SOME INVESTIGATIONS OF PROCESS AND PRODUCTIVITY IMPROVEMENTS IN SMALL AND MEDIUM ENTERPRISES THROUGH LEAN SIX SIGMA IMPLEMENTATION

Thesis submitted to the
UNIVERSITY OF CALICUT

For the award of the degree of
DOCTOR OF PHILOSOPHY
UNDER THE FACULTY OF ENGINEERING

By

RAMKUMAR P. N.
(Registration Order No. 10179/RESEARCH-B-SO/2014/CU dated 19.02.2014)

Under the Supervision and Guidance of
Dr SATISH K. P.
Professor, Department of Production Engineering
Government Engineering College, Thrissur.

DEPARTMENT OF MECHANICAL ENGINEERING
GOVERNMENT ENGINEERING COLLEGE THRISSUR
THRISSUR – 680009

UNIVERSITY OF CALICUT
KERALA – 673635, INDIA.

FEBRUARY 2020

DEPARTMENT OF MECHANICAL ENGINEERING

GOVERNMENT ENGINEERING COLLEGE, THRISSUR

UNIVERSITY OF CALICUT

CERTIFICATE

This is to certify that the work reported in this thesis entitled **"SOME INVESTIGATIONS OF PROCESS AND PRODUCTIVITY IMPROVEMENTS IN SMALL AND MEDIUM ENTERPRISES THROUGH LEAN SIX SIGMA IMPLEMENTATION"** that is being submitted by **Mr. RAMKUMAR P. N.** for the award of the Degree of Doctor of Philosophy, to the University of Calicut, is based on the bonafide research work carried out by him under my supervision and guidance in the Department of Mechanical Engineering, Government Engineering College, Thrissur, University of Calicut. The results embodied in this thesis have not been included in any other thesis submitted previously for the award of any degree or diploma of any other University or Institution.

GEC, Thrissur
02.08.2019

Dr. SATISH K. P.
Professor, Department of Production Engineering,
Government Engineering College, Thrissur

Certified that the suggestions / corrections from the adjudicators as per Ref. Letter No. 160339/RESEARCH-C-ASST-1/2019/Admn Dated: 10.01.2020 from the Director of Research, University of Calicut, have been incorporated in this thesis

GEC, Thrissur
20.02.2020

Dr. SATISH K. P.
Professor, Department of Production Engineering,
Government Engineering College, Thrissur

DECLARATION

I hereby declare that this thesis entitled **"SOME INVESTIGATIONS OF PROCESS AND PRODUCTIVITY IMPROVEMENTS IN SMALL AND MEDIUM ENTERPRISES THROUGH LEAN SIX SIGMA IMPLEMENTATION"** submitted to the University of Calicut, for the award of Degree of Doctor of Philosophy under the Faculty of Engineering is an independent work done by me under the supervision and guidance of Dr. SATISH K. P., Professor, Department of Production Engineering, Government Engineering College, Thrissur, University of Calicut.

I also declare that this thesis contains no material which has been accepted for the award of any other degree or diploma of any University or Institution and to the best of my knowledge and belief, it contains no material previously published by any other person, except where due references are made in the text of the thesis.

Place: GEC, Thrissur

Date: 02.08.2019

Ramkumar P. N.

The suggestions / corrections from the adjudicators as per Ref. Letter No. 160339/RESEARCH-C-ASST-1/2019/Admn Dated: 10.01.2020 from the Director of Research, University of Calicut, have been incorporated in this thesis.

Place: GEC, Thrissur

Date: 20.02.2020

Ramkumar P. N.

Abstract

Lean Six Sigma (LSS) is a process improvement methodology that combines the benefits of both lean manufacturing techniques and Six Sigma. It helps organizations to streamline operations, increase value, reduce waste and reduce resources. Micro Small and Medium Enterprises (MSMEs) play a pivotal role in driving the overall industrial and economic development of a nation. They contribute towards balanced regional development, economic diversification, and social stability in addition to creating employment and driving GDP growth. From the literature survey, it is clear that Small and Medium Enterprises (SMEs) are suffering from certain deficiencies which make it unsuitable for them to implement the LSS concept immediately. Initially it was required to identify the critical success factors in LSS implementation and this was accomplished through a questionnaire survey and further factor analysis. Subsequently the degree of adoption of LSS by the organizations was identified using regression analysis. Organizations grouped on certain characteristics were also compared. SMEs are suffering from the seven types of waste during their processes. The wastes within the enterprise decrease productivity as well as increase the production cost. To identify the influence of the seven wastes in the production processes, non-parametric tests were adopted. Further the interdependency analysis and ranking of wastes was carried out by a matrix approach. The above analysis revealed that certain critical success factors as well as certain wastes during the process strongly influences the implementation of LSS in SMEs. This situation indicates the need for developing a model that can overcome the deficiencies existing in SMEs and enable implementation of the LSS concept for achieving waste reduction and prosperity. This study aimed at development and adoption of a model named Identify Rank Define Analyze Improve Control (IRDAIC). The IRDAIC model has been designed for the resurgence of an SME through the implementation of LSS. Two case studies have been conducted to test and validate the model by implementing and analyzing the results. One was in a handmade paper manufacturing industry, and the next was in a cluster of 10 die manufacturing firms. Further, an analytical study was also conducted to validate the model, through the responses of a questionnaire collected from selected industries. The responses were analyzed using MATLAB with multi non-linear regression based enhanced Grey Wolf optimization. After conducting these studies, it was found that the IRDAIC model would act as a catalyst and sensitize the management of SMEs to successfully implement LSS.

Acknowledgements

Reaching this moment of writing the acknowledgement is something I have long awaited. The completion of this thesis would not have been possible without the support, encouragement and sacrifice of many individuals. This thesis resulted out of my work as a research scholar at the Faculty of Engineering at University of Calicut.

I have to express my deepest gratitude to Dr. Satish K. P., Professor, Department of Production Engineering, Government Engineering College, Thrissur, who not only offered me this opportunity as the research supervisor but also supported me in an unprecedented manner. His pragmatic and down-to-earth sense and the ability to pose the right questions at the right point in time created for me a challenging environment which greatly contributed to the success of this work. Hereby his provision of faith and creative freedom has always been an incentive to challenge myself and my work.

Equal and profound gratitude goes to all my doctoral committee members Dr. Mohandas V.P., Head of the Mechanical Engineering Department and Chairman of Doctoral Committee, Dr. Jayadevan. K.R., Dr. Ramesh. A., Dr. V. Lijo, former Chairmen of Doctoral Committee, Dr. N. Ramachandran, Professor, and Head of the Mechanical Engineering Department, Vidya Academy of Science and Technology, Thrissur, (Former Professor and Head of the Mechanical Engineering Department, National Institute of Technology, Calicut) and Dr. Shalij P. R., Professor, Department of Production Engineering, Government Engineering college, Thrissur for their invaluable support and insightful suggestions during this research work.

I would like to thank Dr. Sheeba V. S., Principal, and Dr. K Vijayakumar, Dr. Indiradvi K P and Dr. B. Jayanand former Principals, Government Engineering College Thrissur, for extending the facilities in the research centre. I am also thankful to Dr. P. Vijayan, Dean (Research), and Dr. Nandakumar M., (Chairman, Engineering Research Council) Dr. Solomon. P.A, Dr. Maneesh K. K., former Deans (Research), Government Engineering College, Thrissur, for providing all the facilities to carry out the research works.

I am deeply indebted to Prof. Varghese Job, Dr. C. P. Sunil Kumar and Prof. E.C. Ramakrishnan, former Heads of the Department, all faculty members and supporting staffs in the Mechanical Engineering Department, Government Engineering College, Thrissur for all support and timely help during the period of the research work. I express my sincere gratitude to Prof. Parameswaran. M and Prof. Jayasree N, former Heads of the Department and Dr. Haris Naduthodi, Head of the Department and all faculty and supporting staff members of Production Engineering Department, Government Engineering College Thrissur, for giving all help and support to carry out my research work in the Department.

I would like to place on record my gratitude to Centre for Research and Development (CERD) Government of Kerala, for selecting me for awarding Ph.D. research scholarship for doing full time research at Government Engineering College, Thrissur.

I also express sincere thanks to the Principal, faculties and staffs of Mechanical Engineering Department, Government Engineering College, Sreekrishnapuram, and MEA Engineering College, Perinthalmanna for the cooperation and support during the time of thesis writing.

Acknowledgement also made for the assistance given by Mrs. Mubashira, Assistant Professor in English, Dr. Anil P. M., Associate Professor in Mechanical Engineering, Mr. Jagath J. L. Research Scholar and Mr. Aryesh V. N., Research Associate, for their help in connection with English language correction and statistical analysis.

My fondest gratitude goes to my fellow research scholars Dr Biju Louis, Mrs. Divya A. H., Dr. Ramadas T., Mr. Muhammed Iqbal C., Mr. Pradeep M., Mr. Rajesh Menon, Mr. Sijo T., Dr Sajan M.P., Dr. Anu P. Anil, Mr. Jagath J. L., Mrs. Salini C. Vijayan and Mr. Vishnu P. Madhanmohan for all your encouragement and support during the long journey of deliberating this thesis.

I am also indebted to the key persons and respondents of the industries participated in the survey and the management of the industries, giving me an opportunity for conducting the case studies, for their patient sharing of information and co-operation. I express my profound gratitude to the officers, staffs and experts of departments and organisations such as MSME DI, DICs, CII, District management association who provided data supports during the various stages of my research process.

I express my sincere thanks to, Librarian, Government Engineering College Thrissur for the help and support extended to me during this research. I place on record my sincere thanks to the Librarians of the, C.H.M.K. Library, University of Calicut and various other institutions.

I express my sincere thanks to, Mr Nidhin K, Mr. Praveen V. Venugopal, Mr. Vivek Viswanath and Mr Sreekanth Unni, students of M.Tech (Manufacturing System Management) for helping in the data collection from various small and medium sized enterprises for doing this research neatly and promptly.

I hereby express sincere thanks to publishers - Transstellar Journal Publications, Research India Publications and Inderscience Publishers, for accepting my papers for publication in their journals

I extend my deep and infinite love to all my friends, relatives and well-wishers for the encouragement and support they have given to me throughout the course of my research work. Acknowledgement also made to Mr. U. M. Narayanan, Mrs. A. M. Leela and Mr. U. N. Narayanan for providing me the guidance and support offered during the period of research. Words are countless for my family for their enormous support and prayers to brighten my days during this research. I express my deepest gratitude to my father Sri. P. M. Narayanan Namboodiri, mother Smt. M. P. Usha, Brother C. A. Krishnakumar P. N., Sister in law Smt. Sreelakshmi V. and their daughter Dyuthi Krishnan for their unflagging love and unconditional support throughout my life and my studies.

Above all, I place my fervent indebtedness to God Almighty for his bountiful blessings

GEC, Thrissur   Ramkumar P. N.

02.08.2019

Publications related to thesis

International Journals:

- Ramkumar P. N., Dr. Satish K. P., (2019). Implementation of Lean Six Sigma Through IRDAIC Model; A Case Study In Indian SME, *International Journal of Mechanical and Production Engineering Research and Development,* Trans Stellar Journal Publications, Vol. 9, Special Issue, pp. 14-20. (Scopus Indexed)
- Ramkumar P. N., Dr. Satish K. P., (2019). Study of the Effect of Lean Six Sigma's Critical Success Factors in Indian SMEs, *International Journal of Mechanical and Production Engineering Research and Development,* Trans Stellar Journal Publications, 9(4), pp. 581-588. DOI: 10.24247/ijmperdaug201957 (Scopus Indexed)
- Ramkumar P. N., Dr. Satish K. P., Praveen V. Venugopal, (2019), Ranking of the seven wastes (Muda) for Lean Six Sigma Implementation in Indian SMEs, *International Journal of Applied Engineering Research,* Research India Publications, 14(6), pp. 1269-1274.
- Ramadas T., Dr. Satish K. P., Ramkumar P. N., (2016). Implementing Lean Manufacturing in Small and Medium Scale Enterprises- Identification and Modeling of Managerial Factors, *International Journal of Lean Enterprise Research,* Inderscience Publishers, 2(2), pp. 159-171.
- Ramkumar P. N., Dr. Satish K. P., "Statistical Investigation of Lean Six Sigma for Waste Reduction in Indian SMEs by Identify Rank Define Analyze Improve Control (IRDAIC) Model" has been accepted and article in press for publication in *International Journal of Productivity and Quality Management* of Inderscience Publishers, DOI: 10.1504/IJPQM.2019.10022211. (Scopus Indexed)
- Ramkumar P. N., Dr. Satish K. P., An Investigation on the effects of Lean Six Sigma implementation in die manufacturing firms, has been communicated to International Journal of Lean Six Sigma of Emerald Publishers.
- Vivek Viswanath, Dr. Satish K. P., Ramkumar P. N., (2016). Lean six sigma - critical success factors for implementation in small and medium enterprises, *International Journal of Engineering Development and Research,* 4(3), pp. 520-523.
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National conference:

- Praveen V. Venugopal, Dr. Satish, K. P., Ramkumar, P. N., (2015). Lean manufacturing by waste elimination - a study of the effect of seven wastes on MSME, *Proceedings of National Conference on Emerging Trends in Manufacturing, Factura 2015,* NSS College of Engineering, Palakkad, pp. 436-444.

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List of Abbreviations

CFA	Confirmatory factor analysis
CII	Confederation of Indian Industries
CSA	Crow search algorithm
CSF	Critical Success Factor
CTQ	Critical To Quality
DFSS	Design for Six Sigma
DIC	District Industries Centre
DMADV	Define, Measure, Analyse, Design, Verify
DMAIC	Define, Measure, Analyse, Improve, Control
DPMO	Defects Per Million Opportunities
EFA	Exploratory factor analysis
EGWO	Enhanced grey wolf optimisation
GDP	Gross Domestic Product
GOI	Government of India
GWO	Grey wolf optimisation
HMP	Handmade Paper
IRDAIC	Identify Rank Define Analyse Improve Control
ISO	International Organisation for Standardisation
JIT	Just in time
KMO	Kaiser-Meyer-Olkin test for sampling adequacy
KVIC	Khadi & Village Industries Commission
LSS	Lean Six Sigma
MNLR	Multivariate non-linear regression
MSME	Micro, Small and Medium Enterprises
MSMEDI	MSME Development Institute
NBMSME	National Board for MSME
NIMSME	National Institute for MSME
PDCA	Plan Do Check Act
PSO	Particle swarm optimiser
ROI	Return on Investment
SME	Small and Medium Enterprises
SMED	Single minute exchange of dies
SOP	Standard operating procedures
SSI	Small Scale Industries

Chapter 1

Introduction

1.1 Introduction

In the present era, the world has become extremely competitive due to global business; therefore, manufacturing firms face pressure to satisfy ever-changing customer necessities rapidly. The process performance and product quality of the industries should be improved to satisfy the client needs and to face the competition of the global market successfully. The industries, especially the Micro, Small and Medium sectors (MSMEs), strive hard to face this competition by improving the quality without increasing the production cost. The managers adopted various strategies to tackle the impact of competition (Kumar et al., 2006). The successful stories such as Lean, Six Sigma, Lean Six Sigma (LSS), the theory of constraints etc. are marked in history, due to the impact they made at business processes.

Lean manufacturing, the philosophy initially put forward by the automobile giant Toyota, hence also known as Toyota Production System, tries to eliminate any non-value adding processes from the industry. Another objective of lean manufacturing is to reduce the total lead time. The set of tools and techniques within the lean strategy, help the industries in reducing scrap, time, rework, inventories, equipment downtime and different hidden wastes of production processes (Radhika and Sukumar, 2017). Lean manufacturing implementation is achieved by the industries through the utilisation of lean tools like value stream mapping, Just in Time, Kanban, Single Minute Exchange of Dies, pull production etc. (Singh et al., 2016). The major concentration of lean philosophy is towards waste elimination, which thus increases the value of product and/ or service. From the last few years, the humankind is constantly monitoring how harmfully the wastes affect the environment. This increases the importance of lean, agile manufacturing philosophies and sustainable engineering.

In 1986, the journey of Six Sigma was started by Motorola. Six Sigma is aimed at reducing the process variation and thus achieving a minimum rate of defects. The ultimate aim of Six Sigma is to achieve a defect level of 3.4 defects per million opportunities (DPMO). Once Motorola started using the Six Sigma, many large industries like GE and many of Fortune 500 industries started using it. Most of the companies who implemented Six Sigma could reduce the defects in their process significantly and thus increase the product quality. Generally, the Six Sigma is achieved through the Define, Measure, Analyse, Improve and Control (DMAIC) methodology (Tagge et al., 2017).

LSS, the synergistic combination of lean manufacturing and Six Sigma evolved during the first decade of the 21st century. LSS tries to improve the situations by taking the advantages of both lean and Six Sigma. It ensures achieving 3.4 DPMO at an improved speed. The target objective of the lean Six Sigma is reduced cost, increased process speed and improved customer satisfaction (Gutierrez et al., 2016). LSS uses all the tools and techniques that are used in lean manufacturing and Six Sigma separately. LSS generally follow the same methodological steps of DMAIC as in Six Sigma. Six Sigma as well as LSS starts from identifying the customer needs, which is termed as Critical to Quality (CTQ). The evolution of LSS, marked the strength of the combination in variety of fields from production and service sectors. LSS has proved its significance in reducing accidents at aviation, industry and hospitals (Panagopoulos et al., 2016; Dino and Bambang, 2016; Arthur, 2011)

Micro, Small and Medium Enterprises (MSMEs) are generally the business units running with lesser capital investments for plant and machinery. The norms for the range of investment under each sector, varies from country to country. The terms Small and Medium enterprises (SME) and MSME are interchangeably used in many literatures as well as in different countries. In this study, the term SME is used, as the study mainly concentrated to Small and Medium enterprises only. SMEs are considered as backbone of economy for many countries. SMEs generally contributes significantly to the GDP of many countries as well as offers a huge employment of about 60-70% of total employment globally (Robu, 2013). In India, government's MSME development act, 2006 provides insight to the classification of sector of enterprises both for production as well as service firms.

A developing country like India which is seventh largest in terms of landmass, have a population of 133.92 Crore as in 2017. Enormous large-scale enterprises and MSMEs runs in India, which contributes to a significant margin to GDP and creates a huge employment opportunity. MSME annual report (2018) estimated the number of MSME in India as 633.88 Lakh. The literatures claim the probability of unregistered industries beyond this number, especially from micro sector enterprises. Micro enterprises are generally single person or family running businesses, which generally do not have a systematic industrial setup, and hence excluded from this study. The government, governmental agencies or departments and some non-governmental organizations (NGO) provide significant promotional programs to improve the situations of SMEs. Government departments, NGOs and the large-scale clients provides supports for clustering activities of SMEs, which can enhance the technical strength and quality without increasing production cost.

In general, the large industries are equipped with good financial capacity as well as personnel support to implement and control quality improvement activities. The studies show that implementation of modern manufacturing management tools is largely suited for scientifically managed large size organizations (Antony et al., 2005; Kureshi et al., 2010). Whereas, the SMEs are striving to achieve good results by implementing quality initiatives, due to limitation in funds, technical know-how and other constraints. Many literatures infer that implementing quality improvement models in SMEs may be challenging, as SMEs are being managed in a non-scientific manner (Temtime, 2003; Thomas et al., 2009; Gnanaraj et al., 2010a). SMEs, being a constant support to GDP growth and employment opportunities, need to conduct significant studies to implement manufacturing management models and to achieve its' benefits (Thomas et al., 2009; Kale et al., 2010). From this motivation, this doctoral research work is directed in developing a suitable model, testing and validating the model through implementing it in SMEs.

This research started with a literature survey which is followed by a questionnaire survey to find out the critical success factors (CSF) of LSS implementation for SMEs. The study identified nine CSFs, out of which process and productivity improvement through waste reduction was considered by the investigator for the further research. The study, further investigated the influence of seven wastes during manufacturing processes and then continued with a questionnaire and matrix approach that helps to identify and rank the processing wastes. A model was developed by the researchers; termed Identify-Rank-Define-Analyse-Improve-Control (IRDAIC), which helps SMEs to achieve LSS standards easily. Later, the researchers did case studies to test and validate the model. The details of the activities carried out during this doctoral research work are presented in the following chapters of the thesis.

1.2 Problem Definition

SMEs plays a major role in the economic growth of countries by providing jobs. SMEs getting plenty of opportunities from local as well as global market. In addition to this, large scale organizations are increasingly outsourcing their activities to SMEs. This necessitates SMEs to follow timely production schedules; with reduced production cost and improved quality. Literatures show that many SMEs tried to implement quality philosophies, but rarely reaped its' entire benefits, due to the limitations in technical knowledge, misconception about time consumption and necessity of continuous support. This research tries to fill this gap by providing support to SMEs in implementing LSS through the tailormade model IRDAIC.

1.3 Objectives of the Doctoral Work

1. To study the critical success factors (CSF) and their effects on LSS implementation
    - To identify the CSF influencing LSS implementation in SMEs
    - Degree of adoption of LSS
    - To compare how the CSF affect various groups of organizations (ISO 9001 certified versus non-ISO 9001 certified, small versus medium, location based etc.)
2. To further analyze the waste reduction factors in LSS Implementation as identified by several literatures.
    - To investigate the effect of seven wastes in SME sector
    - To explore further the interdependency of the various factors as identified.
    - Formulation of hypothesis on the influence of these factors
3. To develop a model for LSS implementation in SME Sector
    - Preparation of implementation model IRDAIC
4. Testing and validation of model
    - Case study on the model implementation in an SME

- Case study on the model implementation in an industrial cluster
- Analysis using machine learning algorithms

1.4 Research Methodology

The research methodology followed by this work is depicted in the figure 1. The research started with the initial literature survey and problem identification. Then the methodology was followed by two questionnaire surveys and its analyses, model development, testing, generalising and validating of the model.

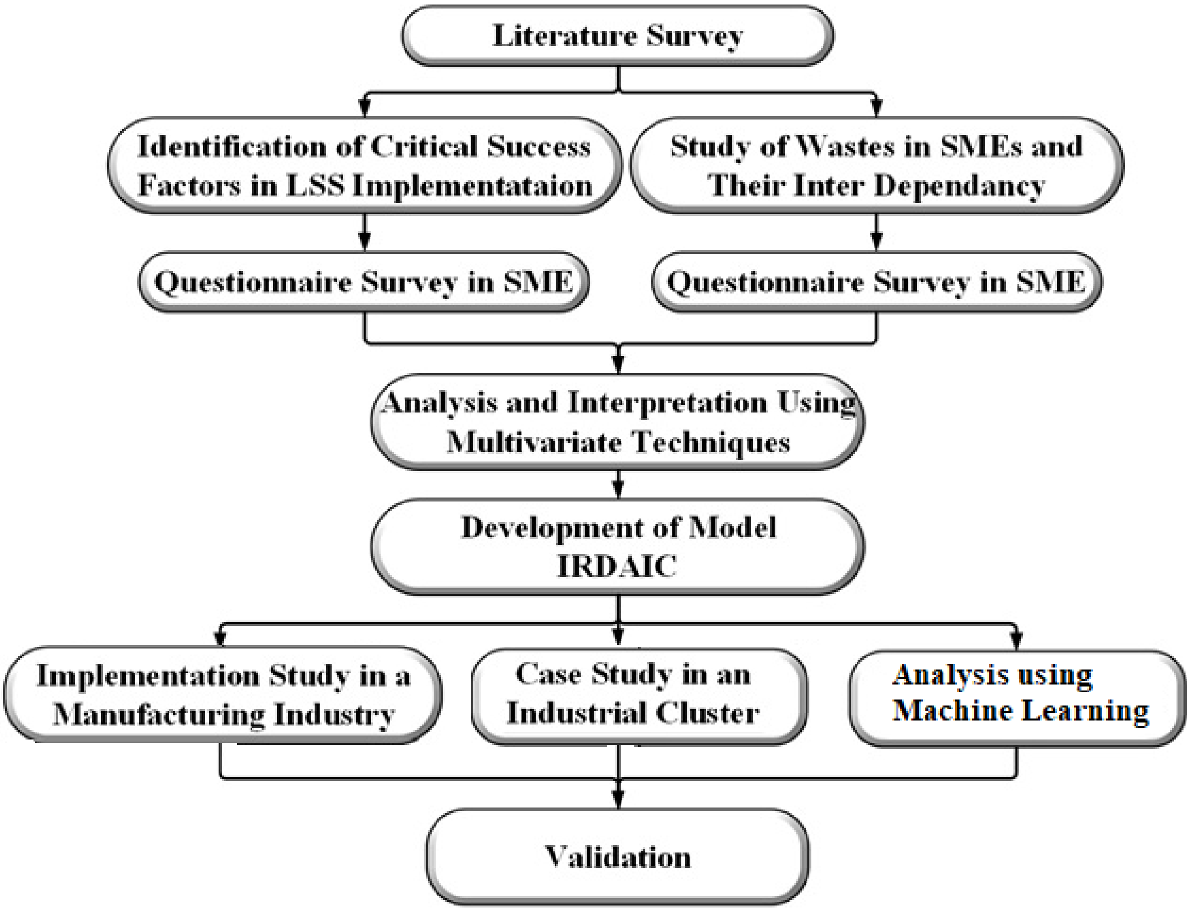

Figure 1.1 Research Methodology

1.5 Chapter Organization

This thesis has been organized into ten chapters as given below.

Chapter 1 mentions introduction.

Chapter 2 reports the detailed literature survey.

Chapter 3 mentions the research design followed for this work. This chapter reports about the scale used, sampling methods used, sampling size and other related data.

Chapter 4 contains the result of questionnaire survey conducted at SMEs and its' analyses. The identified CSFs and comparison studies were reported in this chapter.

Chapter 5 is arranged with the information inferred from questionnaire survey on influence of seven wastes and interdependency of seven wastes. This chapter also reports the method followed in this research for ranking the wastes.

Chapter 6 provides insight to the development of IRDAIC model and the assumptions, methodology followed in this research.

Chapter 7 reports the implementation study of IRDAIC model in an Indian SME. The SME is a manufacturer of handmade paper. The results of the study are also discussed.

Chapter 8 contains the data of case study conducted at an SME cluster of 10 die manufacturing firms, where the IRDAIC model was implemented to achieve LSS results.

Chapter 9 describes the need of generalising the model, the steps taken to check the generalisability, and the software simulation methods used in this research.

Chapter 10 concludes the thesis by summarizing the results and providing the concluding insights. The chapter also details the limitations found during the research, general suggestions for improvement that derived from unstructured interviews with the managers of SMEs and future scopes for the present work.

Chapter 2

Literature Review

2.1 Introduction

Any research work could not be started without the knowledge on prior research happened in related areas. Literature review provides a great insight into the research works happening across the world. The inferences from the literature review carried out by the researchers helped to identify a research gap in the research area and to accentuate the scope of the research objectives.

2.2 Literature Survey Methodology

The literature survey started with the advanced search options of google scholar and reputed journals' websites. The papers from reputed journals, newest as possible, text books from reputed authors and/ or publishers, proceedings of conferences etc. were referred during the entire research period. The available works of literature are arranged in order for useful reference during the research process.

At the initial phase, research survey was aimed to analyse the research scenario across the globe and to find possible research gaps to start with. In the second stage, the literature survey was carried out, to get more insight to the identified problems and thus to underline the research problem and objectives. Later, as the research progressed, further literatures were referred for providing the necessary supports to ensure the quality of work with respect to the existing works happened in the research area. The following sections describe information gained in the subject area that helped in finding and confirming the research problem, from the review of the literature.

2.3 Lean Manufacturing

Enhancing quality has become a key professional strategy for various organizations including manufacturers, suppliers, shipping businesses, financial services, health care, and governmental agencies. An enterprise proficient of delighting clients, through enhancing and controlling quality, has the competence to dominate its competitors. The lean manufacturing is an effective philosophy in manufacturing to extend productivity, for client satisfaction and to reduce wastes (Kumar et al., 2016).

The term lean manufacturing came into existence in 1990s, whereas the studies on the philosophy started from the starting decades of 20th century itself. Till the term lean manufacturing is coined, it was generally known as Toyota Production System, as the philosophy was put forward by Toyota motors of Japan. Tanki et al. (2017) reported the improvements in implementation of lean manufacturing by the Indian manufacturing organizations. Lean manufacturing is an efficient philosophy to increase the value of product/ service through reducing the non-value-added process wastes (Mathaisel, 2005; Dahlgaard and Dahalgaard-Park, 2006; Laureani and Antony, 2010; Eroglu and Hofer, 2011).

Researchers studied the applications of lean manufacturing in various countries as well as various businesses. Many of them resulted in significant improvements in company situations. Many literatures have identified that the tools and techniques like 5S, poka-yoke, cellular manufacturing, pull production, value stream mapping, Kaizen, Kanban, total productive maintenance (TPM), set-up time reduction and visual management can be used to eliminate the waste through the application of lean manufacturing (Kumar et al., 2006; Yang et al., 2011; Badurdeen et al., 2011).

Based on the literature survey conducted on lean manufacturing, it could be concluded that, lean manufacturing is a proven philosophy for achieving improved speed and value of the business through the eliminations of wastes.

2.4 Six Sigma

The concept of six sigma was initially developed by Motorola at the end of 20th century and later many industrial conglomerates proved its success through implementing it. Many researchers have contributed significant literatures on Six Sigma. Researchers reported the critical success factors for implementing Six Sigma in organisations (Schroeder et al., 2008; Rajagopalan et al., 2004). Some researchers reported the success stories of Six Sigma implementation by many popular companies worldwide (Treichler et al., 2002). Some of the practitioners’ books, academic texts printed the significance of Six Sigma for industries and they guided how the industries can successfully implement Six

Sigma (Harry and Schroeder, 2000; Jacobs and Chase, 2008). American Society for Quality (ASQ), National Institute of MSME (NIMSME), Indian Statistical Institutes (ISI) and many such organisations taken efforts to improve the situations by providing education and certification to Six Sigma programs (Hammer and Goding, 2001). Agencies are giving Six sigma certificates such as yellow, green, black & master black belts to the experts based on their courses and successful six sigma implementation projects. As in lean manufacturing, many literatures also insight facts about the CSFs, barriers of Six Sigma implementation, methodologies generally adopted to achieve Six Sigma implementation etc. The literatures, suggests that, Six Sigma is a strong methodology for reducing variations in processes and thus achieving near zero defects.

2.5 Lean Six Sigma

As a combination of successful and proven methodologies, LSS evolved in the beginning of the 21st century. LSS has the advantages of both lean and Six Sigma (Yadav and Desai, 2016). Studies at many industries worldwide where Six Sigma is successfully implemented reported that, Six Sigma does not focus on the process speed and hence does not contribute much to on-time delivery. This situation can be handled by combining lean manufacturing to Six Sigma and thus resulting in a Six Sigma quality with improved lean manufacturing speed, i.e. reduction in lead-time (George, 2002). LSS increases the return on investment (ROI) to the stakeholders and thus can be considered as a business development model. It is achieved through reducing variation, wastes and lead times and thus improving the value of product/ service and the customer satisfaction (Lande et al., 2016; Sunder et al., 2016 a,b,c). The target objective of the lean Six Sigma is reduced cost, increased process speed and improved customer satisfaction (Gutierrez et al., 2016).

Modern manufacturing methods must not be restricted solely on improved technical functionality but should be balanced with green, lean and Six Sigma concepts to ensure sustainable future growth (Timans et al., 2016). Researchers reported from their studies that, SMEs need manufacturing management models to improve the condition. LSS provides a better platform for SMEs to achieve quality goals (Kumar et al., 2006; Thomas et al., 2009; Gnanaraj et al., 2010a; Furterer and Elshennawy, 2005; Byrne et al., 2007; Sharma, 2003). The figure 2.1 represents the objectives of the quality improvement methodologies Lean, Six sigma and Lean Six Sigma. It strongly points that the combination of methodology improves situation through reduction of wastage, non-value-added work and cycle time (Snee, 2010).

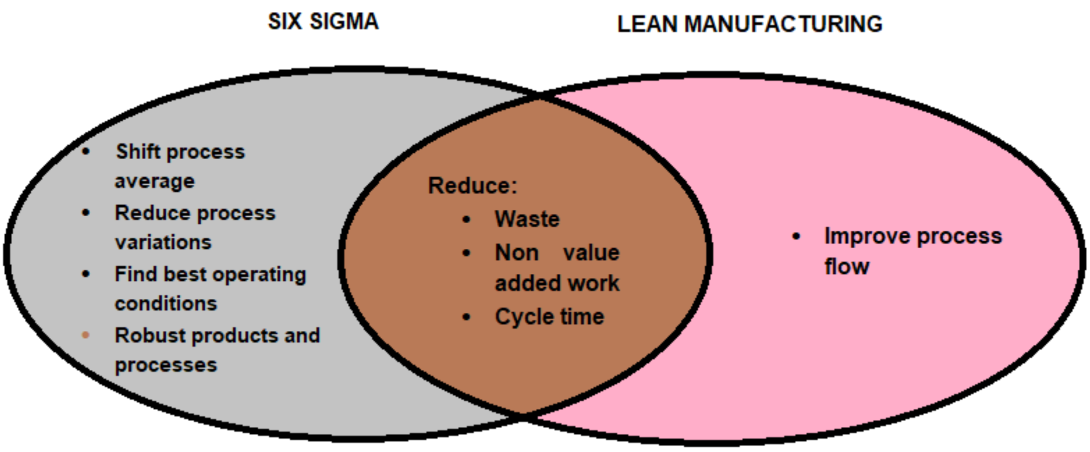

Figure 2.1 Objectives of LSS implementation
(Source: Snee, 2010)

2.5.1 The mechanism of Lean Six Sigma

Lean Six Sigma projects are aimed at achieving bottom level performance improvement. Joseph Juran, a quality Guru, defined the term 'bottom level performance improvement' as the 'return on investment (ROI)' for the management, especially for top level. Integration of the focus on the human needs, focus on the bottom level performance improvements and the better usage of improved tools and techniques. This makes LSS as a better approach than the other quality improvement methodologies (Snee, 2010).

The integrated approach of LSS is said to be using the methodology of Six Sigma, i.e. DMAIC in common; and uses tools and techniques of both lean manufacturing and Six Sigma (De Koning and De Mast, 2006; De Koning et al., 2008) Generally, the companies implementing LSS, starts with tools of lean manufacturing such as 5S, Kanban, visual management etc. and later tries to apply statistical tools of Six Sigma which reduces the defect rates significantly. The tools and techniques used in lean manufacturing, Six Sigma and LSS are summarised in the figure 2.2. Figure 2.2 is prepared from the data collected from various studies regarding lean manufacturing/Six Sigma/LSS implementation (Womack and Jones, 1996; James-Moore and Gibbons, 1997; Hoerl, 1998; Rother, 1998; Breyfogle III, 1999; Harry and Schroeder, 2000; Hines and Taylore, 2000; Pyzdek, 2003;

Antony et al., 2003; Snee and Hoerl, 2003; Gnanaraj et al., 2012; Prasanna and Vinodh, 2013).

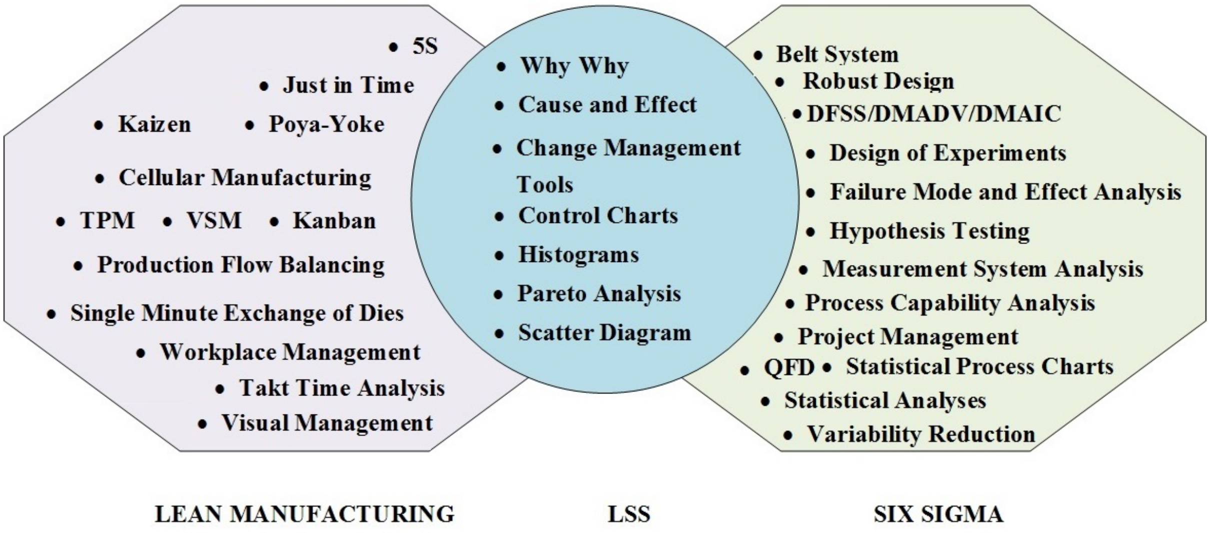

Figure 2.2 Tools and techniques used for Lean Manufacturing, Six Sigma and LSS

(Source: Womack and Jones, 1996; James-Moore and Gibbons, 1997; Hoerl, 1998; Rother, 1998; Breyfogle III, 1999; Harry and Schroeder, 2000; Hines and Taylore, 2000; Pyzdek, 2003; Antony et al., 2003; Snee and Hoerl, 2003; Gnanaraj et al., 2012; Prasanna and Vinodh, 2013)

Abbreviations used in the figure:

5S: Tool to organise workspace

TPM: Total Productive Maintenance

VSM: Value Stream Mapping

DFSS: Design for six Sigma

DMADV: Define, Measure, Analyse, Design, Verify

QFD: Quality Function Deployment

Figure 2.3 concludes the outline of lean Six Sigma implementation. The figure was developed with the insights from researchers regarding research methodology and implementation steps. Most of the literature supported the DMAIC methodology for implementing; but has reported the steps differently (Thomas et al., 2008; Vinodh et al., 2011; Snee, 2010; Box et al., 2005).

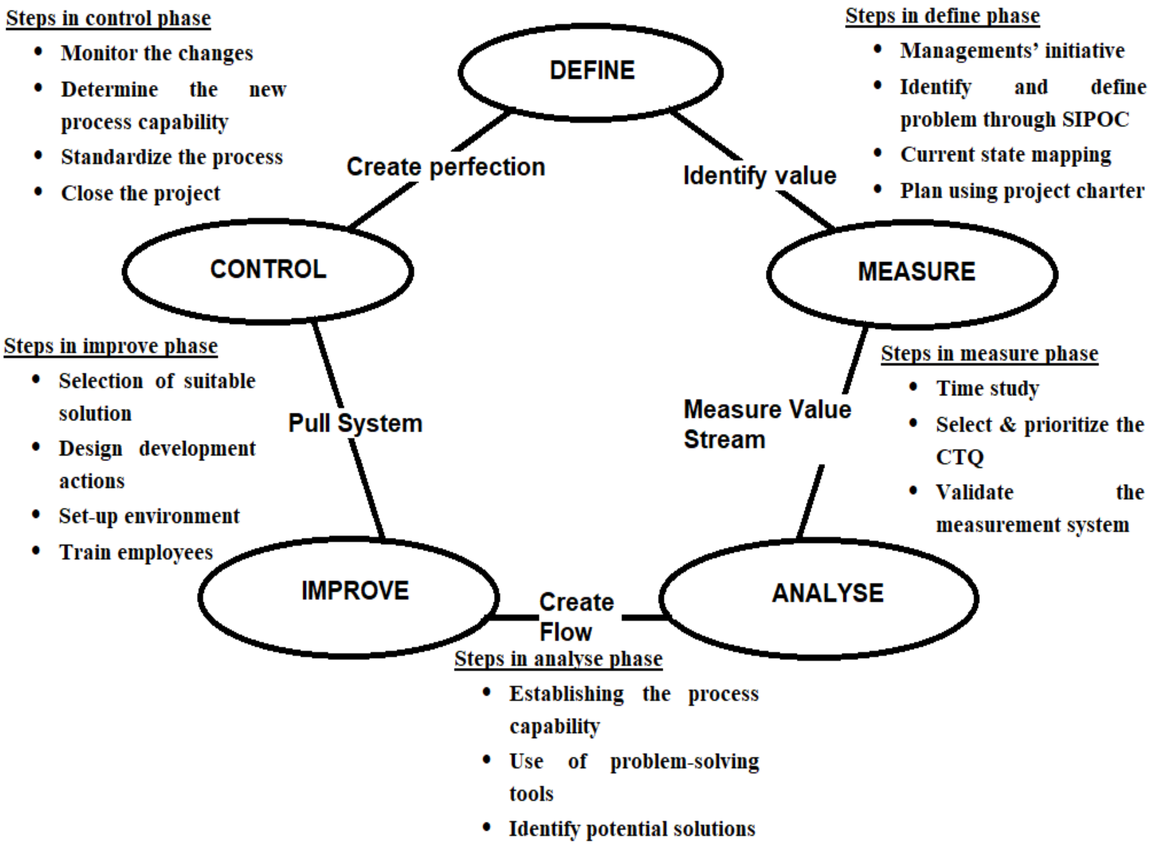

Figure 2.3 Lean Six Sigma outline

From literatures regarding LSS, it could be found that various projects on LSS implementation used the methodologies DMAIC, DFSS or DMADV. Literatures reported that DMAIC is the methodology proven for existing processes; where as DFSS or DMADV could be better used for new processes.

2.5.2 Success factors of LSS

Researchers across the world have studied the factors affecting LSS implementation. The factors which motivate the implementation are referred as success factors or enablers, whereas the factors which act as constraints towards the implementation are termed as barriers or failure factors. In this section few general success factors of LSS implementation most identified by researchers were listed in the table 2.1.

Table 2.1 CSF's of LSS from various literatures

CSF	Papers reporting the CSF
Top management commitment	Henderson & Evans (2000), Harry & Schroeder (2000), Snee & Hoerl (2002), Antony et. al. (2007), Burton & Sams (2005), Sivakumar & Muthusamy (2011), Kumar (2007), Brun (2011), Achanga et al. (2006)
Education and training	Harry & Schroeder (2000), Snee & Hoerl (2002), Antony et. al. (2007), Antony & Banuelas (2002), Antony (2006), Kumar (2007), Brun (2011), Tambunan (2009), Holden et al. (2007)
Cultural change	Erwin (2000), Harry & Schroeder (2000), Snee & Hoerl (2002), Coronado & Antony (2002), Sivakumar & Muthusamy (2011), Kwak et al. (2006), Zu et al. (2010), Brun (2011), Achanga et al. (2006)
Communication	Coronado & Antony (2002), Burton & Sams (2005), Sivakumar & Muthusamy (2011), Kumar (2007), Brun (2011)
Process and productivity improvement	Thomas et al. (2009), Sivakumar & Muthusamy (2011), Kumar (2007), Brun (2011), Achanga et al. (2006), Gunasekaran et al. (2000)
Supplier involvement	Harry & Schroeder (2000), Snee & Hoerl (2002), Coronado & Antony (2002), Sivakumar & Muthusamy (2011), Kwak et al. (2006)
Employee Involvement	Harry & Schroeder (2000), Snee & Hoerl (2002), Antony et. al. (2007), Antony & Banuelas (2002), Antony (2006), Kumar (2007), Brun (2011), Tambunan (2009)
Customer satisfaction	Coronado & Antony (2002), Antony & Banuelas (2002), Antony (2006), Burton & Sams (2005), Brun (2011)
Financial capabilities	Harry & Schroeder (2000), Snee & Hoerl (2002), Coronado & Antony (2002), Antony et. al. (2007), Antony & Banuelas (2002), Zu et al. (2010), Kumar (2007), Brun (2011)
Structured improvement procedure	On (2006), Zu et al. (2010), Harry & Schroeder (2006), Snee & Hoerl (2002)

2.6 Small and Medium Enterprises

According to McAdam (2010), the term SME is an assorted one. The terms SME and MSME have been interchangeably used in literatures. This study concentrates on SMEs. Different countries categorise the sectors differently. The categorisation of sector may be based on any of the following criteria (Harjula, 2008; OECD, 2000; Volery and Schaper, 2007):

- number of employees;
- investment on plant and machinery;
- revenue created;
- asset values;
- annual working hours.

SMEs includes the businesses from both production and service sectors. In almost every country, SMEs support significantly in GDP growth and provide huge employment opportunities. The abbreviation “SME" is used in the European Union and by international organizations such as the World Bank, the United Nations and the World Trade Organization. Some countries consider the SMEs of manufacturing and service sectors separately, while some other countries group them together. The categorization of manufacturing SMEs followed by different countries were tabulated in table 2.2.

From table 2.2, it could be seen that different countries classify SMEs based on different parameters. Similarly, literatures give insight that, general classification exists in European Union; even then some countries within the union, have different criteria. The criteria depend on the economic conditions of country, its’ population and the organisation culture of the country.

2.6.1 MSME in India

In India, the definition for MSME came to existence by Government’s MSME development act, 2006. Till then the classification was Small Scale Industry (SSI) and non-SSI. The history of SSI in India had started from 1948 by the first post-independence ministry. During that time, the Government decided to give priority to cottage industries and SSIs, so as to utilise the local resources and thus improve employment and economy. Industrial policies of 1977 introduced District Industries Centres which acted as a governing body as well as a supporting agency for the industries within. (Sonia and Rajeev, 2009; Lahiri, 2012)

Table 2.2. Categorization of MSME across different countries

Country	Number of employees	Balance sheet	Turnover	Investments
Australia	Small: <20 Medium: 20–199			
Canada	<500		<$50 Mil	
China	Small: <300 Medium: 300-1000		<RMB 20 Mil 20-<RMB 400 Mil	
Egypt	<20			
European Union Countries	Small: <50 Medium: <250	<€10 Mil <€43 Mil	<€50 Mil	
Hongkong	Small: <100			
Kenya	Micro: <10 Small: 10-<50 Medium: 50-100			
Japan	<50-300			<¥50 – ¥300 Mil
Malaysia	Small: 5-74 Medium: 75-200		<RM 15 Mil <RM 50 Mil	
New Zealand	Small: <6 Medium: 6-19			
Norway	<50			
Singapore	<200		<$100 Mil	
South Africa	<200		<R 51 Mil	
USA	Small: <100 Medium: <500			

(Source: Edvardsson, 2009; Urban and Naidoo, 2012; El-said et al., 2014; Hu et al., 2015; Harjula, 2008; Schaper et al., 2010)

From 1948, according to the changes in economic and conditions, the definitions for SSI were changed periodically. For instance, the initial definition for SSI was industries with fixed asset costing less than Rs. 5 Lakh and employment of less than 50/100 persons with/ without power. During 1960, the condition about employment was dropped. From 1960 onwards the capital investment against plant and machinery were the criteria for classifying industries in India. (Venkatesh and Muthiah, 2012; Nikaido et al., 2015)

The table 2.3 shows the criteria for the classification of MSME under MSME development act 2006. The act clearly distinguishes manufacturing and service industries into three significant groups.

Table 2.3. Classification of MSME, India

Enterprise	Investment in lakhs of rupees	
	Manufacturing (Investment in plant & Machinery)	Service (Investment in equipments)
Micro	<25	<10
Small	25 - <500	10 - <200
Medium	500 - <1000	200 - <500

2.6.2 Ministry of MSME

The ministry of MSME, India has a wide organisation structure with various divisions aimed at the improvement of MSME sector India. It runs many subordinate organisations under the office of Development Commissioner, MSME (DCMSME). The subordinate organisations provide the services such as:

- Advice the Government in policy making for the progression of MSME sector.
- Technical/ managerial consultancy
- Common facilities centre with advanced and modern technology
- Providing facilities for technology upgradation, modernization, quality improvement and infrastructure.
- Developing Human Resources through training and skill upgradation.
- Providing economic information services.

The government extend the support to MSME through the agencies like Khadi & Village Industries Commission (KVIC); training institutes like National Institute for MSME (NIMSME); and boards like National Board for MSME (NBMSME). (MSME Annual Report, 2018).

2.7 Contributions of MSME

MSMEs became most vibrant and sensitive sector of business in many countries over the globe from last five decades. The attraction toward MSMEs were due to the low capital and technology necessities, and its' capacity to create huge employment. Other reasons that helps growth of SME are the use of traditional/ local skills and resources within the Mohalla. Literatures and business magazines report the contributions of MSMEs towards the total manufacturing, economy and employment (ADB, 2018; MSME Annual Report, 2018; Onukwuli, 2014). The contributions of Indian MSMEs to the country is described in the following section.

2.7.1 Contributions of Indian MSME

MSME annual report (2018) reported 7.68% growth rate as the contribution by MSME towards country's economic growth, as well as 28.77% of share in total GDP in the financial year 2015-16. India has registered 633.88 lakhs MSME units in which 31% are from the manufacturing sector, 36% of trade and 33% from other service sectors. 51% of total MSMEs were situated in rural areas and the remaining in urban areas. Category wise, India has 3.31 lakhs of small scale, 5000 numbers of medium scale and 630.52 lakhs of micro scale industries. About 600 SME from Kerala & Karnataka states forms population of this study. Indian MSMEs provide total number of 1109.89 lakhs of employment from which 32% in manufacturing, 35% in trade and 33% in other services. Considering rural and urban classification, the total is divided as 51% in rural and the rest in urban (MSME annual report, 2018).

2.8 Problems Faced by SMEs

SMEs are generally run by a single owner or a small group of related people having the same direction. SME generally have wide span of control with limited levels of management (Singh, 2010; Singh et al., 2010). This enables the decision-making power in a centralised manner; which speed up the decision-making process. This results in flexibility during decision making and operations (Floyd and McManus, 2005; Deros et al., 2006, Seitz, 2003; Rymaszewska 2014).

Despite these advantageous features, SMEs are suffering from many deficiencies which prevent them from global competitions. The general drawbacks which hold SMEs back from progress are the lack of expertise, time, money, skilled workforce and managerial and technical support (Singh et al., 2008, Pannizzolo et al., 2012; Rymaszewska 2014; Mathur et al., 2012).

2.9 Lean Six Sigma in SMEs

The concept of LSS was developed by practitioners and researchers to achieve the benefits of the proven methodologies of lean manufacturing and Six Sigma. From the past two decades many organisations across the world adopted LSS methodology in their operations. LSS also got its domain extended by implementing it to manufacturing as well as service organisations such as hospitals and educational institutions (Arnheiter and Maleyeff, 2005). Researchers observed that, implementation of LSS in SMEs enhances wealth and performances of industries (Kumar et al., 2006; Furterer and Elshennawy, 2005; Byrne et al., 2007, Gnanaraj et al., 2010b; Gnanaraj et al., 2012; Prasanna & Vinodh, 2013). These literature underlines the importance of implementation of LSS to improve the conditions within SMEs.

Literatures provides the insight that being an integration of lean manufacturing and Six Sigma, LSS do not have an established step by step procedure for implementation. In practice, commonly the implementors selects the proven Six Sigma methodology of DMAIC and the tools and techniques arbitrarily based on their knowledge or need. Researchers have developed models that could achieve LSS implementation such as DOLADMAICS, LADMAICS etc. (Gnanaraj et al., 2010a, Prasanna & Vinodh 2013). The researchers infer the need for tailormade models for LSS implementation according to the suitability for different SMEs.

2.10 Conclusion

From the literature survey, the importance of MSME/SME and LSS implementation is clear. There are a lot of success stories on the implementation of LSS in large scale sectors, whereas there aren’t many appreciable success stories of LSS implementation in

SMEs. The deficiencies of SMEs were also discussed in the previous sections which infer that technical know-how and lack of time to concentrate on quality procedures are important of all. From these inferences, the objectives of this study are strongly underlined and directed towards developing a model that can be easily be adopted by SMEs and thus get the benefits of LSS implementation.

Chapter 3

Research Design

3.1 Introduction

Chapter 2 discussed about the literature survey carried out by the investigator, which led to finding the research gap and thus formulating the research objective. This chapter explains how and why the particular design used for this research such as sampling method, selection of industries for case studies etc. are chosen. The subsequent chapters discuss about the actual research works carried out during the period.

3.2 Sample Design

The sample for the study was the Indian small and medium sector manufacturing industries. The samples were collected from the firms of Kerala and Karnataka states of India. The random and convenient sampling techniques were used for collecting the samples for the study.

The general concept on sample size provides an assumption that the sample size must be as much large as possible. But the literatures report that, the large sized sample of 500s or above may create problems during the software processing, in the operating features of the software such as iteration speed, data handling capacity etc. Hence the idea to increase the sample size as much as possible could not be accepted (Kline, 2005).

Identifying the minimum sample size is a complex problem as reported by the most literatures. Hence, it is related to many factors such as number of variables, number of groups, total population, homogeneity of population, the statistical methods selected to use etc. The researchers also underline the possibility of bias in estimation. The researchers considered the sample size less than 50 as small (Maas and Hox, 2005; Kline, 2005). Green (1991) and Maxwell (2000) have reported about the rule of thumbs used for minimum number of samples. They concluded that no rule can be superior, every rule of thumb is defined and validated according to researcher’s objectives and situations.

This research used the KMO test for sampling adequacy and was carried out by using SPSS software. In this research, four sets of questionnaires were used, all administered with managerial and supervisorial employees of concerned SMEs. The questionnaires are given in the appendix of this thesis. The first two surveys were for statistical tests. The first questionnaire contained 45 questions and the second contained 49. The total number of responses were 170 and 133 respectively for first and second. The third questionnaire was aimed in developing waste relations matrix for each firm and the fourth questionnaire was used in machine learning processes. The third and fourth sets of questionnaires were entirely used for case studies at selected industries. Hence, the sample adequacy was not calculated.

3.3 The Location of Research

This study took place at the industries situated in two districts of Kerala and a district of Karnataka selected based on geography. The districts were Thrissur and Palakkad of Kerala and Dharwad of Karnataka.

Thrissur and Palakkad are the districts of Kerala, having large number of registered SMEs. Thrissur, being the cultural capital of Kerala, is also rich with many manufacturing industries. Thrissur contains 14596 numbers of MSMEs which provides employment to more than 72980 employees. The major industries within Thrissur district includes plastic industry, die manufacturing industry, forging industry and pen industry. District of Thrissur is well connected by the rail and road ways. Air and water ways also accessible through Kochi the neighbouring city to Thrissur. Hence Thrissur acts as one of the major industrial hubs of Kerala. Significance of Palakkad for being chose as a district for study is because of the border sharing district to Tamil Nadu, especially Coimbatore, an Industrially rich district of Tamil Nadu. This is advantageous to Palakkad, to be with many manufacturing industries from older days itself. Palakkad being Kerala’s largest district in terms of area, is rich with 23288 registered industries, which includes 65 medium sector enterprises. Palakkad is also well connected with rail and road ways, and by air it can be done through Coimbatore or Cochin Airports. Palakkad contains many manufacturing industries such as rolling, forging, casting, die manufacturing industries, valves and valve components, tiles, electronic manufactures and more. Both the districts have many public-sector large-scale units and artisanal/cottage industries. (MSMEDI, Thrissur 2018 a,b,c)

Dharwad, one of the north-western districts of Karnataka, has strong industrial population from micro to large industries. The district has 18877 firms, which includes six medium and six large industries. Dharwad, especially twin cities Hubli-Dharwad is considered as the second city of Karnataka in education and business after Bengaluru. The cities are connected by air, rail and road ways. The district Dharwad is geographically placed in an appreciable position, by being the midpoint of markets viz. Mumbai/ Pune, Hyderabad and Bengaluru. Geographical location and availability of land for industrialisation improves the industrial situations within the districts (MSMEDI, Hubli 2011; MSMEDI, Bengaluru 2016).

Another reason for selecting these geographical locations was the familiarity of the investigator regarding industrial areas.

3.4 Periods of Research

The data collections for this research were carried out by face to face discussions with the managers or supervisors of the SMEs. The data collection for the research has been carried out in different sections. Initially the data regarding industries registered, and the general characteristics have been collected from organisations like MSMEDI, DIC, CII etc. This process took place in the initial periods of research up to October 2014. The first two sets of questionnaires were surveyed in the SMEs and analysed from October 2014 to April 2016. The model for implementation was developed in May 2016. The case study in the paper manufacturing industry was carried out during the period from June 2016 to November 2016. The cluster for case study was identified in December 2016 and the case study was started in January 2017. The case study ended by June 2017. Data collection and analysis for the machine learning and simulations took place in the period from November 2017 to May 2018.

3.5 Data Collection

As discussed above, data collection for two sets of questionnaires were carried out from SMEs. The respondents were managerial or supervisorial staff of the SMEs, who had better knowledge on their organisation's procedures and its' results. Mostly the process took 20-30 minutes for completing each questionnaire. The two questionnaires were circulated at different periods, concerning the improvements in investigator's research process. Hence the interview and questionnaire filling, might have been completed by different respondents, at least in some of the organisations. This happened due to the unavailability of the prior personnel.

3.6 Pilot Study

Pilot studies were carried out for the two questionnaires related to CSF's of LSS and seven wastes. 25 industrial responses were used for completing the pilot study. Cronbach's alpha being a good method for testing the reliability of dataset, was used for pilot study. The researcher reports a value of 0.6 or above as a threshold, where the value could be between 0 and 1 (Sakakibara et al, 1993). The analysis during the pilot study suggested that, the administering of the questionnaire was practical to bring out the necessary information.

3.7 Statistical Methods Used

Various multivariate, inferential and descriptive analyses were carried out during the entire research. The methods used in research include Cronbach's alpha test, KMO-Bartlet test, Exploratory Factor Analysis and Kruskal Wallis test. All these analyses were carried out using SPSS software. Next, in the case studies, the investigator used MS Excel software for making waste relations matrix, which was used to rank the wastes. Later, optimisation algorithms like Particle Swarm Optimiser, Crow Search Algorithm and Enhanced Grey Wolf Algorithm were used in this research for analysing the model. The optimisation and simulation of the model had been carried out using MATLAB software.

The description of each statistical method would be discussed in the chapter, where the method is utilised. This chapter described the research design, period, location etc. of the entire process. Chapter 4 to 10 describes the activities carried out during research and its' results and discussions.

Chapter 4

Study on the Critical Success Factors and their Effects on LSS Implementation

4.1 Introduction

In the literature review section of this thesis, various success factors in quality initiatives of the SMEs were discussed. This research is aimed at developing and implementing a model for the SMEs to achieve LSS benefits. To start developing the model, understanding of the current situation prevailing in the SMEs is a must. This chapter provides insight to the present scenario of SMEs through a regression analysis-based study.

The literature on lean six sigma, provides a variety of CSFs. Various authors termed the CSFs differently. Each and every CSF are having relationships to each other. Some of the different terms put forward by different authors seems to be similar in nature. Here, in this research the investigator identified nine CSFs that affect the LSS implementation of Indian SMEs.

4.2 Objectives

This study is aimed at the following.

- To identify the CSFs influencing LSS implementation in SMEs
- Degree of adoption of LSS
- To compare how the CSF affect various groups of organizations (ISO 9001 certified versus non-ISO 9001 certified, small versus medium, location based etc.)

4.3 Methodology

This study was conducted through a questionnaire survey and its statistical analyses. The questionnaire (Appendix No. 3) was developed from literature review. 5-point Likert scale was used for the survey in which 5 for strongly agree and 1 for strongly disagree. The responses were collected through face to face interviews with managers or supervisors of the firm, which ensured 100 % response rate. The questionnaire contained 45 questions. The research got 170 valid responses.

After the data collection, the responses were entered to the SPSS software for further analyses. Further, various statistical tests such as factor analysis, regression analysis, independent sample t-test etc. have been carried out. The following sections describes the details of the analyses used in this study.

4.4 Factor Analysis

Factor analysis is a technique that is used to reduce a large number of variables into fewer numbers of factors. It extracts maximum common variance from all variables and puts them into a common score. This method analyses the interrelationship among a large number of variables and to group them accordingly to their common core dimensions as factors with minimal loss of information (Hair et al., 2013). By providing an empirical estimate of the structure of the variables considered, factor analysis becomes an objective basis for creating summated scale. The factor analysis is classified into two types as exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) (Taris and Byrne, 2001; Williams et al., 2010).

EFA is used to identify the similarity in responses and hence to group the similar variables considering its' factor loading. This method helps the researcher to draw the main dimensions of the area of interest to derive a model from the reasonably large set of variables. The distinctive feature of EFA is that the factors are derived from statistical results, not from theory (Hair et al., 2013). The EFA is performed without any prior idea of, which factors indeed subsist and which variables loads to each group formed. The groups formed from interrelated variables are called factors (Hair et al., 2013).

On the other hand, CFA tests whether the variables grouped by the researcher is statistically valid or not. This approach tests the hypotheses that the items are associated with specific factors. While conducting CFA, the details such as the number of factors and the factors on which each variable load is to be specified for a given set of variables. Hypothesized models are tested against actual data, and the analysis would demonstrate loadings of observed variables on the factors, as well as the correlation between the latent variables.

4.4.1 Prerequisites of factor analysis

Different tests have been carried out to check the suitability of data for further analysis. The results were reported in table 4.1.

Table 4.1: Prerequisite tests for factor analysis

Items	Numbers
Valid cases	170
Number of items	45
Cronbach's Alpha	0.902
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	0.621
Significance value for Bartlett's Test of Sphericity	0.000

Reliability analysis refers to the fact that a scale should consistently reflect the construct it is measuring. Cronbach's alpha being a good method for testing the reliability of dataset. Sakakibara et al. (1993) reports a value of 0.6 or above is considered "acceptable" in most research situations. In this research, the value of 0.902 was obtained for Cronbach's Alpha, which ensures that the data set has relatively high internal consistency and hence acceptable.

Next, Kaiser Meyer Olkin (KMO) test was employed to measure the sampling adequacy. The KMO value compares the partial correlations to the original zero-order correlation. The test measures sampling adequacy of data for Factor Analysis. KMO value of 0.6 and above are considered as acceptable (Kim, J., and Mueller, L.W 1978). Here, the KMO value obtained was 0.621 which is satisfactory and no deletion of items were necessary to make the value significant.

Bartlett's test of sphericity tests the similarity of variance between the groups or samples and thus the suitability for structure detection. The null hypothesis used for this test was variances are equal across groups or samples. Small value (less than 0.05) of the significance level rejects the null hypothesis and indicate suitability of data for factor analysis.

4.4.2 Exploratory factor analysis

Once the sample adequacy was ensured, the EFA was carried out using the data. The EFA was done using principal component analysis extraction method. Table 4.2 portrays the rotated factor matrix as a result of the analysis. The inferences from the table is discussed in next paragraphs.

Table 4.2 Rotated factor matrix of EFA (Output of SPSS software)

Rotated Component Matrix[a]

	Component								
	1	2	3	4	5	6	7	8	9
VAR00001		.869			.347				
VAR00002	.869								
VAR00003	.382	.681							
VAR00004	.621								
VAR00005				.827	.348				
VAR00006	.690							.324	
VAR00007		.316					.862		
VAR00008							.586		
VAR00009			.310				.671		
VAR00010				.315			.638		
VAR00011						.687			
VAR00012						.468			
VAR00013		.430				.621			
VAR00014						.720			
VAR00015			.762						
VAR00016		.720							
VAR00017			.792					.477	
VAR00018			.821						
VAR00019			.641						
VAR00020						.648	.306		
VAR00021			.593						
VAR00022	.380								.831
VAR00023									.642
VAR00024	.685								
VAR00025				.643					
VAR00026							.798		
VAR00027	.748								
VAR00028		.496				.398			
VAR00029		.538	.311						
VAR00030		.603							
VAR00031								.976	

Table 4.2 Continued

	Component								
	1	2	3	4	5	6	7	8	9
VAR00032								.624	
VAR00033								.567	
VAR00034	.478							.751	
VAR00035	.699								
VAR00036					.762				
VAR00037		.323			.667				
VAR00038	.771								.414
VAR00039	.638								
VAR00040					.583				
VAR00041	.964								
VAR00042				.587					
VAR00043	.584								
VAR00044									.739
VAR00045		.366							.642

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.[a]

a. Rotation converged in 12 iterations.

For the principal component analysis, it was decided to group the 45 variables into 9 typical factors to find out which are the variables belong to these typical factors. For choosing the variable a threshold of factor loading value of 0.4 was taken into consideration (Sakakibara et al, 1993). Thus, by considering the nature of the variables nine success factors were identified and categorized by the investigator as given below.

- Process & Productivity Improvement
- Top management commitment
- Organization culture
- Communication
- Financial capabilities
- Supplier involvement
- Employee involvement
- Education and training
- Customer satisfaction

The following subsections discuss the variables coming under the above factors identified and their significance. The questions grouped under each category checks and ensures the need and the present condition of the industry towards corresponding factor. These variables strongly measure the support from the managements' side for the implementation of manufacturing management models.

4.4.2.1 Process and productivity improvement

From the factor loading obtained, with respect to the responses, various factors related to wastes, process improvement and productivity improvement are grouped together as given in table 4.3. All the variables ensure the companies' willingness or initiation towards waste management. The result underlines that the understanding of the wastes within the firm is necessary to identify the improvements that are needed. Similarly, sometimes the firm might not be able to find the wastes themselves because of the limited knowledge in technical analyses. Those situations should be properly handled by appointing experts or getting service of external specialist. The investment for time being may high, but this can help the organisation to achieve benefits in the future.

Table 4.3 Variables and loading factor for the variables under the factor process and productivity improvement.

Variable Number	Variable	Factor Loading
2	Our company uses external experts/consultants on a regular basis to evaluate the overall company performance and to improve production and quality level.	0.869
4	Our company is capable of eliminating waste (muda).	0.621
6	Our company is ready to invest for the continuous improvement and waste reduction efforts.	0.690
16	The organization is willing to invest on plans that reduce wastage.	0.720
24	Our equipment and procedures are designed in mistake proof manner.	0.685
27	We always try to maintain the minimum level of inventory.	0.748
35	The equipment's are kept clean and under proper loading conditions.	0.699

Table 4.3 Continued

Variable Number	Variable	Factor Loading
38	Our organization has a strategy to identify the wastes.	0.771
39	We have a framework to measure productivity loss comparing with a benchmark/baseline (tracking downtimes, slow cycles, rejection etc).	0.638
41	Our company uses LSS tools.	0.964
43	Company believes in doing things right first time itself.	0.584
Total number of variables: 11 nos.		

4.4.2.2 Top Management commitment

From the literatures, it is clear that top management commitment is one of the important success factors towards implementation of any quality initiatives. The variables supporting this factor are given in the table 4.4.

Table 4.4: Variables and loading factor for the variables under the factor top management commitment.

Variable Number	Variable	Factor Loading
1	Our managers Spend time on the plant floor to thoroughly understand the real-world manufacturing issues.	0.562
3	Our company invests in training programs and encourages cross-job training.	0.681
28	We extensively use statistical techniques to reduce process variance	0.496
29	We monitor and evaluate performance of equipments and processes periodically	0.538
30	We maintain excellent records of all equipment maintenance related activities	0.603
Total number of variables: 5 nos.		

In large scale industries top management commitment generally means, their willingness towards funding, accepting the newer framework for adoption and accepting the risk of failure. As in the case of large-scale firms, top management is supposed to do strategic planning activities rather than operational activities. Instead, in SMEs' case, top management actively participate in both strategic plans as well as operational plans. Hence, the knowledge of the manager about the activities within the firm, problems during operations and knowledge about the quality initiatives is essential for making the manager committed.

4.4.2.3 Organisation Culture

Organisation culture is the term that refers to the policy generally the firm follows with the associated businesses such as suppliers, customers and employees. A good and ethical organization culture will definitely enhance the business. The organisation culture can be developed by sharing the suggestions and feedbacks from the customers to the suppliers. Participation of customers and suppliers at the initial stages of design can ensure the product quality through quality material usage and thus meeting the customer requirements. The questions supporting this factor are given in the table 4.5.

Table 4.5 Variables and loading factor for the variables under the factor organisation culture.

Variable Number	Variable	Factor Loading
15	We give our suppliers feedback on quality and delivery performance	0.762
17	Customer Feedback is sought regularly, and surveys/meetings are often held with customers to improve product design and quality and service	0.792
18	There is a system in place for collecting customer complaints so that problems can be avoided in the future	0.821
19	Customers participate in the initial design process	0.641
21	Production is ''pulled'' by the shipment of finished goods	0.593
Total number of variables: 5 nos.		

4.4.2.4 Communication

The term communication used in the quality philosophy means, the clarity and ease of communications within the firm concerning the organization levels. The vision, mission, objectives and such strategies should be properly communicated to everyone within the firm. Similarly, the standard operating procedures (SOP), usual quality policies and customer requirements should be properly communicated to concerned employees without delays. Also, the proposed improvement models should be properly communicated and trained and educated accordingly. Thus, communication can be considered as a CSF for LSS implementation as the responses infer which is shown in table 4.6.

Table 4.6: Variables and loading factor for the variables under the factor communication.

Variable Number	Variable	Factor Loading
5	Our company communicates the vision of the new initiative at every organizational level.	0.827
25	We try to improve the “value Added” process through step-by-step review and identification of connections, activities, information, and flow.	0.643
42	Company gives a clear and precise communication when it launches a new initiative	0.587
Total number of variables: 3 nos.		

4.4.2.5 Financial Capabilities

This success factor is related to the financial stability of the firm. The questions supporting this factor are given in the table 4.7. It ensures whether the firm can release funds for implementing latest technological machineries, rendering technical services, allocate funds for quality initiatives etc. If the firm is financially strong, they tend to have more confidence to initiate improvement plans and implementations.

Table 4.7: Variables and loading factor for the variables under the factor financial capabilities.

Variable Number	Variable	Factor Loading
36	The organization has plans for expansion and improvement.	0.762
37	Our company is capable of sustaining its initial efforts.	0.667
40	Company uses latest technology wherever available.	0.583
Total number of variables: 3 nos.		

4.4.2.6 Supplier Involvement

Productivity and quality of any industry is directly related to the quality of the supply. From that point of view, the supplier involvement is highly important in LSS implementation. The variables loaded under this factor were reported in the table 4.8. The firm should have a harmonious long-term relation with the suppliers, which ensures quality, timeliness and reliable supplies. Through making long term agreements with the suppliers, the industries can reap the financial benefits such as loyalty benefits. Through finding a better supplier and a cheaper logistic system, the company can practice Kanban and JIT models easily.

Table 4.8: Variables and loading factor for the variables under the factor supplier involvement.

Variable Number	Variable	Factor Loading
11	Suppliers are directly involved in the new product development process	0.687
12	Our key suppliers are located in close proximity to our plants	0.468
13	Our company maintains good relation with suppliers.	0.621
14	We have a purchasing policy emphasizing quality rather than price	0.720
20	Our key suppliers deliver to plant on JIT basis	0.648
Total number of variables: 5 nos.		

4.4.2.7 Employee Involvement

This term, tells the importance of providing authority to the employees. The employees will be more committed once they are delegated with some authority and empowerment. Generally, employees like to get recognized by the organization and to get some sort of autonomy in his/ her workspace. Empowerment could be achieved through education and training of employee for his/ her work. Motivation can be achieved by delegating more authority to them. Recognition and reward by incentives for employees for their better ideas/ suggestions in process/ product improvements can also motivate. The management should develop a culture within the employees to motivate quality and productivity practices and the relations must be harmonious. The variables loaded under this factor were mentioned in the table 4.9.

Table 4.9: Variables and loading factor for the variables under the factor employee involvement.

Variable Number	Variable	Factor Loading
7	Employees are given authority and responsibility to carry out specific activities.	0.862
8	Workers are empowered to stop production line if abnormalities occur.	0.586
9	Suggestions and ideas from shop-floor employees are actively used and implemented.	0.671
10	Incentive programs and reward system are available for employees who lead product/process improvement efforts and eliminate necessary steps.	0.638
26	Our employees practice setups to reduce the time required	0.798
Total number of variables: 5 nos.		

4.4.2.8 Education and Training

The questions loaded by the EFA under the factor education and training were tabulated in table 4.10. The section 4.4.2.7 employee involvement already mentioned the importance of keeping skilled employees with proper authority.

Table 4.10: Variables and loading factor for the variables under the factor education and training.

Variable Number	Variable	Factor Loading
31	The organization provides adequate level of training to its employees.	0.976
32	The organization is flexible in incorporating new ideas.	0.624
33	Our company conducts workshops or training to discuss scope for improvement.	0.567
34	Our company monitors employees to find areas to improve their efficiency.	0.751
Total number of variables: 4 nos.		

For making the employee skilled and empowered, education and training has a big role. The organization should be capable of providing on the job trainings to the new employees to keep them updated about the organizational procedures. Similarly, if the organization could train their employees time to time, even if it is costly, the organization can gain improved productivity and quality.

4.4.2.9 Customer Satisfaction

Customer satisfaction is another important CSF for LSS implementation. The variables and its loading factors were noted in the table 4.11. For the business to sustain, the customer satisfaction is to be achieved continuously. The customer satisfaction can be ensured if customers repeatedly buy products from the firm. Another way to improve customer satisfaction is offering after sale services, warranties, guarantees and loyalty bonuses. The firm can measure the customer satisfaction through feedback surveys related to their product/ services. The customer satisfaction may enhance through on-time launch, availability of products in nearby markets, adequate quality and nominal price.

Table 4.11: Variables and loading factor for the variables under the factor customer satisfaction.

Variable Number	Variable	Factor Loading
22	Our company has satisfied & repeated customers.	0.831
23	We provide real time inventory information to our suppliers	0.642
44	Our organization offers after sales service.	0.739
45	The organization collects customer feedback.	0.642
Total number of variables: 4 nos.		

4.5 Regression Analysis

After the above tests, this research analysed the regression and correlation of the response data. Table 4.12 shows the result of regression analysis. From the nine factors the factor process and productivity improvement was taken as the dependent variable, as the research is directed towards investigations of process and productivity improvements in small and medium enterprises through lean six sigma implementation**.** The other eight factors were considered as independent variables in the regression analysis.

The value of simple correlation is represented by the notation 'R' and the obtained value of R is 0.895. Generally, a value greater than 0.5 represents good correlation and the value nearing 1 shows strong correlation within the data set. R^2 known as coefficient of determination, is the measure of how close to the regression line, the data is. In other words, it could be annotated as the total variation in the variables. The value of R^2 is just a measure of data spread and literatures do not specify any particular value as threshold. Here, the value is 0.801, i.e. 80.1% which signifies a large variation in the variables.

F statistics and Sigificance: The F-statistic is the Mean Square (Regression) divided by the Mean Square (Residual) and got the value of 81.235. The anova value, or F statistics were also reported. The significance value obtained as 0.000 which is lesser than 0.05, which can be considered as a good fit. Hence the data is suitable for linear regression analysis.

Table 4.12 (a) & (b): Tabulation of SPSS outputs of linear regression

Model	R	R Square	F	Sig.
1	0.895	0.801	81.235	.000

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.654	.135		4.850	.000
TMC	.313	.066	.329	2.596	.010
OC	.297	.081	.236	3.374	.002
COM	.394	.041	.452	4.277	.000
FC	.287	.073	.291	2.925	.012
SI	.209	.072	.187	2.590	.017
EI	.327	.072	.284	5.374	.007
ET	.257	.034	.288	2.127	.025
CS	.072	.031	.107	2.404	.036

The standardised coefficient beta shows which of the independent variables have a greater effect on the dependent variable in a multiple regression analysis, when the variables are measured in different units of measurement. From the table the beta value is highest for the factor financial capability and then for education and training and so on. It can be presumed that presence of these factors will enhance the top management commitment. The coefficients were only accepted if the level of significance is less than 0.05. Here, all the significance values except customer satisfaction were lesser than 0.05 and hence acceptable. The significance values also prove that the increase in the corresponding factors will significantly contribute to the top management commitment and thus degree of adoption of LSS. The significance value of customer satisfaction obtained was 0.560, which indicates its poor influence to LSS adoption.

4.6 Comparison of CSF's Effect in Various Groups of Organization

In this section, the data is compared based on the grouping with different criteria. The criteria taken were as:

- ISO 9001 certified companies versus non-ISO 9001 certified, to examine whether quality management has got any influence.
- Location based i.e. organisations within industrial area versus outside industrial area, to examine whether locational factors are influencing.
- Small scale organisations versus medium scale organisations, to examine whether the size of organisations are influencing.

For analysing whether differences exist, independence t-test were carried out as an inferential statistic. Here the data is assumed to follow a normal distribution. The hypothesis used here is as follows.

Ho: No considerable difference for the factors identified between the groups.

H_1: Considerable difference is present for the factors identified between the groups.

Significance level: 95%

Rejects Ho if $p < 0.05$

Table 4.13 provides the insight of numbers of each category participated in this research. Table 4.14 consolidates the significance value of t-test from which, the difference between categories could be identified.

Table 4.13 The numbers of organisations under each category for the study

The numbers of organisations under each category, from a total number of 170	
ISO 9001 certified: 72	Non-ISO 9001: 98
Small scale enterprises: 119	Medium scale: 51
Inside industrial estate: 104	Outside: 66

Table 4.14 t-test results as comparison of various group.

Factor	ISO 9001 vs. non ISO 9001	Within industrial estate vs. outside	Small vs. medium
Process and Productivity Improvement	0.3125	0.2414	0.5614
Top management commitment	0.0022	0.4115	0.0002
Organization culture and infrastructure	0.5728	0.1375	0.2168
Communication	0.0932	0.4739	0.2404
Financial capabilities	0.5520	0.9047	0.0317
Supplier involvement	0.5629	0.2593	0.1690
Employee involvement	0.3219	0.1777	0.4935
Education and training	0.2982	0.0247	0.2404
Customer satisfaction	0.2894	0.1390	0.7013

4.6.1 Comparison between ISO 9001 certified and non-ISO 9001 certified firms

All the factors except top management commitment got a value more than 0.05. Hence the factors waste management, organization culture and infrastructure, communication, financial capabilities, supplier involvement, employee involvement, education and training and customer satisfaction are having same effect for LSS adoption at both ISO 9001 and non-ISO 9001 organisations.

The change in top management commitment is obvious; this is how the ISO 9001 certified organisations derived the advantage even though ISO 9001 certification is not compulsory in the market.

4.6.2 Comparison between organisations within industrial area and outside industrial area

All the factors except education and training have significance value greater than 0.05, which confirms the difference of influence by this factor to LSS implementation. All the other factors do not have much difference in their influence towards LSS implementation. Thus, can be inferred as having the same contribution by other success factors to both categories of industries.

By referring table 4.13, the difference observed in education and training may be because the government and industrial organisations generally set up common facility centre and training centres near industrial areas, which may help the employees to get more education and training. The industries located within the industrial area can share best practices relating to quality standards, quality practices etc. which would be beneficial to all the related industries. These possibilities may not be available for the industries situated outside the industrial areas and specifically those in the rural areas.

4.6.3 Comparison between small scale organisations and medium scale organisations

The values of significance less than 0.05 for most of the factors which ensure the similarity of the conditions within both category of firms. The difference analysed were in top management commitment and financial capability as given in the table 4.13.

The investigator presumes that the medium sector has better financial stability than the small-scale sector. Generally, they have a better investment; better employee strength; are aimed at a greater number of customers; and may have more financial back up etc. This makes the medium sector more stable in terms of financial capability and in-turn drives them to adopt manufacturing management models. Referring variation in the factor top management commitment, the authors feel that this happens due to any of the two reasons such as:

1. The financial background of medium enterprises is stable compared to small enterprises. Thus, the medium enterprises can have more financial flexibility, and funding provision, it makes them to take more initiative towards quality improvement programs.
2. The medium sector industries may have a greater number of managers for monitoring and controlling operations. Hence the top management can more concentrate on planning strategies for the company’s progression.

4.7 Conclusion

This chapter investigated and validated the success factors which were identified from the literature survey. In this research, a questionnaire was developed from the literature, it is surveyed from 170 number of SMEs and the data were analysed for getting the required results. EFA were conducted to group the variables and later termed the groups suitable labels of CSF, regression analysis had been carried out to measure the degree of adoption of LSS for the responded industries. Finally, a comparative study by differentiating the industries using various categorization and inferences were reported. In the next chapter, another objective of research, i.e. study of seven wastes is reported.

Chapter 5

Study on the Effect of Seven Wastes in SME Sector

5.1 Introduction

Chapter 4 discussed about the research work carried out by the investigator in finding out the CSFs of LSS implementation. The research resulted in the identification of nine CSFs from SMEs. Further regression analysis for finding the degree of adoption of LSS in SMEs were carried out. The comparison of effect of factors in the different classifications of industries were also conducted and reported. This chapter describes the importance of studying seven wastes and a method to rank the seven wastes.

Considering the changes in market conditions, Indian SMEs are striving hard to stay competitive and profitable for a long-term period. One of the methods that can add value to the business is by being able to recognise and reduce waste. The lean manufacturing philosophy identified seven waste that act as a barrier for productivity and quality (Poppendieck 2002).

The SMEs all over the world are facing a lot of challenges and problems in doing the business compared to large firms. It is generally, difficult to the managers to identify the wastes, as the wastes are not normally visible and lies like iceberg floating in water. Only few of seven such as defects, over production and inventory are at least visible to some extent.

Yamashita (2004) conducted a study on implementing lean manufacturing in a company at Minneapolis area and found that higher quality products with less recourses and capital are achieved by reducing scrap, rework, returns, and waste by the implementation of lean manufacturing. Domingo in his lecture materials stated the importance of uncovering and eliminating the seven wastes to reach the goal of lean manufacturing. El-Namrouty and AbuShaaban (2013) conducted study at Gaza strip to find out the interdependence of seven wastes as well as the relation between seven wastes, lean manufacturing and production cost. The study concluded that, the identification of wastes can foster lean implementation and can reduce the production cost significantly.

Praveen et al. (2015) studied the effect of seven wastes in Indian SMEs and concluded that seven waste has their own influence in the SME sector. The study also showed that the effect of seven wastes are not same. Ramadas et al. (2016) studied the relationship between number of defects, production cost and lean implementation in the Indian SMEs. The study result shows how the managerial factors contribute towards the lean implementation. Mwafak Shakoor et al. (2017) conducted studies at five retail stores at distinct cities of UAE. The aim of the study was to identify the relation between benchmarking, lean implementation, takt and cycle times, resources and waste reduction. The study infers that reduction of resources as well as the wastes can reduce the cost of providing retail service. Christopher (2014) investigated the importance of seven wastes in clinical pharmacy researches and concluded that the seven wastes significantly influence wasted time of clinical pharmacists. The research also reported that lean techniques could be helpful in reducing wastes and increasing the productivity of clinical pharmacies.

5.2 Objectives

- To investigate the effect of seven wastes in SME sector
- To explore further the interdependency of the various factors as identified.
- Formulation of hypothesis on the influence of these factors

5.3 Seven Wastes (Muda)

The Toyota production system identified three factors that act as a barrier to the business processes. These factors cause to increase the non-value-added activities within the firm. The three factors which were termed in Japanese language and their English meaning within bracket are: Muda (Waste), Mura (Unevenness) and Muri (Overburden). The literatures prove that these factors are interrelated and ultimately are the root causes for any non-value-added activity within the firm (Womack and Jones, 2003). Hence, lean manufacturing constantly tries to remove these factors from operations.

Further lean manufacturing classifies the Muda into seven wastes that act as a barrier to productivity and thus increase the production cost. The seven wastes are termed as: Transportation (T), Inventory (I), Motion (M), Waiting (W), Overproduction (O), Over-processing (P) and Defects (D). Definitions as provided by the lean philosophy for the seven wastes are described in the following lines. (Arunagiri and Gnanavelbabu, 2014; El-

Namrouty and AbuShaaban, 2013; Al-Aomar, 2012; Womack and Jones, 2003; Poppendieck, 2002)

- Transport: When anything (people, equipment, supplies, tools, documents, or materials) is moved or transported unnecessarily from one location to another.
- Inventory: Wastes come from the purchasing, storage of excess materials, and other resources. This waste can also be caused by overproduction as excess materials and work-in-process (WIP) are accumulated.
- Motion: Waste happens when unnecessary body movements are made when performing a task. Examples are searching, reaching, walking, bending, lifting, and other unnecessary body movements.
- Waiting: When resources like people and equipment are forced to wait unnecessarily because of delays in the arrival or availability of other resources including information. Some literatures use the term 'delay' for this waste.
- Overproduction: Waste occurs when more goods are produced than can be sold, resulting in idle finished goods inventory.
- Over-processing: Waste comes from unnecessary processing that does not add value to the item being produced or worked on.
- Defect: When products or service deviate from what the customer requires or the specification. Examples of Defects in manufacturing include scrap parts and products that require rework.

5.4 Waste Relations

It is presumed that all types of wastes are inter-dependent in nature. Every one of seven wastes have their own influence to the operations and it influences or vary the other six wastes. The increase in wastes result in increased production cost (El-Namrouty and AbuShaaban, 2013). For example, if the defect during production is becoming more, transportation, waiting, motion etc. may also increase as the defect product needs rework. In the same way, variations in over-processing, transportation etc. make a variation in waiting time.

It is clear that the relation between each waste may vary according to the condition existing in the particular industry as each industry considers the waste differently. For example, a manufacturer producing customised products may not have overproduction but may have over-processing or any other. But a manufacturer producing fast moving consumer goods may have much waste by overproduction.

5.4.1 Transportation Waste Relation

Transportation-Inventory: If the capacity of transporting equipment is not sufficient to transport the entire inventory or if the numbers of transporting equipment are less than they actually need, the WIP inventory increases.

Transportation-Motion: If the transportation method is not mechanised/ automated the workers effort will be more. Similarly, if the storage and retrieval systems are not efficient it may increase the need for searching and/or handling the materials.

Transportation-Waiting: If the transported materials are not reaching their destination in time due, it may cause materials, machine, and man to wait. This may occur due to poor route planning or some failure in equipment.

Transportation-Overproduction: Items are produced more than needed just to fill materials handling equipment in order to reduce the transporting cost per unit and to minimize number of transports.

Transportation-Over-processing: If the transportation system is slow, then the worker gets more time for processing and hence worker involves in finishing operations than needed.

Transportation-Defects: Unsafe equipment used for transportation, transporting larger quantity than its capacity, improper handling of materials, carelessness of worker, and transportation machine failure can produce defects.

The ‘transportation’ waste may also increase the related wastes. This relation is represented in the figure 5.1.

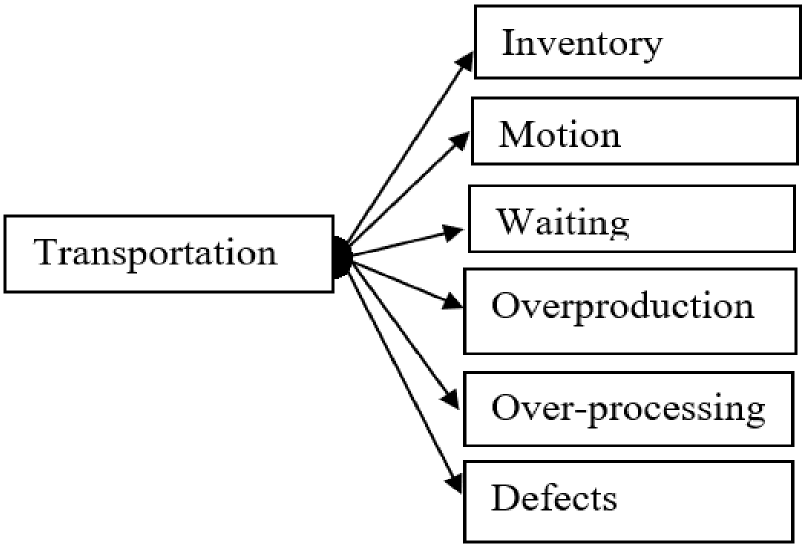

Fig 5.1: Transportation waste relation

5.4.2 Inventory Waste Relation

Inventory-Transportation: Increased finished product inventory shows the need for increased transportation between shop floor and store. Similarly, increased WIP results in increased transportation between the work stations.

Inventory-Motion: Higher levels of WIP and/or unorganised inventory methods increase the effort for searching, selecting, grasping, reaching, moving, and handling.

Inventory-Waiting: Improper location of storage may lead to increased transportation and thus waiting. Similarly, if the materials are not stored in an organised structure, it may lead to increased searching, handling etc. which may also increase the waiting time.

Inventory-Overproduction: If the inventory in the firm is high, then the worker will be forced to produce more than the market demand. Some raw materials can’t be stored for much longer time so the company will be forced to produce more. Also, fluctuation in raw material cost forces the company to produce more.

Inventory-Over-processing: When high inventory is present workers feel relaxed in targets and thus tends to have more finishing operations than required which in turn leads to over-processing.

Inventory-Defects: Some raw materials or finished goods may get damaged when stored for a longer time.

5.4.3 Motion Waste Relation

Motion-Transportation: Due to the carelessness of worker, the material that is dropped in a wrong location, needs to be transported again to the correct location.

Motion-Inventory: motion also includes workers movements during machining. Hence if the worker takes more effort and works more there is a chance of increasing WIP and finished goods inventory. Similarly, if the worker restricts the motion there are chances for accumulation of raw material and WIP inventories. This relation is highly important in mechanised machines.

Motion-Waiting: If the worker is not trained well or unskilled there may occur unnecessary movements and hence waiting waste.

Motion-Overproduction: If worker carelessly continues his machining operations than actual demand, it may cause overproduction. This relation is highly important in mechanised and automated mass-production industries.

Motion-Over-processing: Lack of understanding of the workers on the available technology about the equipments may cause over-processing.

Motion-Defects: If the worker feels lazy to operate the machine and the machine continues its wrong processes, may cause defective products.

5.4.4 Waiting Waste Relation

Waiting-Transportation: When a part has to wait for more than usual it misses its transportation plan. Chances of happening this is more in mass-production automated industries.

Waiting-Inventory: Waiting of materials between workstations and waiting for finished goods in the warehouse increases inventory.

Waiting-Motion: Waiting for parts from WIP may tempt the worker to do more finishing operations to current part, cause unnecessary motion of workers.

Waiting-Overproduction: Due to increased waiting time, the work station forces predecessor station to produce more than what is actually needed to avoid waiting.

Waiting-Over-processing: Waiting for parts from WIP may tempt the worker to do more finishing operations to the current part.

Waiting-Defects: When a part has to wait for a long term, probability of it getting damaged from the surroundings increases.

5.4.5 Overproduction Waste Relation

Overproduction-Transportation: For overproduction, much more raw materials are needed so that it has to be transported to storage space and production facility. Also, inventory has to be transported more due to the higher rate of production. It causes more transportation between the various production stages. The finished goods have to be transported to a warehouse or market at a faster rate.

Overproduction-Inventory: Overproduction means producing at a higher rate than the demand, thus high material inventory is needed. It again increases the WIP as well as need of storage facilities and space.

Overproduction-Motion: When a worker is forced to overproduce, the effort for operations increases and hence the motion waste increases.

Overproduction-Waiting: Because of overproduction, each workstation as well the firm as a whole, produce products than actually needed which increases the inventory. It again increases the waiting time of materials to be in stock.

Overproduction-Over-processing: As all the work stations produce more components, there is increased chance for dimension changes to occur. This tempts the workers to provide more fits and tolerances to the parts which thus increase over-processing.

Overproduction-Defects: The operator will be forced to produce more in less time so that care given by the operator in each item decreases, so that the chance of defect is more.

5.4.6 Over-processing Waste Relation

Over-processing-Transportation: Because of over-processing the part misses its slot and extra transportation is needed to take the over-processed part to next workstation.

Over-processing-Inventory: Over-processing may reduce the WIP inventory. Ideally it seems good, but it may increase the waiting time of successor stations. It also may increase the WIP of predecessor stations.

Over-processing-Motion: Over-processing generally caused by non-standardised procedures which increases worker motions.

Over-processing-Waiting: When over-processing happens, the worker takes more time than usual so the other parts have to wait. Over-processing leads to high setup times and increased downtimes and hence waiting increases.

Over-processing-Overproduction: As the firm tries to reduce the idle time of men and machineries, and thus forces the workers to work continuously, causing overproduction.

Over-processing-Defects: Insufficient and improper processes lead to the production of defects.

5.4.7 Defects Waste Relation

Defects-Transportation: If the defects need to be repaired, then it has to be moved back to the particular workstation which increases transportation. If the defects are to be scrapped then also it has to go out of the facility which needs transportation.

Defects-Inventory: As defective parts increase, the WIP level increases for defects to get reworked. If defects are considered as scrap, special storage space has to be allotted to store it.

Defects-Motion: If defective parts can be repaired, then the worker has to work on it, which will increase the motion of worker.

Defects-Waiting: If a defect is produced, the cause of the error of process or method has to be found out. Also, the error has to be corrected. For the detection and correction of error, time is needed which will create waiting for other parts.

Defects-Overproduction: If a number of defects is found to be large, then to meet the demand the firm has to overproduce. By this way, defects lead to overproduction.

Defects-Over-processing: If the defects need to be repaired, the worker has to give more effort on it. Thus the worker tends to give more care to the process to make it mistake proof.

5.5 Methodology

From the literature review, the researchers identified that seven wastes of lean manufacturing have a great influence in LSS implementation in the SME sector. Studies conducted in many countries show the importance of elimination of those wastes in industries. To validate this in the Indian scenario, the investigator conducted a questionnaire survey to find out the influence of seven wastes in Indian SMEs and followed by a detailed study to identify the interdependency between them. Investigator used the questionnaires and methods developed by El-Namrouty and Abu-Shaaban (2013) for conducting this study. Few changes have been made to the scale values, symbols used, relation weights etc. of their questionnaire and method.

The questionnaire used for finding the first two objectives contained 49 questions, with 5 points Likert- scale. 133 manufacturing firms from the districts of Thrissur and Palakkad, Kerala, India participated in the survey. The questions were responded by the managers or supervisors of the firm with reference to their working conditions. Statistical analyses were carried out using SPSS software for testing various hypothesis.

If these wastes affect the production, there is a possibility of interrelation in them. Therefore, the relation between them also needed to be found out. Research extended to rank the seven wastes based on their interdependency by using the third questionnaire. The managers of 26 die manufacturing industries responded to the questionnaire, considering their working environment. The response was taken through a direct interview by discussing the seven wastes and its effect on each of the other wastes. The questionnaire response was in a Likert 3-point scale. The analysis was completed using Microsoft Excel software. As a result of the analysis, a matrix was formed, which is termed as Waste Matrix. It clearly shows the rank of the seven wastes.

Once the relation among the wastes was identified, ranking of the wastes according to their influence on others to find out the most influenced waste has been done. After finding the most critical one, possible measures can be taken by the management to reduce or eliminate the critical waste which will thus, increase the performance of the organisation to a great extent. When the critical waste is eliminated, automatically the wastes which are influenced by the critical waste will also get reduced, which will reduce the loss to a certain amount. After eliminating the waste having rank one according to the influence, waste having rank two can be selected and eliminated.

5.6 Analysis

A reliability analysis was carried out to check the reliability of the data and a KMO test also was carried out to check the sampling adequacy. Later, non-parametric tests were considered to check the hypothesis for the first two objectives. For ranking the seven wastes a proven method identified by the researchers El-Namrouty and AbuShaaban (2013) was used with some modifications.

5.6.1 Reliability and sample adequacy analysis

Table 5.1: Cronbach's Alpha and KMO test for sampling adequacy results.

Item	Value
Cronbach's alpha	0.755
KMO Test for sampling adequacy	0.590

Reliability of the questionnaire was tested using Cronbach's alpha test and got the results as reported in table 5.1. Here the alpha value was found to be 0.755 which means the data is reliable. Also, there is internal consistency in the data and the scale chosen is appropriate for the questionnaire.

The value for the KMO test was 0.590 which is considered as un-acceptable. Hence, the sample size of 133 may be considered as inadequate. Thus, the investigator decided to proceed further with non-parametric tests for the analyses.

5.6.2 Wilcoxon Signed Rank Test

To find out whether there is an influence for the seven wastes in SME, Wilcoxon signed rank test is used. The Wilcoxon signed rank test is the nonparametric test equivalent to the dependent t-test. A signed ranks test may be carried out in SPSS for any paired-samples data, that is, for situations in which there are two scores per subject (or one score per subject and the subjects are somehow paired).

Table 5.2: Wilcoxon signed rank test's result

	MEDIAN - T	MEDIAN - I	MEDIAN - M	MEDIAN - W	MEDIAN - O	MEDIAN - P	MEDIAN - D
Z	-10.109[b]	-9.294[b]	-9.638[b]	-9.539[b]	-10.076[b]	-10.281[b]	-10.181[b]
Asymp. Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.

Here, the hypothesis is the median for the questionnaire (i.e. 3) is equal to median for each factor. The p-value is found to be less than for all the seven wastes, which means that the hypothesis could be rejected for all the cases. Z values of the result shows the positive rank for all the relations. Hence it could be understand that the median for each set of waste is more than hypothysed median 3 and the seven wastes are present in the SME sector and they influence the processes inside the facility and hence affects the performance of the firm.

5.6.3 Kruskal Wallis Test

Further Kruskal-Wallis test has been carried out. The Kruskal-Wallis test (is similar to the "one-way ANOVA" of parametric tests) is a rank-based nonparametric test that can be used to determine if there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. In this scenario, the hypothesis used was each of seven wastes has the same effect on SME sector.

- H_0: Each of seven wastes have same influence on production (i.e. the median of all wastes is equal)
- H_1: Each of seven wastes do not have same influence on production.
- Significance level: 95%
- Rejects Ho if $p < 0.05$

Table 5.3: Result of Kruskal Wallis Test

	MEDIAN
Chi-Square	29.768
Df	6
Asymp. Sig.	.000

a. Kruskal Wallis Test

b. Grouping Variable: WASTE

Kruskal-Wallis test showed that there was a statistically significant differences in pain score between the different drug treatments, Chi-Square = 29.768, df= 6 and p = 0.000. As the significance value from table 5.3 is less than 0.05, the null hypothesis can be rejected. Hence the investigator concludes that there is a significant difference in the means of the seven wastes and the effect of seven wastes on SME firms is not uniform. Each waste of the seven, has its own influence in SME sector.

5.7 Study of Inter-Relations and Ranking of Seven Wastes

It is already proven that the seven wastes influence the SME sector in their own way and the next step is to find out the inter-relation among them if there exists any. For this, the third questionnaire was used, from which the inter-relation can be easily found out. SMEs have a wide variety of products; a wide variety of technology and production processes are being used in each industry. So, it is not possible to generalise the inter-relation of wastes for all industries. So that a specific manufacturing type industry that is the die manufacturing industry was selected to find out the inter-relation of wastes. Opinions were collected from 26 die manufacturing units, and that was analysed to find out the inter-relation. Microsoft Excel was used for the analysis purpose. The weights for each answer were directly recorded, and the score was calculated to form the waste relation matrix. The method of developing waste relation matrix is discussed in the following sections.

In the questionnaire, each relation was assigned by the symbol "i-j", For instance, "T-I" indicates the direct effect of transportation on inventory, and so on. The weights for each answer are directly recorded, and the score was calculated and tabulated. After collecting opinion from all 26 die manufacturing firms, to create a final waste relation matrix, the mean of all the responses were found. The mean values of 26 responses, total score and the corresponding weights are given in table 5.4.

Table 5.4: Waste relation scores and weights

Waste Relation	1	2	3	4	5	6	Score	Weight
T-I	1.81	1.85	1.65	1.77	1.81	1.62	10.51	2
T-M	1.54	1.31	1.58	1.69	1.38	1.62	9.12	2
T-W	1.62	1.77	1.77	1.85	1.46	1.54	10.01	2
T-O	1.42	1.35	1.54	1.31	1.46	1.54	8.62	2
T-P	1.08	1.04	1.04	1.08	1.08	1.08	6.40	1
T-D	1.19	1.77	1.65	1.62	1.73	1.50	9.46	2
I-T	1.85	1.85	2.04	1.81	1.58	1.46	10.59	2
I-M	1.15	1.15	1.15	1.27	1.04	1.23	6.99	1
I-W	1.81	1.73	1.58	1.77	1.81	1.65	10.35	2
I-O	1.50	1.54	1.46	1.35	1.35	1.46	8.66	2
I-P	1.15	1.08	1.15	1.00	1.04	1.04	6.46	1
I-D	1.31	1.58	1.50	1.73	1.46	1.38	8.96	2
M-T	1.00	1.08	1.04	1.00	1.04	1.08	6.24	1
M-I	1.19	1.19	1.15	1.08	1.15	1.08	6.84	1
M-W	2.00	1.92	1.85	2.00	1.81	2.00	11.58	3
M-O	1.00	1.08	1.00	1.04	1.04	1.00	6.16	1
M-P	1.96	1.85	2.00	1.77	2.04	1.77	11.39	3
M-D	1.54	1.38	1.62	1.54	1.62	1.38	9.08	2
W-T	1.42	1.58	1.73	1.54	1.42	1.27	8.96	2
W-I	1.73	1.81	2.31	1.92	2.00	2.04	11.81	3
W-M	1.00	1.00	1.00	1.00	1.00	1.00	6.00	1
W-O	1.54	1.46	1.50	1.62	1.50	1.23	8.85	2
W-P	1.12	1.62	1.31	1.38	1.42	1.65	8.50	2
W-D	1.08	1.35	1.50	1.46	1.31	1.35	8.05	1
O-T	1.58	1.54	1.42	1.35	1.42	1.54	8.85	2
O-I	1.15	1.58	1.42	1.46	1.23	1.35	8.19	1
O-M	1.35	1.23	1.62	1.46	1.23	1.35	8.24	1

Table 5.4 (Continued)

Waste Relation	**1**	**2**	**3**	**4**	**5**	**6**	**Score**	**Weight**
O-W	1.65	1.58	1.54	1.58	1.31	1.42	9.08	2
O-P	1.08	1.04	1.04	1.15	1.00	1.08	6.39	1
O-D	1.31	1.50	1.46	1.31	1.35	1.35	8.28	1
P-T	1.35	1.27	1.38	1.27	1.23	1.19	7.69	1
P-I	2.19	2.08	2.08	1.96	2.04	2.15	12.5	3
P-M	2.88	2.42	2.46	2.73	2.38	2.54	15.41	4
P-W	2.77	2.77	2.81	2.77	2.81	2.77	16.7	5
P-O	1.00	1.04	1.00	1.08	1.08	1.12	6.32	1
P-D	2.23	1.85	2.19	2.23	1.96	2.08	12.54	3
D-T	2.62	2.19	2.15	2.00	2.12	2.23	13.31	4
D-I	2.85	2.19	2.42	2.65	2.38	2.27	14.76	4
D-M	2.88	2.42	2.38	2.27	2.23	2.35	14.53	4
D-W	2.88	2.54	2.54	2.77	2.58	2.54	15.85	5
D-O	1.08	1.35	1.23	1.19	1.35	1.15	7.35	1
D-P	2.96	2.81	2.73	2.58	2.92	2.85	16.85	5

The score of each relation is found out by adding the points corresponding to six questions. For example, relation Transportation-Inventory score can be found out by

T-I = 1.81+1.85+1.65+1.77+1.81+1.62=10.51

Like this, the score of each waste relation was found out and recorded in the score column. According to the score, the relation is classified into five ranges, and weight is given to each relation as in table 5.5. The absolute necessary relation is given most weight and unimportant relation is given least weight. The weights of every relation were recorded in table 5.6 according to each waste relation. That is from table 5.4, the relation between T-I scored 10.51 and hence is weighted as “2” with an ordinary closeness.

Table 5.5: Type of relation and weight according to relational score

Range	Type of Relation	Weight
15.61 to 18.00	Absolutely necessary	5
13.21 to 15.60	Especially important	4
10.81 to 13.20	Important	3
8.41 to 10.80	Ordinary closeness	2
6 to 8.40	Unimportant	1

Table 5.6: Wastes relations matrix

	T	I	M	W	O	P	D	Score	%	Rank
T		2	2	2	2	1	2	11	12.09	5
I	2		1	2	2	1	2	10	10.99	6
M	1	1		3	1	3	2	11	12.09	4
W	2	3	1		2	2	1	11	12.09	3
O	2	1	1	2		1	1	8	8.79	7
P	1	3	4	5	1		3	17	18.68	2
D	4	4	4	5	1	5		23	25.27	1
Score	12	14	13	19	9	13	11	91		
%	13.19	15.38	14.29	20.88	9.89	14.29	12.09			

In the table 5.6 score was calculated by adding all the weights for each waste row-wise and column-wise. For illustration, transportation "T" row-wise score is 2+2+2+2+1+2=11 and column-wise score is 2+1+2+2+1+4=12. The percentage is obtained by dividing this score to the total score, i.e. (11/91) *100 for row and (12/91) *100 for the column. Likewise, for each waste, the values were found and tabulated.

The highest percentage obtained for row-wise calculation is for the waste which affects the other wastes most critically. The highest percentage in the column-wise calculation is for the waste which is affected more by other wastes. From table 5.6, "defect" was the most critical waste which is affecting other wastes in the die manufacturing industry. Similarly, “waiting” was the most critical waste which is getting affected by all the other wastes.

The waste which has highest value in the row-wise calculation is assigned as ranked one, the next highest as ranked two and so on. The ranks are tabulated at the right-hand side column to the % as given in table 5.6. If tie comes in percentage, the “waste” with a higher percentage in column-wise value was granted the higher rank.

Figure 5.2 shows the pictorial representation of the waste’s relations matrix. The relations with weight more than 2 are marked with arrows. From the figure, it is clear that ‘defect’ is the most critical waste with a greater number of outgoing arrows. When defect rates increase, transportation, WIP, motion, waiting and over-processing may increase. It is also clear that the waiting time will be increased when any of the wastes such as motion, over-processing or defect increases.

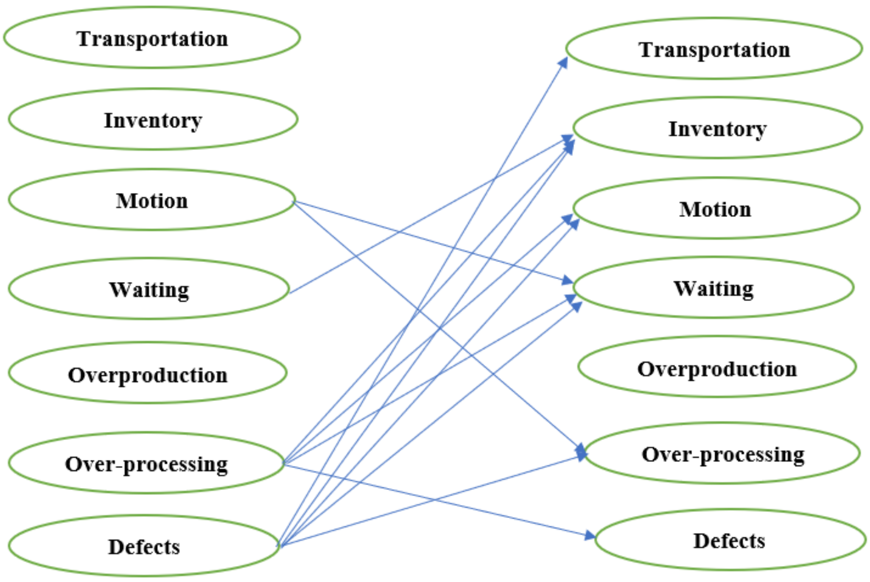

Figure 5.2 Wastes relations obtained

El-Namrouty and Abushaaban (2013), in their studies considered the ranks in rows as well as in columns and the study used only for analytical purposes. But in this study, the researchers only concentrated on ranks in row-wise data and were used further for case study procedures. Similarly, the scale taken in the questionnaire of El-Namrouty and Abushaaban (2013), was 1, 3 and 5. Whereas, here it was 1,2 and 3. The weight given by the previous research were 2, 4, 6, 8 and 10 and in this research, it was 1, 2, 3, 4 and 5.

Slight modification in the questionnaire (Appendix 4) was also made with the help of pilot study and direct discussions with subject experts.

5.8 Conclusion

From the initial studies conducted by the researchers, it was learned that the SMEs are suffering from the seven types of waste in their processes and seven wastes of lean manufacturing are dependent on each other. The wastes within the company decrease the productivity as well as increase the production cost.

This research focused exclusively on die manufacturing industries to rank the inter-related wastes. The result shows that the “defect” is the waste which is affecting the other wastes more critically and “overproduction” is the waste which is influencing other wastes least. Next chapter reports the reasons for model development and the features of the developed IRDAIC model.

Chapter 6

Development of a Model for LSS Implementation in SME Sector

6.1 Introduction

The chapter 5 presented the importance of study about seven wastes within the manufacturing industries. The chapter also proposed a method for identifying and ranking of seven wastes, which is termed as waste relations matrix. The past two chapters suggests the need of a simple model which can help in the implementation of LSS for SMEs. Hence this chapter reports about the model developed by the investigator termed IRDAIC.

6.2 Necessity of a New Model

LSS, being the strong combination of proven philosophies lean manufacturing and Six Sigma, provides great advantages to its' implementors. Lean manufacturing can be considered as a set of tools and techniques, from which the implementor can chose any according to their situations. No researchers reported any well-defined model/ methodology for implementing lean manufacturing. Most of the researchers as well as larger companies started the implementation using value stream mapping (VSM), whereas many others started with the 5S implementation. In case of selection of tools and techniques too, different researchers and/ or organization had followed various considerations, as reported in literatures.

Most literatures which reported Six Sigma implementation, considered DMAIC as the roadmap or model for Six Sigma implementation. Models are available such as Design for Six Sigma (DFSS), Invention-Innovation-Develop-Optimize-Verify (I^2DOV), Concept-Design-Optimize-Verify (CDOV), Identify-Define-Develop-Optimize-Verify (ID2OV), Define-Characterize-Optimize-Verify (DCOV), Define-Measure-Analyse-Design-Verify (DMADV) (Matthew et al. 2004, Hu et al. 2008). All of these models were put forward by different researchers and/or organisations regarding their situations. In general, these models were used to start implementation from the scratch that aimed in designing the product or process to be near error free. Whereas DMAIC model ensures continuous improvement to existing products/ processes, as well as to the new ones.

Researchers reported that no standard framework for LSS implementation was available (Pepper and Spedding, 2010). Similar to lean manufacturing, researchers had developed their own frameworks for LSS implementation according to their findings. The following paragraphs describes few literatures on LSS framework developed by different researchers.

Sharma (2003) used DMAIC model with lean manufacturing tools such as Kanban, TPM, SMED, Poka-yoke etc. for LSS implementation. The author conducted a case study in battery firm and found successful. Furterer and Elshennawy (2005), Kumar et al. (2006) also used lean tools like Kanban, VSM, Visual control, one-piece flow etc. encompassing various stages of DMAIC during their implementation study and found successful.

Thomas et al. (2009) developed a model that helps SMEs to implement LSS. The researcher had a case study using the model and resulted in significant savings of money. Jayaraman and Teo (2010) studied CSFs of LSS implementation and made a framework for LSS implementation, which was conducted in an Electronic Component Manufacturing firm. The study reported that identification and boosting of CSF can enhance the LSS implementation as well as reduce the operational cost.

Gnanaraj et al. (2010 a,b) addressed deficiencies with SMEs in implementing LSS. The researchers developed a model termed Deficiencies Overcoming Lean Anchorage Define Measure Analyse Improve Control Stabilize (DOLADMAICS) as a framework for sensitising and providing guidelines for SMEs. They had been implemented the model in a SME producing cylinder frame and significant improvement in results were reported. Hilton and Sohal (2012) studied about the key variables for successful implementation of LSS. A framework has been framed by the researchers and used for testing the hypothesis, which was formed with black belt and master black belt. Prasanna and Vinodh (2013) developed a framework termed Lean Anchored Define Measure Analyse Improve Control (LADMAIC) model, which was aimed to implement LSS as well as to enable the scientific management of LSS in SMEs. Their study concluded the improved result of a hypothetical case study through the LSS implementation. Swarnakar and Vinodh (2015) developed a framework in LSS by using the lean manufacturing tools within the DMAIC methodology. The framework was validated by implementing it in an automotive assembly firm. The authors mentioned that the framework could be applicable in other type of industries by using suitable lean tools.

Literatures report that the abovesaid models were developed by the researchers based on their area of study and situations. The models were validated by researchers, by implementation study in the location where the researcher concentrated. The generalisability of the model was not reported by the literature. Hence, this research tries to develop a new model that could help Indian SMEs to implement LSS in an easier way and reap its benefit.

Generally, the initial models tried to use the lean manufacturing at the first stages and Six Sigma/ DMAIC model in the later stages. Later, the models tried to use the tools and techniques of both lean manufacturing and Six Sigma simultaneously. The IRDAIC model tries to eliminate seven wastes using six sigma methodology.

6.3 IRDAIC Model

The primary objective of this research was to implement the LSS in SME sector. The extended literature survey, initial questionnaire surveys and interactions with industrialists and subject experts, the investigator reached to a conclusion that a framework is necessary to help SMEs to implement LSS. The initial questionnaire survey result supported the relation of process and productivity improvement through waste elimination to the LSS adoption. From the result it was clear that reducing the wastes can improve the process performances and hence will enhance implementation of quality models. In the second questionnaire survey, the result underlined the presence and influence of seven wastes in the SMEs. The study also forwarded a method to rank the seven wastes in the order of their influence to the manufacturing processes. From this point of view, the investigator developed a specific model Identify Rank Define Analyse Improve Control (IRDAIC) that could support SMEs especially in eliminating waste as well as the CSF identified earlier.

Generally, the prior models of LSS uses mainly quantitative data during the proceedings. IRDAIC model tries to use both the quantitative and qualitative data during the processing steps. The model uses stages similar to DMAIC, except for measure stage. Instead of Measure stage, identify stage identifies the waste and the rank stage identifies the priority to be followed. Generally, LSS starts with identification of CTQ. But this model, directly tries to identify the processing wastes within the industries and thus to eliminate it using LSS tools. The model is designed with the tools and techniques that do not have much statistical and mathematical calculations. This makes the model flexible, which can be even operated by a semiskilled employee of the organisation. Figure 6.1 represents the IRDAIC model.

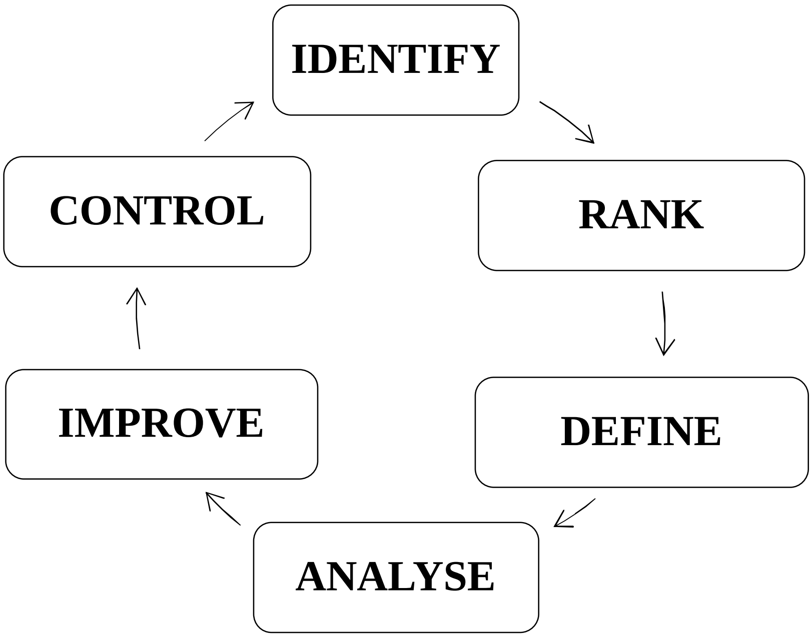

Figure 6.1 IRDAIC Model

6.3.1 Identify

This model is specifically designed to identify and eliminate waste. Hence the initial step is to identify the waste. From literature, we defined the seven wastes. In the chapter 5, the result of questionnaire survey reported that, seven wastes influence the process performance within the firm. This stage tries to identify each waste quantitatively. Each of the seven wastes are being measured in the respective units. The model gives the freedom to its user to use the suitable unit for the particular waste according to industrial conditions. The members of the project can use this method and can easily quantify all the seven wastes. For instance, in a machining job, the employee has 'motion' waste with less effort and with more processing time, whereas in case of a layman job, the worker may have more effort with or without more processing time. Hence in the initial case the waste can be defined only in time of processing whereas in latter, the waste can be defined both by the weight lifting and time needed.

6.3.2 Rank

In this stage, waste relations matrix method is used to rank and prioritise the wastes. The basic idea of waste relations matrix has been taken from the literature of El-Namrouty and Abushaaban (2013). Suitable modifications have been made to the questionnaire and the steps, that were followed by them. The modifications made the method much simple than before.

In this stage the project members are requested to respond to a questionnaire. The responses were tabulated using MS Excel software. After completing the processing steps, the final result could be obtained in a matrix form, which shows the ranks of each waste. By using these ranks as the priority, the remaining stages of the model proceeds.

6.3.3 Define

In this step, the entire project was defined to the company and the project members, using a project charter template. The project charter explains the expected completion time for each step, expected LSS tools to be used in the project, expected results of the project etc. Define stage decides whether to consider all the wastes or negligible wastes could not be excluded from the process etc.

6.3.4 Analyse

The detailed study of each waste has been conducted in this step, to identify the cause for a particular waste. Here all the available data is analysed to find out the root cause for each waste. Observations and time studies were conducted at this stage for finding the root causes. Various statistical and managerial problem solving techniques are used in this stage such as cause and effect diagram, pareto chart, histograms, barcharts etc.

6.3.5 Improve

In this stage, the possible solutions for the identified problem are made. The project team members, using brainstorming, developed the solution for each waste. Next, is finding the better solution from among the alternatives. The solution, which seems most effective, will be selected for implementation. Later the project team make the necessary steps to implement the new solution. The employees are being educated and trained for the new method, necessary changes in working set ups have been made and all the derivative requirements for the implementation must have planned and implemented at this stage. Lastly the new solution is commissioned in the process.

6.3.6 Control

This stage is aimed to monitor the changes made due to the new methods and make sure that the results are improved. The changes in productivity, quality and costs to be observed and documented. The values can be used for statistical analyses for ensuring the reliability and validity. Whether the results are not as planned, we need to start again from analysis stage with present situations as the data. If the results are satisfactory, the project can be closed. As every quality improvement programmes are continuous in nature, and TQM believes that 'there is always a room for improvement', here in this stage also, the firm can search for new opportunity for quality improvement.

6.4 Conclusion

The chapter discusses about the various models developed and practiced by differrent researchers in different organisations and locations. It also underlines the requirement for the development of a new model for LSS implementation at Indian SMEs. The basic concepts and stages of the model also were discussed. The next chapter discusses the case study carried out in an handmade paper industry by implementing the model.

Chapter 7

Case Study on the Model Implementation in an SME.

7.1 Introduction

Chapter 6 discussed about the basic concepts and steps of the model. This chapter reports about the case study on the model implementation, carried out in an Indian SME, which produces handmade paper (HMP), as a part of testing and validating the model.

The investigator was interested to check and validate the model in the process industries, as the situation is more complex in those industries. The investigator had requested many of the questionnaire respondents for their acceptance for implementing and testing the model in their organization to which they responded positively. As this organization was willing to implement the LSS model and was of process type, the investigator selected this industry for the case study. The following paragraphs provide an introduction to HMP industries and its importance in the global scenario.

Growth in population, better literacy, need of communication and documentation, evergreen acceptability of print media and requirements for artistic works increase global paper usage continuously (Enayati et al., 2009). Even though many agencies suggest to reduce paper usage in order to save trees, there isn't a better option most of the times. The word 'paper' is derived from PAPIRUS (the leaves available in the banks of river Nile in Egypt) which were used for writing. In India palm leaves were also used as a media to communicate in the earlier days. The manual craft of papermaking has been in practice from about 2000 years ago. Each and every papermaker find their own way to produce the HMP. Every papermaker believes that his/ her method is best for papermaking by hand (Heller 1978). Various books authored by different researchers during the periods of 20^{th} century put forward claims regarding the origin of Handmade paper. Literature generally identifies Can Lun of China as the inventor of the HMP in AD 105. The authors indicate that the growth of HMP industry is attributed to the craftmanship of the workers from around the world, with different methods being followed at different places, who started making papers at different times (Hunter 1930, 1947; Heller 1978; Premchand 1995).

In India HMP industries existed from the 9th century and flourished during the Mughals regime. Even though Industry suffered a setback during the pre-independence period, the Father of the Nation Sri. M. K. Gandhi, during his independence (swadeshi) movements, promoted making and using of Khadi products. With this, many craftsmen started back their traditional HMP making. The promotion to Khadi products by various Governments nurtured the HMP industries and similar Khadi producers (Hubbe and Bowden 2009; Mcfarlane 1993; Premchand 1995). Krishna Joshi, one of the assistants to Sri. M. K. Gandhi in papermaking, developed newer designs and methods that reduced the effort of papermaking. Still the HMP making is a tedious job for the employees as they have to work with water for a long time in shifts. (Hubbe and Bowden 2009).

The use of Hollander beater for pulp making and other mechanizations were started on 1660s at Europe (Hunter 1947; Toale 1983). During the starting and middle of 19th century, the continuous papermaking with mechanized units were invented and the improved machineries with better productivity were commissioned. This made the European HMP factories to shut down their operations or change to new method because of the cost competitions (Hunter 1947; Heller 1978; Schreyer 1988). The HMP industries had a renaissance through the worlds' drive towards eco-friendly products. This educated the users to reduce the use of papers from wooden pulp, which can save the trees as well. Generally HMP is made from cotton and other natural fibrous materials which do not harm the environment (Turner 1998). Taory (2002) and Biggs and Messerschumidt (2005) inferred that HMP is an industry that can have a positive role in the society through their eco-friendly processes and products. Mandahawi et al. (2012) used LSS to enhance the productivity of the printing section of a paper industry and found significant improvements in the performances. Generally, literatures were scant on quality initiatives in HMP industries.

7.2 About the company

The name of the organisation considered here is kept as X1 to keep the anonymity. X1 is an HMP manufacturing firm which produces genuine handmade papers for drawing, cards and certificates. X1 was started at Tarihal Industrial area of Dharwad district, Karnataka, India in the year 1986. This is a small-scale industry registered under the District Industry Centre, Dharwad, and also recognized by Khadi and Village Industries Commission as a genuine Handmade Paper Manufacturers.

The present management took over the company in the year 1995, when it was a sick unit. The present management have two directors with diploma in HMP making and many years of experience in the same. The directors along with managing director (MD) are involved in managing all the activities of the company i.e. all the sections like production, accounting, marketing etc. are headed directly by the management.

X1 has a good demand for their product from different locations around the globe. About 60% of the total sales are exported to various countries. The company produces about 300 kgs of paper a day and about half of this 300 kg is produced by manually operated machine and the remaining by using semi automatic machine.

Currently fifty employees are working for company and the annual turnover of the company in Indian Rupees is 150 lakhs. The employees are required to perform various activities to make the final product as per the customer requirement. The employees in this industry do not possess any formal educational qualifications.

The rate of rejection at X1 was around 15%. The directors of X1 had not considered this high rejection seriously. The impact of this condition was realized, only when they could not meet the orders frequently in time. They regularly get orders to export a container of paper products every quarter of year. 80% of their export order was for HMP. They are meeting their local orders by using semi automatic machine whereas they have to fulfill the export order by manual paper making. They are purchasing raw material from Tamil Nadu and importing it through road trucks. As the suppliers are not available nearer, the purchase could not be made JIT type.

The investigator had interviewed the directors during the questionnaire survey and held a discussion on the importance of LSS implementation. Considering the state of wastes and especially the defect rate prevailed at that time, the firm did show their interest in implementing the model to reduce the waste and reach LSS benefits. It was because of the willingness from the X1's management the investigator selected the industry for the case study. The following paragraphs describes the proceedings of the case study.

7.3 Implementation

The investigator started collecting data through questionnaires and direct interviews with the directors and experienced senior employees at various sections. A basic understanding of LSS, IRDAIC etc. have been delivered to the workers by conducting a lecture session. The senior employees were selected as team leaders for the project and had more discussions to educate how the model was going to be implemented in the firm. The investigator deputed the team leaders having experience in the related field and having good idea about all the manufacturing operations over the firm to collect the necessary data for the study.

7.3.1 IRDAIC Procedure

The six steps of implementation of IRDAIC are detailed in the subsequent sections.

7.3.1.1 Identify

Detailed data collection has been conducted. Using questionnaire with directors, team leaders and employees the wastes within the firm were identified. The method used for quantifying the wastes by the organisation is described as following:

- Transportation: The unnecessary movements for components, tools, documents or information from one place to another. It was specified in meters per day.
- Inventory: Quantity of items that is in stock than actually needed for a specified period.
- Motion: Motion contributes excessive effort for the employees. But the effort is a qualitative term and difficult to quantify. Hence weight of the component is considered.
- Waiting: Time in minutes of an 8-hour shift.
- Overproduction: Percentage of unwanted stock concerning the normal demand.
- Over-processing: Excess time needed than standard lead time in hours as observed.
- Defects: Percentage of scrap or reworked material to the total product manufactured.
- Sigma level: With respect to percentage defect, from sigma level table.

7.3.1.2 Ranking

Using the waste relations matrix, the ranking of the wastes has also been done. The amount of each waste was quantified in terms of time, material in stock, defect percentage, effort needed to the respective waste etc. Sigma level is calculated using percentage defect. The ranks obtained is tabulated by the waste relation matrix in the table 7.1 and also portrayed in figure 7.1. The raw material and finished goods 'inventory' were not taken into consideration, as changing the supply and marketing pattern were difficult.

Table 7.1: Wastes relation matrix for X1

X1	T	I	M	W	O	P	D	Score	%	Rank
T		2	4	5	1	1	1	14	14.00	3
I	2		2	2	1	2	3	12	12.00	5
M	1	1		2	1	1	5	11	11.00	6
W	1	3	1		1	5	2	13	13.00	4
O	1	1	1	1		1	1	6	6.00	7
P	5	3	5	4	1		3	21	21.00	2
D	5	3	5	4	1	5		23	23.00	1
Score	15	13	18	18	6	15	15	100		
%	15.00	13.00	18.00	18.00	6.00	15.00	15.00			

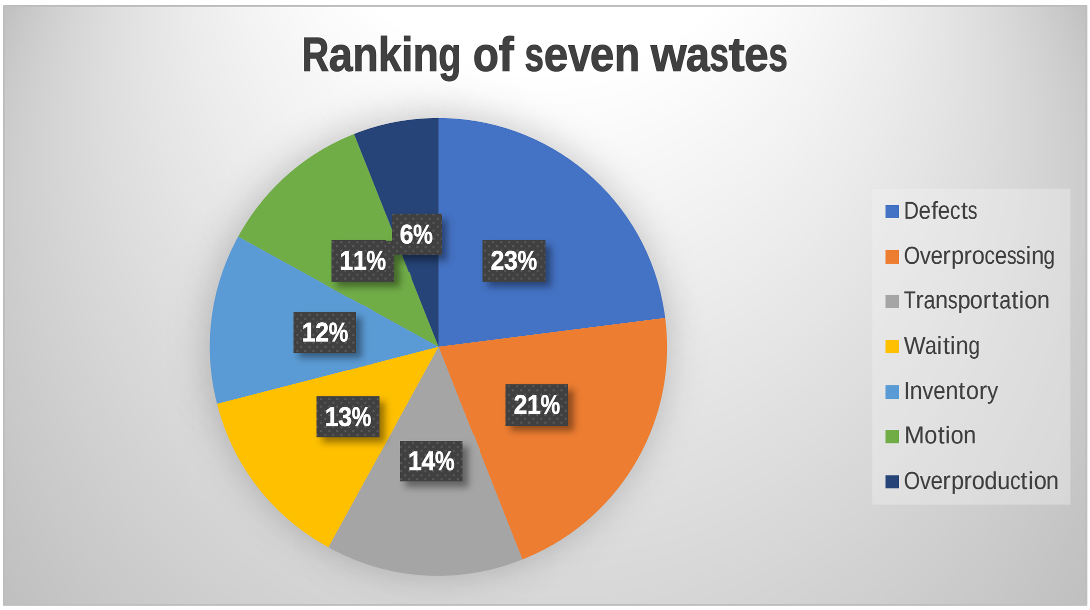

Figure 7.1 Ranking of seven wastes

7.3.1.3 Define

In this step, the goal of the entire project is defined. With reference to the project charter the project durations for the correction of each waste, project completion times etc were fixed. Project charter for this study is reported in the table 7.2. The investigator and directors selected suitable employees as team leaders for different sections, according to the employees' experience as well as passion for the particular work. The identification of solution and implementation started in the order of ranking of wastes i.e. the project started with the waste 'defect'.

7.3.1.4 Analyze

The method for reducing the wastes has been identified through brainstorming with directors, team leaders as well as all level of employees. Some of the lean tools, six sigma/statistical tools etc. were used for identifying the root causes and for designing a better solution. Causes for each waste were identified and the solutions for reducing each of the wastes were proposed.

Table 7.2: Project charter

Project Charter	
Name of the organization: X1	Type of the product manufactured: Customized paper products
Name of the expert: Director 1	Project Manager: Managing Director
Coordinator: Director 2	Project team: Senior supervising employees
Start Date: June 1, 2016	Expected completion date: November 18, 2016
Business case: Higher rate of wastes and could not meet the orders in time	Objective: Study and reduction of seven wastes
Project scope: Production processes and related operations	Measurables: Seven wastes (Muda), Sigma level
Tools & techniques to be employed: project charter, check sheets, cause and effect diagram, bar chart, Pareto analysis, questionnaires, quality circles, 5S, JIT, TPM.	
Expected date for completion of activity: Identify: 24/06/2016 Rank: 26/07/2016 Define: 8/8/2016 Analyse: 30/8/2016 Improve: 20/10/2016 Control: 10/11/2016	Project benefits: Reduction in wastages Improvement in productivity Reduction in production cost

7.3.1.5 Improve

As given by the waste relations matrix, “defect” was having rank one. So, the project tried to eliminate the waste defect first. The solution identified for reducing defects were instructed to the team leaders and employees. Training session for small period were conducted to educate the method to employees and then the method is implemented to a regular way. The initial changes were noticed to check the feasibility. Then the project moves to the waste ranked second. The solution identified for the waste ranked second i.e. over-processing, was educated and trained to the employees and then implemented. In the similar way, solutions for the waste ranked three, four and so on were implemented. The identified wastes and solution for each waste are summarised in the table 7.3.

7.3.1.6 Control

In this stage, after the complete implementation, the result was analysed. If the results were improved as expected, the new method is set as new standard. Then the function of this step is to continouosly monitor the works.

Table 7.3: Identified wastes and actions taken during implementation

Waste	Scenario	Action taken
D	Defect rate at final inspection about 13%	• Employees are trained to check the defects in paper at each process stages • VAT machine operators are trained for improving the quality and to reduce the defects in production
D	Pulp pouring by bucket which makes inaccurate GSM paper	Pulp is collected in a transparent bottle with levels marked, which can be poured directly to the wire net frame. the valve can be operated by helpers.
D	Colour change for paper	Ensuring the sizing solution to be of alkaline (pH between 7-8) can reduce this problem

Table 7.3 Continued

Waste	Scenario	Action taken
P	Submerging paper for longer duration in sizing solution which results in increased drying time and increased chances for colour change.	Employees are directed to dip the paper only for 1-2 seconds.
T	Increased transportation between processes	Modification in lay out (without changing the position of machineries)
W	Waiting time for hydraulic press operators	• Compulsory dynamic rotation of work which increases the productivity and quality • During idle time they are directed to check paper quality
W	Incorrect package lines	Arranged the line properly
M	Weight of the wire net frame	Wooden frames are replaced using aluminium
I	Huge inventory of chopped cotton	The workers directed to go to other departments after chopping 350 Kg/day.
O	More number of sheets are produced considering defects	Reduced

7.4 Results

The company implemented the IRDAIC model and obtained the result as given in table 7.4. Significant improvements were monitored during the case study. The company could achieve 9% reduction in defects, and thus 0.78 points increase in the sigma level. Improvements were seen in all the wastes.

Another important achievement of this case study was that the workers of the firm had a little understanding on the quality initiatives and the importance of the quality. The workers were educated and trained to identify and reduce the wastes starting from the initial stage. Similarly, the workers are motivated to shift themselves to dynamic rotation of work force, so that the workers need not do the heavier tasks for long durations.

Table 7.4: Results of the case study

Type of waste	**Before Implementation**	**After Implementation**
Defects (D)	18.45 kg/ 150 kgs (12.3%)	4.2/ 150 (2.8%)
Over-processing (P)	Takes 30 hours to get dried	Can get dried by 24 hours
Transportation (T)	2300 m	1300 m
Waiting (W)	150 Mins	80 Mins
Motion (M)	Weight of the frame is high (Wire net of 10 kg and deckle of 15 kg)	Reduced frame's weight using aluminum instead of wood (3 kg & 5 kg)
Inventory (I)	Chopped cotton of about 600 kg	Reduced to 350 kg
Overproduction (O)	4.5 kg	3 kg
Sigma level	2.77	3.55

The productivity of the firm with respect to the defect rate was increased by 9.5% as a result of this case study. Production cost for producing one kg of paper may vary slightly according to the specifications such as GSM, size of paper, final machining required etc. Here the production cost for a kg of A4-HMP sheets were considered for comparison. With the help of this project, the company could reduce the production cost from Indian Rupees 460 to 420 and the profit was increased by 7% by considering the selling price as same.

7.5 Conclusion

The chapter discussed the procedure followed and result obtained during the case study carried out at the HMP manufacturing firm. The result shows significant improvement in performances due to the implementation which validates the model. The next chapter will discuss about the case study conducted at an industrial cluster of 10 die manufacturing firms and reports its results.

Chapter 8

Case Study on the Model Implementation in a Cluster

8.1 Introduction

The investigator has also conducted a case study in an SME based cluster for testing and validating the model, as well as for generalising the model by checking the applicability in a variety of industrial units. The investigators with the help of some industry owners identified and developed a cluster of 10 die manufacturing firms from the industrial areas of Kunnamkulam and Athani of Thrissur, Kerala, India. These die manufacturing industries produce customized products for their various customers. These industries manufacture a variety of dies and moulds for plastic manufacturing, jewelry works, steel rule dies, compression mould making, pattern making and many other industrial works. The literature below underlines the importance of studying die manufacturing firms, importance of clustering and the government supports towards industrial clusters.

Paquin and Robert (1962) quoted in their book that die design and manufacturing which is a large division of tool engineering, is a complex, enthralling subject. The tool design and manufacturing require the artistic skill of labourers and precise manufacturing operations. The dies are the important device that decides the quality of the final product. So, defects in dies, as well as cost of dies are critical for the part manufactures. According to Canis (2012), the tool and die manufacturing industries are generally having small businesses using skilled and experienced employees. Most of the tool and die manufacturing firms employ fewer than 50 Workers and runs mainly under private sector. The requirement of frequent changes in design of products, enhances the need for tool, dies and moulds, thus the industry.

While mass production can be done by using same tool, die or mould, the principal tools and dies cannot be produced in mass. The industries may produce thousands of products using the same tool/die or mould. But the tools, especially dies and moulds are custom made against each product, generally one at a time. The manufacturing of tool and die requires skilled labour with precise machining and ultimate surface finish (Arnet and Smith, 1975). Generally, die manufacturing industries follow manufacture-to-order production strategies as they need to prepare customized dies mostly.

Governments, governmental agencies/ departments and various non-government organisations for industrial developments such as CII, Management associations etc. are trying to promote a culture of cluster development among similar industries. The cluster development may be done based on the similarity in the process, industry location, support from local bodies and authorities, dependence on same supplier or customer etc. The literatures give insights that the clustering can nurture the productivity, quality and profit rates of the participating industries.

In his studies on Indian galvanizing machine tool industry, Harbhajan Singh (2011) discusses the overview of industrial scenario, competition, technological factors, governmental supports etc. The paper tells that, there are many factors such as federal laws and cost which limits the SMEs to import and use most modern machine tools. Cluster development can improve the technology support to many industries without much cost investments. Through providing Common Facility Centres (CFCs) and Industrial Cluster Parks (ICP), many related industries can use the latest technology under a single umbrella.

Government of India (GOI) as well as most of the state governments are offering special schemes for industrial clusters to cultivate quality improvement programs especially for implementation of lean manufacturing through MSMEDI and similar organisations. Annual report 2017-18 of MSMEDI underlines that lean manufacturing can enhance the productivity and competitiveness through reduction of wastages, inventory management, space management and energy management. The report also tells that, in the state of Kerala, four industrial clusters have implemented lean manufacturing on a pilot basis; 8 clusters were processing towards lean manufacturing programs; and awareness programs were progressing in another 8 clusters. Similarly, Ministry of MSME, GOI started ‘ZED Certification’ scheme for the industries and the industrial clusters which aims at Zero Effect and Zero defects at each and every participating industry. GOI also offers national level awards for following constant quality initiatives in the industries.

Another scheme for MSME sector by Ministry of MSME, GOI is the Micro and Small Enterprises- Cluster Development Programme (MSECDP). This scheme promotes and develops clusters from Micro and Small firms with close support from state governments and other stakeholders. 19 industrial clusters are running under this scheme in the state of Kerala, India. The records also mention that about 400 registered clusters are there in the different locations of the country. The clusters are of various products and some of them were initiated and promoted by MNCs. (MSMEDI annual report, 2018 a,c)

It is also a known fact that many unregistered clusters as well as artisanal clusters are also functioning in the country. Many of the industries were grouped together for getting some benefits in mass purchases/ mass selling/ ease of processing/ ease to get funding.

8.2 Identification and Development of cluster

The die manufacturing is one of the leading businesses going on at Thrissur. All the industries participated were of small-scale sector concerning their total investment. As the government is offering many facilities for cluster activities, some of these firms were in different clusters under MSMEDI programme previously. Also, some of the owners and employees had attended the training programs conducted by MSMEDI, CII, district management association, other industrial associations etc. Hence, they have a good idea about lean, six sigma and such quality improvement practice.

At this juncture, the researcher considered them as one cluster. Hence the project requires timely start and timely completion, the cluster was not of registered for this project as per government norms. Hence the cost incurred for the meetings and all have divided by the researcher and the 10 firms. The meetings were arranged at the conference halls available at the two firms (of 10) subject to convenience. One of the ten owners, who is a B. Tech graduate in production engineering, interested in quality improvement programmes acted as leader/coordinator for the cluster from their end. The industries were termed as Y1 to Y10 for keeping the anonymity.

During the first meeting, the investigator presented the detailed process of the project like the expected time schedule, duties and responsibilities of the owner/managers. A detailed discussion about the IRDAIC methodology had been conducted. The managers were quite interested in IRDAIC implementation as they were much concerned about the production wastes. The meeting was dispersed by fixing the time schedules for each process for the project completion.

8.3 Implementation procedure

The following sections describe the procedure for implementation of IRDAIC model.

8.3.1 Identify

In this study, the manager of the die manufacturing industry responded to the given questionnaires. The seven wastes were identified in the manufacturing processes through the questionnaire and the detailed interview. The managers and experienced employees discussed and quantified the seven wastes with reference to the working environments and related factor of the particular industry. The researcher also helped the owners and employees, in cases of difficulties. Initial sigma level was calculated and noted. The method used to quantify the waste is as follows:

- Transportation: The unnecessary movements for components, tools, documents or information from one place to another. It was specified in meters per day.
- Inventory: Percentage of items that is in stock than actually needed for a specified period.
- Motion: Motion contributes to two outcomes; excessive effort and increased waiting time. Here the effort was not considered for quantification. Hence, the waiting time in minutes per shift of 8 hours was specified.
- Waiting: Time in minutes of an 8-hour shift.
- Overproduction: Percentage of unwanted stock concerning the normal demand.
- Over-processing: Percentage of excess time used more than the standard lead time in hours as observed.
- Defects: Percentage of scrap or reworked material to the total material manufactured.
- Sigma level: With respect to percentage defect, from sigma level charts.

8.3.2 Rank

In this step, using the waste relations matrix, the wastes were ranked. Different organisations had different ranks for the seven wastes. The ranks obtained by the different firms from the corresponding waste relations matrix were consolidated and tabulated in the table 8.1.

Table 8.1 Ranks of wastes as obtained by waste relations matrix from the industries.

Firm/ Waste	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**	**Y7**	**Y8**	**Y9**	**Y10**
T	6	3	6	4	3	7	3	3	7	7
I	4	4	5	6	6	6	4	5	5	5
M	3	5	4	3	4	3	6	6	4	4
W	5	6	3	5	5	4	5	7	3	3
O	7	7	7	7	7	5	7	4	6	6
P	2	1	2	2	2	2	2	2	2	2
D	1	2	1	1	1	1	1	1	1	1

8.3.3 Define

Project charter was used for defining the project, which helps anyone to understand the entire process at a single glance. The project proceeds with educating about the implementation procedures to the employees involved in the project and arranging them in different teams according to the processing methods. A general template of project charter used in the case study is show in the table 8.2.

8.3.4 Analyse

The team did the detailed examination of the entire procedures and identified how each waste were developed and how they could be eliminated. The LSS tools like cause and effect diagram, pareto chart, why-why analysis, check lists etc. were used for identifying the root causes of each wastes and were identified.

Table 8.2: Project charter template

Project Charter	
Name of the organization: (Y1 to Y10)	Type of the product manufactured: Customized dies/ moulds
Name of the expert: Owners/ deputed managers	Project Manager: Managers/ Supervisors
Coordinator: Owners/ deputed managers	Project team: Skilled employees
Start Date: January 9, 2017	Expected completion date: May 31, 2017
Business case: Increased wastes and production cost	Objective: Study and reduction of seven wastes
Project scope: Production processes and related operations of X1	Measurables: Seven wastes (Muda), Production time and cost.
Tools & techniques to be employed: Project charter, check sheets, cause and effect diagram, bar chart, Pareto analysis, flow diagram, matrix diagram, flow chart, checklists, scales/formulae to measure the levels of wastes and sigma and questionnaires, brain storming.	
Expected date for completion of activity: Identify: 11/2/2017 Rank: 20/2/2017 Define: 9/3/2017 Analyse: 25/3/2017 Improve: 18/5/2017 Control: 31/5/2017	Project benefits: Reduction in wastages Improvement in productivity Reduction in production cost

8.3.5 Improve

The new solutions were identified through brainstorming and discussions by the project mates. The employees were trained to implement the new solution and the changes needed in factory set up and methods, if any to be made. The implementation was started in the production processes according to the rank of the wastes. The wastes identified from the industries and the actions took for reducing each waste are reported in the table 8.2. The industries which reported the scenario are represented by the number within the bracket.

Table 8.3: Identified wastes and actions taken during implementation

Waste to which affects	Current scenario	Action plans
T	Raw material/Tools/ Drawing/Measuring instruments brought from store after starting set up (All firms)	Trained workers to bring all the needed items in their work table before set up
T	Multiple storage locations (Y1,Y2,Y5,Y7,Y9)	Re arranged the locations
I	Cost & space for raw material inventory (Y1,Y2,Y3,Y4,Y5,Y7,Y8,Y9)	Use of KANBAN & JIT as possible & Use of ABC analysis of inventory
I	Huge work in process inventory (Y1,Y3,Y6,Y7,Y8,Y10)	Improved through proper scheduling
I	Low storage space (Y10)	Improved through 5S implementation and arranging stacks
M	Improper scheduling in machining processes which makes more tool changes and set up (Y3,Y4,Y6,Y8)	Trained to schedule work properly
M	The height of the shelves is more (thinking of saving space) which makes employees to make extra effort (Y2,Y9)	The storage spaces are redefined. Less weight tools and materials stored at heights. Medium weight components in lower shelves and weighing components kept at the normal height.
M	Mixed inventory increases the searching of tools and materials (Y1,Y5,Y7,Y10)	5S Implementation
W	Frequent machine repairs / Tool grindings. (Y5,Y9,Y10)	Use of TPM strategies

Table 8.3 Continued

Waste to which affects	Current scenario	Action plans
W	Raw material/Tools/ Drawing/Measuring instruments brought from store after starting set up. (All firms)	Trained workers to bring all the needed items in their work table before set up.
W	Fewer number of machines makes the work to wait (Y9)	Improved through proper scheduling.
O	Overproduction of assembly components (Y1,Y2,Y3,Y4,Y5,Y6,Y7,Y8,Y9)	Improved through proper scheduling
O	Producing large batches because of long setups of machines, which results WIP (Y6,Y8,Y10)	Improved through the communication of the demand time to time to the employees
P	Problems in blue prints/ Frequent change in design (All firms).	Need to collaborate more with clients
P	Ignorance of employees on quality standards/ limit, fits & tolerances/ surface finish (All firms).	Educated and trained Standard Operating Procedures (SOP) to the employees.
P	Worn tools and incorrect maintenance schedules (Y5,Y7)	Use of TPM
D	Defects during machining (All firms).	Training to the workers
D	Poor quality of purchased materials (All firms).	Train workers for quality checking at purchasing.
D	Defects due to faults in drawing at initial production stages (All firms).	Starting production after design finalization
D	Carelessness of employees (All firms).	Improved through educating and training employees

8.3.6 Control

The results were monitored and the newer method is standardised. Control measures could be taken if some variations occur than expected. The final sigma level after implementation were calculated and noted.

8.4 Brief Description About the Industries Participated

The following sections describes the details of the industries participated such as products manufacturing, starting year, number of employees etc.

8.4.1 The company Y1

The firm produces blow moulding machines used to make variety of plastic products. The company produces customized products. The size of machine and design of die varies according to the order received. The company was started in the year 2011 and gives employment to 6 people. The company have large number of customers from Kerala and other places of India.

The company produces some of the components themselves. The bulky and complex designed shapes are procured through outsourcing to other companies having CNC machines. Similarly, PLC and other electronic components are purchased from Coimbatore or Mumbai based on availability and cost.

The owner of the Y1 is a graduate in Production Engineering and has an experience in the industrial sector for more than 28 years. As the owner of the company had idea about various TQM practices, he put some proven lean tools such as 5S, a system similar to Kanban etc. Hence the owner was having keen interest in the IRDAIC implementation and was chosen as a leader of the cluster of 10 firms. The employees also have suitable technical qualifications and years of experience in the machining operations. This helped the company to follow quality procedures easily.

In the plant the operators are directed to keep the work pieces, tools and other materials in the cupboards provided for them. The owners and the employees have good communicational relationship and thus, each and everyone knows the purpose of each process. The company also keeps good relation with the suppliers as well as customers.

Company offers after sale services to the customers. All these conditions made the company to ease to implement IRDAIC to the production processes.

The arrangement of cupboards and stacks for storage of materials was not effective, hence with the help of coordinator and expert the layout is slightly modified, which reduced the total transportation between processes. The company used to order the materials required, as per their need in the production processes. But after implementation of the model, periodic meetings have been arranged and helped the company to order all the needed item at a time (for 1-2 months) which made rate discounts from the suppliers.

8.4.2 The company Y2

Y2 has a history of 29 years of experience in the engineering sector. The company produces machines for different processes and provides after sale services for them. The company has a good number of successful industries as clients. The company runs with a total number of 8 employees. The company has many numbers of products, whereas the study considered the die manufacturing processes only.

Company participated in a cluster arranged by industrial association to promote the lean strategies. The company implemented some aspects of lean practices like 5S, Kanban etc. SOPs are displayed in visual boards kept in relevant positions in the plant making it visible to everyone. Y2 also tries their level best to implement JIT, but the company conditions like location of suppliers need not allow them the implementation to a complete level. The company had installed two new automated machineries which increased the rate of production. The company believes in quality checking and inspection before taking the materials in stock and before the delivery of end products to the customers. Preventive maintenance policy is maintained for their machining units. The employees are strictly directed to maintain and update the record. Purchase and stores department is regulated in a way to centralize all the purchases required and keeps a good relationship with the suppliers. The company's management is in keen interest to implement the possible quality tools, because it has a highly competitive business environment which forces them the fastest delivery of cheap and quality products.

8.4.3 The company Y3

The unit was established in 1988 with 10 employees as a small-scale industry. At present, the company employs 120 employees and made investment in situating modern machine tools and working atmospheres. The organisation is engaged in designing and manufacturing various types of precision machined components. The company has a list of regular customers from public and private sector businesses. The company produces machines for plastic manufacturing, pipe manufacturing, food processing machines, and many other industrial equipment. This study mainly focus on die manufacturing section of the firm. The company supplies around 2,50,000 units of machine components per year as per their customer orders. To meet the demand, the company works in 3 shifts a day and six days per week.

Y3 following good safety practices, which provides a safe working environment for the employees. The installation of CNC machines improved the productivity to a great extant. One of the major problems the company facing at present is the availability of skilled employees. Unskilled, short-term employees are a big barrier for the company to follow quality programs. The company still tries to make the workers efficient through in-plant trainings for the employees. The company follows many aspects of various quality practices like 5S, PDCA cycles, TPM etc. Strict monitoring from the management takes place regularly.

8.4.4 The company Y4

Company Y4 is a specialist in die and mould manufacturing and servicing. The company is a small-scale unit employing 15 people and was set up in 2001. The company has a good set of customers with long years of relationships. This unique position has been achieved through openhanded attention to quality, cost and delivery and through ensuring total customer satisfaction. Y4 has high competition from the nearby competitors, which makes them concentrate on quality policies. The owner has participated in many quality initiative programs organised by MSMEDI, CII, NIMSME etc. from which he has a keen interest in the implementation of LSS models and use of tools like 5S, Kanban etc. The company has many barriers to implement LSS because of the fund limitations, skill level limitations of employees and the unavailability of time for the owner to manage these and educate and motivate the employees.

8.4.5 The company Y5

Company Y5 is involved in the manufacture and supply of dies and moulds for various purposes. The company runs successfully for the past two decades. Y5 have a good list of customers including large scale public and private sector companies. It has developed a good reputation among the clients.

Manpower management, availability of suitable and sufficient human resource, marketing, and fierce competition from local markets are the major challenges that the company faces. Management is trying hard to maintain best in class quality with competitive pricing of the product. This policy forces Y5 to follow quality practices in their manufacturing processes. The company employs about 15 people, but only have 4 employees in permanent nature.

The management has directed the workers to always keep the materials and tools in the proper places as assigned, to follow strict adherence of work time and schedule etc. Y5 tries to fit 5S, JIT, Kanban, SMED etc. to their production lines. The layout of the plant is designed most suitably to enhance productivity. Firm enhances the customer relations through proper communications, freedom to visit plant and 24x7 technical consultancy.

8.4.6 The company Y6

Y6 is engaged in the manufacture and distribution of plastic injection mould and blow moulding machines. The company also had another unit of plastic pellets distribution. This study was conducted in the moulding machine manufacturing unit of the firm. This unit had started production in 1996 and have now became one of the largest producers and supplier in Kerala, India.

Company manufactures dies and machines for variety of plastic products. The product range starts from small medicinal bottles to tanks of 1000s of litres. The company have a large set of customers across Kerala, India. The company employs 10 people in a regular manner and hires whatever needed for shorter periods when workload increases with demand. The manager of the company, a diploma holder in Mechanical Engineering with a huge industrial experience over various countries. The manager has a good view in the implementation of quality initiatives.

The company tried for the implementation of lean manufacturing to their units and successfully implemented some aspects of 5S, Kanban and JIT. As the company is away from some of the suppliers, JIT makes delays in production by increasing waiting time. Y6 had arranged the layout in a manner which reduces the transportation to a minimum level. The company has SOPs and follows the documentation of processes. The instructions are communicated in the local language, which makes easy to communicate with every employee. Y6 follows preventive maintenance to their machineries. A few pieces of dies and mould are made and kept in stock always, expecting irregularities in demand and considering faster lead time, thus increases the inventory too. The company conducts customer surveys for getting feedbacks and any suggestion from the customers are incorporated in the next design. Y6 is keeping a harmonious relationship with all of its suppliers as well as customers. Customer complaints are very seriously attended by the company and products are replaced according to the severity of the complaints.

8.4.7 The company Y7

Y7 started the business in 2008. The company involves in manufacturing of various ranges of dies, moulds, press tools, precision machined components jigs and fixtures. The company has regular supply of moulds for jewellery items for nearby customers. Y7 used to get orders from government or public sector companies for different supplies. Company runs with 20 employees and have only few skilled labours. The company lacks employee support towards quality initiatives due to employee’s ignorance and unwillingness to change the environment as they fear of competency. This makes the company to follow incorrect operating procedures, improper layout design and excess storage of materials. As the customer complaints became more, the owner became interested in quality improvement programmes.

8.4.8 The company Y8

Y8 is a small-scale company employing 30 staff and started working in 2001. The company produces a wide range of dies and moulds for their customers. The company also has a subsidiary business in all engineering works. The study has been focused to the die and moulds division of the company. The company had installed CNCs for automating the processes as well as to improve the product quality. The layout is arranged in a way that both die manufacturing and most of the engineering works to be done in the same area, which makes the transportation more. As the company is working in a complex structure, the problems faced by the company also slightly differs from the others listed here. The company has a dissimilar waste relations matrix having similar rank 1, 2 and 3 wastes. But rank 4 is given to overproduction. As the company do many works in a single area, the work schedule could not be strictly followed. This makes the company to produce the components more and thus to stock more. The company couldn't identify waiting, because of large number of machineries and operators making the workflow without any idleness. The company delivers quality products within the delivery time promised to the customers. After-sale, customer feedbacks are also welcomed by the company. Due to these reasons, the company has a good list of regular customers from various locations of Kerala, India. One of the major barriers the company has is the lack of permanent work force. Only 10 of the total number of employees were continuing with the company for past many years.

8.4.9 The company Y9

Y9 produces dies for various purposes. The company specialises in producing progressive dies for stamped metallic components with the high precision machine tool using Mosfet technology (SPARKONIX-S35 EDM). The company has been in working from past two decades. Company provides a reputed product quality and a customized service provision for their clients. This helps Y9 to have a better relationship with their clients. 10 employees are working in the firm. The management considers commitments with their employees with high regard and hence the employees as well have a high involvement in the company development activities. 4 of the employees are skilled labours without any formal technical qualifications and the remaining employees are technicians with industrial training or diplomas in related fields. This makes the company strong for progression and development. Y9 uses limited number of machineries for completing the activities. The company has a good layout design by considering the processes to be carried out. Company already participated in some quality development programs conducted by MSME DI, Thrissur and successfully runs some aspects 5S, Kanban, JIT as possible, SMED etc. The company has a well-designed SOP and it is visibly hoarded in the work floor for the workers to have a look at it always. The company follows health and safety precautions to a great extent.

8.4.10 The company Y10

Company Y10 established in the year 2010 for producing moulds and dies for complex die casting applications is managed professionally. The company is also involved in the production of jewellers die and dies for paper cutting and so on. The company have a large set of regular customers from variety of product ranges. The company manufactures moulds and dies for automotive and engineering components too.

The company has about 10 employees. The company has a smaller work/ floor space area and a good plant lay out which reduces the total transportation waste. The machineries and work tables are arranged in a manner to reduce the transportation of materials, tools and information. The company do not concentrate on employee empowerment and constant employment. This makes the company to lose experienced employees frequently. Once the employee gets experienced in the machineries, he leaves for better jobs. This makes the company in high employee turn overs. As the company don't have a constant workforce, it highly affects the quality of the product. The company tries to compete in market by reducing the selling price. For that the company compels the workforce to reduce the production cost. This is generally doing through poor quality materials, faster machining without considering quality aspects. At this juncture, the company is in a struggling position towards competition. Hence the owner is interested in implementing quality tools in the firm which can improve the business situations. Though the company tried to start TQM practices previously, due to the limitations in fund, and attitudes of employees, it did not progress.

8.5 Results and Discussions

The study was completed in the expected period without any delay. All the companies participated in the case study had cooperated with the researcher and gave the relevant data as per agreement on time. Since the limitation in the sharing of cost and profit matters between the competitors the companies were reluctant in giving much of those data. So, the study concluded by quantifying the changes in seven waste and sigma level. The results obtained due to the implementation of IRDAIC model is tabulated in the table A8.1 to A8.8 in the appendix section of this theses. A summary of the results is mentioned in the table 8.4 and table 8.5 to show the range of improvement obtained by different industries.

Other factors which changed during implementation were qualitatively analysed and reported in the following points:

- The results found in successful implementation of 5S in all the industries changed the peripheral look of the workplace.
- The employees empowered through associating with the project had become committed to keep the quality procedures.
- Documentation of the production procedure became compulsory, which made a systemic arrangement of record keeping.
- The idle time of employees and machineries were reduced significantly through proper monitoring and scheduling.
- The use of TPM practices improved the maintenance strategies of the company.
- The OEE of each equipment was improved through reducing the idle time.

Table 8.4 Results of implementation

Type of waste	**Changes in waste**			
	Maximum		**Minimum**	
	Industry	**%**	**Industry**	**%**
Transportation	Y8	47.37	Y9	20.00
Inventory	Y9	66.67	Y9	33.33
Motion	Y2	27.27	Y7	22.22
Waiting	Y6 & Y10	41.67	Y7	25.00
Overproduction	Y5	60.00	Y3	25.00
Over-processing	Y10	62.50	Y2	20.00
Defects	Y1	66.67	Y4	25.00

Table 8.5 Changes in sigma level

	Changes in sigma level			
	Maximum		**Minimum**	
	Industry	**Sigma level**	**Industry**	**Sigma level**
Sigma level	Y1	0.66	Y4	0.17

8.6 Conclusion

The chapter discussed the procedure followed and result obtained during the case study carried out in the cluster of die manufacturing firm. The result shows significant improvement in performances due to the implementation which validates the model. The next chapter discusses about the machine learning analysis to validate the model and reports its results.

CHAPTER 9

Analysis Using Machine Learning Algorithms

9.1 Introduction

Chapter 8 discussed the details of case study by implementing the model in a cluster of die manufacturing firms and the reported its benefits. This chapter reports an analysis using optimisation algorithms regarding the changes in wastes, sigma level, quality cost ratio etc.

In the present, quick paced, globalized business world, competition among organizations is strong. The methodology of LSS helps the companies to reduce wastage, improve productivity and quality and thus reducing the total quality cost and hence the total production cost. For the past two decades the metaheuristic algorithms were highly used in researches for optimisation. The researchers developed the algorithms by observing and identifying the techniques that were used by natural phenomenon as well as by animals and insects. Because of the easiness in using the metaheuristic algorithms in research, at present many researchers uses the well proven algorithms such as Genetic Algorithm (GA), Ant Colony Algorithm (ACA), Bee Colony Algorithm, Crow Search Algorithm (CSA), Particle Swarm Optimiser (PSO) etc. (Bonabeau et al., 1999; Dorigo et al., 2006; Kennedy and Eberhart, 1995). These metaheuristic algorithms became common in researches because of the simplicity and flexibility in usage, its' derivation free mechanism and local optima avoidance (Mirjalili et al., 2014).

It is understandable that the natural phenomenon occurs for a reason i.e. because of some special conditions. For example, different animals having different eating habits are accordingly designed with suitable attacking methods against their prey. Similarly, each researcher may develop the metaheuristic algorithms according to their conditions which may not be suitable for another set of problems. This concept is well defined by 'No Free Lunch theorem'. It states and proves that no metaheuristic is well suited for all problems, i.e. a well proven algorithm used for a particular problem may give bad results for another set of problem (Wolpert and Macready, 1997).

Generally, the metaheuristic algorithm can be considered having two classes. They are single-solution based and population based. Single solution-based algorithms are aimed at solving for a problem with a single variable and its related data. Whereas in population-based algorithm may have many numbers of variables and a greater number of data for the analysis. Here, cases of many candidates could be handled in a single process (Kirkpatrick et al., 1983). In this study we use a population-based algorithm for analysing.

In this study, three algorithms were used and compared. All the algorithms were proven by different researchers for their problem sets. The algorithms used were Grey Wolf Optimiser (GWO), CSA and PSO. The GWO inspired by Grey Wolf (Canis lupus) and mimics the leadership hierarchy of the Grey Wolf and their hunting mechanism (Mirjalili et al., 2014). The CSA was put forwarded by Askarzadeh (2016), which is based on the simulation of the intelligent behaviour of crow flocks. PSO mimics and simulates the social behaviour of flocking of birds and fish schooling. The flying style, velocity and the identification of position etc. were analysed and simulated. All these algorithms were proven by researchers by using it in different complex problems (Salimi, 2016). Further it has also been identified that GWO algorithm has yielded better solutions (Mirjalili et al., 2014).

9.2 Methodology

In this study, the data were collected from 15 manufacturing SMEs where LSS was not in practice. The data were collected using two sets of questionnaires (Appendices 5 & 6) prepared by the investigator. The initial questionnaire had questions regarding factors that affect LSS implementation in any industry, which were taken from various literatures. Since the nature of variable differs the investigator considered the data as non-linear.

The second questionnaire was used to make the waste relations matrix and rank the seven wastes within the firm. Here, the percentage of each waste that was obtained from the waste relations matrix was utilised for the analysis. The data regarding production cost, quality cost etc. were also discussed and documented. The data were collected by direct interviews with the managers or supervisors of the respective firms. The multivariate non-linear regression (MNLR) based enhanced Grey Wolf optimisation (EGWO) algorithm was used for the analysis. The proposed hybrid statistical assessment and optimization process are executed and evaluated in the working platform of MATLAB in terms of quality cost ratio. The quality cost ratio was compared using different proven algorithms such as PSO and CSA. The least quality cost ratio was obtained by the GWO and hence further analyses were carried out using the GWO.

9.3 Multivariate Non-linear Regression Based Enhanced Grey Wolf Optimization

Non-linear regression is a regression in which at least one factor or variable shows non-linear relation with the other factors. The Grey wolf optimization approaches are fundamentally utilized for directing purposes. The leadership hierarchy of grey wolves is mimicked for the development of the algorithm. The grey wolves are grouped into four kinds according to their role in the hunting operations such as alpha, beta, delta, and omega. Each kind of grey wolf has some particular responsibility (Mirjalili, 2015; Mirjalili et al., 2014). The alpha wolfs which are also known as the dominant wolf acts as the leader of the group. Beta, delta and omega wolfs have to obey the orders from alpha. The beta helps alpha in decision making and other activities. Beta wolves obey the alpha, and commands the lower level wolves further. Delta wolves have to submit to alphas and betas, but they dominate the omega. Scouts, elders, hunters, and caretakers belong to this category. Omega are the last wolves that are allowed to eat. It may seem the omega is not an important individual in the pack. The simulating hierarchy was developed by considering the leadership pattern of these four kinds of grey wolves.

The layered and cluster-based design is utilized to cover the whole area of the hunting. The grey wolf optimization enhances the procedure parameters and the calculations (Salimi et al., 2014).

9.3.1 Multi non-linear regression model

Non-linear regression is an extension of linear regression technique. It is used to predict the relationships between the dependent and independent variables, from which at least one variable shows non-linear relation with others (Manganelli et al., 2016; Choudhari and Selokar, 2018). A vector $\underline{\theta} = \{\theta_1, \theta_2, \ldots, \theta_n\}$ of n non-linear parameters for optimization is considered. $\underline{I} = \{i_1(\underline{\theta}),\ i_2(\underline{\theta}), \ldots,\ i_m(\underline{\theta})\}$ is considered as the set of *m* quality indices which characterize different perspectives (e.g., mean squared error, statistical determination coefficient). A simple and empirical strategy to face the model selection issue according to all the *m* metrics could be the definition, a single error function

E(I) combining the quality indices through a weighted average which is given by equation 9.1.

$$E(\underline{I}) = \sum_{j=1}^{m} c_j \, i_j(\underline{\theta}) \qquad (9.1)$$

Where C_j is the vector of weights of the average function which is given as $C_j = \{c_1, c_2, \ldots c_m\}$. The definition of the weights C_j is very critical because of the different variables considered for the analysis. The weights are allocated by the user and there is a probability of allocating wrong weights which may lead to wrong optimisations. So as to conquer these downsides, in this work, the optimisation issue is mentioned by multi-objective function $g(\underline{\theta})$ which is comprised of m number of functions $g_1(\underline{\theta})$, $g_2(\underline{\theta}), \ldots, g_m(\underline{\theta})$ that represent the set of adopted quality metrics computed for various estimations of the free parameters. The objective is to minimise the function $g(\underline{\theta})$ and the multi-objective problem can be formulated by the equation 9.2.

$$\min_{\underline{\theta} \in s} \left\{ g\left(\underline{\theta}\right) \right\} \qquad (9.2)$$

Where, $\underline{\theta} = [\theta_1, \theta_2, \ldots, \theta_n] \in S \subseteq \Re^n$ and *S* is the hyper-parameters space. This issue is described by a vector-valued objective function $g(\underline{\theta})$; therefore, it cannot be solved by developing a single solution. Despite what might be expected, a lot of ideal arrangements $\underline{P}$ can be got following the idea of Pareto dominance. In more detail, an arrangement of the free parameters $\underline{\theta}^*$ is said to be Pareto optimal if it is not controlled by any other configuration in the search space *S*, i.e., there is no other $\underline{\theta}$ with the end goal that,

$$g_1(\theta) \leq g_1(\underline{\theta}^*) \ (\forall_i = 1,2, \ldots, m) \qquad (9.3)$$

$$g_j(\underline{\theta}) < g_j(\underline{\theta}^*) \quad j = 1,2 \cdots m, \quad j \neq i \qquad (9.4)$$

In other words, $\underline{\theta}^*$ is Pareto optimal if there exists no other subset of free hyper-parameters $\underline{\theta}$ that would diminish an objective without increasing another one at the same time. Because of the dimensionality and the unpredictability of the search space, a comprehensive search of the set $\underline{P}$ of optimal solutions is generally unfeasible. As an alternative way, rather than recognizing the correct set of Pareto optimal solutions, the method aims at estimating a set $P*$ of non-dominated solutions with objective values as close as possible to the Pareto front. This estimation can be performed with multivariate non-linear regression based Grey Wolf algorithm, which have been proposed in this work. It preserves the physical meaning of each index and allows one to effectively identify different possible optimal trade-offs between different quality estimations. The final selection of the optimal solution to the model selection problem is assigned to the user, who can identify the best trade-off among the considered quality metrics on the basis of the specific requirements of the considered retrieval problem.

9.3.2 Modelling of multi non-linear regression model

Multi non-linear regression (MNLR) is a technique used to display the non-linear connection between a dependent variable and at least one independent element. MNLR relies upon least squares, the model is fit to such a degree, that the entire set of squares of differentiation of watched and foreseen characteristics is constrained. Multivariate calibration (MC) is a genetic technique and is the way towards developing a transfer function $y = f(x)$ that predicts a specific property variable y with adequate exactness and accuracy from a lot of non-selective estimation factors $x = (x_1, x_2, \ldots\ldots xK, \ldots\ldots xK)$. Multivariate calibration is the transfer function, $y = f(x)$ together with its arrangement of basic suppositions of how x and y ought to be estimated, and for what populaces of material (or) article types the adjustment is viewed as appropriate. A nonlinear regression model can be written in the given equation 9.1.

$$Y_t = f(x_t, \theta_0) + u_t \qquad (9.5)$$

In this model, the irregular variable Y_t, which indicated to the reaction for the case $n, n = 1,2, \ldots, N$. Where, f is the desired function, x_t and u_t are the regressor and regression errors, respectively variables or independent variables for the n^{th} case. θ_0 is a true parameter which lies in the parameter set.

While examining a specific arrangement of information think about the vectors x_n, $n = 1,2, \ldots\ldots, N$, as fixed and focus on the dependence of the normal reactions on θ. Equation 9.6 develops the N-vector with the nth element and $\eta(\theta)$ with n_{th} element.

$$\eta_n(\theta) = f(x_n, \theta) n = 1, \ldots\ldots, N \qquad (9.6)$$

The model for N cases and the nonlinear regression model can be written as,

$$Y = \eta(\theta) + Z \qquad (9.7)$$

Where Y is the vector of arbitrary changeable signifying the data that is obtained and Z is the vector of arbitrary changeable signifying the disturbances, with Z assumed to have a spherical normal distribution.

The presumption of a spherical distribution for the aggravation term Z drives us to consider the Euclidean geometry of the N-dimensional reaction space. The N-vectors $\eta(\theta)$ characterize a P-dimensional surface called the desired surface in the reaction space, and the least squares to the point on the desired surface.

9.3.3 Enhanced grey wolf optimization (EGWO)

Optimization algorithms appear trying to locate a surmised answer for various issues. Grey wolf optimization is another metaheuristic seeking calculation inspired by the social conduct of leadership and the hunting of grey wolves. The GWO calculation is well known for better convergence and improved computing time. Think about the fittest arrangement as the alpha (α), the second beta (β) and third best arrangements delta (δ) separately. The remainder of the competitor arrangements is thought to be omega. The grey wolves are pinnacle predators and are at the highest level of the food chain. The GWO is ended up being better or focused than other established metaheuristics, for example, GA, PSO. The EGWO algorithm gives improved execution when contrasted with the GWO calculation (Kamboj et al., 2016). The task completed in the algorithm is clarified in the below sections.

9.3.3.1 Attacking prey (Exploitation)

Grey wolves can perceive the area of prey and encompass them. The hunting is normally guided by the alpha. The grey wolves complete the hunt by attacking the prey when it quits moving. Algorithm statistically analyse moving toward the prey and the best positions of prey and grey wolf. The GWO algorithms enable its hunt operators to refresh their position dependent on the area of the alpha, beta, delta and attack the prey.

9.3.3.2 Search for prey (Exploration)

Grey wolves look for the prey according to the positions of the alpha, beta, and delta. They separate from each other to check for prey and converge to assault prey. This underscores investigation and empowers the GWO calculation to look for all around. Grey wolves complete their strategy of pursuing by repeating the revolving around and chasing adventures as explained previously. The seeking behaviour of prey is utilized for finding the best commitments for the improvement strategy (Joshi *et al* 2017).

9.3.3.3 Random walk

Random walk is a random process consists of consecutive steps; it can be simply called a random walk.

$$R_N = \sum_{i=1}^{N} S_i \qquad (9.8)$$

Where S_i are the random steps that can be from any random distribution. Step size S_i can be fixed or vary. So, for a wolf starting with a point x_0 suppose its final position is x_N then a random walk can also be defined as

$$x_n = x_0 + \sum_{i=1}^{N} \alpha_i S_i \qquad (9.9)$$

Where, $\alpha_i > 0$ is a parameter that controls the step size S_i in each iteration. The GWO starts with an initial population of inputs, $x_i = (i = 1,2,\dots,n)$. Then in each iteration a random walk has incorporated for α, β & δ of the population.

9.3.3.4 Encircling prey

As referenced above, grey wolves surround the prey during the chase. The enclosing behaviour of the prey is taken as the parametric selection of input function to mathematically modelling the enclosing behaviour of prey, the following equation is employed.

$$Y_{t+1} = Y_{p,t} - \tau \cdot dv \qquad (9.10)$$

Where Y_{t+1} the position of the input function at $t + 1$ iteration, Y_t is the position of the inputs at t^{th} iteration. $Y_{p,t}$ is the position of prey at t^{th} iteration. dv is the difference vector, τ is coefficient vectors.

9.3.3.5 Selection and Updation

Grey wolves can perceive the area of prey and enclose them. The hunt is generally guided by the alpha. The accompanying conditions are utilized to refresh the places of each wolf.

$$Y(t+1) = \frac{Y'_1 + Y'_2 + Y'_3}{3} \tag{9.11}$$

Where, $Y'_{(1,2,3)}$ are the positions approximated by α, β and δ. In this section, the hunting behaviour of the grey wolf is taken for the optimal selection of input and updating. After each hunting process the system updates, thus the system will run to the next iteration. The flow chart of the proposed grey wolf optimization is explained in figure 9.1 below.

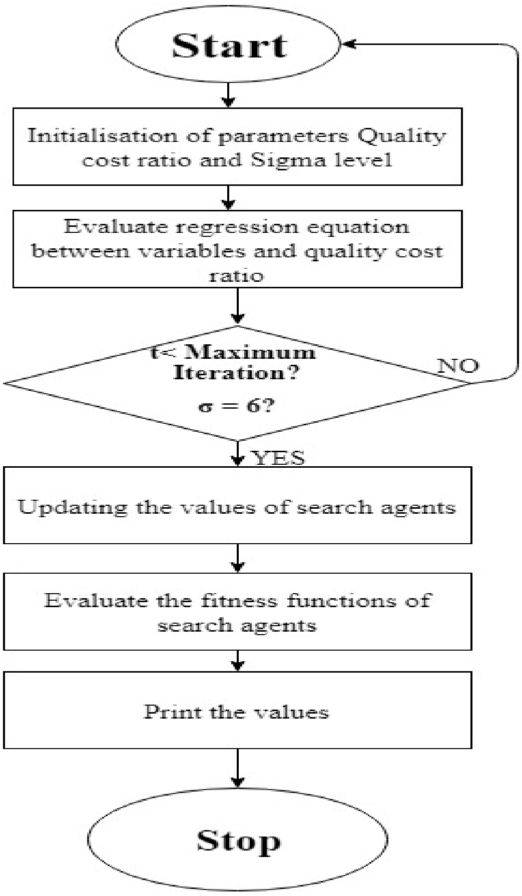

Figure 9.1: Flow chart of proposed algorithm

Figure 9.1 shows the flow chart for the proposed grey wolf optimization algorithm. By utilizing this algorithm, the optimized results can be obtained by reducing the wastes and increasing the sigma level.

9.4 Experimental Analysis and Result Discussion

The data was collected using the questionnaires through direct interviews with managers or supervisors of each firm. The collected data was entered to the MATLAB software for further analyses. The proposed analysis is actualised through MATLAB simulation. Table 9.1 indicates the system specification, which is used for the execution of the simulation.

Table 9.1 System Specifications

Processor	Intel Core 2 Quad @ 2.5 GHZ
RAM	3GB
Operating System	Windows 7
Mat Lab Version	R 2016a Version 9.0

The ratio of the quality cost (i.e. percentage of quality cost to the total production cost) with initial data and after simulating using different optimisers were tabulated in table 9.2. The prediction is carried out through different optimization technique such as GWO, CSA and PSO respectively. The results indicated that the proposed GWO algorithm has less quality cost ratio than the other methods.

Table 9.2 Predicted ratio of quality cost

Industry type	Non-LSS	GWO	CSA	PSO
Textile	65.41	30.88	53.3	37.94
Rubber	45.48	8.06	42.7	29.45
Plastic	55.28	11.92	50.58	40.46
Paper	45.16	13.85	41.94	34.72
Furniture	55.64	25.1	52.36	35.11
Electrical	56.11	21.63	53.1	39.3
Clay/ Tile	49.08	19.57	44.95	37.46
Chemical	41.76	31.4	42.19	30.18
Ayurveda	41.25	10.71	37.9	27.61
Agriculture	41.42	17.5	40.41	32.8
Paint	51.87	19.35	52.35	35.89
Aqua	31.28	14.47	31.32	22.41
Packaging	33.52	14.2	31.25	22.78
Pipe	37.85	18.93	40.12	29.46
Glass	35.42	7.31	34.52	25.36

Table 9.3 shows the initial positions of wastes and sigma level calculated from % defectives. The values were taken by the qualitative analysis through the questionnaire survey conducted through the direct interview. The values represent the percentage of the particular waste to the total waste from the waste relations matrix and the sigma level with respect to the percentage defects.

Table 9.3 Initial positions of wastes and sigma collected by questionnaire

	T	I	M	W	O	P	D	SIGMA
Textile	8.1	13.1	10.1	9.1	13.1	19.2	27.3	2.2
Rubber	11.8	14.7	11.8	11.8	12.7	14.7	22.5	2.4
Plastic	10.8	15.7	12.0	13.3	18.1	15.7	14.5	2.7
Paper	12.9	16.8	11.9	11.9	14.9	12.9	18.8	2.5
Furniture	9.6	9.6	11.7	13.8	12.8	19.1	23.4	2.3
Electrical	9.3	10.5	14.0	7.0	19.8	19.8	19.8	2.5
Clay/ Tile	12.5	9.4	12.5	10.4	14.6	18.8	21.9	2.4
Chemical	10.5	10.5	12.8	11.6	11.6	17.4	25.6	2.2
Ayurveda	14.0	11.8	11.8	10.8	16.1	18.3	17.2	2.6
Agriculture	11.5	10.6	10.6	8.7	14.4	21.2	23.1	2.3
Paint	8.9	11.4	13.9	15.2	17.7	16.5	16.5	2.6
Aqua	10.4	11.7	14.3	15.6	18.2	15.6	14.3	2.7
Packaging	12.3	13.6	14.8	7.4	21.0	11.1	19.8	2.5
Pipe	14.3	13.1	13.1	10.7	21.4	13.1	14.3	2.7
Glass	10.1	14.6	11.2	12.4	16.9	19.1	15.7	2.6

From table 9.4 it could be seen that the waste levels are reduced significantly through reducing the sigma level. But the percentage of wastes reduced was not the same as the rank of the wastes. Similarly, the Sigma level reached 6 for few companies with minimum quality cost ratio. It can be concluded that if the company could reduce the waste percentage to these values, then the company can achieve a near six sigma levels in their process.

Table 9.4: Final positions of wastes

	T	I	M	W	O	P	D	SIGMA
Textile	0.8125	1.313	0.1401	0	0.8545	1.723	0.0023	5.9
Rubber	0.7062	1.472	1.21	0.5917	1.31	1.275	0.0006	5.97
Plastic	1.73	0.1566	2.98	1.97	2.05	0.525	0.0004	5.98
Paper	1.18	1.683	2.03	1.22	0.1655	0.934	0.0007	5.97
Furniture	0.5813	0.957	1	0.425	0.1218	1.37	0.1264	4.83
Electrical	0.105	0.105	0.1811	0.105	0.1354	1.02	0.0139	5.4
Clay/ Tile	0.7659	0.9375	1.32	0.675	0.1559	1.22	0.000146	5.99
Chemical	0.3	1.046	0.5172	0.005	1.07	1.57	0.09	4.9
Ayurveda	1.36	1.182	2.36	1.46	1.24	0.7977	0.0156	5.32
Agriculture	0.6125	1.057	1.05	0.466	1.01	1.34	0.0034	5.85
Paint	1.456	1.139	0.251	0.159	0.2056	7.29	0.0000034	6
Aqua	1.723	0.1168	1.9	1.96	1.85	0.526	0.00007	6
Packaging	0.998	0.1358	0.1721	1.05	0.1559	1.03	0.00003	6
Pipe	1.7	0.1309	0.2931	0.1966	2.06	0.556	0.0213	5.07
Glass	0.582	1.46	1.03	0.1758	1.94	6381	0.00004	6

Further the fitness values of each factor were calculated and tabulated. Table 9.5 specifies the second-best fitness (positional) values for the LSS factors in various industries and with respect to the quality cost ratio, i.e. the percentage of quality cost for the particular factor for reaching the particular sigma level and the quality cost ratio and table 9.6 specifies the best fitness values (alpha) for the LSS factors in various industries and with respect to the quality cost ratio.

Table 9.5 Second best fitness (Beta) values towards quality cost ratio of LSS factors in Various Manufacturing Industries

Factors of LSS/Industries	Textile	Rubber	Plastic	Paper	Furniture	Electrical	Clay/Tile	Chemical	Ayurveda	Agriculture	Paint	Aqua Product	Packaging	Pipes Manufacturing	Glass products
Process and Equipment	4.10	4.20	4.25	4.35	4.38	4.22	4.25	4.17	4.55	4.81	4.11	4.20	4.11	4.16	4.41
Production Planning and Control	4.11	4.12	4.11	4.27	4.42	4.23	4.27	4.28	4.15	4.83	4.13	4.14	4.18	4.34	4.45
Human Resources	4.39	4.32	4.15	4.17	4.16	4.28	4.24	4.29	4.32	4.42	4.37	4.22	4.21	4.27	4.22
Supplier Relationship	4.05	4.06	4.04	4.07	4.05	4.02	4.02	4.02	4.08	4.02	4.06	4.04	4.08	4.09	4.06
Customer Relationship	4.36	4.37	4.34	4.36	4.32	4.31	4.29	4.32	4.27	4.44	4.38	4.37	4.36	4.37	4.35
Company Culture	2.57	2.61	2.54	2.31	2.51	2.47	2.49	2.48	2.64	2.61	2.47	2.73	2.75	2.41	2.62
National Culture	2.69	2.62	2.64	2.57	2.52	2.62	2.72	2.54	2.71	2.73	2.74	2.54	2.68	2.54	2.57
Attitude of Shop Floor Employees	2.88	2.71	2.76	2.72	2.61	2.76	2.79	2.76	2.84	2.85	2.78	2.84	2.81	2.64	2.62
Attitude of Middle Management	2.75	2.68	2.64	2.67	2.62	2.73	2.69	2.64	2.64	2.79	4.81	2.94	2.64	2.73	2.71
Top Management Commitment	2.94	2.84	2.78	2.71	2.73	2.89	2.92	2.86	2.88	2.86	2.88	2.73	2.98	2.78	2.73
Infrastructure	2.44	2.32	2.45	2.34	2.42	2.41	2.42	2.34	2.52	2.48	2.48	2.41	2.24	2.41	2.53
Financial capability	3.71	3.67	3.61	3.72	3.67	3.68	3.64	3.64	3.64	3.65	3.73	3.76	3.84	3.76	3.64
Quantification of Benefits	3.36	3.34	3.55	3.66	3.65	3.33	3.25	3.34	3.42	3.43	3.41	3.43	3.64	3.74	3.74
Communication	3.86	3.88	3.48	3.42	3.54	3.75	3.76	3.76	3.72	3.79	3.84	3.82	3.38	3.49	3.43
Understanding on LM Concepts	4.14	4.16	4.17	4.12	4.21	4.10	4.12	4.18	4.17	4.16	4.19	4.18	4.19	4.22	4.23
Waste Reduction	5.25	5.26	4.58	4.25	4.25	5.64	4.65	5.65	5.22	5.17	5.32	5.41	4.65	4.35	4.32
Energy Utilized	5.16	4.33	5.22	5.33	5.46	5.60	4.45	5.14	5.64	5.52	5.18	4.53	5.24	5.16	5.66

Table 9.5 Continued

Factors of LSS/Industries	**Textile**	**Rubber**	**Plastic**	**Paper**	**Furniture**	**Electrical**	**Clay/Tile**	**Chemical**	**Ayurveda**	**Agriculture**	**Paint**	**Aqua Product**	**Packaging**	**Pipes Manufacturing**	**Glass products**
Excess Production	4.33	3.99	3.59	3.87	3.87	3.48	4.46	4.14	3.19	4.52	4.22	3.78	3.57	3.74	3.73
Recycling of Waste	4.30	4.27	4.25	4.40	3.15	3.35	4.45	5.68	4.34	4.20	4.27	4.41	4.35	4.88	3.25
Quality Cost ratio	31.9	12.1	12.7	14.8	30.1	24.6	21.2	35.7	11.7	20.7	19.5	16	17.5	23	10.6
Production Time	5.54	4.52	5.65	4.52	4.65	4.69	4.49	4.25	4.16	4.51	5.46	4.96	5.55	4.62	4.53
Delivery Performance	5.54	5.57	5.11	4.12	4.54	5.15	4.54	4.21	4.65	4.16	5.52	5.51	5.24	4.26	4.53
Quality of The Products	5.21	5.19	5.19	4.16	5.94	5.19	5.52	5.25	5.56	5.64	5.11	5.89	5.26	4.18	5.83
Market Demands	5.22	4.15	4.65	3.52	4.49	5.52	4.59	4.68	5.65	4.49	5.34	4.22	4.67	3.81	4.54
Customer Satisfaction	5.22	4.32	4.50	3.55	5.52	5.41	4.66	3.16	5.48	4.64	5.65	4.95	4.65	3.54	5.76
Product Flexibility	5.63	5.55	3.65	3.65	4.15	3.54	3.17	3.44	3.26	3.55	5.72	5.64	3.72	3.73	4.24

Table 9.6 Best fitness (Alpha) values towards quality cost ratio of LSS factors in Various Manufacturing Industries

Factors of LSS/Industries	Textile	Rubber	Plastic	Paper	Furniture	Electrical	Clay/Tile	Chemical	Ayurveda	Agriculture	Paint	Aqua Product	Packaging	Pipes Manufacturing	Glass products
Process and Equipment	3.10	3.80	4.15	4.28	4.27	4.18	4.16	4.13	3.15	4.71	4.05	4.08	4.12	4.11	4.18
Production Planning and Control	3.11	4.04	4.08	4.24	4.37	4.27	4.22	4.24	3.54	4.68	4.08	4.15	4.18	4.27	4.31
Human Resources	3.32	4.24	4.09	4.12	4.18	4.26	4.19	4.25	4.12	4.52	3.45	4.16	3.84	4.18	4.15
Supplier Relationship	3.07	3.97	4.02	4.05	4.02	4.06	4.01	4.01	3.98	4.04	3.62	4.07	4.81	4.02	4.01
Customer Relationship	3.33	4.16	4.27	4.29	4.29	4.18	4.27	4.32	4.06	4.32	4.25	3.61	3.86	4.28	4.26
Company Culture	2.25	2.34	2.43	2.22	2.41	2.32	2.37	2.32	2.84	2.51	2.75	2.15	3.21	2.18	2.18
National Culture	2.14	2.42	2.72	2.47	2.44	2.51	2.68	2.56	3.71	2.64	3.31	3.81	3.74	2.62	2.42
Attitude of Shop Floor Employees	2.35	2.67	2.68	2.54	2.57	2.58	2.72	2.67	2.86	2.47	3.68	3.41	2.65	2.73	2.41
Attitude of Middle Management	2.52	2.41	2.51	2.58	2.58	2.67	2.54	2.48	2.72	3.81	4.52	1.46	2.93	2.68	2.82
Top Management Commitment	2.64	2.74	2.63	2.64	2.64	2.72	2.46	2.72	2.88	3.15	3.78	1.60	3.51	2.82	2.61
Infrastructure	2.25	2.27	2.42	2.28	2.36	2.34	2.37	2.26	2.41	3.25	2.74	2.44	3.81	2.34	2.48
Financial capability	3.44	3.54	3.55	3.63	3.51	3.62	3.72	3.41	3.75	2.74	3.62	3.65	3.24	3.62	3.57
Quantification of Benefits	3.17	3.27	3.41	3.54	3.57	3.24	3.17	3.26	3.27	2.61	3.76	2.51	3.58	3.69	3.62
Communication	3.73	3.76	3.43	3.41	3.43	3.42	3.61	3.67	3.68	3.62	3.84	3.44	4.21	3.52	3.84
Understanding on LSS Concepts	4.07	4.08	4.08	4.10	4.11	4.15	4.13	4.16	4.11	4.11	4.15	4.18	4.32	4.35	4.18
Waste Reduction	2.15	3.16	1.51	2.65	2.76	3.13	1.55	2.83	3.37	3.25	4.15	5.94	4.66	4.26	4.25

Table 9.6 Continued

Factors of LSS/Industries	Textile	Rubber	Plastic	Paper	Furniture	Electrical	Clay/Tile	Chemical	Ayurveda	Agriculture	Paint	Aqua Product	Packaging	Pipes Manufacturing	Glass products
Energy Utilized	9.18	9.15	7.38	7.87	6.71	8.54	6.42	6.45	7.55	6.34	4.44	3.41	5.88	4.82	5.11
Excess Production	8.54	7.12	7.99	5.84	5.79	6.54	7.11	6.42	8.92	5.47	3.66	4.26	3.57	3.65	3.42
Recycling of Waste	1.15	2.91	1.84	3.81	6.62	1.74	2.84	1.79	2.55	2.35	4.52	4.11	4.23	4.22	3.10
Quality Cost Ratio	30.9	8.1	11.9	13.9	25.1	21.6	19.6	31.4	10.7	17.5	19.4	14.5	14.2	18.9	7.3
Production Time	7.67	6.32	6.66	5.50	6.13	6.67	5.47	6.23	5.14	5.54	4.88	3.76	4.68	4.26	4.35
Delivery Performance	3.52	3.27	4.10	3.17	3.35	4.13	3.54	3.22	4.55	3.14	4.24	4.97	4.33	4.39	4.29
Quality of The Products	5.43	4.10	3.17	3.24	4.57	4.16	4.52	4.24	5.54	4.68	4.92	5.84	4.97	4.56	5.25
Market Demands	5.37	4.14	4.64	2.54	4.28	4.53	3.56	3.67	4.63	4.47	4.74	4.35	3.88	3.61	4.22
Customer Satisfaction	3.26	4.35	3.48	2.53	3.17	3.42	2.65	2.15	4.47	3.70	4.95	3.95	3.91	3.48	5.24
Product Flexibility	4.19	3.59	2.62	2.65	3.55	2.53	2.11	2.43	2.23	2.59	3.85	4.81	4.99	3.69	4.22

From the tables, the best values of the quality cost component of each factor can be identified. It means, for instance value of process and equipment in table 9.6 for textiles is mentioned as 3.1, i.e. 3.1% of total quality cost need to be at least incurred to reach the Six Sigma level. The results obtained were supporting the rule of thumb that quality cost reduces as the quality of product increases.

9.5 Conclusion

Simulation based analysis has been carried out using MATLAB software. The research is carried out using the data collected using a questionnaire survey regarding the factors of LSS. The responses were entered into the software and three proven optimisers were used to study the results. GWO optimiser gave the better result than the others such as PSO and CSA. The objective was to minimise the quality cost ratio with the sigma level and number of iterations as the constraints. The quality cost ratio, productivity and performance were improved significantly through optimisation of the variables and by increasing the sigma level through GWO optimiser. The fitness value of each variable shows the corresponding importance of the variable towards the quality cost ratio for LSS implementation. For example, the values of the factor 'excess production' increased after the analysis. From this, it can be presumed that more care or quality cost component need to be allocated to reduce the excess production and thus to reach LSS.

This chapter acts as an introduction to simulation-based studies of LSS implementation. Here, qualitative data along with quantitative data such as cost is analysed. The optimisers could be improved in future researches, so that the analysis can be made using quantitative real time data of industries. This, chapter would be a road map to those who try to simulate the LSS implementation using optimisation algorithms. The chapter 10 discusses the results, discussions, summary and scopes for future researches of this entire thesis.

CHAPTER 10

The Summary and Conclusions

10.1 Introduction

With the advancement in technologies, the global market became much innovative and trendy in recent days. Hence any product and/or service needs to be modified by its' features, to get accepted by the customers progressively (Mu et al., 2007). The latest technology products also become 'old' in a very shorter time frame in the market. This increased the competition between the organisations. This situation made large organisations to strive hard to get huge market in this shorter time frame. This prompted the large industries to outsource some of their work to SMEs, which boosted the lives of SMEs around the globe (Antony et al., 2005; Subrahmanya, 2007). Thus, the SMEs became a stronger support to global economy (Kale et al., 2010; Nieto and Santamaria, 2010; Malik and Nilakant, 2011; Elkhalek 2019; Heydari and Khoshnood, 2019). Obi et al. (2018) reported that SMEs of developing countries are contributing to economic growth whereas Elkhalek (2019) and Litau (2018) referred that SMEs from both developing and developed countries supports in economic growth as well as job opportunities.

This situation represents the importance of improving productivity and quality in SMEs. At present, many of the governments and industrial associations support SMEs by providing support to their quality initiatives (Dominguez, 2018; Hasbi and Madiawati, 2019; Elkhalek 2019; MSMEDI, 2019). Through implementing quality initiatives, the SMEs can achieve a sustainable growth. This research concentrated on improving the process and productivity through implementing a new model -IRDAIC- in Indian SMEs, and thus obtaining a significant improvement.

The following sections describe the summary of results of each chapter, limitations of the research, and future scopes of the research. General conclusions and the investigator's viewpoints are reported in the final section.

10.2 Summary of the Research

This research started with the basic objective of implementing LSS in the MSME sector to improve the manufacturing performance. Based on the initial studies and the discussions with industrial and subject experts, micro scale enterprises were excluded from the study. This is because, the Micro enterprises are huge in number, but do not have any homogeneity in its working. Most of the Micro firms are running as family / cottage/ artisanal businesses. It generally does not follow a standardised layout and/or procedure.

The investigator conducted an extended literature review and found that SMEs are facing difficulty to implement and follow LSS and to reap its' full benefits. These finding supported the investigators' idea about developing a model for LSS implementation at manufacturing SMEs.

To test the CSFs' which affect the LSS implementation at SMEs a questionnaire-based survey was carried out on a sample of 170 SMEs. The research identified nine CSFs through EFA. The study extended by a regression analysis to find out the degree of adoption of LSS. The factor process and productivity improvement were considered as the dependant variable, as the research is directed towards investigations of process and productivity improvements in small and medium enterprises through lean six sigma implementation. All the factors were represented good correlation to the degree of adoption of LSS. Further a comparison study between different categories of SMES in CSFs was also undertook. Study revealed that most of the CSFs act same in all the types of industries, but few CSFs such as financial capability, top management commitment, education and training etc. varies slightly between different categories.

Above study identified process and productivity improvement as a significant CSF. This factor is much affected by the wastes created during manufacturing processes which has also been identified by many of the previous literatures. Hence to validate these findings, a questionnaire survey had been carried out in 133 SMEs regarding seven wastes in manufacturing processes. The study results show that all the seven wastes significantly influence the manufacturing processes and act as a barrier for process and productivity improvement. The study also revealed that all the seven wastes are interdependent in nature.

From the above studies the investigator considered that process or productivity improvement as a major construct from the CSFs. The research later directed to develop a model that can ease the identification and elimination of seven wastes and thus to improve process performances. The investigator developed the model IRDAIC, which aimed to easily identify and reduce the seven types of wastes.

In order to accept the research model, it is required to test and validate it. Hence, here two case studies had been carried out. The initial one was in a handmade paper manufacturing unit. The firm was a small-scale unit having 33 years of service. The company implemented the model as per the instructions of the investigator. The data were collected before, through and after the implementation processes. The results were analysed. Significant improvement in productivity and production cost were obtained due to the implementation. The results were statistically analysed and reported.

The second case study had been carried out in an industrial cluster of die manufacturing firms. 10 die manufacturing firms were in the cluster and all belonged to small scale. The instructions were given by the investigator at the cluster meetings as well as during the direct visits to the firms. The companies were directed to follow the model and its steps. Progresses were observed and monitored by the respective staff in each firm and data were given to the investigator for the purpose of analysis. From the analysis, improvements achieved as the effect of IRDAIC model implementations were identified.

Subsequently, an analytical study has been conducted through machine learning systems to validate the model. The quality cost ratio was considered as the objective function. Two sets of questionnaires have been processed in 15 SMEs of variety of businesses. Quality cost ratios were analysed with the current values i.e. non-LSS condition and further by considering LSS using different proven algorithms such as GWO, PSO and CSA. GWO gave a better result than the other alternatives. Further analyses have been actualised by using GWO algorithm. The qualitative analysis reported that the quality cost ratio can be reduced by reducing the seven wastes and thus improves the process, productivity and Sigma level. The fitness values of all the variables were also reported.

From the above, it is understandable that IRDAIC model could provide a road map to implement LSS in SMEs. IRDAIC model is achieved through identifying and eliminating processing wastes that limit the productivity and quality. It is generally, difficult to the managers to identify the wastes, as the wastes are not normally visible and lies like iceberg floating in water. Only few of seven such as defects, over production and inventory are at least visible to some extent. The managers have difficulty in identifying and quantifying the other types of waste (Ramkumar et al., 2019; Akdag et al., 2018). This model helps the manager and project mates to identify and rank the wastes, and thus to try for reduction the wastes.

10.2.1 Benefits resulted by the research

The research provided the insight on how the CSFs affect the SMEs participated in the study. Generally, the industries in this research were of customized production firms. The study also concluded that the seven wastes significantly affects the production processes. The defects and over-processing were found to be the higher ranked wastes in most cases.

By implementing this model, the companies reduced the wastes significantly, and got the corresponding improvement in sigma level and productivity. The sigma level has been improved 0.5 on average for the industries participated in the study. By the implementation, 5- 20 % reduction in production cost is also obtained.

Sustainable improvements were monitored in the industries participated, like implementation of 5S, a more systematically arranged work layouts, improved displays and communication systems. The implementation also resulted increasing workers knowledge on quality initiatives and the importance of improving quality. The workers got motivated as they became the part of quality initiatives, and the organisation recognised his/ her decisions. This results in better employee involvement.

The organisations achieved an appreciable reduction in wastages which thus improved the productivity and hence reduced the production cost. This increased the profit margins of the organisation which is the ultimate aim of any management. An increase of 5-15 % in the marginal profit was reported due to this project. This result enhanced the top management support towards the quality initiatives.

10.2.2 Findings beyond objectives

Research may not be completely useful, if all the research findings are not reported. Hence, this section describes the points that studied by the investigator during research, that were beyond the research objectives.

The literature survey, interviews and discussions with industrialists and subject experts revealed that, currently in India, the government could achieve a better control over the MSME firms and makes them following the norms. During the past decade many of the industries those were running unregistered, have taken the registration as per government norms because of the improved government's industrial policies and with the help of development in IT & communications.

MSME-DI state profile report on Kerala 2016-17 and some economic magazines report the lack of availability of skilled employees contributes a major setback for the quality initiatives within the SMEs. The interactions by the investigator with the managers confirmed that the fact is true. Generally, as the facility for formal education is improved, most of the youth are acquiring higher educational qualifications. This reduces the availability of candidates to do blue-collared jobs in small companies.

Many government policies are aimed at Institution-Industry-Interaction. Many education institutions are promoting industry-based research works and provides quality improvement programmes for their employees. Similarly, the industries also have many benefits for offering their employees formal education and research on a continuous basis. Most of the industries are ignorant about these norms. The governmental agencies and consultants should educate the management about these schemes and thus promote research activities on real industrial problems. With the help of these schemes the companies can have the empowered and committed workforce and hence may increase the relationships with the employees.

10.3 Limitations of the Study

Different sets of questionnaires have been used for the study at different periods and might be at different industries. The respondent from same industry for different questionnaires may not be the same. This may induce some bias in the responses, even if the questionnaires are prepared by taking due care to eliminate bias.

In general, the companies keep a limit in sharing the data to the academic world, as suspicious of competition. This sometimes may lead to hesitation from respondents in giving the details, which may affect the quality of findings to some extent.

The research study collected data from organisations chosen through suitable sampling techniques and possible sampling errors are expected.

10.4 Future Scopes of Research

The study progressed with implementation of solution in the order of ranks. But the study did not focus in the accompanying changes made to the other wastes. For example, in most cases defect was the first ranked waste. The wastes like over-processing, motion etc. might have increased due to the effect of increased defects. As the implementation started, we first tried to reduce the defects, which made changes in the related wastes too. But this, situation was not focussed in the study as it cannot be analysed without a suitable computer program.

The case studies have been conducted only at small scale industries. The study may be extended to micro, medium and large-scale industries. This research mainly conducted and reported the cases of manufacturing and process type of industries. Future researches may be extended with service sector industries and mass production type manufacturing industries.

Software programmes may be developed further that can help managers to easily identify the wastes within processes. Software based simulation was carried out in the research using qualitative questionnaire data from different set of industries and using different algorithms. This could act as a stepping stone for the future researches to use the real-time industrial data to analyse and implement LSS in the industries. Suitable software programmes and algorithms may be developed further that can help managers to easily identify the wastes within processes.

10.5 Conclusion

This chapter discusses the results of this entire research work. The results infer that this model can help SMEs to implement LSS easily. Findings beyond the objectives, limitations of the study and scopes for future works were also discussed in the later sections of this chapter. With this, the formal chapters of the thesis end and the references and appendices follows this chapter.

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APPENDIX 1

INTRODUCTORY LETTER

Dear Sir/Madam,

I, Ramkumar P. N. doing Ph.D. on the topic “Implementation of Lean Six Sigma in MSME Sector” under University of Calicut, Kerala. This is to request you to kindly spare your valuable time to respond to a questionnaire designed to gather information on lean six sigma systems on manufacturing enterprises for my research.

I assure that Responses given by you will be used only for academic purpose and not used for any other purpose. Data given by you will be strictly kept confidential and individual company analysis will not be done.

Thank you very much for your help and cooperation.

Ramkumar P. N.,
Research Scholar
Dept of Mechanical Engineering,
Govt .Engineering College, Thrissur.
Mob: 9446316486
Email: rampavutty@gmail.com

APPENDIX 2

ORGANISATION DETAILS

<table>
<tr><td>Name of the organization:</td><td colspan="4"></td><td>Name of Respondent:
Designation:</td><td></td></tr>
<tr><td rowspan="2">Scale of the organization:</td><td>Micro</td><td>Small</td><td>Medium</td><td>Large</td><td rowspan="2">Email id:</td><td rowspan="2"></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Products Manufacturing:</td><td colspan="4"></td><td>Contact No.</td><td></td></tr>
<tr><td>*Number of employees.</td><td colspan="4"></td><td>*How long has the organisation been operating?</td><td></td></tr>
</table>

Practices and Systems implemented in your organization:							
ISO 9001 QMS	ISO 14001 EMS	OSHAS 18001	KAIZEN	6-SIGMA	LEAN PRODUCTION	BENCHMARKING	SPC
Any other:							

*- Question only included in the questionnaires used for case study.

APPENDIX 3

QUESTIONNAIRE 1

1-strongly disagree; 2-disagree; 3-neutral; 4-agree; 5-strongly agree

1	Our managers Spend time on the plant floor to thoroughly understand the real world manufacturing issues.	1	2	3	4	5
2	Our company uses external experts/consultants on a regular basis to evaluate the overall company performance and to improve production and quality level.	1	2	3	4	5
3	Our company invests in training programs and encourages cross-job training.	1	2	3	4	5
4	Our company is capable of eliminating waste (muda).	1	2	3	4	5
5	Our company communicates the vision of the new initiative at every organizational level.	1	2	3	4	5
6	Our company is ready to invest for the continuous improvement and waste reduction efforts.	1	2	3	4	5
7	Employees are given authority and responsibility to carry out specific activities.	1	2	3	4	5
8	Workers are empowered to stop production line if abnormalities occur.	1	2	3	4	5
9	Suggestions and ideas from shop-floor employees are actively used and implemented.	1	2	3	4	5
10	Incentive programs and reward system are available for employees who lead product/process improvement efforts and eliminate necessary steps.	1	2	3	4	5
11	Suppliers are directly involved in the new product development process.	1	2	3	4	5
12	Our key suppliers are located in close proximity to our plants.	1	2	3	4	5
13	Our company maintains good relation with suppliers.	1	2	3	4	5
14	We have a purchasing policy emphasizing quality rather than price.	1	2	3	4	5
15	We give our suppliers feedback on quality and delivery performance.	1	2	3	4	5
16	The organization is willing to invest on plans that reduce wastage.	1	2	3	4	5
17	Customer Feedback is sought regularly, and surveys/meetings are often held with customers to improve product design and quality and service.	1	2	3	4	5
18	There is a system in place for collecting customer complaints so that problems can be avoided in the future.	1	2	3	4	5
19	Customers participate in the initial design process.	1	2	3	4	5
20	Our key suppliers deliver to plant on JIT basis.	1	2	3	4	5
21	Production is ‘‘pulled’’ by the shipment of finished goods.	1	2	3	4	5
22	Our company has satisfied & repeated customers.	1	2	3	4	5
23	We provide real time inventory information to our suppliers.	1	2	3	4	5
24	Our equipment and procedures are designed in mistake proof manner.	1	2	3	4	5

25	We try to improve the "Value Added" process through step-by-step review and identification of connections, activities, information, and flow.	1	2	3	4	5
26	Our employees practice setups to reduce the time required.	1	2	3	4	5
27	We always try to maintain the minimum level of inventory.	1	2	3	4	5
28	We extensively use statistical techniques to reduce process variance.	1	2	3	4	5
29	We monitor and evaluate performance of equipment and processes periodically.	1	2	3	4	5
30	We maintain excellent records of all equipment maintenance related activities.	1	2	3	4	5
31	The organization provides adequate level of training to its employees.	1	2	3	4	5
32	The organization is flexible in incorporating new ideas.	1	2	3	4	5
33	Our company conducts workshops or training to discuss scope for improvement.	1	2	3	4	5
34	Our company monitors employees to find areas to improve their efficiency.	1	2	3	4	5
35	The equipment are kept clean and under proper loading conditions.	1	2	3	4	5
36	The organization has plans for expansion and improvement.	1	2	3	4	5
37	Our company is capable of sustaining its initial efforts.	1	2	3	4	5
38	Our organization has a strategy to identify the wastes.	1	2	3	4	5
39	We have a framework to measure productivity loss comparing with a benchmark/baseline (tracking downtimes, slow cycles, rejection etc).	1	2	3	4	5
40	Company uses latest technology wherever available.	1	2	3	4	5
41	Our company uses LSS tools.	1	2	3	4	5
42	Company gives a clear and precise communication when it launches a new initiative.	1	2	3	4	5
43	Company believes in doing things right first time itself.	1	2	3	4	5
44	Our organization offers after sales service.	1	2	3	4	5
45	The organization collects customer feedback.	1	2	3	4	5

APPENDIX 4

QUESTIONNAIRE 2

1-Never; 2-Rarely; 3-Once in a while; 4-Sometimes; 5-Almost Always

1	Minimizing overproduction in your company leads to preventing accumulation of units within the store?	1	2	3	4	5
2	Minimizing overproduction in your company leads to reducing defects in your products?	1	2	3	4	5
3	Minimizing overproduction in your company allows more space within the work that can be exploited?	1	2	3	4	5
4	Minimizing overproduction in your company leads to better exploiting of the available human and material resources?	1	2	3	4	5
5	Minimizing overproduction in your company reduces the staff and machines waiting in the other units?	1	2	3	4	5
6	By the nature of your work, minimizing overproduction in your company reduces transport of materials between work stations and machines?	1	2	3	4	5
7	According to your experience, minimizing overproduction in your company reduces the need for re-manufacturing of the product?	1	2	3	4	5
8	Excess inventory minimization balances the flow of materials through the stages of production so as to ensure there is no idle capacity?	1	2	3	4	5
9	When you minimize the excess inventory through working, your production defective units are less?	1	2	3	4	5
10	Policy of minimizing the excess inventory leads to lower following-up and conditioning costs of production units?	1	2	3	4	5
11	When you minimize the excess inventory through working, you are better exploiting areas of the workplace?	1	2	3	4	5
12	Excess inventory minimization reduces the number of workers needed in your production?	1	2	3	4	5
13	By the nature of your work, excess inventory minimization reduces the materials transport between work stations and machines?	1	2	3	4	5
14	According to your experience in your work, excess inventory minimization reduces the re-manufacturing of the product?	1	2	3	4	5
15	Over-processing minimization leads to a better use of time and efforts?	1	2	3	4	5
16	Over-processing minimization helps in reducing the movement barriers of people and materials during the work?	1	2	3	4	5
17	Over-processing minimization balances the flow of materials through the stages of production so as to ensure there is no idle capacity?	1	2	3	4	5
18	Over-processing minimization in your company can reduce the workers useless movements?	1	2	3	4	5

19	By the nature of your work, over-processing minimization reduces the materials transport between work stations and machines?	1	2	3	4	5
20	Over-processing minimization reduces the materials used in your product line?	1	2	3	4	5
21	According to your experience in your work, over-processing minimization reduces the workers stress?	1	2	3	4	5
22	Workers motion minimization facilitates the task of management in controlling the work?	1	2	3	4	5
23	Workers motion minimization in your company reduces the waiting machines and leads to greater exploitation of the potential?	1	2	3	4	5
24	Workers motion minimization in your company reduces the energy wasted?	1	2	3	4	5
25	Workers motion minimization reduces the injuries at work?	1	2	3	4	5
26	Workers motion minimization leads to better exploiting of the areas?	1	2	3	4	5
27	By the nature of your work, workers motion minimization reduces the production of defective units?	1	2	3	4	5
28	According to your experience in your work, workers motion minimization reduces the re-manufacturing of the product?	1	2	3	4	5
29	Workers and machines waiting minimization help in greater exploitation of the potential of working?	1	2	3	4	5
30	Workers and machines waiting minimization during your production reduce the work injury?	1	2	3	4	5
31	Workers and machines waiting minimization improve the skills of communication between departments, and thus reduce errors during the production process?	1	2	3	4	5
32	Workers and machines waiting minimization facilitate the task of management in the control of human resources?	1	2	3	4	5
33	Workers and machines waiting minimization facilitate the monitoring of product quality?	1	2	3	4	5
34	By the nature of your work, workers and machines waiting minimization reduces the materials transport between work stations and machines?	1	2	3	4	5
35	According to your experience, workers and machines waiting minimization reduces the product re-manufacturing?	1	2	3	4	5
36	Defects minimization leads to better reputation with customers and increasing the marketing of the product?	1	2	3	4	5
37	Defects minimization reduces the bottlenecks that impede the movement of workers and materials during the work?	1	2	3	4	5
38	Defects minimization reduces re-manufacturing the same products?	1	2	3	4	5
39	Defects minimization reduces the excess movement of workers?	1	2	3	4	5
40	Defects minimization leads to the optimal use materials and human resources?	1	2	3	4	5
41	By the nature of your work, defects minimization reduces the materials transport between work stations and machines?	1	2	3	4	5

42	According to your experience in your work, defects minimization reduces the re-manufacturing of the product?	1	2	3	4	5
43	Materials and products transportation minimization reduces the necessary energy, such as, number of workers and electricity?	1	2	3	4	5
44	Materials and products transportation minimization reduces the bottlenecks that impede the movement of people and materials during the work?	1	2	3	4	5
45	Materials and products transportation minimization in your company reduces the risk of damaged units or defects?	1	2	3	4	5
46	Materials and products transportation minimization reduces the waiting workers and machines?	1	2	3	4	5
47	Materials and products transportation minimization leads to better exploiting of the areas?	1	2	3	4	5
48	By the nature of your work, materials and products transportation minimization facilitates the control of materials and human resources?	1	2	3	4	5
49	According to your experience in your work, materials and products transportation minimization reduces the re-manufacturing of the product?	1	2	3	4	5

APPENDIX 5

QUESTIONNAIRE 3

1- Does "i" produces "j"?	
Always	3
Sometimes	2
Rarely	1
2- Relation between "i" and "j"?	
"i" increases "j" increases	3
"i" increases "j" reaches a constant level	2
Random relation	1
3- The effect of "j" due to "i"?	
Appears directly and clearly	3
Often appears	2
Rarely appears	1
4- Eliminating the effect of "i" on "j" is achieved by?	
Engineering and complex methods	3
Simple and direct	2
Only by an instruction	1
5- The effect of "i" due to "j", mainly influences on?	
Qualtiy and productivity	3
Quality only/ Productivity only	2
Random influences	1
6- In which degree does the effect of "i" on "j" increases Manufacturing Lead time?	
High degree	3
Medium degree	2
Low degree	1

APPENDIX 6

QUESTIONNAIRE 4

1-Much Worse; 2-Somewhat Worse; 3-About the same; 4-Somewhat Better; 5-Much Better

1	The organization have better process and equipment.	1	2	3	4	5
2	The organization have good production planning and control.	1	2	3	4	5
3	Our company have the optimum human resource.	1	2	3	4	5
4	Does the organization maintain good relation with suppliers.	1	2	3	4	5
5	Customer Feedback is sought regularly, and surveys/meetings are often held with customers to improve product design and quality and service.	1	2	3	4	5
6	Our company is ready to invest for the continuous improvement and waste reduction efforts.	1	2	3	4	5
7	Our national culture helps promoting quality initiatives.	1	2	3	4	5
8	Our workers are concerned in work quality improving.	1	2	3	4	5
9	Supervisors are positively practicing quality improvement initiatives.	1	2	3	4	5
10	Owner/ managers spend time, invest capital to ensure the product quality.	1	2	3	4	5
11	We have modern manufacturing facilities that can reduce waste & increase productivity.	1	2	3	4	5
12	The organization have fund for expansion and improvement.	1	2	3	4	5
13	Our company able to monitor the benefits always.	1	2	3	4	5
14	Company gives a clear and precise communication to the employees.	1	2	3	4	5
15	We understands the use and benefits of LSS.	1	2	3	4	5
16	We follow Waste reduction practices.	1	2	3	4	5
17	Energy conservation methods are followed.	1	2	3	4	5
18	The company do not have excess production.	1	2	3	4	5
19	Recycling of waste is done.	1	2	3	4	5
20	Our company tries to reduce the quality cost.	1	2	3	4	5
21	We regularly monitor and try to reduce production time.	1	2	3	4	5
22	Our company has a good delivery performance.	1	2	3	4	5
23	We maintain quality of the product.	1	2	3	4	5
24	Our company has good market demand.	1	2	3	4	5
25	We always try to keep customer satisfaction.	1	2	3	4	5
26	Our design makes product flexibility.	1	2	3	4	5

APPENDIX 7

SIGMA LEVEL TABLE

SIGMA LEVEL	DEFECTS PER 100	DEFECTS PER MILLION
1	69	691,462
2	31	308,538
3	6.7	66,807
4	0.62	6,210
5	0.023	233
6	0.00034	3.4

References:

Moosa, K. and Sajid, A., 2010. Critical analysis of Six Sigma implementation. *Total Quality Management*, *21*(7), pp.745-759.

Eckes, G., 2003. Six sigma for everyone. Hoboken.

Appendix 8

Changes in waste by reduction during case study 2

Table A8.1: Reductions in transportation waste

Industry	A. Before Implementation (meters per day)	B. After Implementation (meters per day)	Reduction in % {(B-A)/A}*100
Y1	1800	1100	38.89
Y2	2400	1400	41.67
Y3	1850	1000	45.95
Y4	2250	1300	42.22
Y5	2200	1500	31.82
Y6	1200	800	33.33
Y7	1800	950	47.22
Y8	1900	1000	47.37
Y9	1000	800	20
Y10	900	600	33.33
Y8	Maximum Reduction		47.37
Y9	Minimum Reduction		20

Table A8.2: Reductions in inventory waste

Industry	A. Before Implementation (percentage of items that is in stock than actually needed per day)	B. After Implementation (percentage of items that is in stock than actually needed per day)	Reduction in % {(B-A)/A}*100
Y1	15	9	40.00
Y2	16	8	50.00
Y3	12	6	50.00
Y4	8	5	37.50
Y5	9	6	33.33
Y6	9	5	44.44
Y7	17	8	52.94
Y8	13	7	46.15
Y9	12	4	66.67
Y10	13	6	53.85
Y9	Maximum Reduction		66.67
Y5	Minimum Reduction		33.33

Table A8.3: Reductions in motion waste

Industry	A. Before Implementation (waiting time in minutes per shift of 8 hours)	B. After Implementation (waiting time in minutes per shift of 8 hours)	Reduction in % {(B-A)/A}*100
Y1	68	52	23.53
Y2	55	40	27.27
Y3	55	42	23.64
Y4	65	50	23.08
Y5	60	45	25.00
Y6	70	52	25.71
Y7	45	35	22.22
Y8	50	38	24.00
Y9	60	46	23.33
Y10	68	50	26.47
Y2	Maximum Reduction		27.27
Y7	Minimum Reduction		22.22

Table A8.4: Reductions in waiting waste

Industry	A. Before Implementation (time in minutes per shift of 8 hours)	B. After Implementation (time in minutes per shift of 8 hours)	Reduction in % {(B-A)/A}*100
Y1	110	75	31.82
Y2	105	70	33.33
Y3	105	75	28.57
Y4	115	85	26.09
Y5	100	70	30.00
Y6	120	70	41.67
Y7	80	60	25.00
Y8	70	50	28.57
Y9	120	80	33.33
Y10	120	70	41.67
Y6 & Y10	Maximum Reduction		41.67
Y7	Minimum Reduction		25.00

Table A8.5: Reductions in overproduction waste

Industry	A. Before Implementation (percentage of unwanted stock concerning the normal demand)	B. After Implementation (percentage of unwanted stock concerning the normal demand)	Reduction in % {(B-A)/A}*100
Y1	8	4	50.00
Y2	7	5	28.57
Y3	8	6	25.00
Y4	6	4	33.33
Y5	5	2	60.00
Y6	15	8	46.67
Y7	8	4	50.00
Y8	12	8	33.33
Y9	10	7	30.00
Y10	9	5	44.44
Y5	Maximum Reduction		60.00
Y3	Minimum Reduction		25.00

Table A8.6: Reductions in over-processing waste

Industry	A. Before Implementation (percentage of excess time used)	B. After Implementation (percentage of excess time used)	Reduction in % {(B-A)/A}*100
Y1	10	6	40.00
Y2	15	12	20.00
Y3	18	10	44.44
Y4	8	6	25.00
Y5	14	9	35.71
Y6	13	7	46.15
Y7	17	10	41.18
Y8	15	8	46.67
Y9	16	9	43.75
Y10	8	3	62.50
Y10	Maximum Reduction		62.50
Y2	Minimum Reduction		20.00

Table A8.7: Reductions in defect waste

Industry	A. Before Implementation (percentage of scrap or reworked material)	B. After Implementation (percentage of scrap or reworked material)	Reduction in % {(B-A)/A}*100
Y1	12	4	66.67
Y2	11	6	45.45
Y3	20	12	40.00
Y4	8	6	25.00
Y5	10	6	40.00
Y6	15	9	40.00
Y7	18	10	44.44
Y8	12	7	41.67
Y9	17	9	47.06
Y10	16	8	50.00
Y1	Maximum Reduction		66.67
Y4	Minimum Reduction		25.00

Table A8.8: Increases in sigma level

Industry	A. Before Implementation	B. After Implementation	Change (B-A)
Y1	2.78	3.44	0.66
Y2	2.82	3.11	0.29
Y3	2.45	2.78	0.33
Y4	2.94	3.11	0.17
Y5	2.86	3.11	0.25
Y6	2.66	2.90	0.24
Y7	2.53	2.86	0.33
Y8	2.78	2.99	0.21
Y9	2.57	2.90	0.33
Y10	2.61	2.95	0.34
Y1	Maximum increase		0.66
Y4	Minimum increase		0.17

CURRICULUM VITAE

Ramkumar P. N. is a faculty member of Mechanical Engineering Department, MEA Engineering College, Perinthalmanna, Kerala, India. He received Bachelor degree in Mechanical Engineering in 2007 from University of Calicut, Kerala and Master degree in Production Management from Visvesvaraya Technological University, Karnataka in 2010.

He joined the PhD programme of Calicut University, Calicut, India, at Department of Mechanical Engineering, Government Engineering College Thrissur, under Centre for Engineering Research Development (CERD) fellowship of Government of Kerala in the year 2013. He has a teaching experience of 5 years and his areas of academic interest include Lean Six Sigma and Total Quality Management.