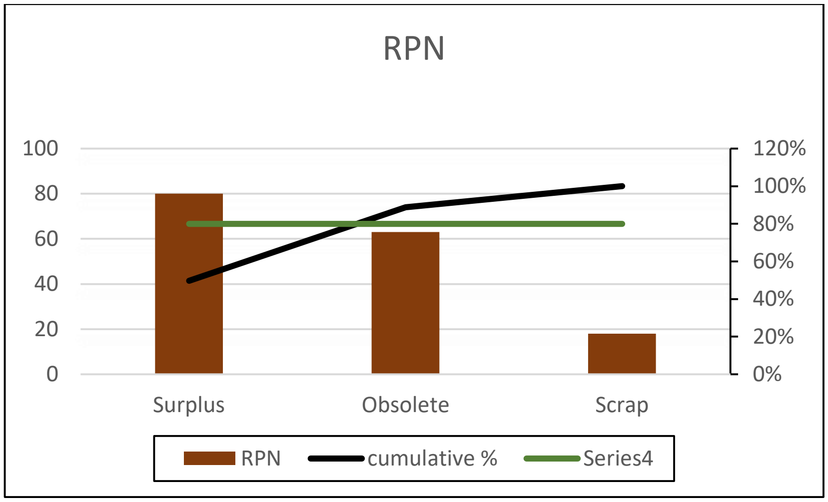

Figure 4.15 RPN of each waste category.

The recommended control actions for surplus waste materials are:

- Promoting the products using public medias;
- Producing & purchasing what customers want only (avoid incase mentality);
- Creating awareness & means of communication with customers;
- Producing with plan & schedule;
- Selling idle materials by discount price;
- Working on quality rather than quantity;
- Giving trainings & short term courses on planning, forecasting & marketing for the respective department personnel;
- Using kyzien principles.

The recommended control actions for obsolete waste materials are:

- Purchasing right materials;
- Keeping & handling materials in a safe way;
- Salvaging;
- Providing for educational institutions;
- Always understanding what customers really want.

Finally, the recommended control actions for scrap materials include:

- Salvaging;
- Selling for byproduct users;
- Providing or selling for surrounding society for energy purposes;
- Reuse for the company purpose;
- Working on reduction of materials damage & keeping safety;
- Careful processing & measurement.
- Generally, (Rethink, Reduce, Recover, Reuse and Recycle).

4.3. Integrated LGSS Model for Materials Waste Reduction

Moreover, until now, a generic framework to integrate Lean, Green and Six Sigma to guide companies of any industrial sector and size to improve their sustainability performance has not yet been proposed. Consequently, a contemporary research problem in the area of Green Lean Six Sigma is to effectively integrate and implement Green and Lean Six Sigma in companies with different processes and organizational cultures (Cherrafi, 2017).

To minimize materials waste as well as to stay the company in the world of competition the following model is developed as a general improvement option. Using this model as a tool to control materials waste, the material oriented problems currently exist in AAMI will be solved. Figure 4.16 below, illustrates the LGSS model developed to reduce materials waste of AAMI. The model converges the principles of lean, green and six sigma. Before implementing this model it needs motivation and awareness of all employees from higher managers to low level workers. Employees should have an interest to learn the LGSS principles and be aware of them. Awareness is created through providing trainings, short courses, educational opportunities, experience sharing with other organizations those were practiced and familiar with the methodologies etc. and employees can be motivated through empowerments, assigning peoples to their right positions, providing incentives and awards as well as providing educational opportunities. Without implementing the whole philosophies of LGSS, the company able to solve the current problems using this model.

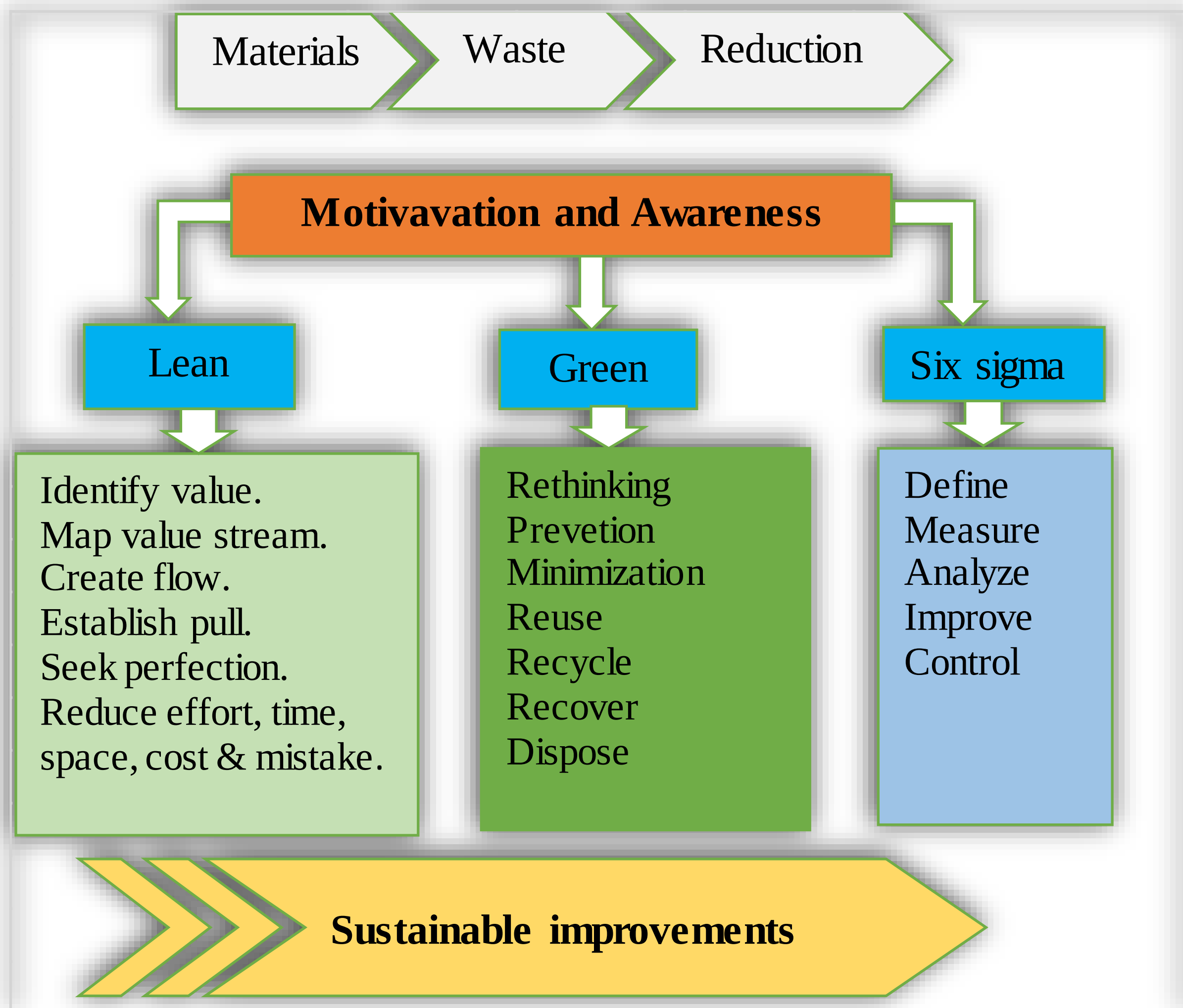

Figure 4.16 An integrated model of lean, green and six sigma principles.

4.4. Critical success factors to implement lean, green and six sigma model

Critical Success Factors are those factors necessary or preconditions to the successful implementation of certain initiatives, in the sense that, if goals associated with the factors are not achieved, the implementation of the initiative will perhaps fail catastrophically. The challenge to implement Green Lean Six Sigma is to recognize how to integrate Lean Six Sigma and Green as a systematic approach and identify the best way to sustain the results. Thus, the determination of CSF is critical as it helps organization to focus their efforts and resources on these factors to increase the chance of success (Cherrafi Anass, 2016b).

Accordingly, the following factors are the key to the successful implementation of LGSS, as it was stated by (Cherrafi Anass, 2016b).

1. Organizational readiness to implement Green Lean Six Sigma

It is important to first understand the preparedness of an organization to implement Lean Green Six Sigma initiative. This action increases the probability of success of the project before an organization invests its resources heavily on the strategy. It is suggested that, a company should identify its weaknesses, strengths and understand its own maturity level in to evaluate their own positioning in the LGSS journey.

2. Project selection and prioritization

Project selection methodology helps organization to prioritize the project that will give the best return. In addition, selection of the right project will develop confidence in management and employees towards the LGSS strategy. This in turn will encourage organization to invest and take future efforts into the initiative.

3. Commitment of Top Management and Employees

While it is possible to build management support from the bottom up through pilot projects, securing top-down management commitment helps to ensure the long-term success of LGSS efforts. Top management must define the vision, strategic direction and develop an organization culture that promotes continuous improvement in order to improve sustainability performance. According to (EPA, 2006) Management can show support through the following types of activities:

- Invest in LGSS training.
- Provide resources, tools and incentives to enable employees to succeed.
- Include LGSS concepts in speeches, newsletters and other communications.
- Set performance goals and objectives related to LGSS.
- Track LGSS progress and hold individuals accountable for meeting those objectives.
- Recognize and reward LGSS accomplishments.

4. Communication

Different stakeholders may have misunderstanding about the Green Lean Six Sigma initiative and their impact on sustainability performance. Only through effective communication, stakeholders will be more engaged and the employees can work as a team for solving different sustainability problems which facilitate the Green Lean Six Sigma implementation.

5. Resource and skills to facilitate implementation

The employees should be able to understand and use the Lean Six Sigma tools and techniques into daily operations in order to improve sustainability performance. Team members should be given the necessary resources (financial and technique) and adequate time to implement and execute a project which results in improved economic, environmental and social performance.

6. Focus on measurement and results

The performances of LGSS should be measured and evaluated. The measurement system allows any influencing parameters to be detected and can serve also as a basis for decision making. In addition, organization should to keep in mind that Green Lean Six sigma is not about tools or methodologies. It is about improving sustainability performance and outcomes in order to achieve better results. In this context, top management should make sure results are the cornerstone of any messaging about the initiative.

4.5. Applicability of LGSS model in the real case of AAMI

None of three methodologies were adopted in the company till now, this makes difficult and long journey to implement the proposed model. It takes a long time to implement at the maturity level and to assess the performance of the model. However, it is possible to successfully implement the model through the adoption of the key success factors discussed above. First the company should invest on awareness creating, cultivating and managing knowledge on the issues under study, and transforming the previous production culture to LGSS norms. Also the company should clean the way to implementation of the model, the current waste materials should be removed in a proper way using Green manufacturing strategies, 5Ss, and other tools. Then, production should be proceeded based on lean principles of this model.

It consists of the following Guide lines:

- **Identifying value**; the exact product that meet customers' need regarding to quality, delivery time and cost.
- **Mapping value stream**; establishing sequence of activity line from supplier to customer.
- **Creating a flow;** materials and information should be flow through the system.
- **Establishing Pull;** producing when customer need it only, avoiding incase mentality.
- **Seeking Perfection;** removing NVA from the production processes, enhancing flow
- **Reducing** lead times, efforts, space, costs and mistakes as much as possible.

When the model is implemented, production processes proceed based on the lean manufacturing principles, quality products are produced, and if all purchased as well as produced items have quality no material is rejected and disposed as a waste.

The six sigma principles provide an insight to identify and analyze problems from its root, through systematic, data driven and statistical methods. According to (EPA, 2009), Six Sigma methods are used to support and guide organizational continual improvement activities. By using Six Sigma statistical tools, companies are able to diagnose the root causes of performance gaps and variability, thereby improving productivity and product quality.

The green principles provide an alternative actions to be taken on the problems identified and analyzed through six sigma principles. These options, from least to the most favored contains; disposing, recovering, recycling, reusing, minimizing, preventing and rethinking actions. The waste materials previously exist in the company must be removed and the working area should be suitable for implementation of lean principles. The waste materials currently exist can be removed by the green strategies (reuse, recovery or recycle). Once this model is implemented, it must be continued to bring sustainable improvements. AAMI and other companies those seeking sustainability, have an option to improve their business performances through implementation of this model.

4.6. Recommended LGSS tools to reduce materials waste

4.6.1. Lean manufacturing tools

Most Lean tools are implemented in short bursts of activity that include focused and intensive planning and implementation phases. In this context, there is a strong bias toward implementation, as opposed to prolonged planning. This fits within the continual improvement philosophy that emphasizes making changes to address problems and eliminate waste, tracking performance, and making additional changes to further increase performance (EPA, 2009).

Among many tools lean manufacturing the following tools were selected by EPA and presented in table below.

Table 4. 2 Lists of recommended Lean manufacturing tools (Adopted from, EPA, 2009).

Tool	Description
5S (or 6S)	5S is a systematic, five-step process for developing and maintaining a clean and orderly workspace. 6S refers to 5S plus safety considerations.
Cellular Manufacturing	An approach in where manufacturing work centers (cells) have the total capabilities needed to produce an item or group of similar items; contrasts to setting up work centers on the basis of similar equipment or capabilities, in which case items must move among multiple work centers before they are completed.
Just-in-Time Production	Just in time is a production scheduling concept that calls for any item needed at a production operation whether raw material, finished product, or anything in between to be produced and available precisely when needed.
Kaizen	The kaizen philosophy implies that small, incremental changes routinely applied and sustained over a long period result in significant improvements. Lean is typically implemented through kaizen events, which are 2-5 day rapid process improvement events.
Kanban	Kanban (signals) are used to control levels of inventory and work in process.
Point of Use Storage	In point of use storage, raw material in right-sized quantities is stored at the workstation where it is used.
Production Preparation Process (3P)	3P is the Lean method for process and/or product design. 3P designs and implements production processes, tools, and equipment that support one-piece flow, are designed for ease of manufacturing, and achieve appropriate cost, quality, and lead time. Also known as Pre-Production Planning.
Standard Work	Standard work represents the sequence of activities needed to perform a given operation. Improvements made during kaizen events are immediately documented as standard work to ensure that all employees understand and consistently implement the new process.

Lean manufacturing tools cont…	
Total Productive Maintenance (TPM)	TPM is an approach to enlist operators in the design, selection, correction, and maintenance of equipment to ensure that every machine or process is always able to perform its required tasks without interrupting or slowing down defect free production.
Value Stream Mapping	A process mapping method used to document the current and future states of the information and material flows in a value stream from customer to supplier.
Lean Enterprise Supplier Networks	A set of buyer-supplier relationships where organizations apply Lean concepts across the supply chain to reduce costs, delays, and other wastes.

4.6.2. Six sigma tools

The Six Sigma toolkit has a number of tools and techniques that help teams work through the Six Sigma DMAIC process. The tools outlined below are divided into two categories: 1) tools that analyze sources of variation and problems in the process, and 2) tools that evaluate potential solutions to improve the process (EPA, 2009). Both tools are selected and presented in table below.

Table 4. 3 List of recommended six sigma tools (Adopted from EPA, 2009).

Problem Identification and Analysis Tools	
Tool	**Description**
Descriptive Statistics	Statistical tools are used to organize, summarize, and describe data that is collected.
5 Whys	The approach of asking "why" five times is used to explore the cause/effect relationships underlying a particular problem. By applying the 5 Whys method a company can determine a root cause of a defect or problem.
Pareto Charts	Pareto Charts weigh each type of defect according to severity, cost of repair, and other factors in order to determine which types of defects occur most frequently. It is a bar graph arranged in descending order of size of importance from left to right.

Cause and Effect diagram	This is a useful technique used to trigger ideas and promote a balanced approach in group brainstorming sessions where individuals list the causes and effects of problems. The six areas (causes) that can contribute to effects are: materials, machine, method, people, measurement, and environment.
Tools for Evaluating Potential Solutions	
Design of Experiments	DOE offers a structured statistical approach to help you understand the factors that affect a process and then create meaningful and effective tests to verify possible improvement ideas or theories.
Failure Modes and Effects analysis	FMEA is a technique used to identify potential failure modes or causes of failures that may occur as a result of design or process deficiencies.

4.6.3. Waste management tools

To reduce the existing waste materials in a company, the 'R' hierarchies are recommended. From least to most preferable they include; recovering, recycling, reusing, reducing, preventing and rethinking. These tools are presented in table 4.4 below.

Table 4. 4 Waste management tools (source; Author).

Tool	Description
Recovering	It is the process of extracting energy from the waste materials.
Recycling	Using the utilizable and valuable materials exist in waste materials as an input for the company because, it is cheaper than extracting them from the raw materials. For example scrap metals from AAMI can be recycled by metal casting industries.
Reusing	Using materials more than once. For example providing idle Tractors and water pumps for educational institutions for education purposes.
Reducing	Decreasing the generation of waste or decreasing the sources of waste through production of quality products, optimizing materials use and releasing very few trashes per unit product.
Preventing	It involves efforts to reduce hazardous waste and other materials by modifying industrial production. It also involves changes in manufacturing technology, raw material inputs, and product formulation.
Rethinking	It is an effective system of waste management which may need an entirely new way of looking at waste. Many of the things wasted could be kept out of the landfill by simply rethinking the concept of waste.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The purpose of this thesis work is to present a model composed of Lean, Green and six sigma philosophies to reduce materials waste. The results of case study are concluded as follows.

1. All waste materials currently exist in AAMI are documented and categorized in to three as; Surplus, Obsolete, and Scrap based on their current status. Surplus waste category consists of materials which have no immediate use but, are accumulated as they will be useful and valuable in the future. Obsolete waste category consists of materials which have economic worth but no longer useful for company operation owing to many reasons, such as change of materials, designs, products and production methods. Defective products which cannot meet the current customers' needs are also categorized under obsolete waste. Scrap waste category contains residue of raw materials, worn out materials, deteriorated obsolete items, rejected components and pallets.
2. The root causes of each waste category are identified using focus group brainstorming method. Accordingly, problems oriented to personnel, methods, materials, measurements, planning, marketing and environment are identified to be the root causes of Surplus, obsolete and scrap materials waste. Also, due to long time accumulation surplus materials are deteriorated to obsolete and obsolete materials are deteriorated to scrap.
3. Waste materials are prioritized using FMEA. The RPN of surplus, obsolete and scrap materials are 80, 63 and 18 respectively. This indicates, surplus materials waste have the highest RPN which means it is the most severe and need immediate action. The potential causes and effects of each waste category are mentioned and the recommendation actions are stated.
4. To minimize materials waste as well as to stay the company in the world of market competition, a model which converges principles of lean, green and six sigma is developed as a general improvement option. The model requires motivation and awareness of employees on LGSS principles before implementation and needs to be sustained if implemented once. Since the company did not adopted any of the methodologies previously, it may take a long time to implement the model at a maturity level.

However, through the application of key critical success factors such as organization readiness, project selection and prioritization, top management and employee commitment, communication, resources and skills and focus on results and measurement, it is possible to start implementation of the model from scratch.

5.2. Recommendation

This article presents a model for materials waste reduction as an application of environmental concern (green) with lean and six sigma principles. Many literatures reveal the importance of convergence of the methodologies, as it is able to improve production and business performances. The model developed in this study may bring a tangible improvements to a waste minimization program and it can be a part of options for AAMI as well as other organizations seeking to achieve sustainability, if they will implement it.

Nevertheless, complementary research to this preliminary study will demonstrate more precisely the relevance of the model. The implementation of the model needs a long time, due to this reason the reliability of the model in the real case of a company did not assessed in this thesis work, which needs the future work in this area. The quantitative study on applicability of lean, green and six sigma integration for materials waste reduction also needs another attention, which will be the work of future researchers. The LGSS integration model in this contribution has been specifically based on reduction of solid materials waste. In the next step it should be extended to all materials, energy and natural resources. These expansions are parts of a recommended future research area.

References

AbdulRahman, S. M. (2013). Lean Manufacturing Case Study with Kanban System Implementation. *Procedia Economics and Finance, 7* , 174 – 180.

Adrian, R. S. (2016). Using Six Sigma Methodology to Improve the Assembly Process in an Automotive Company. *Procedia - Social and Behavioral Sciences, 221*, 308-316.

Allen, D. (1994). Waste minimization and treatment: an overview of technologies. *Greener Manag. Int., 5(1),* 22-28.

Anass Cherrafi, S. E. (2016). The integration of lean manufacturing, Six Sigma and sustainability: A literature review and future research directions for developing a specific model. *Journal of Cleaner Production , 139,* 567-578.

Andrés López, I. G. (2015). Lean Service: Reassessment of Lean Manufacturing for Service Activities. *Procedia Engineering, 132,* 23 – 30.

Arunagiri, G. (2014). Identification of Major Lean Production Waste in Automobile Industries using Weighted Average Method. *Procedia Engineering, 97* , 2167 – 2175.

Banawi, B. (2014). A Framework to Improve Construction Processes: Integrating Lean, Green and Six Sigma. *International Journal of Construction Management, 14 (1),* 45–55.

Bhuiyan, N. B. (2005). An overview of continuous improvement: from the past to the present. *Manag. Decis., 43 (5),* 761-771.

Bicheno. (2000). *The Lean Toolbox,* (second ed. ed.). Buckingham, UK.: PICSIE Books.

Bicheno, J. (2004). *The New Lean Toolbox.* Buckingham: Picsie Books.

Brue, G. (2002). *"Six Sigma for Manager".* New York: Mc-Graw Hill.

Carvalho, H. D. C. (2011.). Lean, agile, resilient and green: divergencies and synergies. *Int. J. Lean Six Sigma, 2*, 151-179.

Cherrafi Anass, E. S. (2016b). Critical Success Factors of Implementing Green Lean Six Sigma for Developing a Specific Framework. *Proceedings of the International Conference on Industrial Engineering and Operations Management.* Kuala Lumpur, Malaysia.

Cherrafi, E. G. R. (2017). A framework for the integration of Green and Lean Six Sigma for superior sustainability performance. *International Journal of Production Research,, Vol. 55*, 4481–4515,.

Corbett, C. K. (2006). Extending the horizons: environmental excellence. *Manufact. Serv. Oper. Manag. 8 (1),*, 5-22.

Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (4th ed. ed.). California: Thousand Oaks , SAGE Publications, Inc.

Darlington, S. T. (2009). Analytical methods for waste minimization in the convenience food industry. *Waste Manag., 29*, 1274-1281.

Dhingra, K. U. (2014). Does lean mean green? *J. Clean. Prod., 85*, 1-7.

Dues, C. M. (2013). Green as the new lean: how to use Lean practices as a catalyst to greening your supply chain,. *J. Clean. Prod., 40*, 93-100.

Dumrak, S. M. (2015). Waste elimination for manufacturing sustainability. *Procedia Manufacturing , 2*, 11-16.

Ellis, S. F. (2016). *The Application Of Lean Six Sigma To Improve A Business Process: A Study Of The Order Processing Process At An Automobile Manufacturing Facility (Master's thesis).* Retrieved April 20, 2018, from http://scholarcommons.sc.edu/etd/3944.

EPA. (2006). *The Lean and Environment Toolkit.* Retrieved from http://www.epa.gov/Lean/environment/toolkits/index.htm

EPA. (2009). *The Environmental Professional's Guide to Lean & Six Sigma.* Retrieved July 10, 2015, from www.epa.gov/Lean/

Farish, M. (2009). Plants that are green. *Eng. Technol. , 14 (2)*, 68-69.

Fercoq, L. C. (2016). Lean/Green integration focused on waste reduction techniques. *Journal of Cleaner Production, 137*, 567-578.

Fercoq, L. (2013.). Combining lean and green in manufacturing: a model of waste management. *7th IFAC Conference on Manufacturing Modelling, Management,and Control.* Saint Petersburg, Russia: International Federation of Automatic Control.

Garza-Reyes, G. M. (2014). Lean and Green - Synergies, Differences, Limitations, and the need for Six Sigma. *IFIP International Conference on Advances in Production Management Systems (APMS), Sep ,,* (pp. 71-81). Ajaccio, France.

Garza-Reyes, J. A. (2015). Lean and green - a systematic review of the state of the art literature. *J. Clean. Prod., 102*, 18-29.

George, M. (2010). *The Lean Six Sigma Guide to Doing More with Less Cut Costs, Reduce Waste,and Lower Your Overhead.* John Wiley & Sons, Inc., Hoboken,: New Jersey.

Gray, D. E. (2014). *Doing Research in the Real World* (4th edition ed.). Thousand Oaks, California: SAGE Publications Inc.

Harmon, P. (2007). *Business Process Change A Guide for Business Managers and BPM and Six Sigma Professionals.* (2nd ed ed.). USA: Morgan Kaufman.

Hobbs, D. P. (2004). *LEAN Manufacturing Implementation: A Complete Execution Manual for Any Size Manufacturer.* Florida: J. Ross Publishing.

Ibrahim, C. A. (2017). A Comparative Exploration of Lean manufacturing and six sigma in terms of their critical success factors. *Journal of Cleaner production, 164*, 325-337.

Indrawati, R. (2015). manufacturing continuous improvement using lean six sigma: an iron ores industry case application. *procedia manufacturing, 4*, 528-534.

Issa Bass, B. L. (2009). *Lean six sigma using sigmaxl and minitab.* New York: McGrow Hill .

Jasiulewicz, k. (2014). integrating lean and green paradigms in maintenance management. *proceedings of the 19th world congress.* Cape Town, South Africa: The international federation of automatic control.

Khan, M. J. (2012.). Impact of learning on the environmental performance of a two level supply chain,. *17th International Symposium on Inventories.* Budapest, Hungary,.

Kumar, S. (2006). *Production and Operations Management (with skill development, caselets and cases)* (2nd edition ed.). New Delhi: New Age International (P) Ltd., Publishers.

Kurdve, Z. M. (2014). Lean and green integration into production system models - experiences from Swedish industry. *J. Clean. Prod., 85*, 180-190.

Laura, A. C. (2013). Sustainable Work Environment with Lean Production in Textile and Clothing Industry. *International Journal of Industrial Engineering and Management (IJIEM), 4* , 183-190.

Lonnie, W. (2010). *How to implement lean manufacturing.* New York: McGaw Hill.

Margaret, Melissa B. (2009). *Data Collection Methods: Semi-structured interviews and Focus Groups.* RAND. Retrieved from http://www.rand.org

Martínez, M. F. J. (2014). Lean management, supply chain management and sustainability: a literature review. *J. Clean. Prod., 85*, 134-150.

Melton, T. (2005). The Benefits of Lean Manufacturing: What Lean Thinking has to Offer the Process Industries,. *Chemical Engineering Research and Design., 83*, 662-673.

Monden. (1998). *Toyota production system: an integrated approach to just-in-time.* Norcross: Engineering & Management Press,.

Mourtzis, P. P. (2016). Lean Rules Identification and Classification for Manufacturing Industry. *Procedia CIRP*, *50*, 198 – 203.

Musee, N. L. (2007). Cellar waste minimization in the wine industry: a systems approach. *J. Clean. Prod. , 15*, 417-431.

Norman, W. M. (2004). Getting to the bottom of triple bottom line. *Business Ethics Quarterly*.

Nunes, B. B. (2010). Green Operations Initiatives in the Automotive Industry: An Environmental Reports Analysis and Benchmarking Study. *Benchmarking: An International Journal., 17, 3*, 396-420.

Pepper, M. S. (2009). The evolution of lean Six Sigma. *Int. J. Qual.Reliab. Manag., 27 (2)*, 138-155.

Pyzdek, K. (2010). *The Six Sigma Handbook, A Complete Guide for Green Belts, Black Belts, and Managers at All levels* (3rd ed.). New York: McGraw-Hill.

Rahani, M. (2012). Production Flow Analysis through Value Stream Mapping: A Lean Manufacturing Process Case Study. *Procedia Engineering, 41*, 1727 – 1734.

Rohac, M. J. (2015). Value Stream Mapping Demonstration on Real Case Study. *Procedia Engineering, 100*, 520-529.

Salah, R. C. (2010). The integration of Six Sigma and lean management. *Int. J. Lean Six. Sigma, 1(3)*, 249-274.

Shah, W. P. (2007). Defining and developing measures of lean production. *Journal of Operations Management., 25/4*, 785–805.

Snee, R. (2010). Lean Six Sigma - getting better all the time. *Int. J. Lean Six. Sigma , 1*, 9-29.

Stern, T. V. (2016). *Lean Six Sigma International Standards and Global Guidelines* (2nd ed. ed.). Boca Raton, Florida: CRC Press.

Sundar, A. N. (2014). A Review on Lean Manufacturing Implementation Techniques. *Procedia Engineering, 97* , 1875 – 1885.

Tiachi. Ohno. (1988). *Toyota production system: beyond large-scale production,*. Portland: Productivity Press.

Torgeir, G. (2016). Beyond waste elimination: Assessing lean practices in product development. *Procedia CIRP, 50*, 179 – 185.

Tushar, S. (2008). Six Sigma – A New Direction to Quality and Productivity Management. *Proceedings of the World Congress on Engineering and Computer Science*, (pp. 1047-1052). San Francisco, USA.

Verrier, B. R. (2014). Combining organizational performance with sustainable development issues: the Lean and Green project benchmarking repository. *J. Clean. Prod., 86*, 83-93.

Waliman, N. (2011). *RESEARCH METHODS THE BASICS.* New york: Routledge Taylor & Francis group.

Womack, J. D. (2003). *Lean thinking: banish waste and create wealth in your corporation* (2nd ed ed.). New York: Free Press.

Yang, M. H. (2011, february). Impact of lean manufacturing and environmental management onbusiness performance: An empirical study of manufacturing firms. *International Journal of production economics, 129*, 210-220.

Yin, R. K. (2014). *Case Study Reserch: Design and Methods* (5th ed. ed.). Thousand Oaks, California : SAGE Publications, Inc.

Yu, V. T. C. J. (2009). Assessing the greenness effort for European firms,. *Manag. Decis., 47(7)*, 1065-1079.

Appendix I

Lists of materials waste documented from AAMI.

S.N	Waste material	specification
1	Tractors	Old/new
2	Tractor tires	Old/new
3	Wheels	-
4	Disk arrows	Old/new
5	Ploughs	Old/new
6	Tractor Engines	Old/new
7	Crankshafts	-
8	Oil tanks	Old/new
9	Pistons	-
10	Gears	-
11	Engine blocks	-
12	Tractor bodies	Old/new
13	Water tanks	-
14	Non-functional vehicles	-
15	Barrels	-
16	Wooden boxes/pallets	-
17	Pumps	Old/new
18	Walking tractors	Old/new
19	Angle iron	-
20	Structural steels	-
21	Shafts	-
22	Trailers	Old/new
23	Axles	-
24	Cylinders	-
25	Crashers	-
26	Gear boxes	-
27	Cylinder heads	-
28	metal scraps/fragments	-
29	Pump beds	Old/new
30	Pump motors	Old/new
31	Tractor seats	-
32	Bearings	-
33	Bolts	-

Appendix II

Focus Group Brainstorming Questions

1. Introduction.

   Well come to our Focus group brainstorming session and thank you for your willingness, for our request to be a respondent.

   My name is M.D and my fellow is N.D, we come from Adama Science and Technology University, school of Mechanical, chemical and Materials Engineering; program of manufacturing Engineering, to collect data for the research conducting on "lean, green and six sigma integration to reduce material: a case on Adama agricultural machinery industry".

2. Objective

   The purpose this brainstorming session is to collect the root/main causes of waste materials exist in AAMI.

   Waste materials include all items from produced Tractors to smaller metal scraps which are stored and disposed. They can be divided as surplus, obsolete and scrap materials.

   Surplus materials are processed products that are not delivered to their end users/customers but waiting the customers' request and items that are made ready for processing to a product. Obsolete materials are the items that are not used for the current company purpose or for the production process because of certain reasons like, change of material, change of design, materials defect etc. but, they are simply stored. Scrap materials are those items disposed after the end of their function because of they have no more use.

3. Rules and Directions

   - There is No right and wrong answer, just react what you think and feel freely for the questions provided to you.
   - Each respondent Take one card from cards labelled by a number and show it before reacting to give answer.
   - This session is required just to gather and identify the root causes of the above mentioned material wastes, so feel free to give your answer.

Icebreaker question

What do you feel if you see that all of the products you have produced are sold and used by the customers?

Main question

1. Why raw material storing is needed?
2. Why the finished/end products (Tractors, pumps, accessories etc.) are stored?
3. How often these materials are stored?
4. What do you think about the degree of influence of storing (raw and products) materials on the production process of the company, environment and others.

   ☐ No effect ☐ low ☐ medium ☐ high ☐ very high
5. Why obsolete materials are generated?
6. How often these materials are stored/discarded?
7. What do you think about the degree of influence of storing obsolete materials on the production process of the company, environment and others? ☐ No effect

   ☐ Low ☐ medium ☐ high ☐ very high
8. Why and when scrap materials are discarded?
9. How often this will happen?
10. What do you think about the degree of influence of storing obsolete materials on the production process of the company, environment and others? ☐ No effect

    ☐ Low ☐ medium ☐ high ☐ very high

Exit question

Is there any missed idea that should be raised?

Answer sheet

1. ____________________ ____________________
____________________ ____________________
____________________ ____________________
2. ____________________ ____________________
____________________ ____________________
____________________ ____________________
3. ____________________
4. ____________________
5. ____________________ ____________________
____________________ ____________________
____________________ ____________________
6. ____________________
7. ____________________
8. ____________________ ____________________
____________________ ____________________
____________________ ____________________
9. ____________________
10. ____________________

Exit question

____
____
____

Appendix III

Focus groups responses on root causes of surplus (raw) materials waste.

Q	R	G1	G2	G3	G4
Q1	R1	Fear of cost increment in the future	To use discount opportunity	To avoid material shortage during production	Lack of organized material planning (MRP)
	R2	Lack of material management	To reduce customers waiting (lead time)	Lack of market network to supply raw materials on time	Lack of research & technological advancements
	R3	To use as spare parts	Fear of transportation cost inflation in future	Lack of well-organized production planning	B/c of previous products do not delivered (Bottlenecking)
	R4	To produce large batch size	Interest of management personnel	Knowledge gap in marketing department	Raw materials Order without customer demand
	R5	To accept large amount of order	To produce parts in short period of time	To control production interruption	Knowledge gap in planning and marketing departments
	R6	Fear of raw material shortage in the future	For spare parts during maintenance	To easily access materials	Traditional material management

Description:
Q = Question (Why raw material storing is needed?);
R = Respondents;
G = Group of respondents.

Appendix IV

Focus groups responses on root causes of surplus (finished products) materials waste.

Q	R	G1	G2	G3	G4
Q2	R1	Lack of advertisement	Customer dissatisfaction on quality of products	Overproduction	To protect spare parts from sunlight and moisture
	R2	Producing without Order	To prevent parts from damage (Mechanically & Chemically)	Lack of market promotion to attract customers	No customer demand b/c of low quality of products
	R3	Lack of customers' interest on produced Products	Lack of qualified Planner and Forecaster	Lack of market networks b/n company & customers	parts are produced without considering our country's climate, soil type & altitude
	R4	Producing more products than ordered quantity	To supply ready made products within required time	Customers change their idea after ordering	Lack of communication b/n company & customers
	R5	higher costs than customers' financial capacity	production without understanding of customer demands	To use as a means of promotion to attract customer	Customers' lack of awareness on the products & technology
	R6	Customers demand to buy better products	Lack of scheduled production practices	To deliver products easily within short period of time	Lack of market research & trainings

Description:

Q = Question (Why the processed/end products (Tractors, pumps, accessories etc.) are stored?);
R = Respondents;

G = Group of respondents.

Appendix V

Focus groups' responses on root causes of obsolete materials waste.

Q	R	G1	G2	G3	G4
Q3	R1	some products do not wanted currently	Completion of contract term with the raw materials suppliers	Introduction of New & better design	Damaged surplus materials in the stock
	R2	Lack of spare parts access	Cannibalization	Lack of efficiency on material management	Overproduced surplus products stored for long time
	R3	Damage on transportation & movement	B/c of low quality products	Failed & under qualified surplus materials	Unprofessional marketing
	R4	wear & corrosion attacked surplus materials	Rationalization	Obsolete technology used but customers need new things	Forecasting problem
	R5	Introduction of new & better products	wrong material purchased	Damaged products returned from customers for maintenance	Lack of market promotion
	R6	Carelessness of individuals on material handling	Long time storage of surplus materials	Change of suppliers	Safety problems for raw materials & products

Description:

Q= Question (Why the Obsolete materials are generated?);

R= Respondents;

G= Group of respondents.

Appendix VI

Focus groups' responses on root causes of scrap materials waste.

	R	G1	G2	G3	G4
Q4	R1	Parts broken on transportation	Extremely wear & corrosion attack of products & raw materials	Deterioration of obsolete materials	Lack of well experienced & trained operators & technician
	R2	Low quality parts & spare parts	Machining, off-cutting, drilling chips	Material handling problem	Chips of machining & cutting during prototyping
	R3	Lack of attention	Knowledge gap on maintenance	Breakdown of equipment	Lack of experience sharing practices with other companies
	R4	Change of parts during maintenance	Breakdown of parts during motion from store to workshops & b/n workstations	Mismatched parts	Used pallet materials
	R5	Measurement errors during maintenance	Breakdown of parts before, during & after production process	Measurement error & wrong material usage	Lack of interest & moral to generate ideas to reduce scraps
	R6	Ended function materials	Damaged spare parts b/c of wrong equipment usage on maintenance	Office used materials	Replacement of damaged spare parts

Description:

Q= Question (Why and when scrap materials are discarded?);

R= Respondents;

G= Group of respondents.

Appendix VII

Severity scoring Guidelines.

Score	**Severity Guidelines**		
	Automotive Industry Action Group **AIAG (PFMEA 4th ed.)**	**Six Sigma**	
10	**Failure to Meet Safety and/or Regulatory Requirements:** May endanger operator (machine or assembly) without warning.	Injure a customer or employee	Bad
9	**Failure to Meet Safety and/or Regulatory Requirements:** May endanger operator (machine or assembly) with warning.	Be illegal	
8	**Major Disruption:** 100% of product may have to be scrapped. Line shutdown or stop ship.	Render product or service unfit for use	
7	**Significant Disruption:** A portion of the production run may have to be scrapped. Deviation from primary process including decreased line speed or added manpower.	Cause extreme customer dissatisfaction	
6	**Moderate Disruption:** 100% of production run may have to be reworked off line and accepted.	Result in partial malfunction	
5	**Moderate Disruption:** A portion of the production run may have to be reworked off line and accepted.	Cause a loss of performance which is likely to result in a complaint	
4	**Moderate Disruption:** 100% of production run may have to be reworked in station before it is processed.	Cause minor performance loss	
3	**Moderate Disruption:** A portion of the production run may have to be reworked in station before it is processed.	Cause a minor nuisance but can be overcome with no performance loss	Good
2	**Minor Disruption:** Slight inconvenience to process, operation, or operator.	Be unnoticed and have only minor effect on performance	
1	**No Effect:** No discernible effect.	Be unnoticed and not affect the performance	

Appendix VIII

Occurrence scoring Guidelines.

Score	Occurrence Guidelines			
	Automotive Industry Action Group AIAG (PFMEA 4th ed.)	**Six Sigma**		
10	**Very High:** ≥ 100 per thousand; ≥ 1 in 10	More than once per day	> 30%	Bad
9	**High:** 50 per thousand; 1 in 20	Once every 3-4 days	< 30%	
8	**High:** 20 per thousand; 1 in 50	Once every week	< 5%	
7	**High:** 10 per thousand; 1 in 100	Once per month	< 1%	
6	**Moderate:** 2 per thousand; 1 in 500	Once every 3 months	< 0.03%	
5	**Moderate:** 0.5 per thousand; 1 in 2,000	Once every 6 months	< 1 per 10,000	
4	**Moderate:** 0.1 per thousand; 1 in 10,000	Once per year	< 6 per 100,000	
3	**Low:** 0.01 per thousand; 1 in 100,000	Once every 1-3 years	< 6 per million	
2	**Low:** ≤ 0.001 per thousand; 1 in 1,000,000	Once every 3-6 years	< 3 per 10 million	Good
1	**Very Low:** Failure is eliminated through preventive control.	Once every 6-100 years	< 2 per billion	

Appendix IX

Detection scoring Guidelines

Score	Detection Guidelines		
	Automotive Industry Action Group **AIAG (PFMEA 4th ed.)**	**Six Sigma**	
10	**Almost Impossible**. No detection opportunity: No current process control; cannot detect or is not analyzed.	Defect caused by failure is not detectable	
9	**Very Remote**. Not likely to detect at any stage: Failure Mode and/or Error (Cause) is not easily detected (e.g., random audits).	Occasional units are checked for defects	
8	**Remote**. Problem Detection Post Processing: Failure Mode detection post-processing by operator through visual/tactile/audible means.	Units are systematically sampled and inspected	Bad
7	**Very Low**. Problem Detection at Source: Failure Mode detection in-station by operator through visual/tactile/audible means or post-processing through use of attribute gauging (go/no-go, manual torque check/clicker wrench, etc.).	All units are manually inspected	↓
6	**Low**. Problem Detection Post Processing: Failure Mode detection post-processing by operator through use of variable gauging or in-station by operator through use of attribute gauging (go/no-go, manual torque check/clicker wrench, etc.).	Manual inspection with mistake-proofing modifications	↓
5	**Moderate**. Problem Detection at Source: Failure Mode or Error (Cause) detection in-station by operator through use of variable gauging or by automated controls in-station that will detect discrepant part and notify operator (light, buzzer, etc.). Gauging performed on setup and first-piece check (for set-up causes only).	Process is monitored (SPC) and manually inspected	↓
4	**Moderately High**. Problem Detection Post Processing: Failure Mode detection post-processing by automated controls that will detect discrepant part and lock part to prevent further processing.	SPC is used with an immediate reaction to out of control conditions	↓
3	**High**. Problem Detection at Source: Failure Mode detection in-station by automated controls that will detect discrepant part and automatically lock part in station to prevent further processing.	SPC as above, 100% inspection surrounding out of control conditions	↓
2	**Very High**. Error Detection and/or Problem Prevention: Error (Cause) detection in-station by automated controls that will detect error and prevent discrepant part from being made.	All units are automatically inspected	Good
1	**Almost Certain**. Detection not applicable; Error Prevention: Error (Cause) prevention as a result of fixture design, machine design or part design. Discrepant parts cannot be made because item has been error-proofed by process/product design.	Defect is obvious and can be kept from affecting the customer	