EFFICACY OF LEAN SIX SIGMA ESSENTIALS FOR PRODUCTIVE CAPACITY UTILIZATION IN INDIAN MSMES: A CASE STUDY

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December 19, 2020

DECLARATION

I declare that the thesis entitled "Efficacy of Lean Six Sigma Essentials for Productive Capacity Utilization in Indian MSMEs: A Case Study" has been prepared by me under the guidance of Dr. Rajeev Rathi, Associate Professor, School of Mechanical Engineering, Lovely Professional University, India. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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CERTIFICATE

This is to certify that the thesis entitled "Efficacy of Lean Six Sigma Essentials for Productive Capacity Utilization in Indian MSMEs: A Case Study", which is being submitted by Mr. Mahipal for the award of the degree of Doctor of Philosophy in Mechanical Engineering from the Lovely Faculty of Technology and Sciences, Lovely Professional University, Punjab, India, is entirely based on the work carried out by him under my supervision and guidance. The work reported, embodies the original work of the candidate and has not been submitted to any other university or institution for the award of any degree or diploma, according to the best of my knowledge.

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DEDICATION

"I would like to dedicate my thesis to My beloved mother Late Smt. Sunita Devi. "

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Date: December 19, 2020 Mahipal

Abbreviations

Abbreviations	Description
AHP	Analytical Hierarchy Process
BO	Best-to-Others
BWM	Best Worst Method
CFFs	Critical Failure Factors
CI	Consistency Index
CIMTC	Corrected Item Minus Total Correlation
CME	Carbon Monoxide Emission
CR	Consistency Ratio
CSO	Central Statistics Office
CU	Capacity Utilization
DEA	Data Envelopment Analysis
DEMATEL	Decision-Making Trial and Evaluation Laboratory Method
DMs	Decision Makers
DPMO	Defects Per Million Opportunities
EFA	Exploratory Factor Analysis
EH	Extremely High
EL	Extremely Low
EVSM	Environmental Value Stream Mapping.
FAHP	Fuzzy Analytical Hierarchy Process
FICCI	Federation of Indian Chamber of Commerce and Industry
FMEA	Failure Mode Effect Analysis

GDP	Gross Domestic Product
GLS	Green Lean Six Sigma
GOI	Goverment of India
GRA	Grey Relational Analysis
H	High
IF	Intuitionistic Fuzzy
IFN	Intuitionistic Fuzzy number
ISM	Interpretive Structural Modeling
ISO	International Standard Organization
KMO	Kaiser-Meyer-Olkin
L	Low
LCL	Lower Control Limit
LLSBs	LSS Barriers
LM	Lean Manufacturing
LSS	Lean Six Sigma
M	Medium
MADM	Multi-Attribute Decision Making
MCDM	Multi Criteria Decision Making
MDL	Modified Digital Logic
MH	Medium High
ML	Medium Low
MRO	Maintenance Repair and Overhaul
MSMEs	Micro Small and Medium Enterprises
NMP	National Manufacturing Policy
OEE	Overall Equipment Effectiveness
OTR	Order to Receipt
OW	Others-to-Worst
PAT	Perform, Achieve, and Trade
PCA	Principal Component Analysis
PDCA	Plan-Do-Check-Act
PMH	Poor Material Handling
PPM	Parts Per Million
RBI	Reserve Bank of India
RPN	Risk Priority Number
SIPOC	Supplier Input Process Output Customer
SLR	Systematic Literature Review

SMEs	Small Manufacturing Enterprises
SPSS	Statistical Package for Social Sciences
SSIM	Structural Self -Interaction Matrix
SSM	Soft Systems Methodology
SVAR	Structural Vector Auto-Regression
SVM	Support Vector Machine
TFP	Total Factor Productivity
TPS	Toyota Production System
UCL	Upper Control Limit
VAS	Value-Added Service
VH	Very High
VL	Very Low
VMC	Vertical Milling Center
VOB	Voice of Business
VOC	Voice of Customer
VSM	Value Stream Mapping
VVH	Very Very High
ZED	Zero-Effect-Zero-Defect

ABSTRACT

In today's global scenario, the primary goal for organizations is to be successful in gaining large profit and to achieve a gain in the market share. So, organizations must find new cost-effective methods and practices to meet the market needs on time. As a response to this, many organizations are adopting continuous improvement programs like Total Quality Management, Six Sigma, Lean and Lean Six Sigma (LSS) in their business processes to stay competitive in the global market. At this time, the Micro-Small and Medium Enterprises (MSMEs) sector, which is so vital for economic growth of India, is experiencing critical Capacity Utilization (CU) level. This has led to increase in costs, locking up resources and reduction in profitability for manufacturers. In the quest for better operational performance and increase capacity utilization level, MSMEs sector must be incorporate LSS as a strategy for business improvement. Literature reveals that MSMEs has not been encouraging in terms of awareness of LSS and most of the time LSS project fails. Moreover, MSMEs do not know whether they are ready for LSS implementation or not.As per RBI report 2017, the CU rate of manufacturing sector is around 72% and it most likely goes down when comes to MSMEs, i.e. about 57%. Even though, 45 million registered MSMEs are there in India. So, to overcome the low CU rate and help the Indian MSMEs sector in implementing LSS practices successfully, an easy implementation plan is a must. Hence, there is a need for an investigation of LSS practices in the context of Indian MSMEs. This research work has been undertaken for accomplishing this purpose.

The main aim of this research work is to check the efficacy of the LSS program for productive capacity utilization in Indian MSMEs. Though LSS is an emerging approach and may get fail if not focused on enablers and barriers at the initial phase of program. So, failure factors of LSS should be considered while implementing LSS in the organizations. So far, the authors have identified 26 barriers (LSSBs) with the help of literature and industrial visits. Further, 22 LSSBs were screened and validated by means of a reliability test which confirms the good consistency with Cronbach's alpha of 0.820. Finally, a study of ISM and MICMAC is used to classify the relationship and clustering between screened LSSBs. ISM results recognize about the ranking of LSSBs to enable the management to take necessary action. Other side, 30 enablers were extracted from the literature and grouped them using Exploratory Factor Analysis. The final screening of grouped enablers were done through Importance-index analysis and corrected item minus total correlation method. For prioritization of finalized 22 enablers, a robust decision-making technique, Best Worst Method (BWM) was employed. The research outcomes reveal that strategic-based enablers are leading in nature, followed by environmental-based enablers.
Further, a new LSS model was developed, which is having the clear road map for LSS implementation. The model systematically guides MSMEs through the DMAIC (Define-Measure-Analyze-Improve-Control) phase for effective implementation of LSS projects. The CU level has been estimated using existing production data of case industry. The developed LSS framework has been tested and implemented to increase the CU levels in a medical equipment manufacturing industry in India. After successful completion of the case study, significant improvements are noticed with key performance parameters like CU level, lead time, cycle time, change-over-time, and environmental footprints. The case study result reveals that cycle time decreases by 30.08%, lead time decreases by 37%, 63.08% reduction in unnecessary movement, 27.45% reduction in change over time, and production level per annum increases by 15.18%. Moreover, improvement in environmental perspectives is observed by reducing the IAQ level with the adoption of suggested Kaizen. The indoor air quality level is reduced from 156.87 $(\mu g)/\ m^3$ to 86.85 $(\mu g)/\ m^3$ contributing 44.5% improvement

and carbon monoxide emission reduced from 33 ppm to 1.5 ppm reflecting 95.5% improvement. These improvement in the process metrics helped to improve the sigma level of the case company from 1.95 to 3.15. The effective implementation of the LSS framework facilitates several non-tangible benefits like cultural change, employee behaviors, customer satisfaction, etc. in the selected case company. The key takeaways of this doctoral research work consist of contributions as follows:

- Investigation and prioritization of enablers associated with LSS implementation in MSMEs.
- Modeling of the barriers responsible for LSS failure in MSMEs.
- A customized Lean Six Sigma framework based on DMAIC (Define-Measure-Analyze-Improve-Control) methodology with the synergy of advanced lean tools.
- Rendered the strategy to estimation for capacity utilization in MSMEs.
- Testing the efficacy of developed LSS framework for productive capacity utilization in Indian MSMEs.

From these contributions, barriers can help the managers to overcome the factors that lead to LSS project failure. LSS enablers can assess manufacturing Industries preparedness for Lean Six Sigma program. The proposed LSS framework will help the manufacturing industries to get started with Lean Six Sigma implementation. The knowledge gained during the research work is reported in this thesis has validated the findings of global research. According to the results of global research, manufacturing industries faced challenges in implementing strategies like LSS. Similarly, Indian MSMEs also faced such challenges in LSS implementation. However, the research work has enabled the MSMEs to overcome the reported challenges. This study is focused on assessing the industrial manager's awareness on LSS and helped them in understanding the LSS practices.

Furthermore, the customized LSS framework was tested in one MSMEs leading to better cost savings, reduction of part defects and improving CU level. This is suggested to conduct further research on implementation of LSS in other sectors like hospital, banking, educational institutions and process industries. Moreover, the knowledge and information gained through the case study may be used for refining enablers and barriers of LSS and make the framework more robust for periodic evaluation. In concluding remarks, to achieve the organizational goal, Indian MSMEs need to be motivated for implementing LSS framework and thereby attaining competitive strength.

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CHAPTER 1

Introduction

1.1 Pretext

The primitive economy of any productive nation primarily depends upon the three sectors i.e. agriculture, manufacturing, and service [1]. The agriculture sector consists of forestry, mining, fishing, agricultural and these directly connected with natural resources of country. Through these resources, the agriculture sector produces raw material and elementary product to fulfilling the demands of manufacturing organizations. It shows that agriculture sector act as a driver to support the development in both, manufacturing and service sector. The manufacturing sector converts the raw materials in to finished goods and tangible products by using manufacturing processes. The service sectors are having intangible nature and it consist of healthcare, education and financial sector of the nation. The development rate any nation is judged through the growth of agriculture, manufacturing, and service sector. If the country's Gross Domestic Product (GDP) is based on the agricultural sector, then it comes under-developed country. If the country's GDP is majorly based on manufacturing sector contribution, then it labeled as developing country. In case of major contribution in country's GDP by service sector, the country may be considered as developed country. The contribution of these said sectors in GDP [1] and employment of India is shown in Table 1.1. The service sector perceived a prompt growth in last two eras and play significant role in boosting of nation development. After service sector, the manufacturing sector is the major contributor to the country's GDP.

TABLE 1.1: *Sector wise contribution in GDP and employment of India*

Sector	**Contribution in India's GDP**	**Contribution in employment**
Agriculture	17.2%	52%
Manufacturing	26.4%	14%
Service sector (healthcare, education, financial)	57.2%	34%

The manufacturing sector plays major role to improving the economy of country due to healthy support towards country's inflation and employment. This sector is capable to reduce the discriminations in wealth and income circulation among people; increase national's income level, results to minimize poverty level. As per literature, the increment in GDP by 1% in developed country reduces 0.8% poverty level, but, in Indian context, only 0.3% poverty level is being reduces through 1% increment in country's GDP [2]. This happens because of Indian GDP growth rate is primarily based on service sector as compared to manufacturing sector [3]. So there are needed to be more focus on the development of manufacturing sector.

Based on possibility of dismantling of final goods, the manufacturing industries are classified broadly in two categories:

- *Process manufacturing:* in this category, the production takes place in huge amount and some thermal or chemical reaction are adopted to convert the raw material in to ended or semi-ended product. Some example of process manufacturing industry is like cement, paint, food industry, chemical etc.

- *Product manufacturing:* Under product manufacturing, the product are produce in discrete manner with care of workers working in various shops in the plant. In this category, the final product can be dismantled into original component, if required. Example like car industry, two wheeler industries etc.

According to Central Statistics Office(CSO) report 2008, the manufacturing sector in India is classified mainly in three categories i.e. automotive industry, heavy/large industry and MSMEs as shown in Figure 1.1. The automotive sector is the fastest

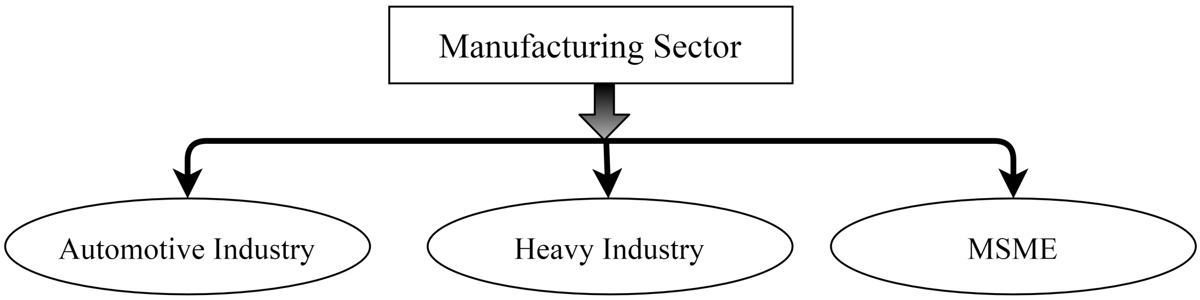

FIGURE 1.1: *Classification of Manufacturing Sector.*

growing area of Indian manufacturing sector which become the 4th largest sector in manufacturing of car and 7th largest in manufacturing of commercial vehicles in the world. The total GDP of India is about $ 2.26 lakh crore and GDP growth rate is 7.1% [4]. The automotive sector contributes about 7.1% in nation's GDP as well as 46% to total manufacturing output in India [5]. Secondly, the heavy industries like steel plant, power plant, locomotive plant etc. having vital role in country growth and development. It contribution in Indian GDP is about 7.8% and 9% in contributions in total manufacturing at national level [6]. Finally, MSMEs play significant role in entrepreneurship development and creating employment occasions through the nation. It helps in economic and social growth of the country. This sector is subsidizing to about 8% of nation's GDP besides 45% to the total manufacturing output and 40% to the exports from the country, which specifies huge opportunities for growth and venturing its support in numerous domain [7].

From this statistics, it has been observed that there are much more chances to improve the influence of MSMEs in country growth by increasing the productivity level at MSMEs sector. The automotive and heavy industries are well developed and having lot of resources and financial capabilities to enhance the overall productivity and performance of their plant. But MSMEs are still struggling sector in growth and development of themselves due to lack of financial capabilities, lack of management support, lack of knowledge about quality improvement tools etc. As directed by Government of India(GOI) in their NMP-2025, the contribution of manufacturing MSMEs to increase up to 25% of the nations GDP by 2025 and provides additional 100 million job opportunities by 2025. These set targets could be achieved if we primarily focus on growth of MSMEs sector. The automotive sector and heavy industry are looking much more towards their growth and continuous improvement, but MSMEs lacking in growth and development as per set target [8]. The provision specified by the state and the national governments to the MSMEs is not enough to explain their glitches. For the small scale industries to utilize their resources at full potential, it is necessary to make strategies for continuous improvement within the organizations with the help of government support. Therefore, MSMEs is considered for case study in present research and looking forwards for their development and growth at national level.

1.2 Micro, Small and Medium Enterprises

MSMEs sector is a highly pulsating and active domain providing significant support to Indian economy over the previous few decades. It is at comparatively lower capital cost, next only to agriculture. The MSMEs are flared their field across segments of the economy, making various range of products and services to encounter demands of local and global markets. According to 'MSME at a Glance' report of the Ministry of MSMEs, it contains of 36 million companies and offers employment to more than 80 million peoples. This sector is helping about 8% of nation's GDP increment and 45% to the total manufacturing output. This specifies huge opportunities for growth and expressing its support in different sectors (Source: *Annual Report Fy 2017-18, Ministry Of Micro, Small And Medium Enterprises, Govt. of India*). This report exhibits that there are 64 million enterprises registered under MSMEs category accountable for completing the set targets of big industries. These MSMEs are categorized as per investment made within plant and machinery if they are functional in manufacturing sector and investment in equipment for service sector industries. According to act 2006, data is shown in Table 1.2.

TABLE 1.2: *Categorization of MSMEs*

Categorization of MSMEs	**Investment limits in MSMEs**	
	Manufacturing MSME	**Service MSME**
Micro	Below 25 lakhs	Up to 10 lakhs
Small	25 lakhs to 5 crores	10 lakhs to 2 crores
Medium	5 crores to 10 croces	2 crores to 5 croces

1.2.1 Contribution of MSMEs to Indian Economy

The involvement of MSMEs sector to nation's GDP is fluctuating time to time. Table 1.3 describes the percentage of share of MSMEs in the nation's GDP over the few years. It has been observed that manufacturing MSMEs contribution in GDP growth has slightly decreased i.e. 7.73% in 2006-07 to 6.92% in 2015-16. But the contribution of service sector MSMEs in nation GDP has been increased form 27.4% in 2006-07 to 31.3% in 2015-16. The share of MSMEs manufacturing output in total output has been decreased, which is the main concern for government of India. For increasing the share of manufacturing MSMEs in Indian's GDP as well as in total output, the Government of India has launched the National Manufacturing Policy (NMP) in 2016-17. According the annual report, it has been observed that total 633.88 lakhs are working MSMEs which provides near about 1315 lakhs employment opportunities to skilled and semi-skilled worker throughout the nation (Annual report Fy 2017-18 MSMEs). MSMEs provide employment and ultimately self-dependency.

In country like India, deflation of Indian Rupees can be cured by self-dependency. Therefore, MSMEs can be an emerging and beneficial sector for Indian economy in future.Now it's necessary to utilize all available resources properly, ultimately productivity of MSMEs would be increase which further more contribute in Indian GDP growth and employment.

TABLE 1.3: *Contribution of MSMEs in GDP*

Year	Share of MSMEs Sector in total GDP (%)	
	Manufacturing Sector MSMEs	**Service Sector MSMEs**
2006-07	7.73	27.4
2007-08	7.81	27.6
2008-09	7.52	28.6
2009-10	7.46	28.6
2010-11	7.39	29.3
2011-12	7.27	30.7
2012-13	7.04	30.5
2013-14	7.02	31.7
2014-15	6.94	31.9
2015-16	6.92	31.3

1.2.2 Status of Capacity Utilization in MSMEs

In the present competitive scenario, an industry can only be survived by improving its productivity levels. Productivity growth is an essential factor for economic development in countries like India because of the huge role in the productive capacity of economy. Productivity is closely related to the use and availability of inputs which means that productivity is reduced if an industry inputs are not properly used. The improved productivity levels are always attained with higher production rates and lower costs. Therefore, proper use of available resources improves the capacity utilization level which further increases the productivity level of industry. It would assist in the development of any industry and ensuring the competitiveness at global level. Indian MSMEs founded in 2007 with amalgamation of ministry of agro and

Table 1.4: *Status of capacity utilization in India*

S.N.	Domain in Indian context	CU rate	References
1	Manufacturing	72%	[9]
2	Automotive	78%	[10]
3	MSMEs	57%	[11]
4	Paper industries	88.40%	[12]
5	Healthcare	75.95%	[12]
6	Education	83.20%	[13]
7	Food industries	78%	[14]
8	Textile	75.48%	[15]

small scale industries and rural industries. The registrations of MSMEs are increased continuously and recorded 45 million registrations in 2019-20. But, the productivity level of Indian MSMEs is poor because of shortage of resources found the main barrier for the growth of this sector. Production can be enhanced by increase in input factors, while productivity can only be improved by increase the output with less or no change in input. The MSMEs can survive in this competitive environment with proper capacity utilization which ensures the use of available resources in organized manner.

As per reported in Table 1.4, the capacity utilization rate of manufacturing sector is around 72%. This is most likely goes down when it comes to MSMEs, i.e. about 57%. This report exhibits that resource under-utilization among MSMEs are the major issues for low productivity. As per an associated chambers of commerce and industry of India report, 79 small industries are turning financially unviable in India every day. As per FICCI report, MSMEs are in turbulent phase with CU rate about 55%, whereas in manufacturing sector is about 75%. Other side, to achieve the target set by the GOI through National Manufacturing Policy-2025, MSMEs needed to be focus on capacity utilization concept. The available critical status of capacity utilization in MSMEs provides the direction to conduct the present research work and make the strategy for increasing capacity utilization.

1.3 Concept of Capacity and Capacity Utilization

Capacity is directly related with the industry growth and expansion. The basic concept of capacity was elaborated in 1968 by Johansen and he proposed that capacity is maximum amount that can be produced per unit time with available equipment in plant without any restrictions in use of production resources [16]. The capacity concept simply relates to level of production in any industrial unit. Capacity is potential ability to perform and produce output without increasing input variables [17]. The capacity as an output could be increased with full use of all input variables under normal condition like without extend the working hours and considering regular holidays and machine maintenance [18]. All capacity concepts based on seriousness use of facilities and it can be increased to fulfill the demand by working more days or working hours [19]. The capacity of plant is inter-link with the all facilities and machineries involve to producing final product. It seems that capacity limit is connected with weakest link in the process used to manufacture the product [20]. Many processes in a plant may be under-utilized which may be manual or mechanical, when capacity concept is considered. The capacity can be upgrade by balancing equipment amongst the sub processes of the plants. The researcher's view about the capacity has been shown in Table 1.5. The capacity is subjected to intensiveness of use of the facilities. Capacity possesses large degree of vagueness, so it hard to measure and manage. This potential state may necessitate the use of different methodologies tools for its assessment, estimation and proper utilization.

Another side, Capacity Utilization (CU) is a concept which expresses the rate to which an industry actually uses its available capacity. In past era, industries did not familiar with CU concept and its significance to enhance the productivity. After 1990, Kim H. Y. proposed an index used to provide the rating to capacity of the plant, called CU [21]. CU is the relation between actual outputs is produced with installed setup and the potential output could be produce if capacity was fully utilized. According to Abel A., CU is the ratio of observed output to design output of plant [22]. CU is the relative index which provides the rating of utilized capacity of the plant. If the value of this relative index is 60%, then it shows that only 60 % of whole capacity of plant is going to be used and rest 40% is wastage. If resource wastage can be estimated in any unit, then it is quite easier to make plan to reduce the wastage of resources and express the productive efficiency [23]. The organization can achieve their objective and customer satisfaction with the help of proper CU [24][25]. Thus the CU is having pivotal role in the business success because of:

- It used for assign the rating to capacity of plant.
- It provides the measures for productive efficiency.
- It reduces the unit cost by utilizing the available resources properly. It gives the information about utility of all available resources in the plant

TABLE 1.5: *Researcher's views about capacity*

SN.	**Researcher's views**	**References**
1	Capacity is sometimes used to describe fixed factors of any manufacturing unit.	[26]
2	Capacity is known as the output obtained at optimal cost with stock of plant and existing tools and technique.	[27]
3	Capacity is maximum quantity that can be created per unit time with available equipment in industry without any restrictions in use of production resources.	[16]
4	Capacity as an output could be increased with full use of all input variables under normal condition like without extend the working hours and considering regular holidays and machine maintenance.	[28]
5	Capacity is potential ability to perform and produce output without increasing input variables.	[17]

6.	Capacity is main factor to define the time taken starting from customer order to deliver the finished product.	[29]
7	There are many natural tool used to estimate the capacity, but co-integration is one best method out of them in context of developed country.	[30]
8	Optimize the use of productive capacity and finalized that CU rate always less than one.	[31]
9	The profit of company and cost of product can be reduced by better capacity management.	[32]
10	The efficiency and effectiveness of firm are affected by CU rate.	[20]
11	Industries are having constraints in stock of capital, inputs, techniques etc. due to short run concept of capacity.	[33]
12	By using statistical tool, capacity management can improved in any business sector.	[40]
13	Capacity means organization's potential to produce finished product or deliver good service in a specific time period.	[34]
14	In report of second quarter 2018-2019, the CU rate in Indian manufacturing sector is 74%.	[35]
15	Capacity waste management can be reduced by utilizing all resources properly.	[36]
16	With proper capacity management, the energy of plant can be saved.	[37]

1.3.1 Estimation of Capacity Utilization

The literature presents large number of concepts and fallacies exist in perception, measurement and management of capacity. Figure 1.2 is presenting a framework which used to clarify the concept of capacity and ease to understand by every concern. In this framework, the capacity related terms are described as following:

- *C1- Theoretical Installed Capacity:* In this perception, it assumes 365 working days with all three working shifts (i.e. $365 \times 24 = 8760$ hours per year) for each equipment and operational time is based on collaborator' s tine , or established through appropriate techniques .
- *C2- Theoretical Rated Capacity:* The capacity also assumes 8760 hours per year bit operational time is being considered after being down rated due to poor methods applications, faulty work measurement or low labour productivity etc. This capacity is also called as 'design capacity'.
- *C3 - Planned Capacity:* This capacity is less than theoretical rated capacity as labour is employed to work less number of shifts or less than 8760 hours per year, depending on the load planned, taking care of the demand trends, availability of power and other inputs.
- *C4 - Real Capacity:* This capacity refers to actual productions levels achieved after tackling breakdowns, absenteeism, power failure, material shortage, scheduling inadequacies etc.

Here the significance of notations is given as:

1. **A** Poor method of application, faulty work measurement, low labor productivity
2. **B** Work in fewer shifts, less working hours, demand trends, poor power availability and poor input availability
3. **C** Material shortages, machine breakdowns, absenteeism, scheduling problems
4. **CW**- Capacity Waste

The relation used to estimate CU is shown in Equation 1.1.

$$CU = \frac{Real\ \ Capacity}{Installed\ \ Capacity} \times 100\% \tag{1.1}$$

Here it can be seen that CU will be 100% if the real capacity is equal to installed capacity, but practically it's not possible due to expected and unexpected variation in process. So for calculating the CW, Equation 1.2 is used.

$$CW = 1 - CU \tag{1.2}$$

Literature reveals that numerous methods and strategies like survey, time series

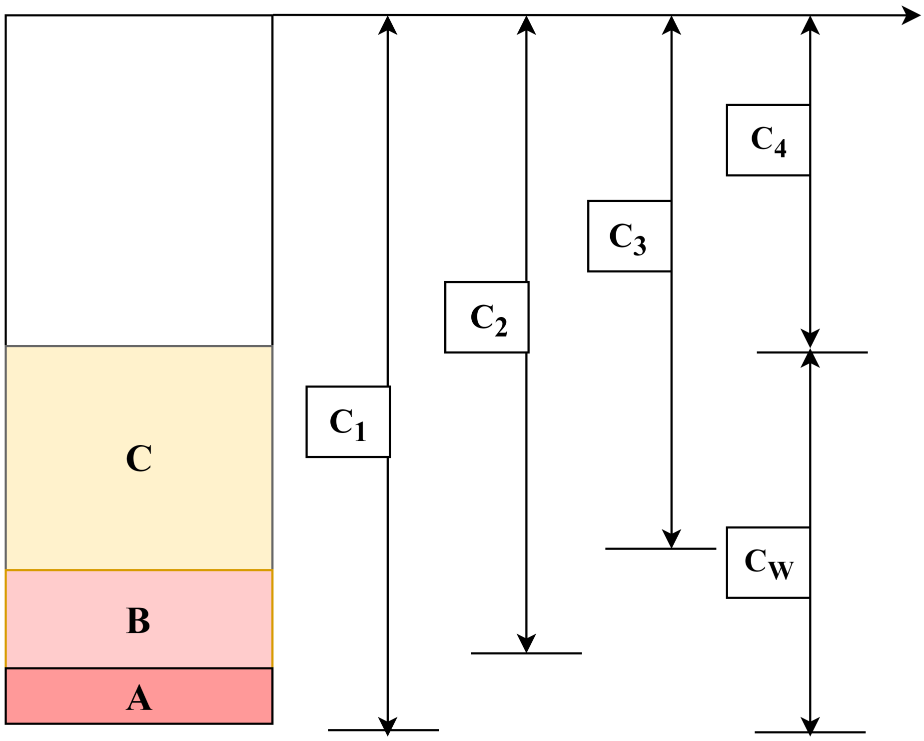

FIGURE 1.2: *Capacity Perception.*

method, regression analysis, economic concept, engineering concept, etc. were adopted by the researchers for estimating the CU rate in various domains. But, these adopted methods are conventional in nature and has various limitations for estimation of CU as per reported by investigators [38] [39]. Besides, these strategies are fail to highlight a particular section in the unit responsible for low CU and also fail to provide a structured path to improve CU further [40]. Moreover, such methods are not providing the way to controlling the non-value adding steps of processes, results degradation in CU. To overcome such issues, there are need a robust strategy which estimate CU and provide a path to improve it. In this context, Lean Six Sigma is prominent business strategy for estimating and improving the CU level with controlling the non-value adding steps in the processes. Therefore, in the present research work, Lean Six Sigma strategy is adopted for improving the CU level of MSMEs in Indian context.

1.4 Lean Six Sigma

Volatile market economics and customer demands have forced the manufacturing sector to produce quality products at a low cost [41]. This has increased the pressure on manufacturing firms to reduce operating costs by improving efficiency not only to maintain profit margins but also to survive [42]. In this context, continuous progress has been acknowledged as a fruitful management approach in the manufacturing sector [43]. Among various continuous progress practices, Lean Six Sigma (LSS) was extensively adopted and recognized to be the utmost effective approach to enhance an industry's productivity and efficiency at minimal operating cost [44]. LSS is a amalgam strategy for continuous improvement, which merges the Lean concept and Six Sigma approach [45]. The Lean concept can be recognized to the Toyota Production System (TPS) that concentrated on enhancing value and minimizing waste in processes [46]. Seven waste parameters that focused by Lean concept are overprocessing, inventory, motion, overproduction, waiting, transportation, and defects. Additionally, under-utilization of creativity of people and waste from environment are also wastes controlled through Lean concept [47].

Another side, Six Sigma is a statistical well-established continuous improvement method used to reduce the process variation and improve the quality of products [48]. Six Sigma word specify three essentials as measure, target and philosophy. Six Sigma measure process variations, target to achieve 3.4 Defects Per Million Opportunities (DPMO), and to reduce overall cost with by minimizing the inconsistency during process and product [49] [40]. The commencement of Six Sigma as upgrading tool was approved by Motorola in 1980 for their business and it was fully implemented in 1988 [50]. After 1990, many other companies like Honeywell, GE, Sony etc. also have implemented Six Sigma strategy in their business for improving quality and service of products [48] [51]. Six Sigma is a prominent strategies which recognizes and eliminate defects, breakdown or faults, reduce cycle time, increase quality and reliability, decrease unit cost in systems or processes [40]. Six Sigma is differ from other quality improvement tools due to systematic and rigorous structure of implementation, fact based decisions and control plan to ensure ongoing quality control in a process.

Overall, it was observed that Lean approach cannot control process statistically, whereas Six Sigma strategy unable to eliminate the non-value adding activity from the production process [52]. Thus, both, Lean and Six Sigma approach has been merged and formed new approach as LSS. The literature reveals that LSS approach was adopted by various organizations for solving the real-life practical problem like improving the pass percentage in higher education [44]; to enhance the productivity in printing industry [53]; for reducing the defects in process industries [44]; to improve the production of textile industries [54]; to increase the performance facility in hospital [55]; to save the energy of coal mining industry [56]; to increase the productivity of automotive industry [57] etc.

Despite the success of LSS in corporate sector, not all organizations can gain the real benefits of LSS deployment. An improper implementation of LSS can reduce its efficacy and effectiveness [58]. By considering this as a motivation, the present study is conducted to understand the factors that cause LSS failure, and other factors which drive the LSS system smoothly. It also focuses on developing the framework for better implementation of LSS within the scope of small and medium-sized industries.

1.4.1 Evolution of Lean Six Sigma

Lean Six Sigma was industrialized by merging the Lean concept and Six Sigma approach for continuous improvement, because both Six Sigma and Lean had assured

weaknesses and restrictions as mentioned in previous section. In 1980s, Six Sigma was established by Motorola and in early 2000s; it was merged with Lean concept [59] [60]. Numerous corporations attained the quality brand images at starting phase of Six Sigma, but later on, some factor associated with cost and productivity was met in Six Sigma approach [61]. For cost reduction, Lean methodology eliminates the waste by extracting non-added behavior whereas Six Sigma mainly focuses on eliminating the quality related problem by counting the number of process opportunities [62]. When combination of both strategies considered, then it is very essential to finalize that where the value adding step could be applied either within process or in between two processes. The Lean concept deals with the simple tools which are easy to apply and not based on any mathematical model [63]. Six Sigma adopt statistical tools to investigate the problem and to find the feasible solutions [64]. But, LSS approach uses the tools of both Lean methodology and Six Sigma strategy.
Figure 1.3 exhibits that Lean methodology mainly focused on information flow in between two processes and Six Sigma focuses on the improvement within the processes. So this combined approach solely emerges as methodology for achieving best in class quality, cost, production and customer satisfaction. This would be achieved by merging rules, tools and topology of Lean and Six Sigma and based on grounded theory [45]. Therefore, LSS is an organized strategy from a business perspective that enables industries to effectively recognize the customer desires, eliminate the variability within the production and reducing all non-value added activities. It manage the quality through effective and precise operating steps which support to control the errors and time wastage during manufacturing processes [65]. The success rate of LSS implementation depends upon its adoption time, position of the organization, and involvement of company employees [41].

1.4.2 Benefits of Lean Six Sigma

The rapid development of Lean and effectiveness of Six Sigma makes an emerging management strategy for evolution of LSS to achieve quality excellence. LSS

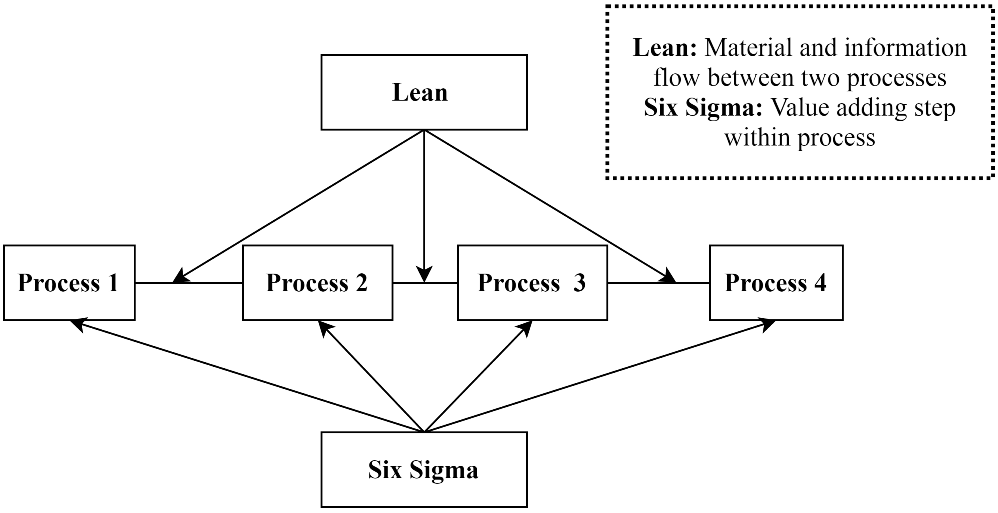

FIGURE 1.3: *Lean Six Sigma approach.*

helps to deploy better quality mindset with fruitful planning, strategies, and various tools within the organization. The quality mindset of any organization is based on investment, strategies, insights, and techniques. Even though, Lean and Six Sigma unable to integrate manpower and operational steps individually, so the amalgamated LSS approach requisites for superior control on processes as well as human. The organizations with LSS adoption proves their efficacy in terms of improved customer pleasure, gain profits, high quality products, better teamwork, more productivity, innovative management, and beat their competitors [66] [67]. Overall, LSS acts as an emerging management strategy to assist in increment in customer satisfaction, process performance, and profits. Therefore, the organizations from worldwide have adopted the LSS strategy in their business and achieved commendable benefits with business excellence as shown in Table 1.6. Here, it has been observed that the organizations like 3M, Caterpillar, Maple Leaf, and General Electric etc. from developed countries gained significant tangible benefits through LSS adoption. In developing countries also, the businesses like Wipro, Honeywell etc. adopted LSS strategy for the improvement in operational performance [68]. Generally, the organizations may also expect the following benefits through adoption of LSS strategy:

- LSS implementation assists to enhance the quality of product with minimization of process variations. This would help to producing quality product at optimal

Table 1.6: *Gains through LSS implementation in various economies worldwide*

Company/Country	**Gains**	**Reference**
3M, USA	$ 32.8 billion/annual	[191]
McKesson Corporation	$100 million/annual	[145]
Caterpillar,USA	Total revenue $54.7 billion in 2018	[218]
Textron, US	$1.5 billion/annual	[273]
Maple Leaf, Canada	$3174.5 million sales increased in 2019 as compared to 2018 years.	[295]
Bank of America	Revenue increased by US$ 91.24 billion in 2019	[161]
Wipro, India	Revenue increased by US$ 9.0 billion in 2019	[79]
General Electric, US	US$ 95.21 billion in 2019	[103]

cost, so that customer satisfaction will upsurge, which leads to enhance customer loyalty.

- In LSS deployment, the processes can be simplified through elimination of unnecessary steps and waste with the help of value stream mapping. In the simplified processes, it is easy to tract any fault/error and also reduce the manufacturing time, which leads to minimize the overhead cost.

- In the successful execution of LSS projects, the ideas and performance of each employee plays the crucial role. With effective completion of project, the self-importance among employees would increase, which leads to an escalation in motivation and better job performance.

- Through simplify the processing steps and examining the root cause of waste in the organization, LSS severely decreases the defects and inaccuracies.

1.5 Need of the Study

Manufacturing sector is the main driver for industrial development of the country, which intended to wealth and development of the country. This sector builds the initial steps for the evolution of other sectors like service and agriculture. Any problem in manufacturing sector will have to impact on other sectors and lastly, on economy at large. Therefore, manufacturing sector is of massive significance for the inclusive improvement of any economy and the prosperity of the nation. For highlighting the importance of the manufacturing sector, the GOI proclaimed the National Manufacturing Policy. According to this policy, following points are presented.

- Increase the contribution of manufacturing MSMEs in Indian's GDP up to 25% by 2025.
- Foundation of 100 million additional job opportunities by 2025.

This will support India to become fifth largest manufacturing country throughout the world. In manufacturing sector, the MSMEs are measure essential for a nation's performance and became even more significant in context of any developing country like India. The fast growing population of India leads to increase the demand of quality products at lowest cost. Also, as per the initiatives of "Made in India" taken by the Government of India, it essential to be more focus on the growth and development of MSMEs sector.

As per Global Competitive Index (2017), India possesses 40th rank among 137 participating countries. To improve the rank, India has to require better innovation in manufacturing industries for better performance in the goods markets. Also, needs to produce better quality product at low cost to fulfill the customers demand. This makes a hard challenge especially to MSMEs in India to produce high quality products at minimal cost. Although, the large industries are also depends upon MSMEs to achieving their production targets.

In the study on Indian manufacturing sector, Deshmukh and Thampi (2014), state that there are various strategies like Six Sigma and Lean for continuous improvement. But, the efficiency of small scale industries is truncated due to least top management involvement, lack of resources, and limited training on tools and methods. Albliwi et al., (2014) suggested that non-availability of roadmap for LSS implementation in small scale industries is the prime issue. This issue is not only within India, but also in many countries around the globe. The implementation of LSS in MSMEs is very difficult task. So there is essential to propose a generalized framework to enhance the efficacy of LSS in MSMEs. LSS is an emerging approach which provides improved effective efficacy, cost saving and efficiency [69]. A thorough understanding of LSS barriers, enablers, and tools are necessary when industries have to work under high competitive environment [70].

The industrial managers and practitioners in Indian MSMEs are not aware of the LSS practices. Also, the researchers in the past have not considered these following questions for their study in the Indian context.

- How to prevent the failure of LSS projects?
- What are the factors those increase the success rate to LSS projects in MSMEs?
- How to implement LSS in a MSME with the right tools and techniques?

1.6 Scope of Study

The Indian manufacturing sector is the second largest contributor to the nation's GDP next to the services sector. The manufacturing sector is having dynamic role to enhancing the economy as they have a through influence on the country's inflation and occupation. By minimizing the inequalities level in income of peoples, the poverty level can be reduced. In World Bank survey (refer Table 1.7), it has been observed that CU rate of manufacturing sector lies at 12th position among the productive nations. Other side, the GOI had launched the 'Made in India' scheme in 2020 to place the India on the world map as a manufacturing hub and provide worldwide acknowledgement to the Indian economy. Also, India is expected to become the fifth largest manufacturing country in the world by the end of year 2025. Other side, Make in India initiative taken by GOI, push the MSMEs to produce the high quality products at optimal cost. Also, the companies need to enhance the productivity level without increasing the input of resources. Hence, there is a strong need to adopt some breakthrough strategies to increase the utilization rate of India manufacturing sector.

Literature reveals that several approaches have been used to increase the CU rate, but not get success up to target level. Even the Six Sigma approach also has been implemented to improve CU rate in Indian automotive sector in few studies, but get success up to some limit extent [34][57]. So the present work explores the Lean tool with LSS strategy to improve the CU rate in Indian MSMEs.

Table 1.7: *CU rate worldwide*

Country	**CU rate**
Canada	86.10
UK	82.30
Mexico	81.60
South Africa	81.10
Denmark	80.70
Belgium	80.00
Tunisia	78.40
USA	78.00
Turkey	77.10
China	76.80
Romania	76.20
India	71.80

1.7 Organization of the Thesis

The thesis is structured into seven chapters. This chapter exhibits an introduction to the evolution of Lean Six Sigma, role of MSMEs in Indian economy, and concept of CU followed by the need for the study and organization of the thesis. The brief explanation of rest six chapters are given below.

Chapter 2 describes a systematic literature review relevant to LSS, Six Sigma, and CU. The literature is focused on extraction of barriers, success factors, framework, and implementation plans. Based upon the available literature, the research gaps have been identified and further, the research objectives of the present study is shown at the end of the chapter.

Chapter 3 presents the research design adopted for conducting the present study. In the adopted research methodology, the problem formulation was done with the help of selected case industry. Further, the LSS framework has been developed and briefly explained the all tools adopted in this framework.

Chapter 4 deals with the analysis and prioritization of LSS enablers in MSMEs. This chapter exhibits the steps involved to ranking the identified enablers using Best Worst Method (BWM). The BWM steps were conducted with the help of case study in Indian MSMEs. Moreover, the discussion on findings was done followed by the managerial implications and concluded remarks.

Chapter 5 describes the investigation on barriers associated with LSS implementation in Indian MSMEs sector. Initially, a statistical analysis has been conducted to finalize the critical barriers. Thereafter, the mutual interrelationship among finalized barriers have been found using ISM approach. To clustering the barriers as per their driving and dependency power, MICMAC analysis has been conducted. At the end of chapter, the managerial implications are given with conclusion.

Chapter 6 presents the implementation steps of LSS approach in a selected case industry (MSMEs) from the North India. In this case study, LSS approach is adopted to improve the CU level of selected MSMEs without neglecting their existing boundaries. The implementation steps guides to engineering managers and practitioners to adopt effective tools and guidelines during LSS deployment. The managerial implications and conclusion of case study have been explained at the end of this chapter.

Chapter 7 summarizes the outcome of the research with research contributions, limitations and scope for future research.

CHAPTER 2

Literature Review

2.1 Introduction

This chapter represents the review of literature which pacts with the vital aim of finding the contributions of investigators towards Lean Six Sigma (LSS) in the manufacturing sectors. The research papers, books, journals, and reports are the sources of the review. The review of literature exposed a wide opportunity for investigation and analysis of LSS initiatives in Indian manufacturing industries. The key findings from the review helped to define the research gaps.

2.2 Aims of Literature Review

The prime objectives of the literature review are:

- To determine the scope of the research work that has been done on emerging approaches such as Lean, Six Sigma, and LSS.

- To collect extreme knowledge about continuous improvement programs like Lean, Six Sigma, and LSS.
- To find out the significance of the capacity and Capacity Utilization (CU) concept in the industrial sector. Also to extract the role of CU in productivity improvement in the manufacturing industries.
- To recognize the research gaps in the LSS employment in Indian Micro-Small and Medium Enterprises (MSMEs).
- To recognize and state the research work carried out in the implementation of LSS.

2.3 Methodology Adopted for Literature Review

In this chapter, the literature review is carried out based on a Systematic Literature Review (SLR) methodology. The SLR approach provides transparent, comprehensive, and clear information that provides utmost consistency in process [71]. It includes the investigation of decided papers from various sources and databases [72]. The articles were collected from search engines like Elsevier, Emerald, Springer, Taylor & Francis, Scopus, Wiley online library, etc. using the search strings Lean, Six Sigma, LSS, Capacity Utilization, manufacturing, and sustainability. The irrelevant articles, books, conferences paper, and paper other than the English language are discarded from the literature. Finally, 302 articles are selected for the analysis and to achieve the targeted set of objectives. Table 2.1 explores the various steps of Systematic Literature Review for literature selection process [73].

An extensive literature review is required for deep analysis of the research area as well as comes across the latest developments and trends. For this, the literature are classified into three groups as shown following:

- Literature based on Capacity and Capacity Utilization
- Literature based on Six Sigma

- Literature based on Lean Six Sigma

TABLE 2.1: *Step of Systematic Literature Review*

S.N.	Steps	Definition	No. of articles
1	Research objective	Define the goal of the review	
2	Design a research procedure	Make a protocol that consists of scope, criteria, quality, etc.	
3	Outline significant criteria	Fix research criteria to include only pertinent articles	
4	Explore and gather literature	Search and download the pertinent articles from renowned databases	Total articles searched= 1260
5	Selection of papers	Based on defined research criteria, consider the relevant studies	Total articles selected= 350
6	Screening of relevant articles	Based on the adopted methodology, screen each article for quality	
7	Data extraction	Extract the data through systematical review of each article in-depth	
8	Analysis of data	Illustrate the main conclusion through qualitative or quantitative analysis	Total articles analyzed= 302
9	Writing the review	Make the report of results obtained through review the articles	
10	Dissemination	Publish the knowledge in the good academic journals	

2.4 Literature based on Capacity Utilization

In recent years, the practitioners/researcher have started to focus on the issue of capacity and CU rate [74][75]. The first discussion on capacity was made by Cassels and stating that excess capacity is sometimes used to describe fixed factors of any producing unit [26]. In the Sixties, it was concluded that CU is defined as the fraction of actual output to potential output [28]. As per Johansen, capacity is the maximum output that can be created per period of time with existing facilities in the plant [16]. In a cross-industry, regression examination was performed to describe a discrepancy in CU levels [76]. In one survey, it has been found that the CU rate in automobile industries was near about 52 to 60 % [77]. The Chinese company having a capacity waste of 58 % to 66 % in ten years i.e. 1985-1995 due to a shortage of power, outdated technology and resources catastrophe [78]. Bayard focused on capacity waste in the water transport sector and found that near about 35% to 46 % capacity waste was there [79]. The CU in the Nigerian industrial sector was reported and found that CU was 44 % assessing by combined rapid appraisal techniques [80]. In the manufacturing sector of Nigeria, CU estimated with the help of expert opinion technique and found the CU rate of 44.2% for the sector. In the food sub-sector, the CU rate was recorded as 44.75% while wood and textile having a rate of 41.88 % and 44.53% respectively [81]. The effect of change in government policies on the Nigerian economy in the real sector was estimated through CUfrom official resources of the years 1991 to 2003. The CU was calculated by descriptive statistics and least square method and results show that CU trends in real sectors were 30% to 60% during the period [23]. During the period 1970 to 1988, the real exchange rate and federal government capital expenditure of Nigeria are having positive impacts on CU rate and inflation and real loans having a negative impact on CU rate [82]. In the study of US manufacturing sector, some determinants i.e. the price of material, capital stock, capital price etc. are observed which have negative impact on economic CU rate; while some determinant like labor price, energy price and output having positive significant effect on economic capacity [22]. Aghion and Burgess collected the data of two firms through the survey method from two countries as India and the UK and then analyzed the data through the Schumpeterian growth model. The result of this study shows that firm CU level increase during the implementation of liberalization policies on industrial performance [83]. The relation between CU and investment shows that CU is a better predictor for investment. In the South Korea manufacturing sector, it has been observed that material price and output having positive significant influenced on the CU rate, whereas rental price, labor price and price of energy exhibit negative relationship with CU rate [21][84]. The time series method has been applied to the quantitative data of the period 1974 to 2005 of the sugar industry in India to analyze the trends of CU. The results show that CU is about 13% and the most significant variable is the availability of raw material to explaining CU in Indias sugar industry [85]. Some more case studies have been carried out to see the impact of CU and wastage of capacity in Indian industries like welding industries [86][87]), process industries [75][88], textile industry [168], cement industry [89], steel plants [90][91][92]), Tata auto industry [93], thermal power plant [94], automotive industries [40][57] etc.

In the Turkish rubber industry, the significant factor affecting the CU of plant with the industries were investigated. From the outcomes it is revealed that site and size of company affects the CU significantly. Company had more CU rate that are located near international markets with large infrastuucture [17][39]. Apart from the location and size of the plant, source of power had a significant and positive effect, but inflation and interest rate impacts CU negatively. The interest rate is having a more significant impact at 5% level with 88.54% variation in CU explained by and the regression model [93]. In period of 1970 to 2010, from the data of sugar industry of India, it has been observed that CU rate of sugar industry was affected by the inflation rate, power consumption, federal expenditure, real GDP, and liberalization time [19][95]. The productivity growth in the Canadian business sector has been investigated and found that the productivity growth decrement occurs due to the pro-cyclical nature of growth of productivity [96][95]. The productivity directly related to CU and for this data of the period 1996 to 2004 has been collected from Indian industries. The CU has been estimated using the regression model and results reveal that CU decrease between 1995 and 2001, but the increase between 2001 and 2004. The conclusion of the results shows that firm size, share of markets and market awareness positively effects the CU [75][97]. The overall concluded researchers views about the CU rate and its effect on any business organization are illustrated in Table 2.2.

TABLE 2.2: *Literature related to CU concept in context of developed and developing countries*

Reference	**Country**	**Researchers Views**
In context of developed Country		
[18]	UK	Economic concept was implemented to estimate actual capacity in service sector.
[98]	USA	The authors have presented Federal Reserve's measures to capacity and CU.
[100]	Mexico	A simple queuing model was used to estimate the CU and results shows that firm was able to savings in excess of $100,000 by implementing the suggested comments by author after analysis.
[101]	USA	This paper presents the negative and positive determinants effect the CU of the US manufacturing sector.
[84]	USA	The result of paper reflects that shift level as the stochastic variable is significant model to estimate the CU in a convenient way with accuracy.
[103]	USA	The author shows that how productivity measurement are direcly and indirectly related to different aspects of CU.
[82]	USA	The author estimated the CU with the help of economic approach in USA business sector.

[104]	Canada	CU estimated by Data Envelopment Analysis (DEA) and result shows that market based approach are significant factor to improve the efficiency in multi-product industries.
[105]	USA	The author was presented the concept of capacity and its measurements by analyzing the conceptual and theoretical base of capacity in a fisheries case study.
[107]	USA	The result shows that the average CU for the Danish Gill-net fleet was expected within range of 0. 85 and 0.95 in USA fisheries.
[101]	USA	This paper presents that material price and output having positive significant influenced, whereas rental price, labor price and price of energy having negative effect on CU rate in the South Korea manufacturing sector.
[83]	UK	The data of two firms have been collected through survey method from two countries as India and UK and then analyzed the data through Schumpeterian growth model. The result of this study shows that firm CU level increase during the implementation of liberalization policies.
[109]	USA	This article presented the integration method to estimate the CU in OECD countries.
[110]	USA	The author presented the direct and indirect non-parametric method (i.e. DEA) for estimating the CU in USA manufacturing industries.
[112]	USA	A new method Structural Vector Auto-Regression (SVAR) system of equation has been proposed to estimate the CU.

[115]	USA	Capacity waste of water transport sector has been calculated with time series method and found capacity wastage is near about 35% to 46 %.
[96]	Belgium	This research work presented the link between short and long run economic analysis and avoiding conflating inefficiencies and differences in CU.
[123]	Romania	This paper is presenting the relation between CU and productivity.
[129]	Canada	The productivity growth in the Canadian business sector have been investigated and found that the slowdown in productivity growth is due to pro-cyclical nature of productivity growing from CU.
[131]	USA	The author presented the non-parametric method (i.e. DEA) for estimating the CU in USA manufacturing industries.
[135]	Russia	The CU of Russian manufacturing industry have been calculated using time series method and result shows that there are strong correlation between CU rate and inflation rate.
[139]	USA	Storage capacity can have better impact on urban water flow system in the plant.
In context of developing Country		
[99]	India	The result of this paper shows that the main reasons of underutilization of capacity are raw material shortage, infrastructure bottleneck and demand constraints.
[78]	China	The outcome shows that capacity waste of 34 % to 42 % in ten years i.e 1985-1995 due to shortage of power, outdated technology and resources catastrophe.

[17]	Turkey	The outcome of paper presents that the site and company size are important factors effecting CU more in Turkish rubber industry.
[92]	India	The outcomes reveal that an increase in Total Factor Productivity (TFP) improve the growth of manufacturing industries in the posttrade reform period.
[113]	Denmark	CU estimated by two approaches as physical and economic approach and then results were compared.
[74]	India	The authors were presented the variation of CU level in time period of 1985-90 using a generalized Leontief variable cost function, with capital as a quasi-fixed input.
[111]	Nigeria	In manufacturing sector of Nigeria, the CU rate of 44.2% for the sector. In food sub-sector, CU rate was recoded as 44.75% while wood and textile having rate as 41. 88 % and 44.53% respectively.
[114]	India	The authors proposed an exchange algorithm to increase the CU of vehicle transportation in an Indian steel plant.
[102]	India	The rate of CU in Indian paper industry has been estimated by using the theoretical framework of variable cost function.
[106]	Nigeria	The CU in Nigerian industrial sector was reported and found that CU was 44 % assessing by combined rapid appraisal technique.
[108]	India	The CU of Indian Airlines over a period of 1964 to 1999 had estimated by using trans log variable cost function and outcome exhibits that the CU in Indian Airlines has been reduced over a given period.

[116]	India	The CU has been estimated using regression model and found that infrastructure of company, sharing in market and market awareness positively impact the overall CU.
[117]	India	This paper presents estimated the average rate of CU during period of 2001 to 2011 in Indian goods industry with the help of time series method.
[118]	India	The result shows that CU is about 13% and most significant variable is availability of raw material to explaining CU in Indias sugar industry.
[23]	Nigeria	The CU was calculated by descriptive statistics and least square method and results shows that CU trends in real sectors was 30% to 60% during the period.
[33]	India	The result reveals that demand of products and their supply are important factors that control the CU Indian manufacturing sector.
[91]	China	This research exhibited the systematic reviews of water resource carrying capacity in China. The results of study shows that water resource carrying capacity through three phases: initial, success and growth.
[119]	India	The authors used economic concept to estimate CU of Indian fertilizer industry and furthermore, to measure the TFP.
[120]	China	This article was presenting the economic approach to estimate agricultural water resources in Shandong province.
[121]	Nigeria	This paper analyzed CU rate in sugar industry in Nigeria and extract positive and negative factors related with CU in period of 1970 to 2010.

[122]	India	CU level has been found and noted that CU growth rate decline due to stagnated demand probably.
[124]	Nigeria	It was found that the interest rate is having more significant impact at 5% level with 88.54% variation in CU explained by regression model.
[125]	India	The authors presented the issues and challenges faced in full CU of Indian manufacturing sector.
[126]	India	The author had presented the overview of CU in India and Abroad business sector and provides remarkable research gap in empirical research.
[127]	Turkey	CU level has been estimated by various methods and found that Support Vector Machine (SVM) provides better results than others.
[94]	India	This paper presented the main reason of capacity waste of thermal power plant and found that economizer, super heater and re-heater are main cause of capacity waste.
[128]	Tunisia	The authors used the direct and indirect production function of Shephard to drive a measure CU rate using DEA.
[19]	Nigeria	The result of this paper shows that CU rate in the sugar industry was affected by the inflation rate, power utilization, federal expenditure, real GDP and liberalization time.
[130]	South Africa	The authors identified the reasons of underutilization of capacity in South African industries and found major three factors i. e. week infrastructure, unavailability of water and electricity, across all provinces.

[132]	Nigeria	This paper presented the framework which can increases 1% in real gross of domestic product and 77% in imports of raw materials.
[152]	India	This article presents that conveyor malfunction is the key factor of capacity wastage among all alternatives selected in an Indian automotive sector.
[133]	India	This paper presented the average rate of CU of capital goods industry in India over a period of 2001-2011 with the help of time series method.
[134]	India	The result of this paper shows that non-electric machinery group has CU of 73.71% followed by transport equipment industry with 70.69% and electrical machinery & general purpose machinery group with 65. 65% and 65. 3% respectively.
[136]	Tunisia	CU level has been estimated and found that capacity is under-utilization in Tunisian manufacturing industry.
[88]	India	The authors find out the main reason behind the capacity wastage of thermal power plant and found that economizer, super heater and re-heater are main cause of non-availability of system.
[37]	China	The authors proposed two models for CU level estimation and found that CU level was fluctuating in the range of 89 % to 105 %.
[137]	China	The authors proposed state space model and kalman filter algorithm to estimate the over capacity of coal industry in China which provides better results.

[138]	India	Perform, Achieve, and Trade (PAT) has been proposed for CU estimation and CU level increase and the energy savings of 0. 456 million tons of oil equivalent/year is achieved.
[140]	China	The authors proposed two models for CU level estimation and found that CU level was fluctuating in the range of 90 % to 98 %.

2.5 Literature based on Six Sigma

This section is presenting the literature review of the Six Sigma method employed in the various sector for improving the performance. Six Sigma is an emerging approach and widely adopted by the organizations in context of developed and developing countries. The brief descriptions of the literature in both context are given in the next sub-sections.

2.5.1 Six Sigma Literature in Context of Developing Economy

Sunder et al., (2020) adopted the Six Sigma DMAIC strategy for reducing the claim processing errors in the healthcare sector. Through this case study, the error-free delivery of medicines was increased, results the firm was able to save US$ 0.53 million [141].

Uluskan et al., (2020) directed a case study to analyze the oven door panel defects in household appliance manufacturing company. In this case study, Six Sigma approach was adopted defect reduction and minimizing non-value-adding steps. Through the successful implementation of Six Sigma, process performance in terms of Sigma level was increased to 4.4 from 3.1 [142].

Maged A. et al., (2019) used Six Sigma framework as a continuous improvement strategy in an injection molding industry. In this case study, especially the quality of the product was increased using DMAIC methodology. On completion of the project, the selected case organization was obtained the Sigma level to 4.50 from 4.06 and the rejection rate reduced by 45% [143].

Rahman A. et al., (2018) implemented DMAIC methodology for productivity improvement through defect reduction in Bangladesh garments manufacturing industry. The result shows that the defect rate was reduced near about 2% and increase overall productivity [144].

Noori, B., & Latifi, M. (2018) implemented the Six Sigma approach to reduce defect and enhance overall performance in the automotive industry of Iran. The outcomes show that the performance has been improved from 27% to 93.3% and cost-saving was near about 40000$ [145].

Srinivas, S. S., & Sreedharan, V. R. (2018) identified the root causes of failure of automotive components using DMAIC approach in the Indian automotive industry. The result shows that the slight variation in the packing process reduces the chance of failure of components in the spare distribution center [146].

Nupur, R., et al., (2018) used DMAIC approach to minimize flaws during cutting process causes Sigma level increament from 3.1 to 4.7 in garment manufacturing industry [147].

Bhowmik, C. et al., (2018) implemented the synergy of Six Sigma and the theory of constraints for reducing the defects in the production system. The re-engineering of the system elevates the constraints of production and increases the quality of the product by reducing the defects [148].

Rathi R., et al., (2017) adopted a fuzzy-VIKOR method for prioritizing the Six Sigma project in the Indian automotive sector. In this context, 7 selection criteria were measured for selecting best alternative. The weight of selection criteria was computed with the help of the Modified Digital Logic (MDL) method. Based on this weightage, the available project alternatives were prioritized by using the Fuzzy-VIKOR approach. The results revealed that the Shox machine shop was utmost suitable Six Sigma project from the development perspective in the selected case company [57].

Desai, D., & Prajapati, B. N. (2017) were implemented DMAIC methodology to improve the products quality using improved injection molding process in the plastic part manufacturing unit India. The results of this case study show that critical factors such as contamination, short molding, and flash and injection point were reduced by saving annual cost of INR 10.80 lacs annually [150].

Rathi R., et al., (2016) developed a roadmap to select best Six Sigma projects in the Indian automotive industry. The developed roadmap is having a combination of Multi-Attribute Decision Making (MADM) and fuzzy logic method. The results exhibited that the proposed roadmap can be significantly used in the practice of proper Six Sigma project selection problems [152].

Rathi R. et al., (2015) offered a agenda for the assortment of factors responsible for capacity waste in the Indian automotive industry. The proposed framework utilized the fuzzy AHP scheme. The outcomes illustrated that conveyor malfunction was the most critical issue accountable for capacity waste at a selected site [40].

Sekhon, M. S. et al., (2014) utilized Six Sigma methodology to identify the forging faults occurs in small scale forging units in India. From the results, it has perceived that almost 83% faults happen because of cracks, scaling, and low rigidity [156].

Singh, B. J., & Khanduja, D. (2014) proposed a framework to access the control phase of the Six Sigma strategy. The efficacy of the proposed framework was checked through a case study in the foundry industry. The results found a significant contribution of the Six Sigma approach in the overall improvement in the selected case industry [157].

Singh, R., & Kumar, A. (2014) implemented Six Sigma for improving production by reducing the rejection rate in the small manufacturing industry in India. The results showed that the implemented approach reduces rejection rate of the hydraulic laser machine and effectively increases Sigma level from 2.21 to 5.64. The nozzle hole diameter was noted as the main reason for the rejection of manufactured components [158].

Parsana, T. S. (2014) expressed the review of Six Sigma and DMAIC methodology in the context of the Indian manufacturing environment. In the investigation, the most successful factors for Six Sigma were highlighted and proposed for manufacturing units. [159].

Kaushik, P.K. & Sandeep (2013) implemented DMAIC methodology for diminishing the rejection rate of pump head of hydraulic jack set by improving methods and reducing errors in the process. The results showed that the adopted approach was able to increase Sigma level from 2.21 to 5.64 with annual cost saving 0.01929 million/annum [160].

Sambhe, R. U. (2012) investigated the success factors of Six Sigma implementation in any business environment in India. In the study, a medium scale auto ancillary industry was considered for Six Sigma implementation and found satisfactory results towards business excellence [161].

Kaushik, P. et al (2012) adopted the DMAIC methodology for diminishing the bush rejection rate with the help of process variations reduction in the Indian manufactruing industries. The result shows that implemented method increased Sigma level from 1.40 to 5.46 and saved US$ 3840 annually [162].

Desai D. et al., (2012) highlighted the CSFs of Six Sigma implementation in a developing country like India. The result listed 12 critical success factors out of 39 and prioritized them according to rating [163].

Shanmugaraja, M., et al., (2011) implemented DMAIC methodology to improve quality and productivity in the Aluminium Die Casting Industry, India. The results showed that the adopted approach decreased products defect level from 17.22% to 4.8% [164].

Kumar M. et al., (2011) proposed a Six Sigma framework applicable to the manufactruing environment. The proposed method was tested by implementing it in three different manufacturing industries and found satisfactory results towards improvement in production [165].

Rao P. et al., (2009) implemented Six Sigma in a manufacturing company G.I Ltd. Gurgaon, India, and found that 60% rejection Part Per Million (PPM) achieved against the target of 75% [168].

Chakravorty, S. S. (2009) proposed a Six Sigma model for successful implementation in Network Technology Company. In this research, six easy steps were given for the successful implementation of the Six Sigma initiatives for reducing variation in the process [169].

Desai, D. A. (2006) implemented the DMAIC methodology for improving customer delivery commitments of an Indian small scale industry and satisfactory results achieved [172].

Raisinghani, M. S., et al (2005) investigated the relation between Sigma methodology and other quality initiatives. The results revealed that the Six Sigma approach mainly focused on process variation reduction and act as a project-oriented approach. This is a toolset and can be adopted with the synergy of other more comprehensive quality standards for getting faster results [51].

2.5.2 Six Sigma Literature in Context of Developed Economy

Antony, J., et al., (2019) developed the roadmap for implementation of Six Sigma in healthcare and extracted the critical success factors of Six Sigma employment. The study revealed that Six Sigma implementation in healthcare provides an improvement in patient safety, process speed, and revenue enhancement. Other side, the top management contribution and awareness about Six Sigma methodology found the utmost important success factors of Six Sigma implementation [149].

Yao, H. C., et al., (2017) implemented the Six Sigma approach for reducing waiting time and remove non-value-added activity in procedure at an MRI machine in a hospital. The result reveals that the number of examined patients increased from 260 to 288 per month [151].

Marzago, D. S. L., et al., (2016) identified and proposed the association between critical success factors and Six Sigma projects. The analysis found the significant impression of the Six Sigma approach and project management on operational performance [153].

Malek, J., & Desai, D. (2015) implemented the DMAIC methodology for minimizing the rejection happens during pressure die casting process. On the completion of the project, it was observed that the Sigma level was improved to 3.7 from 3.1, rejection rate reduced to 4.47% from 15.50%, and got the annual profit of US$ 24365. [154].

Gijo E. V. et al., (2014) adopted the Six Sigma strategy to reduce the rejection rate and rework in the small scale manufacturing process. The outcome of the study indicated that the overall rejection was reduced from 48.33% to 7.9% and was saved an annual profit of US$ 8,000 [155].

Gijo, E. V., et al., (2011) implemented the Six Sigma approach for defect reduction in the USA manufacturing industry. The results revealed that the Sigma level was increased from 0.868 to 3.207 and defects reduced by 94% [166].

Soti, A. et al., (2010) investigated enablers of Six Sigma and finding the relationship between them using ISM. In the results, eleven enablers investigated and ISM modeling represents a relation between them [167].

Su, C. T., & Chou, C. J. (2008) developed a novel approach to create a critical six sigma project and identify the priority of these projects. This approach was implemented in a semiconductor manufacturing company and the outcomes provides satisfactory performance [170].

Antony, J., et al., (2008) completed a pilot study to gearing up Six Sigma in the UK manufacturing company. In the study, the authors find out some crucial success factors which were most responsible for success for Six Sigma. The results showed that management involvement, linking Six Sigma to customers and business strategy are the utmost critical factors responsible for the fruitful utilization of Six Sigma in manufacturing industries [171].

Wessels G. et al., (2004) implemented the Six Sigma approach in small scale industries of Germany and extracted specific requirements based on approach. The result offered that ten imperatives functions were essential for the effective employment of Six Sigma [173].

Antony, & Banuelas, (2002) investigated some key success factors for the operative application of Six Sigma in business administrations. From the results, it was observed that top management contribution and assurance are the most significant success factor, whereas linking Six Sigma to the employee found the least significant success factor [48].

2.6 Literature based on Lean Six Sigma

This section is presenting the literature review on LSS implemented for continuous improvement in various organizations in context of developing and developed countries. The brief descriptions of literature are given in the next subsection.

2.6.1 Literature of LSS in Context of Developing country

Narottam et al., (2020) proposed the critical success factor for successful adoption of LSS in Indian manufacturing, service and healthcare sector. A survey questionnaire method was circulated in 450 industries and responses from 180 industries were collected back. The results revealed that top managing initiative towards LSS; LSS review process for managing quality upgrading events, and organizational roles and responsibilities linkage were top ranked critical success factors in Indian industries [174].

Yadav G. et al., (2020) proposed a framework using Lean manufacturing (LM) for enhancing its embracing rate in manufacturing environment at developing economy. In proposed framework, Fuzzy Analytical Hierarchy Process (FAHP) and DEMATEL tools were utilized to quantify the interrelationship among drivers for implementation of LM. It can be perceived from results that improved shop-floor management, quality management, and manufacturing policy were utmost critical drivers [175].

Costa et al., (2020) conducted a detailed review on LSS and Six Sigma relevant to food industry. The survey was conducted in 145 food industries and analyzed the data through structural equation modelling. The result of analysis revealed that training found essential enabler to enhance the LSS awareness among managers and workers [176].

Sordan et al., (2020) conducted a detailed review on LSS to explore the current status and future research direction in manufacturing sector. The literature concluded that the rate of successful adoption of LSS strategy in developed economies in their manufacturing sector is higher as compared to developing economy [177].

Sodhi et al., (2020) proposed a conceptual framework using Lean, Six Sigma and LSS for minimizing waste in manufacturing SMEs. The proposed framework was tested pragmatically for reducing the scrap in a manufacturing company in India. The results revealed that the scrap was reduced by 13.5% and production was increased by 15% [178].

Swarnker et al., (2019) highlighted the Critical Failure Factors (CFFs) of LSS implementation in Indian manufacturing organizations. The total 12 CFFs of LSS were identified and found the interrelation among them with the help of ISM and MICMAC analysis. The results revealed that the top ranked CFFs were weak LSS deploy infrastructure; high implementation cost and lack of continuous monitoring approach [179].

Kaswan and Rathi (2019) investigated the enablers and proposed a model for successful implementation of Green LSS (GLS). The modelling of key enablers was constructed through Interpretive Structural Modelling (ISM) technique and MICMAC analysis. This study was facilitated the manufacturing organizations for successful implementation of GLS by detailed understanding of mutual relations among the enablers of GLS [181].

Priya S. et al., (2019) implemented LSS for defect reduction and waste eliminations in an assembly line at automotive assembly plant. A through defect analysis was carried out to examine the possible defects, resulted 12 crucial defects found. The implementation of proposed solutions were able to reduce the defects and non-value adding activity drastically [183].

Trehan et al., (2019) developed a LSS framework based on DMAIC methodology for reducing product failure rate. The developed framework was tested pragmatically in a large manufacturing industry. The results of case study showed that the aging failure rate was reduced to 0.13% from 9.4% and non-functioning of LED driver was reduced to 1.6% from 12.6% [184].

Yadav, G., et al., (2018) proposed a hybrid framework to facilitate LSS implementation in Indian manufacturing industries. In this research work, Fuzzy AHP-PROMETHEE was used to prioritize and rank LSS barriers and its possible solution approach. The outcomes of the implemented framework revealed that managerial barrier are most critical barriers. These barriers can be minimized with the help of administration participation towards LSS implementation [185].

Gupta S.K. et al., (2018) investigated the potential causes behind student dropouts in higher education institutions by using LSS. In this qualitative study, data has been conducted through interview process with nine university employee and 3 LSS experts. Further, the analysis was carried out using decision tree analysis and fishbone diagram. This provided the improvement using DOE and benchmarking tool [186].

Shamsuzzaman, M., et al., (2018) proposed a framework for LSS implementation within telecom company to expand customer gratification by response time to customer necessities. In this study, both qualitative and quantitative methods have been used to meaningful conclusion. The results have been shown that the proposed approach reduced average order fulfillment and Value-Added Service (VAS) orders from 10.3 to 5.9 days and 1.5 to 0.5 days, respectively [187].

Raja Sreedharan, V. et al., (2018) proposed various contract to identification the awareness of LSS in manufacturing sector in India [189]. Antony J. et al., (2017) used LSS in policing services to extract the factors responsible for continuous growth in the same [190].

Yadav G. et al., (2017) extracted LSS enablers through literature review and interaction among enablers were analyzed using hierarchical model by engaging Interpretive Structural Modeling (ISM). The driving and dependence power of these enablers were determined through Matriced Impacts Croise's Multiplication Applique'ea 'un Classement (MICMAC) scheme. The result presents that twenty key enablers were identified with the help of expert opinion that act as the utmost important factors for LSS implementation [191].

Ben Ruben R. et al., (2017) developed a LSS framework with environmental consideration for enhancing the operative and environmental profits. The developed model was endorsed with the help of case study in an automotive manufacturing business. This framework was used suitable sustainable tools with Six Sigma DMAIC strategy. On successful execution of developed framework, internal flaws were decreased to 6000 ppm from 16000 ppm and the influence of environment decreased from 42 point to 33 point at selected automotive manufacturing organization [192].

Ambekar S et al., (2017) highlighted the barriers responsible for failure of LSS projects in Indian manufacturing and service sectors. The study proposed five barriers such as higher management role, cultural revolution, probable attitude, obtainability of assets and quality level. LSS employment desires to eliminate these barriers in project [193].

Sunder M. V. (2016) implemented LSS in banking sector and focused on reject reduction in retail line. The result shows that bank got benefits of INR 1.6 million and improvement in bottom line results along with motivating the employees to contributing towards LSS implementation [195].

Swarnkar S. and Vinod S. (2016) showed a case study that was conduted within automotive manufacturing company in Indian context. In case study, LSS framework based on DMAIC methodology was used for defect reduction and waste eliminations. The result of case study revealed that defect per unit reduced by 50%, change over time decreased by 14.9%, cycle time reduced by 7.10%, and got 50% increment in production per day [197].

Tsironis L. K. et al., (2016) proposed the factors that influence the employment of LSS in service sector. The result reveals that top management active involvement, HR support activity and practices & systems found the most significant factors [198].

Mohd Norzaimi Che Ani et al., (2016) improved the quality by reducing the rejection rate with the help of process mapping, Ishikawa diagram, VOC as lean tool with

DMAIC methodology. The result shows that the adopted scheme increases quality improvement program and reduced the rejection rate from 4.7 percent to 3.1 percent [199].

Indrawati, S., & Ridwansyah, M. (2015) used LSS for continuous improvement in an iron ore industry in Indonesia. The result reflects that there were 33.67% non-value added action and 14.2% non-necessary steps in manufacturing process. After analysis, found that product defect, waiting and inappropriate processing were manufacturing waste occurred frequently and finally, redesigning of dust collector and weighing standard operation procedure suggested [200].

Isa, M. F. M., & Usmen, M. (2015) implemented LSS to upgrades the strategy and assembly facilities within the university. The result reveals that the rework is responsible for time delay and higher cost within design and construction processes [201].

Vinod S. et al., (2014) implemented the synergies of Lean tool and Six Sigma strategy for reducing the defect and non-value adding steps in manufacturing of rotary switches components in the organization. To improve the performance and customer loyality, the proposed model has integrated with lean tool and six sigma approach [25].

Hassan, M. K. (2013) applied LSS for waste reduction and increasing the yield of manufacturing process in welding wire manufacturing plant and ranking for causes of waste done by AHP. The result reflects that machine was cause for waste and in sub causes, old fashion equipment and process shut down due to lack of raw material was get high rank [204].

Imam S. et al., (2012) proposed a Lean Sigma model applicable for Indian Automotive sector to improve their performance in term of reduce rejection rate and improving the quality of product [206].

Hardeman C. et al., (2011) implemented LSS strategy for improving the performance of airfoil extrusion shimming process. The result shows that the defect rate reduced by 94% and increased Sigma level from 0.868 to 3.207 [208].

Vinodh S. et al., (2011) reduced the flaw and improve the customer gratification by using various lean tools such as 5S, Pareto chart, control chart, DOE, brainstorming, VOC, current state map, VSM with DMAIC methodology in MSMEs. The outcomes

of study shows that the proposed scheme improved customer gratification from 98.2 to 99% [47].
Kumar M. et al., (2006) offered a Lean Sigma model to decrease the defects rate that occurs during die casting process in Indian SMEs. In this framework, the integration of Lean tool (5S, TPM, Current state map) with DMAIC methodology improves the performance in terms of defects reduction, Overall Equipment Effectiveness (OEE) and a substantial financial savings [214].
Achanga P. et al., (2006) identify seven critical successful factors for Lean implementation in SMEs. The result of study reveals that leadership is most appropriate factor responsible for fruitful implementation of lean within SMEs organization [215].

2.6.2 Literature of LSS in Context of Developed country

Alexander et al., (2019) conducted a review on LSS in Small Manufacturing Enterprises (SMEs). For this, systematic literature review methodology was adopted in three phases as plan, conduct, and report. The literature revealed that SMEs are still in early stage to LSS adoption properly and managers are hesitant to adopt new technique like LSS in their core business [180].
Nascimento et al., (2019) proposed LSS framework for improving the performance in the oil and gas sectors. The proposed framework was based on integration of lean principle, DMAIC and Plan-Do-Check-Act (PDCA) cycle. On completion of case study, the selected firm was able to enhance their efficiency by 22% and minimized waste by 17.5% [182].
Cudney E. A. et al., (2018) explored the systematic role of Lean and Six Sigma for continuous improvement in quality of education system. This study suggested that LSS can be applied to improve administrative processes, teaching method and student satisfaction in education system. Apart from this, several challenges also pointed out in implementation of LSS in education system such as lack of awareness about LSS, difficulty in understanding methodology of LSS, lack of commitment etc [188].
Hills J. et al., (2018) implemented LSS framework to increase operational performance

in an aerospace Maintenance Repair and Overhaul (MRO) facility. The efficacy of implemented framework was checked through case study and result showed that performance of supply chain can be increased by minimizing the late material calls and stabilizing Order to Receipt (OTR) times [55].

McLean R. S. et al., (2017) provides a conceptual based LSS framework which was implemented in UK manufacturing company. The proposed LSS framework is applicable only for UK manufacturing sector and not validated for other region and sectors [194].

Garza-Reyes et al., (2016) adopted LSS framework for reducing the ship loading commercial time in iron ore pelletizing industry. The adopted framework was based on DMAIC methodology and validated trough a case study. The LSS framework helped the case company to improve ship loading process capability as well as commercial time by 30%, resulted in saving of US$ 300000 per annum [41].

Lande M. et al., (2016) explored and listed the Critical Success Factors (CSFs) of LSS model that impacts the performance of SMEs in terms of quality, and financial factors. The outcomes of the proposed model assists researchers and practitioners for identifying utmost significant set of CSFs within various application frameworks. The implemented results also provides assistance to both developing and developed country [196].

Albiwi S. et al., (2015) highlighted the important themes of LSS employment in any manufacturing sector and explored the research gap also. The outcome presents that most important themes were benefits, motivation factor, limitation and impending factors of LSS [202].

Jie, J. C. R., et al., (2014) implemented LSS in printing industry to increase the overall productivity of the plant. After effective employment of LSS strategy, it was perceived that the productivity of industry is increased by 21.93% [53].

Timans W. et al., (2014) revised the existing framework of one study done by Kumar M. et al., 2011 with amalgamation of Lean tool. After implementation of new LSS framework in manufacturing enterprise, the results have been compared and found improvement in performance [203].

Akbulut-Bailey, A. Y. et al., (2012) adopted Kanban and cause & effect tool to reduce the overall cost of operations and upgrades competitive position of company across Indian markets. The result reveals that the adopted tools diminishes waste in company, inventory, labor and production cost. The sales of product was improved from 30 million USD to 205 million $ per year [205].

Wang F. K. et al., (2012) implemented LSS strategy for continuous improvement in panel manufacturing company. Soft Systems Methodology (SSM) is beneficial for complex problesm and has adopted for improvement phase to improve the performance. The outcomes exhibit that the integration of LSS with SSM efficiently upgrades the performance for manufacturing processes [207].

Franchetti M. et al., (2011) analyzed and reduced the cost and waste of manufacturing industry in USA by using lean tools SIPOC, CTQ, brainstorming, VSM, root cause analysis, Pareto chart, FMEA with DMAIC methodology. The result shows that adopted tools decreased the overall cost 660000 dollar per year and reduced work cell 50% [209].

Timans W. et al., (2011) explored and analyzed the CSFs and impending factors of LSS implementation in manufacturing sector. The outcome of the study exhibits that linking to customer found the utmost significant CSF and internal resistance found the most strongest obstructing issue [210].

Jeyaraman K. et al., (2010) highlighted the CSFs for LSS implementation in electronics manufacturing services. The outcomes of the research guides to LSS experts for selecting most appropriate CSFs which avoids momentum trailing during LSS implementation [211].

Roth N. et al., (2010) identified the waste of USA manufacturing industry by using lean tool i.e. SOP, Pareto chart, check sheet with DMAIC methodology. Finally, customers mandate has been accomplished successfully with the help of improved process steps within industry [212].

Thomas A. et al., (2008) proposed an integrated model of Lean and Six Sigma applicable for performance improvement in any manufacturing company. The validation of this framework has been checked after implementation it in a company A of UK and satisfactory results found in terms of cost saving and reducing defects of products [213].

2.7 Research Gaps

Based on the literature of CU, Six Sigma, and LSS in context of developing and developed countries, the following research gaps are identified.

- There is a wide gap between installed and actual capacity of manufacturing industries as reported in literature. To achieve target set by the NMP-2025 (Government of India), the serious problem of under-utilization of manufacturing firm to be analyzed at upmost priority.
- Till now, the national agencies are mainly responsible for estimating CU at national level only. Literature lacks much evidence about estimation and proper utilization of capacity at industry level.
- The major challenge with organizations is that no standard tool sets are available for solving capacity and CU issues. Till now, mainly conventional mathematical models were used to solve the capacity issues.
- LSS as process improvement strategy was successfully executed in various manufacturing organization for improvement in process and quality. But literature lacks any evidence about LSS implementation for proper CU.
- In past, most of studies on LSS were only limited to corporate organizations; still MSMEs are not much familiar about the benefits of LSS strategy.

2.8 Research Objectives

As per the identified research gaps, the objectives of the present study are framed as follows:

- To identify and investigate the success factors and barriers in implementation of LSS in MSMEs.
- To devise a comprehensive framework for effective implementation of LSS in Indian MSMEs without neglecting their existing boundaries.
- To render a strategy for estimating and analyzing capacity and CU for MSMEs.
- With a case study, to evaluate the competence of LSS for ameliorating CU levels in MSMEs.
- To examine the real and subtle gains of LSS accomplishment for capacity management.

CHAPTER 3

Research Methodology

3.1 Problem Formulation

In current industrial environment, the large sized organizations are outsourcing their activities to MSMEs for gratifying the market demands. Therefore, the contribution of MSMEs in wealth generation and societal development has been increased significantly. Consequently, the Government of various countries is providing effective provision to running and development of MSMEs. In the context of development, researchers have also been reviewing the working nature of MSMEs. As a result, the researchers found that the working nature of MSMEs varies from country to country. But, the lacking characteristics of MSMEs found common in global scenario during the researcher's investigation. Some of lacking characteristics of MSMEs are poor top management involvement, lack of training communicated to the employees, poor planning and insufficient use of available resources. Such characteristics act as the barriers for successful implementation of LSS program. This type of improvement program is suitable for lacking characteristics free organizations. This situation suggests that MSMEs need to adopt such models that control the lacking characteristics prior to

implementation of LSS within the organizations.
Secondly, the MSMEs are struggling with poor levels of Capacity Utilization (CU) and productivity. Due to the lower CU level, the production costs became high and efficiency of the plant goes down. There are various reasons of low CU like reworks, rejections, poor work force arrangements, faulty plant layout, manual operations, unorganized resources and excessive workers movement etc. These reasons raise the concern for plant managers and industrial engineers in term of productivity and quality of the products. The above mentioned reasons can be competently dealt with adopting of operations and production management strategies. In this viewpoint, LSS is being explored as advanced strategy to improve the productivity and quality through productive capacity utilization in MSMEs. In present research, the efficacy of LSS as a productivity improvement technique has been checked by using case study approach. The case study was carried out at a medical equipment manufacturing industry which had substantially low level of CU. In this study, formulation of problem is to make the strategy for successful initiation and implementation of LSS program in an Indian MSMEs to achieve excellence in capacity utilization.

3.2 Research Plan

The research design is the logical flow chart that expresses the various stages used to achieve the ultimate objectives and reach a conclusion with the help of a case study. It includes methods of investigation, analysis and assets required for implementation. The desired results will not be attaining if the research design is not comprehensive as much as essential. A reliable research design is prepared for the present case study and shown with the help of flow chart in Figure 3.1. In the first phase of research design, a detailed literature review on LSS, Six Sigma, and capacity utilization in manufacturing sector is carried out. From the extensive literature, the research gaps have been recognized and based upon them, the research objectives of the study are framed. During second phase, the case company is selected and LSS framework is executed successfully for end result assessments. The appropriate solutions for productive CU are proposed and company officials agreed for implementing the solutions in case company. In last phase, the managerial implications and conclusions are exhibited with the future research work.

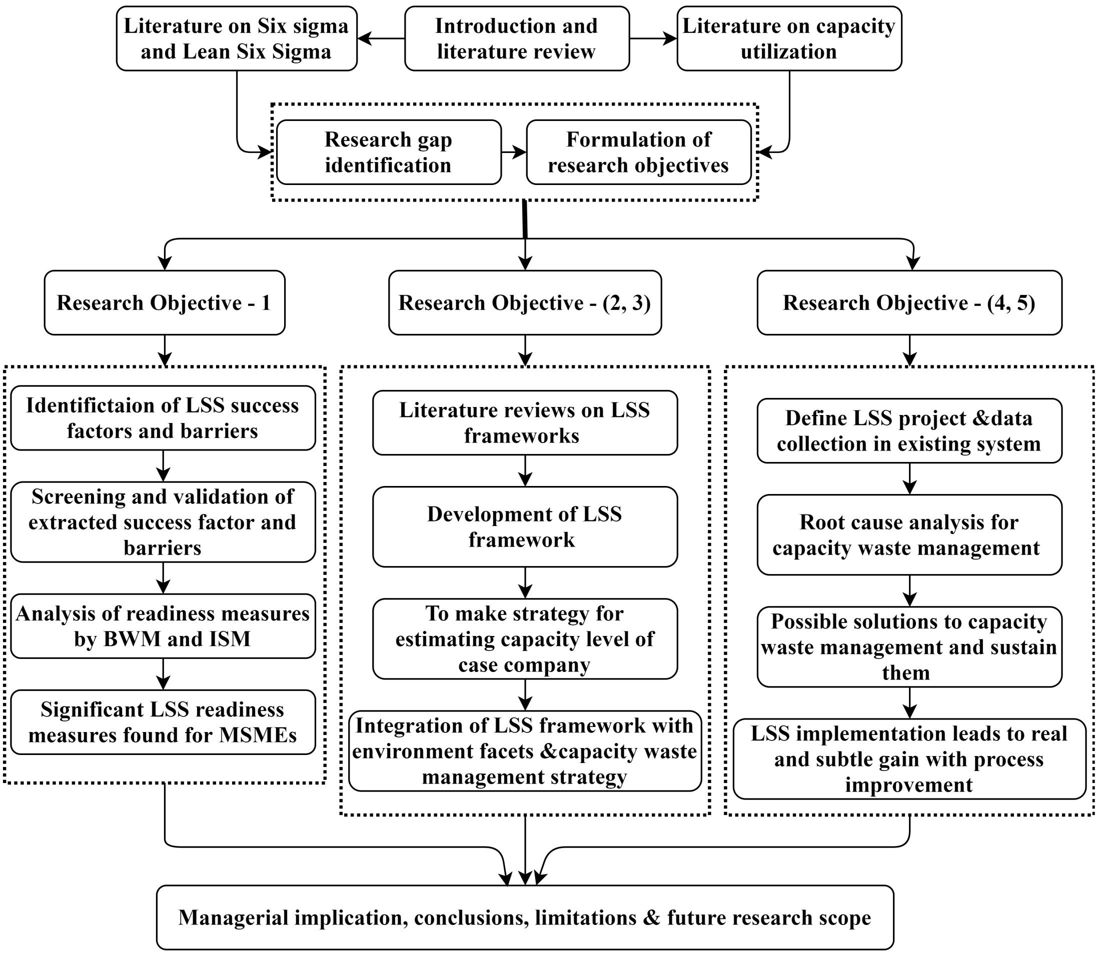

FIGURE 3.1: *Research plan.*

3.3 Proposed LSS Framework

LSS is a breakthrough strategy which consist huge potential in improving process, environmental and sustainable performance of organizations. It deals with performance improvement of a system by measuring the rejection rate, CU level, quality, delivery time, cost, and customer satisfaction. The strategy is popular among manufacturing organizations not only for its plucky tools set but also for its well organized application of DMAIC methodology. It includes all essential steps for deciding a quality process, starting from project selection to control using sustainable tools into a system. The success rate of LSS implementation in MSMEs is majorly depends upon the framework and guidelines [44]. In this chapter, we have recognized fifteen frameworks through the detailed literature search and classified and analyzed thoroughly as shown in Tables 3.1 and 3.2, respectively.

The literature presents substantial evidence relevant to frameworks of Lean, and Six Sigma, but there is no framework that can be implemented irrespective of the type, size, and culture of the MSMEs. Few studies have proposed the frameworks of LSS with environmental consideration, but the concerned organizations faced challenges during the implementation due to generic nature of the framework [192]. These frameworks begin the process of implementation by assessing the present state of sustainability performance before selecting the right tools and techniques to transform into advance sustainable development. Banawi and Bilec, (2014) proposed a framework for integrating Lean, Green, and Six Sigma to reduce the adverse effect of the environment on the process in the construction industry [216]. The structure of the framework is based on the DMAIC and was implemented in the construction industry for the pile cap installation process and able to reduced waste through a retrospective diagnosis. Sagnak and Kazancoglu, (2016) proposed a model that integrates Lean, Green, and Six Sigma approaches. This framework only based on the conceptual aspects and further needs a strong empirical analysis for the validation in real-time applications [223]. Ben Ruben et al., (2017) developed a framework through the integration of LSS and environmental aspects for continuous improvement. The framework was based on the DMAIC methodology where Lean tools and environmental aspects assessment tools were integrated. The efficiency of this framework has been tested in an automotive industry and obtained results as anticipated by the researchers. The fundamental limitation of the framework is that it is applicable to automotive sector and moreover it is not at all suited for Small and Medium-sized Enterprises (SMEs)[225]. Sreedharan V et al., (2018) developed an integrated model of Green and LSS for process improvement in the public sector [245]. This integrated model is in generic nature and not suitable for the manufacturing sector. Sony and Naik, (2020) proposed a framework based on the integration of LSS and Green concept. The framework is based on the DMAIC phase, and Lean thinking cycle. The framework was implemented in the mining industry with some basic tools of LSS. But, the framework requires further involvement of advanced tools and techniques with additional validation for increasing the efficiency and effectiveness [218].

TABLE 3.1: *Classification of frameworks, models, and methodologies*

S.N.	**Author's/ Year**	**Research domain**	**Novel/ adapted**	**Mode of verification**	**Sectors**
1	[219]	Lean and Green	Novel	Yes/ Preliminary study	Automotive industry
2	[220]	Lean and Green	Novel	Yes/ Preliminary study	Forming tube industry
3	[216]	Green and LSS	Adapted	Yes/ Preliminary study	Construction industry
4	[221]	Lean and Green	Novel	No	—
5	[222]	Lean and Green	Novel	Yes/ Preliminary study	Metal industry
6	[223]	Green, Lean and Six Sigma	Novel	No	—
7	[224]	Green and LSS	Novel	Yes/ Preliminary study	Food industry

8	[225]	LSS and Green	Novel	No	——
9	[226]	Green, Lean and Six Sigma	Novel	No	——
10	[192]	LSS and Green	Adapted	Yes/Case study	Automotive industry
11	[217]	Green and LSS	Novel	No	——
12	[227]	Lean and Green	Novel	No	——
13	[228]	Green and LSS	Novel	No	——
14	[218]	Green and LSS	Novel	Yes/ Preliminary study	Mining industry
15	[229]	Sustainable LSS	Novel	No	——

TABLE 3.2: *Pros and Cons of existing frameworks.*

S.N.	**Author's**	**Key contributions**	**Limitations**
1	[219]	The theoretical framework is proposed for examining the impact of lean and green initiatives on the sustainability of the supply chain.	The framework is developed for the automotive industry in Portugal and the results cannot be generalized in other sectors and countries.
2	[220]	The proposed model of Lean and green provides a significant improvement in sustainability.	The proposed framework does not consider the Six Sigma concept for sustainable development.

3	[216]	The integrated framework of lean, green and Six Sigma reduces the adverse effect of the environment in the construction industry.	The developed framework is applied in construction industries and it requires more validation in other sectors.
4	[221]	Proposed a new model through the integration of lean and green concepts to improve sustainability.	The efficacy of the proposed model is not tested and validated.
5	[222]	Proposed an integrated model of lean and green metrics for metal industries.	The developed framework may not be generalized in other industries.
6	[223]	A novel framework is proposed through the integration of lean, green, and Six Sigma approaches.	The efficiency of the model was not tested with a case study.
7	[224]	Proposed an integrated framework of green and LSS for sustainable development in manufacturing industries. It is tested in different four manufacturing processes and obtained favorable results.	The developed framework fails to provide significant results in some manufacturing processes like painting, chemical treatment, and metal finishing, etc.
8	[225]	Proposed a novel framework of LSS with consideration of environmental aspects.	The efficacy of the proposed framework was not checked through the case study.

9	[226]	An integrated framework of lean, green and Six Sigma has been proposed for sustainable development.	The proposed framework is only applicable to the service industry and also needs testing to check its effectiveness.
10	[192]	Proposed a novel framework by the integration of LSS and environmental aspects for continuous improvement.	The proposed framework is only applicable to developed /large industries that are working at more than 3 Sigma level. There is a wide scope of improvement in this framework so that it can fit small manufacturing industries.
11	[217]	Proposed a novel framework to improve the operational excellence in healthcare, telecommunication, and construction sector.	This framework applies to public sectors only and fails to provide significant results in the manufacturing sector.
12	[227]	The proposed framework capable to provide significant results in terms of waste reductions and minimization of adverse environmental effects.	The proposed framework still has room for integration of Six Sigma strategy to control the process variations.
13	[228]	Proposed the framework through the integration of green, lean, and Six Sigma approach for sustainable development.	The efficacy of the proposed framework was not checked through practical application in any industry.

14	[218]	The proposed framework provides excellent results in the mining industry.	The framework is tested only in one industry. It requires additional validation.
15	[229]	In the proposed model, only critical failure factors of sustainable LSS are identified by using total interpretive structural modeling.	The proposed model fails to provide the implementation steps in any industry and also testing is required to check its effectiveness.

To overcome the identified limitations and achieve sustainable development, an inclusive and simplified LSS implementation framework is constructed and proposed. In the proposed framework, each phase of DMAIC methodology is systematically linked with lean tools to achieve operational benefits in the MSMEs sector (refer Figure 3.2). In the proposed framework, the LSS tools are integrated with DMAIC

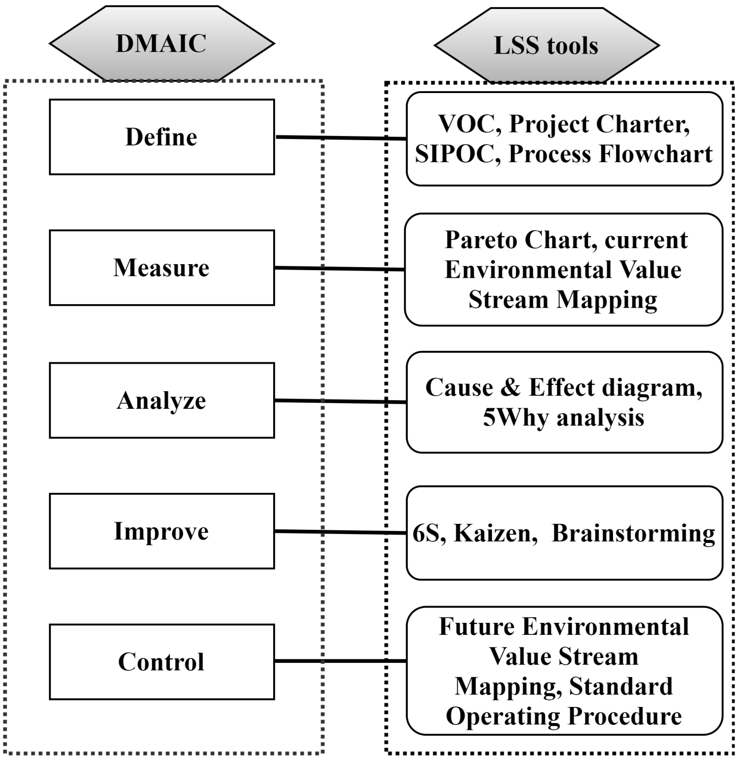

FIGURE 3.2: *Proposed LSS implementation framework.*

approach to deliver both operational and environmental performance. Each phase contains a set of well-defined activities that aims to improve productivity and diminish environmental impacts. Define phase consists of the problem definition and sets a vision for exposing the objective, opportunities, and goals of the selected LSS project. The opportunities and goals are to be set for improving the operational and environmental performance of the firms. Measure phase elaborates the present state of the organization and provides significant parameters affecting positively towards quality and environmental sustainability. In this phase, data relevant to process inadequacy and environmental aspects are being composed in computable form. Analyze phase explains the possible reasons for process variation and capacity waste. In this phase, the composed data are being assessed in terms of root causes of variation, defects, and waste and documented appropriately. Also, the association between quality, productivity, and environmental metrics are validated correctly. Improve phase possesses suitable solutions and ways to implement them accordingly. After the implementation of proposed solutions, the production data is compared with before implementation to ensure the potential benefits in quality, productivity, and environmental perspective. Control phase targets to withstand the improved performance by continuously screening and controlling the implemented solutions within the firm. The productivity, quality, and environmental performance need to be adjusted with mutual compatibility for development according to the project outcomes.

3.4 LSS Tools

In the proposed LSS framework, the LSS tools adopted under Six Sigma DMAIC methodology as shown in Figure 3.2. The brief descriptions of adopted LSS tools are as follows:

- *Voice of Customer (VOC):* VOC is an extensive tool used to collecting the viewpoint of customers about the product and process. Every business exists due to its customers and willing to pay for the product as he or she treasures value in it. If any organization wants to implement LSS, the few questions essentials to be ask and try to find an answer through individual interviews. What is important to the customers in the product? What adds value? Firstly, determine customer reaction to the product and then based upon it, need to think about measures that could be useful.

- *Brainstorming:* Brainstorming is an improvement tool which was presented by Alex Osborne in 1930s. It is used to prompt the ideas of individual team members to quickly generate large number of ideas related to possible causes of particular problem. Even though the capability of individual human being is rather limited, the creation of ideas increases tremendously if there are more people involving together. The main aim of this technique is to provide criticism free environment for innovative exploration of solutions. This technique having capability to create impulsive ideas by which it can leads to novel solutions to problems and higher acceptance of proposed solutions. Brainstorming provides quick responses, full involvement of team members and input to other improvement tools.

- *Project Charter:* A project charter is a report of the whole project work plan signified in a table form. This table provides clear information about project objectives, descriptions, scope, profits, deficits, uses of tools and techniques, project schedule and end product. It also delivers the details of experts, suppliers, stakeholders, coordinators, customers, project deadlines, roles and responsibilities of team members, project starting and end date. Overall, a project charter is having all information about the project from initial to end. This can be used as a benchmark for addressing the future of the project.

- *SIPOC Chart:* SIPOC chart explores the information of the whole manufacturing process of a product from initial to end and is summarized in the form of a supplier, input, process, output, and customer. This chart is suitable for providing a detailed visualization of the product from raw material to finished product.

- *Value stream mapping:* Process mapping is a crucial step in the LSS project, mainly when the DMAIC roadmap is being used. There are numerous ways to describe the current process like a flow chart, rational process mapping, value stream mapping, specific approach that suit the process, etc. But Value Stream Mapping (VSM) lies at topmost priority for current process mapping. Through VSM, it is easy to analyze the flow of material and information currently exists and identifies opportunities for improvement during the process.

- *Process capability chart:* Process capability is the ratio of process tolerance (voice of customer) to process variation (voice of process) and denoted by C_p. It indicates inherent process ability without considering the effect of process centering and estimated by Equation 3.1. The processing capability with process centering is defined by C_{pk}, which is the minimum of C_{PU} and C_{PL} as shown in Equation 3.2. Here USL is upper specification limit and LSL is lower specification limit. μ indicates the estimated means; σ presents the standard deviation and $\bar{\bar{x}}$ is a grand mean of the process. Using this empirical data, process capability charts are needed to be constructed which shows deviation in the process if any.

$$C_p = \frac{USL - LSL}{6\sigma} \tag{3.1}$$

$$\begin{cases} C_{PU} = \frac{USL - \bar{\bar{x}}}{6\sigma} \\ C_{PL} = \frac{\bar{\bar{x}} - LSL}{3\sigma} \\ C_{pk} = \text{Minimum of } C_{PU} \;\; and \;\; C_{PL} \end{cases} \tag{3.2}$$

- *Activity Categorization:* Activity categorization is the process of identifying the value-adding and non-value adding activities exist in the manufacturing process. Through this categorization, the speed of the process can be increased and delay time can be reduced just by eliminating the non-value adding activities from the process.

- *Cause and effect diagram:* The purpose of this diagram is to perceive the number of flaws occurring in the product and define the actual source of flaws from which they transpired. This diagram shows the impact of man, material, method, equipment, environment, and measurement on problem statements in the manufacturing sector. The cause and effect diagram also is known as a fishbone diagram because of its final looks like a fish skeleton. This diagram is analyzed by information arranged at each attribute and creates action items.

- *Pareto analysis:* Pareto analysis is based on the 80/20 principle, which means 80 percent of problems come due to 20 percent of causes. This analysis is used to rank the problem in a graphical manner from the most frequent down to the least frequent. Based on this analysis, the Pareto chart is constructed which is the combination of bar and line. The individual values are represented by a bar and cumulative value is presented by line. The most serious problem can be identified easily with the help of the Pareto chart. For constructing a Pareto chart, a minimum of 6 to 8 months of past data is required.

- *FMEA:* Failure Mode Effect Analysis (FMEA) is a systematic approach to investigate the potential failure that may exist within the design or process of a product. Failure mode signifies the way in which products can fail. Further, effect indicates the manner in which these failure leads to waste, defect or destructive for the customers. Overall, failure mode and effect analysis are intended to recognize, rank and bound these failure modes. In FMEA form, there are essentials to Likert scaling (1-10) of severity, occurrence, and detection. The severity is scaled as 1 for not severe and 10 for very severe, occurrence scaled as 1 for not likely and 10 for very likely, detection scaled as 1 for easy to detect and 10 for not easy to detect. Furthermore, the Risk Priority Number (RPN) is estimated using Equation 3.3 and prioritize the actions taken to reduce the risk from high to low RPN.

$$RPN = severity \times occurrence \times detection \tag{3.3}$$

- *6S:* It is a Japanese improvement technique of building a self-sufficient culture which maintains a clean and well-organized workstation and removes all excesses from the workplace. The arrangement of essential items in such a way that they can easy to find, use, and maintain. It stands for Sort, Streamline, Shine, Standardize, Sustain, and Sustainability. Sort means assess the workstation and eliminating items which are not in used in the process and make sure only essentials should present. Streamline includes thoughts of customers related to design modifications result in quality improvement. It also make simpler path for tools, materials and work flow. Shine aims to maintain the workstation clean and sanitized items all time. The items should be stored at their original place at the end of the working shift. Standardize means the work practices operating in a steady and standardized manner to accomplish the targets. Sustain means maintaining the established process and resources for longer time. Sustainability means making the process and working station eco-friendly and environment safely.

- *Kaizen:* Kaizen is process focused on a continuous improvement strategy involving each person in the organization from top management to workers. It is a Japanese philosophy based on concept of huge improvement comes from a lot of small changes build up over time. It is using small changes in existing plant layout, scientific method using statistical tools, adaptive framework of organizational ideals and thinking of management and workers targeted on zero defects. It is based on the thought of never being satisfied with achieved results of improvement and accesses the obtained results which provide opportunities for further change.

- *Future value stream mapping:* The future value stream mapping is the process based on convinced improvements that are identified in the current state mapping. The purpose of future VSM is to illustrate certain improvements after the execution of the LSS framework in the plant. The future value stream mapping is drawn for total improvement and benefit for convincing the top management to implement the LSS framework in the plant.

- *Control chart:* A control chart is a statistical process control tool, used for showing either the process is under control or out of control. It is constructed using the Upper Control Limit (UCL) and Lower Control Limit (LCL) with a mean value of process parameter. It indicates how much variation is occurred in the manufacturing process from the mean, results defect followed. If the control chart reveals the process is under control, then there are no needs for the action plan. In the case of out of control process, assured parameters are needed to be changed for reducing the process variation from the mean value.

3.5 Multi-Criteria Decision Making Methods

Multi Criteria Decision Making (MCDM) is an approach to resolve the problems which comprise solution from a set number of criteria. This approach provides the way to counter the information to attain at a desirable solution. These methods require pair wise comparison among each selection criteria and contain suitable negotiations. The prime elements required to make fruitful decision based on MCDM approach are selection criteria, weight of each criteria, available alternatives, performance measures against criteria. MCDM approach provided highly efficient results in case of complex decision making task in the industrial field. This approach has competency to decide the best possible option from to the existing resources within the plant. MCDM approach is further classified in to two categories as multi attribute decision making and multi objective decision making method. Multi attribute decision making method is efficient for selections of best possible alternative whereas multi objectives decision making provides reliable solution of best objective from the available objectives. In present study, numerous MCDM approaches like Entropy method, AHP, BWM, modified TOPSIS, VIKOR, and DEMATEL have been adopted to carry out the case study. These approaches have been implemented under Fuzzy logic environment.

1. *Entropy Method:* Entropy is a measure of ambiguity in data drawn up by the

theory of probability. It originally derived from Rudolph Clausius's thermodynamics and was used as an irreversible process phenomenon firstly and now it has been used extensively in the economy, engineering, industrial, finance, and many more applications [230]. The entropy is a system which can measure disorder and useful information from the provided data [231]. In entropy theory, the weight determination is based on the divergence and entropy value of evaluating criteria [232]. If the divergence value is high and entropy value is low, then entropy weight would be high and vice-versa [233]. Entropy weight is a parameter that describes how much the alternatives are distanced from one another [234].

2. *AHP:* It is a powerful multi-criteria decision making approach invented by Saaty in 1980 and improved by Vargas in 2001 for providing solutions for complex decision-making applications. This approach deals with the measurement of intangible criteria and to interpret in the measurement of tangibles [235]. AHP approach helps in dividing the complex problem into several sub-problems with the help of a hierarchy structure where every level is having a set of criteria and sub-criteria [236].

3. *BWM:* It is an MCDM approach developed by Rezaei to prioritize and select the best and the worst alternative among a set of alternatives [237]. This method can be used by one decision-maker or a group of decision-makers [238]. It becomes popular due to its salient features, such as it requires fewer comparisons matrix data, having a more consistent relationship among alternatives and requires only integers number (e.g., 1, 2, 4, 5, etc.) to make comparison matrix scale [239]. In this technique, the number of pairwise comparisons is lesser as compared to other MCDM approach, i.e., AHP, ANP, etc. [240]. Consider n criteria and

make a pairwise comparison matrix A, as shown in Equation 3.4.

$$A = \begin{bmatrix} a_{11} & a_{12} & .... & a_{1n} \\ a_{21} & a_{22} & .... & a_{2n} \\ .... & .... & .... & .... \\ a_{n1} & a_{n2}, ... & a_{nn} & \end{bmatrix} \tag{3.4}$$

Here a_{11} to a_{nn} consider as a_{ij} which presents the relative importance of criteria i to criteria j. $a_{ij} = 1$ reveals that criteria i and j are of the same importance. $a_{ij} \geq 1$ shows i is more significant than j and $a_{ij} = 9$ presents more important i to j. It is possible to make a comparison among i to j into two categories, i.e., reference comparison and secondary comparison [239]. The definition of said comparisons is the following:

Definition 1: The comparison among a_{ij} is said to be a reference comparison if i is the best criteria and/or j is the worst criteria and vice-versa.

Definition 2: The comparison among a_{ij} is said to be secondary comparison if i or j is the best or the worst criteria and $a_{ij} \geq 1$.

In Equation 3.4, for n criteria, all conceivable comparisons are n^2. Among these, n comparisons are $a_{ii} = 1$ and in rest n(n-1), half of which $a_{ij} > 1$ and another half is reciprocal of the first half. From $n(n-1)/2$ comparisons, $(2n-3)$ are reference comparisons, and rest are secondary comparisons [240].

4. *Fuzzy Logic:* The decision making becomes quite difficult in uncertain or fuzzy ambiance. To reduce the vagueness in the human perceptions the favorites are represented as fuzzy numbers rather than binary or classical logic [241]. The fuzzy logic is used in the ambiguity environment to account for the uncertainty. To evaluate the direct influences of one variable on another there is the need of the experts or decision maker's opinion. In the simplest manners they are represented as the crisp value, but the crisp numbers cannot handle the uncertainty and vagueness accompanied by the expert's judgments because these assessments are based on human judgments and these are highly subjective. To

overcome this drawback, fuzzy numbers that mitigate these limitations and provide more reliable evaluations are used. Fuzzy logic represents ambiguous and indefinite favorite information from chosen, not chosen and unstated points of view.

5. *Modified TOPSIS:* Modified TOPSIS is a well-known approach among such MCDM methods, invented by Deng et al., 2000 for resolving the complex decision-making problems [242]. It is the advance version of TOPSIS approach. It uses different weighting schemes and distance metrics to compare results of different sets of weights applied to set of multiple criteria data. This method is based on principle of shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The ideal solution is a solution that maximizes the cost criteria and minimizes the benefit criteria. The cost criteria are being treated for maximization and the benefit criteria treated for minimization. In modified TOPSIS method, the normalized decision matrix formed by the multiplying the each column with relative weight of criteria. In this method, Euclidean distance has been computed for instead of formulation of weighted decision matrix.

6. *VIKOR:* In 1998, Opricovic was developed VIKOR method for multi-criteria optimization of intricate structures [243]. VIKOR prioritizes alternatives and examine the feasible solution, which is the nearest to the ideal solution. This method focuses on ranking of alternatives and determines compromise solutions for a problem with conflicting criteria, which can help the decision makers to reach a final decision. The compromise solutions could be involving the agreement and preferences of decision maker regarding criteria. This method uses linear normalization to diminish the units of criterion function and offers robust ranking of alternatives.

7. *DEMATEL:* Decision-making trial and evaluation laboratory method (DEMATEL), a mathematical procedure was developed from the Geneva Research Centre of the Battelle Memorial Institute designed to study and solve the intricate

problem group [244]. The DEMATEL method provides a structural model of the cause and effect relationship among the factors. In this method, factors are constructed in two categories: cause and effect; these categories are designed by using influence values that occur between factors. The categorization provides a better understanding of parts of the system and subsequently provides solutions to preclude issues of convoluted systems [245].

8. *GRA:* Grey Relational Analysis (GRA) is an incidence model that was proposed by Deng (1982) to use by the decision-makers in real-life applications. It has proved to be quite efficient in situations where the information is incorrect and uncertain. It has applied in various real-life situations like analyzing the sustainable supply chain barriers [246]; green supplier selection [247]; cotton fabric selection [248], etc. GRA has a distinct advantage over other decision-making approaches (AHP) like dynamic nature that gives opportunities for the change in the number of parameters; transformation in computer algorithm for the quick solution and its emphasis on objective factors rather than dependency or trust.

CHAPTER 4

Lean Six Sigma Enablers in MSMEs

4.1 Introduction

Micro-Small and Medium Enterprises (MSMEs) is having prime contribution in the development of industrial sector and the economy of any country [52]. In the Indian industrial scenario, MSMEs contribute about 45% of total manufacturing output and 40% of total exports [250]. Additionally, the contribution of MSMEs in Indian GDP accounted for 16% and provided more than 80 M employment opportunities [251]. This indicates that the MSMEs sector is much important for Indian economic development. Despite its huge role in economic growth, it faces dynamic challenges relevant to environmental, competitiveness, and continuous improvement [252]. The competitiveness of MSMEs are trapped due to limited financial and managing capabilities, resource constraints, poor monitoring obligations, and quality [253]. These issues are more pertinent for developing countries like India, which is at a lower position in the global competitive index (40 ranks amongst 137 participating nations)

[254].

Several researchers had focused on Indian MSMEs improvement by providing innovative solutions like reducing delivery time, manufacturing cycle time, operational and technological factors, vendor rationalization, etc. [255] [256] [257]. Such studies provided some good insights into the growth and development of specific areas in MSMEs. But these studies are limited to solve individual issues and unable to provide solutions for continuous improvement and environmental issues under one roof comprehensively. Thus, there is an immense need for such an approach that works for sustainable development and continuous improvement without compromising environmental stewardship. LSS, with the synergy of the environmental aspect, diminishes the negative environmental impact in manufacturing and services, results in cleaner production, and a healthy environment [258]. Despite the evolution of LSS, MSMEs managers are still hesitant to adopt this strategy in their core business due to lack of readiness measures and fear of failure [259]. MSMEs managers have limited resources in their hands, so they are much hesitant to adopt new technologies without working on their enablers [260]. Enablers or readiness measures can drive the system smoothly and efficiently [261] [262]. There is an immense need to adopt the enablers according to their impact and driving characteristics for the successful adoption of LSS in MSMEs. Hence, this chapter focuses on investigation of LSS enablers with consideration of environmental aspects and prioritization using BWM approach.

4.2 Lean Six Sigma Enablers

The main objective of the study is to investigate the prime enablers from available list of 26 enablers to facilitating the management in successful execution of LSS projects. The investigation, analysis, and validation of enablers are expressed in this section.

4.2.1 Research Design: LSS enablers

The research design adopted in this chapter is organized and accessible in Figure 4.1. Initially, the research papers are collected from the reputed databases such as Elsevier, Springer, Science Direct, Taylor & Francis, Emerald, Sage, etc. Through the detailed literature review and visiting MSMEs, a list of enablers is framed, which influences the LSS implementation in MSMEs. For the categorization of listed LSS enablers, expert's opinions and Exploratory Factor Analysis (EFA) are adopted. The classified enablers are further analyzed through statistical tools like Importance-index analysis and Corrected Item Minus Total Correlation (CIMTC) method. The consistency of finalized enablers is computed through Cronbach's alpha using the Statistical Package for Social Sciences (SPSS) software. The validated LSS enablers are prioritized using the Best Worst Method (BWM) approach with the help of a practical case. To get accuracy in results, comparisons are made with Analytical Hierarchy Approach (AHP) and Analytical Network Process (ANP). The discussion is explored with practical and managerial implications along with concluded remarks.

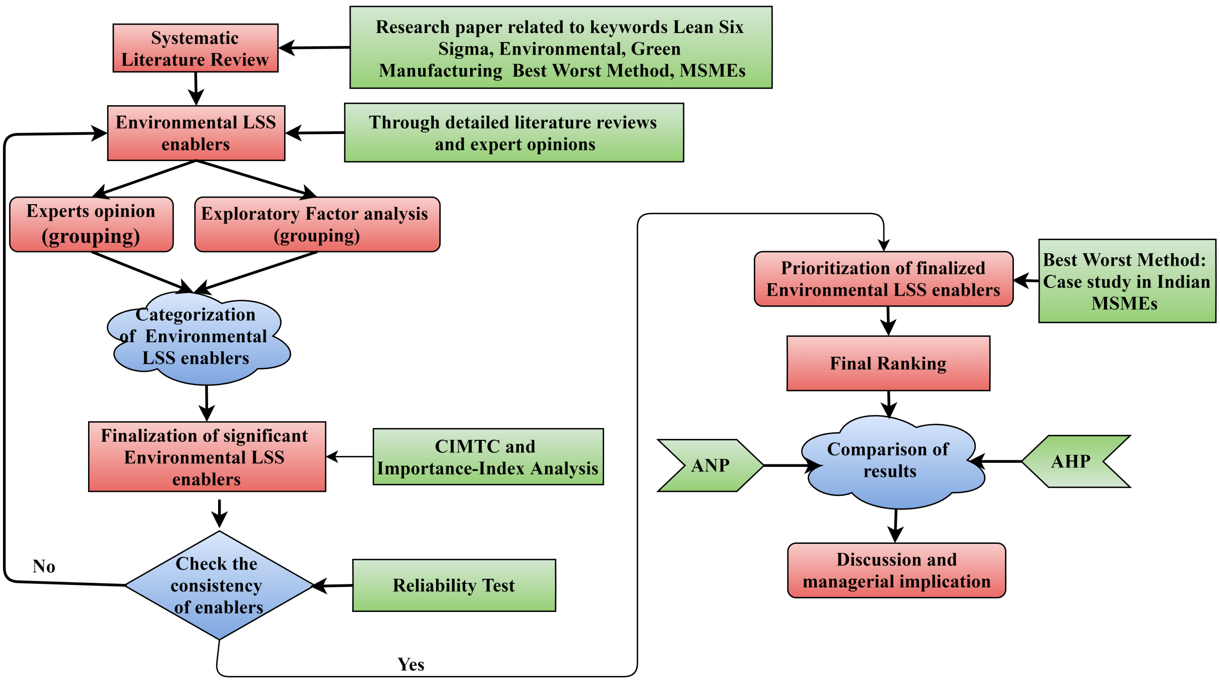

FIGURE 4.1: *Research design of study.*

4.2.2 Extraction of LSS Enablers

Thirty LSS enablers are extracted through the detailed literature review and industrial visit. Each enabler is having individual characteristics and implementation areas in the organization for successful LSS execution. Hence, the enablers are categorized as per their appropriate traits through fundamentally as well as statistically. For fundamental categorization, the experts are selected from an industrial and academic background. The detailed description of experts is provided in Table 4.1. Through the expert's inputs, the extracted enablers are grouped into five categories as environmental-based enablers (ELSSE), strategic-based enablers (SLSSE), culture-based enablers (CLSSE), resources based enablers (RLSSE) and linkage based enablers (LLSSE) as shown in Table 4.2.

Table 4.1: *Detailed information of experts.*

Experts	**Academic/ Industry**	**Current Position**	**Professional Experience**
Expert 1	Industry	Director of the Manufacturing Company	20 Years
Expert 2	Industry	General Manager	17 Years
Expert 3	Industry	Plant Head	10 Years
Expert 4	Industry	Production Manager	12 Years
Expert 5	Industry	Industrial Engineer	10 Years
Expert 6	Academic	Professor and Six Sigma Black Belt	33 Years
Expert 7	Academic	Associate Professor	19 Years
Expert 8	Academic	Assistant Professor and LSS researcher	8 years
Expert 9	Academic	Research Scholar	4 Years

The enablers are categorized statistically through Exploratory Factor Analysis (EFA). Factor analysis is a data reduction technique which reduces the large number of variables into significant number of factors for modeling purpose [263]. It is used to determine the minimum number of factors that represent the covariation among all elements. The factors with a variance greater than 1 are extracted for the analysis ($Eigenvalue > 1$). The loading of 30 enablers in suitable factors is achieved using EFA with a sample size of 300 (n=300). In this analysis, the Kaiser-Meyer-Olkin (KMO), and the Bartlett test of sphericity are estimated using Principal Component Analysis (PCA) with Varimax rotation [264]. The Varimax rotation reduces the number of variables to strengthen the interpretability during loading on orthogonal factors [265]. The factor extraction is based on Eigenvalue; it might be more than 1 and the minimum three items should be loaded in individual factor with a factor loading value higher than 0.40 [266]. The Cattell scree plot represents the LSS enablers on X-axis and corresponding Eigenvalue on Y-axis (refer Figure 4.2). The eigenvalue of LSS enablers is reduced as elbow curvature moves toward the right in the scree plot. The enablers having Eigenvalue more than 1, are selected for further analysis. The outcome of the scree plot reveals that 22 enablers are selected for measuring the performance of LSS.

Further, extracted enablers are loaded into five factors, which authenticate the expert's inputs as well as the reason for the categorization of enablers into five factors. In Table 4.3, the numeric numbers 1, 2, 3, 4, and 5 represent the main categorized enablers as ELSSE, SLSSE, CLSSE, RLSSE, and LLSSE, respectively.

TABLE 4.2: *Grouping of LSS enablers.*

Main Criteria	**Sub-criteria**	**Abbreviation**	**Author Support**
Environmental based enablers (ELSSE)	Carbon reduction initiatives	E1	[267] [268] [269] [270] [271] [272]
	Environmental friendly packing of products	E2	
	Incentives for producing green products	E3	
	Practices of Green design	E4	

	Environmental friendly transportation	E5	
	Green operational practices	E6	
	Market demands for green products	E7	
Strategic based enablers (SLSSE)	Effective project leadership	S1	[69] [273][242]
	Rewards and incentives for employee	S2	
	Top-management commitment, Involvement and support	S3	
	Environmental LSS supportive organizational Infrastructure	S4	
	Performance measurement system	S5	
	Consistent and accurate data collection	S6	
Culture based enablers (CLSSE)	Selection and retention of employee	C1	[274][71][57]
	Team work	C2	
	Effective communication among departments	C3	
	Sufficient time to solve problems	C4	
	Employee empowerment	C5	
	Share project success stories	C6	
	Organizational culture and ethics	C7	

Resources based enablers (RLSSE)	Understanding of Environmental LSS methodology	R1	[253] [275] [276] [277]
	Project selection and prioritization	R2	
	LSS awareness program and training	R3	
	Financial benefits sharing among employees due to Environmental LSS	R4	
	Fund for operational expenditure	R5	
Linkage based enablers (LLSSE)	Supplier relationship management	L1	[278] [265][279][197]
	Customer satisfaction and delight	L2	
	Understanding the customer demand	L3	
	Linking Environmental LSS to buyer-suppliers	L4	
	Linking Environmental LSS to core business processes	L5	

4.2.3 Analysis of Extracted Enablers

To get significant LSS enablers from the extracted ones, CIMTC and Importance-index analysis are employed. CIMTC is the Pearson correlation coefficient between individual items and the total score excluding that item [280]. The items having a correlation value less than 0.3, are eliminated before further analysis. Table 4.4

Table 4.3: *Grouping of LSS enablers using EFA .*

Rotated Component Matrix[a]					
	Component				
	1	2	3	4	5
E1	.971				
E2	.934				
E3	.904				
E4	.911				
E5	.857				
E6	.645				
E7	.542				
S1		.987			
S2		.857			
S3		.942			
S4		.947			
S5		.579			
S6		.651			
C1			.977		
C2			.840		
C3			.887		
C4			.909		
C5			.663		
C6			.504		
C7			.589		
R1				.966	
R2				.905	
R3				.824	
R4				.915	
R5				.635	
L1					.941
L2					.876
L3					.913
L4					.877
L5					.943

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization[a]
[a]Rotation converged in 5 iterations.

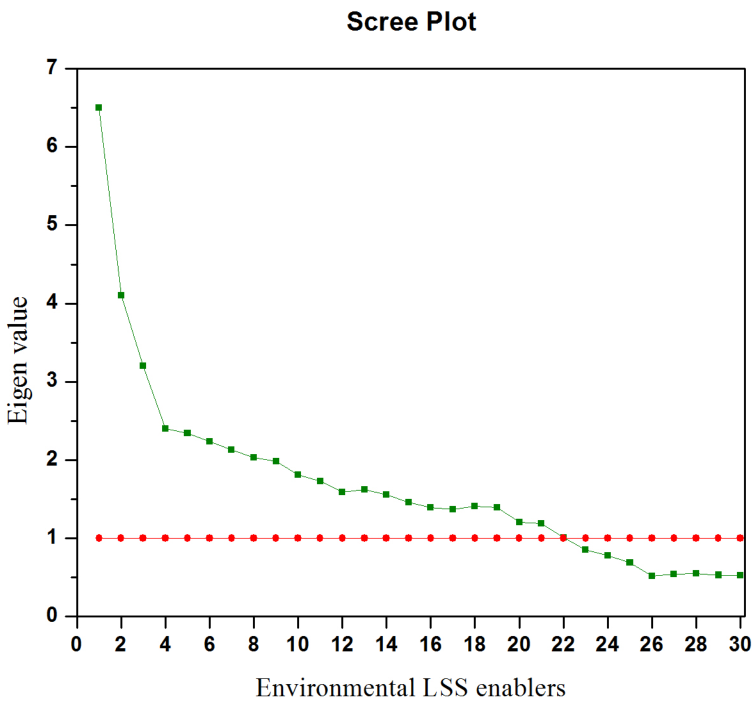

FIGURE 4.2: *Scree plot of LSS enablers.*

demonstrates the detailed statistics and CIMTC analysis for LSS enablers. The statistical analysis reveals that CIMTC values of eight LSS enablers (i.e., enabler code E6, E7, S5, S6, C5, C6, C7, and R5) are lower than 0.3 (cut off value); hence these enablers are not considered for further study. The remaining twenty-two LSS enablers contain CIMTC value in the range of 0.5421 to 0.8920, which ensures that selected enablers are important. Also, the finalized enablers achieve a mean value above 3.8545 and a maximum standard deviation of 1.0987, which indicates the importance of LSS enablers in MSMEs. Further, Importance-index analysis is employed to strengthen the expert's opinion gathered through the questionnaire survey. The numerical scores are consequently altered into the relative Importance-index by using Equation 4.1.

$$Importance - index\ (I_x) = \frac{\sum_{(i=1)}^{5} p_i x_i}{5 \sum_{(i=1)}^{5} x_i} \tag{4.1}$$

Here p_i= constant presenting weight given to i.

x_i = variable presenting frequency of response for i and $i = 1, 2, 3, 4, 5$.

The importance index range is lies from zero to 1. The importance index has been classified into five clusters to indicate the respondent's rating, as shown in Equation 4.2.

$$\begin{cases} Very\ \ Important\ : 0.8 < I_x \leq 1.0 \\ Important\ : 0.6 < I_x \leq 0.8 \\ Preferred : 0.4 < I_x \leq 0.6 \\ LessImportant : 0.2 < I_x \leq 0.4 \\ Not\ Important : 0 < I_x \leq 0.2) \end{cases} \tag{4.2}$$

The importance index analysis of LSS enablers have been computed using Equation 4.1, and its outcome is shown in Table 4.4.

TABLE 4.4: *Importance Index analysis, enablers statistics, and CIMTC .*

Sr. No.	**Enablers Code**	**LSS Enablers**	**Mean**	**Standard Deviation**	**Importance Index**	**CIMTC**
Environmental based enablers (ELSSE)						
1	E1	Carbon reduction initiatives	4.3745	0.9841	0.897	0.8102
2	E2	Environmental friendly packing of products	3.9074	0.7243	0.795	0.6650
3	E3	Incentives for producing green products	4.2753	1.0120	0.805	0.7952
4	E4	Practices of Green design	3.8566	0.8915	0.687	0.7458
5	E5	Environmental friendly transportation	4.9053	1.0072	0.907	0.8920

6	E6	Green operational practices	2.9121	0.5472	0.194	0.2738
7	E7	Market demands for green products	2.8124	0.4739	0.173	0.2943
Strategic based enablers (SLSSE)						
1	S1	Effective project leadership	4.1013	0.9725	0.745	0.6542
2	S2	Rewards and incentives for employee	4.2123	0.9365	0.798	0.7102
3	S3	Top-management commitment, Involvement and support	4.0341	0.8754	0.699	0.7584
4	S4	Environmental LSS supportive organizational Infrastructure	4.8923	0.9214	0.892	0.7258
5	S5	Performance measurement system	3.0017	0.4578	0.172	0.2981
6	S6	Consistent and accurate data collection	2.7842	0.5782	0.189	0.2784
Culture based enablers (CLSSE)						

1	C1	Selection and retention of employee	4.2745	0.9012	0.798	0.7254
2	C2	Team work	3.8545	1.0214	0.657	0.5421
3	C3	Effective communication among departments	4.1589	0.9325	0.697	0.5821
4	C4	Sufficient time to solve problems	4.3510	1.0891	0.759	0.6248
5	C5	Employee empowerment	3.0121	0.8742	0.124	0.1981
6	C6	Share project success stories	2.8794	0.4748	0.184	0.2244
7	C7	Organizational culture and ethics	2.9578	0.3842	0.147	0.2421
Resources based enablers (RLSSE)						
1	R1	Understanding of Environmental LSS methodology	4.4755	1.0741	0.785	0.6987
2	R2	Project selection and prioritization	4.2529	0.9421	0.824	0.7559

3	R3	Environmental LSS awareness program and training	4.6725	0.9129	0.764	0.8721
4	R4	Financial benefits sharing among employees due to Environmental LSS	4.1572	0.9458	0.812	0.8102
5	R5	Fund for operational expenditure	2.9872	0.4274	0.098	0.2824
Linkage based enablers (LLSSE)						
1	L1	Supplier relationship management	4.0542	0.9348	0.685	0.7452
2	L2	Customer satisfaction and delight	4.0892	1.0254	0.773	0.6298
3	L3	Understanding the customer demand	4.2101	0.9548	0.649	0.7648
4	L4	Linking Environmental LSS to buyer-suppliers	4.1924	1.0987	0.625	0.7235

5	L5	Linking Environmental LSS to core business processes	4.0122	0.9654	0.694	0.6928

These outcomes are compared with cut off values as mentions in Equation 4.2 and finally concluded that out of thirty, twenty-two LSS enablers are found significant and selected for further study (refer to Table 4.5).

TABLE 4.5: *Finalized LSS enablers in Indian MSMEs .*

Main Criteria	**Sub-criteria**	**Abbreviation**
Environmental based enablers (ELSSE)	Carbon reduction initiatives	E1
	Environmental friendly packing of products	E2
	Incentives for producing green products	E3
	Practices of Green design	E4
	Environmental friendly transportation	E5
Strategy based enablers (SLSSE)	Effective project leadership	S1
	Rewards and incentives for employee	S2
	Top-management commitment, Involvement and support	S3
	Environmental LSS supportive organizational Infrastructure	S4
Culture based enablers (CLSSE)	Selection and retention of employee	C1

	Team work	C2
	Effective communication among departments	C3
	Sufficient time to solve problems	C4
Resources based enablers (RLSSE)	Understanding of Environmental LSS methodology	R1
	Project selection and prioritization	R2
	Environmental LSS awareness program and training	R3
	Financial benefits sharing among employees due to Environmental LSS	R4
Linkage based enablers (LSSLE)	Supplier relationship management	L1
	Customer satisfaction and delight	L2
	Understanding the customer demand	L3
	Linking Environmental LSS to buyer-suppliers	L4
	Linking Environmental LSS to core business processes	L5

4.2.4 Reliability Assessment of Finalized Enablers

It becomes necessary to validate the sorted data before its further use; otherwise, results may be false [281]. The reliability test is conducted to check the authentication

TABLE 4.6: *Reliability test result*

Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**No. of Items**
0.890	0.903	22

of finalized enablers in SPSS software. In this test, Alpha is a significant parameter used for the assessment of considerable state in statistical and medical sciences [282]. It was developed by Lee Cronbach in 1951 which exhibits the internal consistency among items, and its value lies between 0 to 1 [283]. For better internal consistency, homogeneity, and length of the test, the value of alpha was recommended from 0.70 to 0.90 [284]. In the present case, the value of Cronbach's Alpha is computed as 0.890, which represents good internal consistency among finalized enablers (refer to Table 4.6).

4.3 Best Worst Method

BWM is an MCDM approach developed by Rezaei to prioritize and select the best and the worst alternative among a set of alternatives [238]. This method can be used by one decision-maker or a group of decision-makers [239]. It becomes popular due to its salient features, such as it requires fewer comparisons matrix data, having a more consistent relationship among alternatives and requires only integers number (e.g., 1, 2, 4, 5, etc.) to make comparison matrix scale [240]. Consider n criteria and make a pairwise comparison matrix A, as shown in Equation 4.3.

$$A = \begin{bmatrix} a_{11} & a_{12} & .... & a_{1n} \\ a_{21} & a_{22} & .... & a_{2n} \\ .... & .... & .... & .... \\ a_{n1} & a_{n2} & .... & a_{nn} \end{bmatrix} \tag{4.3}$$

Here a_{11} to a_{nn} consider as a_{ij} which presents the relative importance of criteria i to criteria j. $a_{ij} = 1$ reveals that criteria i and j are of the same importance. $a_{ij} > 1$

shows i is more significant than j and $a_{ij} = 9$ exhibits the extreme importance of i to j. It is possible to make a comparison among i to j into two categories, i.e., reference comparison and secondary comparison [240]. The definition of said comparisons is explained as follows:

Definition 1: The comparison among a_{ij} is said to be a reference comparison if i is the best criteria and/or j is the worst criteria and vice-versa.

Definition 2: The comparison among a_{ij} is said to be secondary comparison if i or j is the best or the worst criteria and $a_{ij} > 1$.

In Equation 4.3, for n criteria, all conceivable comparisons are n^2. It concludes that n comparisons are $a_{ii} = 1$. The rest is $n(n-1)$, for half of which $a_{ij} \geq 1$, while another half is reciprocal of the first half. From the first $n(n-1)/2$ comparisons, $(2n-3)$ are reference comparisons, and rest are secondary comparisons.

4.4 Application of BWM with Practical Case

The present study is conducted in the Indian MSMEs engaged in the manufacturing of medical equipment. The prime intention of current research is to facilitate the LSS implementation at the selected site through the analysis of vital enablers. BWM approach is adopted for the prioritization of the selected enablers by solving the practical case study. BWM steps used in the present practical case are as follows [240].

Step 1: Determine a set of decision enablers

A set of five main criteria and twenty-two sub-criteria of LSS enablers are finalized statistically and fundamentally by expert's input of the selected industry (refer Table 4.5).

Step 2: Determine the best and worst enabler

In this step, a brainstorming session is conducted among selected experts from industry and academia background (refer to Table 4.2). They have selected the most important enabler and the least important enabler among finalized twenty-two enablers.

TABLE 4.7: *Best-to-others (BO) and others-to-worst (OW) pairwise comparison of main criteria.*

BO	**ELSSE**	**SLSSE**	**CLSSE**	**RLSSE**	**LLSSE**
Best criteria: SLSSE	2	1	4	3	8
OW				**Worst criteria: LLSSE**	
ELSSE				4	
SLSSE				8	
CLSSE				2	
RLSSE				3	
LLSSE				1	

Step 3: Determine the preference of best enabler over all other enablers using a scale of 1 to 9.

The experts provide the preference of best enabler over all other enablers and the best-to-other vector is shown in Equation 4.4.

$$A_B = (a_{B1}, a_{B2}, a_{B3}, ..., a_{Bj}) \tag{4.4}$$

Here a_{Bj} represents the preference of best enabler B over the j enabler. In this case, the comparison matrix of main criteria enablers is shown in Table 4.7 that represents the preference of best enabler (SLSSE) over all other main enablers.

Step 4: Determine the preference of all other enablers over the worst enablers using a scale of 1 to 9.

The top management and plant head suggested the preference of all enablers over the worst enabler and written in the form of vector, as shown in Equation 4.5

$$A_w = (a_{1w}, a_{2w}, a_{3w}, ..., a_{nw})^T \tag{4.5}$$

Here,a_{jw} indicates the preference of enabler j over the worst enabler W. It is clear that the value for $a_{ww} = 1$. The vector presents the preference of all enablers over the worst enabler (E4) is shown in 4.8. The pairwise comparisons of all sub-criteria of main criteria are formulated by considering the inter-dependency of LSS enablers.

TABLE 4.8: *Best-to-others (BO) and others-to-worst (OW) pairwise comparison for environmental based enablers.*

BO	E1	E2	E3	E4	E5
Best criteria: E2	2	1	5	9	3
OW					Worst criteria: E4
E1					3
E2					9
E3					2
E4					1
E5					7

TABLE 4.9: *Best-to-others (BO) and others-to-worst (OW) pairwise comparison for strategy based enablers.*

BO	S1	S2	S3	S4
Best criteria: S4	5	3	2	1
OW				Worst criteria: S1
S1				1
S2				2
S3				3
S4				5

TABLE 4.10: *Best-to-others (BO) and others-to-worst (OW) pairwise comparison for culture-based enablers.*

BO	C1	C2	C3	C4
Best criteria: C2	8	1	3	2
OW				Worst criteria: C1
C1				1
C2				8
C3				2
C4				3

The outcomes of best-to-others and other-to-worst sub-criteria are shown in Tables 4.8 to 4.12. The pairwise comparisons of sub-criteria for environmental based enablers are shown in Table 4.8. The pairwise comparisons of sub-criteria for strategy based enablers are shown in Table 4.9. The pairwise comparisons of sub-criteria for culture-based enablers are shown in Table 4.10. The pairwise comparisons of sub-criteria for resources based enablers are shown in Table 4.11. The pairwise comparisons of sub-criteria for linkage based enablers are shown in Table 4.12.

Step 5: Calculate the optimal weights $(w_1^*, w_2^*, w_3^*, ..., w_n^*)$

TABLE 4.11: *Best-to-others (BO) and others-to-worst (OW) pairwise comparison for resources based enablers.*

BO	R1	R2	R3	R4
Best criteria: R3	2	5	1	7
OW				Worst criteria: C1
R1			5	
R2			2	
R3			7	
R4			1	

TABLE 4.12: *Best-to-others (BO) and others-to-worst (OW) pairwise comparison for linkage based enablers.*

BO	L1	L2	L3	L4	L5
Best criteria: L2	2	1	4	2	8
OW				Worst criteria: L5	
L1				4	
L2				8	
L3				2	
L4				4	
L5				1	

The sum of optimal weights of all sub-criteria should be 1 which consists of all set of pair $(\frac{w_B}{w_j})$ and $(\frac{w_j}{w_w})$ equivalent to a_{Bj} and a_{jw}, respectively. To estimate the optimal weights of sub-criteria, the maximum absolute difference of all set of j criteria should be minimized, as shown in Equation 4.6.

$$Maximum\ Absolute\ Difference = |\alpha_j - a_{Bj}|, |\beta_j - a_{jw}| \tag{4.6}$$

where α_j and β_j are computed using Equations 4.7 and 4.8, respectively.

$$\alpha_j = \frac{w_B}{w_j} \tag{4.7}$$

$$\beta_j = \frac{w_j}{w_w} \tag{4.8}$$

Equation 4.6 can be represented in the form of min-max model 1, as shown in Equation 4.9.

$$Model\ 1 \qquad \left\{ \begin{matrix} min\ max(j)\{|\alpha_j - a_{bj}|, |\beta_j - a_{jw}|\} \\ \sum_{(j=0)}^{n} w_j^* = 1) \end{matrix} \right\} \tag{4.9}$$

where n represents the number of alternatives. Model 1 can be transformed into the linear programming model, as shown in Equation 4.10.

$$Model\ 2 \qquad \left\{ \begin{array}{c} for\ min\ \xi \\ |\alpha_j - a_{bj}| \leq \\ |\beta_j - a_{jw}| \leq \xi\xi \\ \sum_{(j=0)}^{n} w_j^* = 1 \\ w_j^* \geq 0 \end{array} \right\} \tag{4.10}$$

By solving model 2, the values of optimal weights are estimated $(w_1^*, w_2^*, w_3^*, ..., w_n^*)$ at the optimal value of $\xi^*(0.10534)$ as shown in Table 4.13. The maximum value of Consistency Index (CI) according to a_{Bw} is considered from Table 4.14. With the help of consistency index and ξ^*value, the Consistency Ratio (CR) is estimated as 0.04580 using Equation 4.11.

$$Consistency\ ratio = \frac{\xi^*}{\text{consistency index}} \tag{4.11}$$

Consistency ratio $\in (0, 1)$, indicates that value close to 0 possesses more consistency and close to 1 possess less consistency. Furthermore, the global weights of all sub-criteria are computed using Equation 4.11 and ranking to sub-criteria is assigned as per their global weights (refer to Table 4.13).

$$Global\ weight = main\ enabler_{w^*} \times sub - enabler_{w^*} \tag{4.12}$$

To prove the effectiveness and consistency of BWM results, comparisons are made with other MCDM approaches i.e. AHP and ANP. The comparison of results among MCDM approaches provides vigorous and realistic outcomes for the professional and industrial personals [285]. The comparison of results is shown in Table 4.15.

Table 4.13: *Final ranking of LSS enablers.*

Main criteria	**Weight of main criteria**	**Sub-criteria**	**Weight of sub-criteria**	**Global weight**	**Rank**
Environmental based enablers (ELSSE)	0.2945	Carbon reduction initiatives (E1)	0.2095	0.0617	6
		Environmental friendly packing of products (E2)	0.1361	0.0400	8
		Initiatives to producing green products (E3)	0.4051	0.1193	3
		Practices of Green design (E4)	0.1430	0.0421	7
		Environmental friendly transportation (E5)	0.1063	0.0313	9
Strategy based enablers (ELSSE)	0.4461	Effective project leadership (S1)	0.1623	0.0724	5
		Rewards and incentives for employee (S2)	0.1846	0.0824	4
		Top-management commitment, Involvement and support (S3)	0.2112	0.1242	2
		Environmental LSS supportive organizational Infrastructure (S4)	0.4419	0.1971	1
Culture based enablers (CLSSE)	0.0983	Selection and retention of employee (C1)	0.2091	0.0205	18
		Team work (C2)	0.3015	0.0296	12
		Effective communicationamong departments (C3)	0.2578	0.0253	15
		Sufficient time to solve problems (C4)	0.2316	0.0227	16
Resources based enablers (RLSSE)	0.1063	Understanding of LSS methodology (R1)	0.2912	0.0309	11
		Project selection and prioritization (R2)	0.2592	0.0275	13
		Environmental LSS awareness program and training (R3)	0.2950	0.0312	10
		Financial benefits sharing among employees due to LSS (R4)	0.1546	0.0264	14
Linkage based enablers (LLSSE)	0.0548	Linking Environmental LSS to core business processes (L1)	0.2945	0.0161	19
		Customer satisfaction and delight (L2)	0.1575	0.0086	20
		Understanding the customer Demand (L3)	0.1025	0.0056	21
		Linking Environmental LSS to buyer-suppliers (L4)	0.4025	0.0220	17
		Supplier relationship management (L5)	0.0430	0.0023	22

TABLE 4.14: *Consistency Index value.*

a_{Bw}	1	2	3	4	5	6	7	8	9
Consistency Index	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

TABLE 4.15: *Comparison of BWM, AHP and, ANP.*

Main Criteria	**BWM weight**	**BWM Rank**	**AHP weight**	**AHP Rank**	**ANP weight**	**ANP Rank**	**BWM CR**	**AHP CI**	**ANP CI**
ELSSE	0.2945	2	0.2858	2	0.2093	2			
SLSSE	0.4461	1	0.4412	1	0.4763	1			
CLSSE	0.0983	4	0.0998	4	0.1349	4	0.0458	0.1093	0.0726
RLSSE	0.1063	3	0.1394	3	0.1514	3			
LLSSE	0.0548	5	0.0338	5	0.0281	5			

4.5 Discussion on Findings

This chapter aims to make LSS adaptable so that it can be readily adopted by Indian MSMEs for sustainable development. Initially, thirty LSS enablers are extracted using an extensive literature review and expert's opinions (refer to Table 4.3). The extracted enablers are further classified into five main groups, such as ELSSE, SLSSE, CLSSE, RLSSE, and LLSSE through EFA (refer to Table 4.4). The classification of enablers is based on their nature and area of implementation. The Eigenvalue and factor loading values should be more than 1 and 0.40 respectively, which ensures the validation of classified enablers.

Further, Importance-index analysis and CIMTC methods are adopted to identify highly significant enablers (refer to Table 4.5). Statistical analysis shows that eight enablers are not having a significant impact on LSS implementation in MSMEs. It happens because of their CIMTC and Importance-Index values lesser than 0.3 and 0.2, respectively. Such enablers are eliminated from the study to improve consistency and reliability in results. Finally, twenty-two enablers are finalized for further prioritization (refer to Table 4.6). The consistency of finalized enablers is validated through the reliability test which ensures bias-free enablers. In the reliability test, Cronbach's Alpha value is 0.890, which represents that LSS enablers are highly consistent (refer to Table 4.7). It is essential to know the ranking of finalized LSS enablers based on their importance and effectiveness so that key impacted enablers can be targeted at the utmost priority. Therefore, the BWM approach is applied to prioritize the finalized enablers with a practical case at the selected site. BWM results are compared with AHP and ANP approaches for checking the robustness, consistency, and validation of results.

The BWM results depict that environmental LSS supportive organizational infrastructure (S4) (enabler belongs to main criteria SLSSE) got 1st rank in prioritization with a global weight 0.1971 (refer to Table 4.14). In developing countries, the economic growth of the organization is primarily based on well-structured and extensive infrastructure [284]. India has 87^{th} rank in terms of infrastructure among 148 participating countries [253], which highlights the importance of essential infrastructure for enhancing competitiveness in Indian MSMEs.

The next emerged enabler is 'top-management commitment, involvement, and support (S3)' which gets 2nd rank with a global weight 0.1242. This enabler expedites the project managers and financial experts to ensure the availability of funds for sustainable development within the organization [262]. Management involvement also plays a significant role in the organization for allocating adequate human, technical, and economic resources to implement a new strategy. Rewards and incentives to employees (S2) enabler boost up the morale of staff towards LSS implementation to produce green products. Also, effective project leadership (S1) motivates the employees to work efficiently for the implementation of LSS in a cooperative manner. The above-mentioned enablers come under the main-criteria SLSSE, which shows a strategic-based connection among enablers.

Initiative to produce green products (E3) (enabler of main criteria ELSSE) got 3rd rank with the global weight 0.1193. The production of green products will solve multiple environmental issues and develop a sustainable workplace [285]. Such initiation motivates the employees to work towards the practice of green product design (E4) by integrating the concept of 3Rs (reduce, reuse, and recycling) of the available resources. Besides, carbon reduction initiatives (E1) also contributes to the transition from the customary process to an eco-friendly process [286]. It is essential to focus on the packaging and transportation of products from manufacturing companies to end-users for carbon reduction initiatives [287]. For this, the organizations need to more emphasize the usages of eco-friendly and bio-degradable materials for packaging the products (E2) [288]. Environmental friendly transport (E5) enabler also addresses the carbon emission issues and achieves economic sustainability. By putting more intention on the enablers as mentioned above, environmental issues of manufacturing units can be addressed.

The enablers 'environmental LSS awareness program and training (R3)' (10th rank) and 'understanding of environmental LSS methodology (R1)' (11th rank) belongs to the main criteria RLSSE. A well-intended training program will help to pact with change and to enhance the skills of the staff about new technology [273]. A good training program provides staff with the necessary expertise, abilities, and strategies to implement LSS comprehensively. The training develops a culture of understanding LSS and motivation to work vigorously towards its adoption for manufacturing sustainability.

'Teamwork (C2)' (Rank 12) and 'Effective communication among departments (C3)' (Rank 15) are found significant enablers under main criteria CLSSE. Effective teamwork provides a strong relationship among employees and buildup confidence to adopt a new approach in a business environment [289]. For an organization, it is essential to have a favorable culture and efficient communication among different departments for the execution of a sustainable program. Personal resources must be adaptive and fully involved with the evolving culture [255].

The main criteria LLSSE consist of the significant enablers i.e. 'Linking environmental LSS to buyer-suppliers (L4)' (Rank 17), and 'Linking environmental LSS to core business processes (L1)' (Rank 19). Linking the environmental LSS approach to business tactics facilitates the organization for achieving sustainable development using 3Rs concept. The profit and competitiveness of industry should be linked with the features of LSS and buyer-suppliers in the supply chain [290]. Such integration benefits the environment and society together with the organization in terms of reduced costs, eco-friendly processes, and increased market share.

Finally, the comparison of BWM results is made with AHP and ANP methods to check the robustness of obtained results. All three MCDM approaches provide a nearby, similar ranking to the main-criteria of LSS enablers (refer to Table 4.15). This shows the robustness of results and depicts that the prioritization of LSS enablers is accurate and consistent. The BWM consistency ratio reveals that it is less than 4% (0.04580) for the prioritization of LSS enablers. Another side, the consistency index in AHP and ANP is found to be 10% (0.10925) and 7% (0.07034) respectively. It signifies that BWM provides more consistent results as compared to AHP and ANP.

4.6 Managerial and Practical Implications

In developed countries (U.S.A, European Union), strict policies and regulations promote the effective implementation of LSS to achieve business excellence [291]. But LSS is still in its infancy stage in developing nations [292][225]. Literature reveals that the majority of Indian companies are not adequately aware of the LSS approach due to deficiency of readiness measures and framework [263] [257]. In this perspective, the present research outcomes encourage to Indian MSMEs managers and practitioners to implement LSS effectively by providing required readiness measures. It will be helpful for MSMEs managers to uplift their organization in the context of operational and environmental improvement. For LSS initiation in any organization, key enablers must be required as per their need and priority.

In the Indian context, MSMEs manufacture the products in terms of low and high margins [118]. Due to the availability of limited resources and resistance to culture change, MSMEs fail to adopt LSS in both cases, i.e., low and high margin products [254]. In this context, the present research provides key LSS enablers for MSMEs to achieve manufacturing sustainability. The consideration of such enablers provides the path for successful initiation of the LSS program comprehensively. Environmental LSS supportive organizational infrastructure (S4) emerges as the most dominating enabler with prioritized rank '1'. As India possesses 87^{th} rank in organizational infrastructure, S4 enabler provides awareness to engineering managers about the importance of infrastructure for being competitive in the global market. The next dominating enabler

is the top-management commitment, involvement and support (S3). The extensive participation and engagement of top management are highly viable for the successful adoption of a new approach [262]. The initiatives to produce green products (E3) emerged as a driver of LSS adoption in MSMEs. The green product manufacturing and carbon reduction initiative provides liberty from air and water pollution and simultaneously saving energy resources [285]. Moreover, environmental LSS awareness programs and training (R3) improves the skills of the employees and management required for the execution of the program. This enabler enhances the morale and confidence of staff, results they would be ready for change. This will also support plant managers for making sound strategies and tactical decisions relevant to controlling adverse effects on the environment during production.
From a societal perspective, the investigation of LSS enablers will assist decision-makers in building a healthy working environment inside the firms as well as in society. The society would be benefited by reducing pollution levels in terms of minimizing carbon footprints through the successful execution of LSS program in the industry. Through LSS implementation, the industries can quickly develop green products at an optimal cost, further supports excellent living standards with a safer environment. The LSS experts and consultants can achieve cleaner production by resolving environmental issues through the adoption of present research insights.

4.7 Conclusion

The present study provides a path for effective implementation of LSS in MSMEs to achieve the goal of various sustainable initiatives like Make in India, NAPCC-2018, NMP-2025, and Paris pact 2030. Industrial managers and practitioners need to understand the features and driving nature of LSS enablers before its application. In this lieu, the present study explored thirty LSS enablers from the extensive literature review and expert's inputs. Twenty-two LSS enablers are finalized and categorized by using CIMTC and EFA respectively. Further, BWM approach is adopted for the prioritization of finalized LSS enablers. The research findings reveal that the most dominating enablers are the following: Environmental LSS supportive organizational infrastructure; top-management commitment and involvement; initiatives to producing green products; rewards and incentives for the employee; effective project leadership; carbon reduction initiatives; environmental LSS awareness program and training respectively. The BWM result exhibits that the main criteria enabler 'SLSSE' emerged as the most dominating in nature followed by 'ELSSE,' 'RLSSE,' 'CLSSE' and 'LLSSE' respectively. At the initial stage of LSS implementation, MSMEs managers pay more attention to strategy and environmental based enablers to get success. Under environmental regulations and customer requirements, present research can expedite practitioners and consultants to identify appropriate enablers for fluent implementation of the program.

The researchers can restructure analogous results for the enablers and variables associated with their problem. The prioritization of enablers will also help managers and practitioners to classify their attention according to enabler's position and importance to achieve sustainable gains. Besides, society would be benefited by reducing pollution levels in terms of minimizing carbon emission through the successful execution of LSS programs in the industry. Finally, BWM results are compared with AHP and ANP approaches for checking the robustness and consistency of results. The outcome shows that the BWM results are in good agreement with AHP and ANP results (refer to Table 4.15).

CHAPTER 5

Lean Six Sigma Barriers in MSMEs

5.1 Introduction

Micro Small and Medium Enterprises (MSMEs) is the main contributor in economic and social growth of any developing country like India. It consist second highest contribution in Indian Gross Development Product (GDP) after automotive and process industries [41]. It also providing 600 million job opportunities and contributing 8% in GDP growth in Indian context [42]. Despite of this huge contribution, MSMEs is struggling with their low productivity, quality issues and resource wastage. Even though big corporations also dependent on MSMEs for completing their production targets and fulfill the market demands [43]. This situation enforces the MSMEs to adopt such approaches which overcome the resource wastage, improve quality and production level. In literature, various approaches have been suggested by the researchers and practitioners and among them, Lean Six Sigma (LSS) is an emerging continuous improvement approach targets to achieve business excellence [44]. This approach is the amalgamation of Lean manufacturing and Six Sigma strategy. The

LSS approach was started to adopt in 2003 and further implemented by big corporations after 2010 onwards. Despite of the evolution of LSS, MSMEs is struggling to adopt this approach in their core business due to poor initiation, weak strategy and planning. Literature also reveals that about 60% projects get failed due to improper initiation of LSS program [45]. Therefore, it is essential to focus on barriers associated with LSS implementation and control them at initial phase of program [46]. In this context, the present chapter is exhibiting the investigation of LSS barriers and prioritization them using Interpretive Structural Modeling (ISM) and MICMAC analysis.

5.2 Extraction of Lean Six Sigma Barriers from Literature

The barriers of LSS implementation in MSMEs have been extracted through systematic literature review which reveals 26 LSS barriers as shown in Table 5.1.

TABLE 5.1: *Identified LSS barriers (LSSBs) .*

S.N.	LSS Barriers	Author's Support
1	Lack of resources	[58]
2	Poor organizations capabilities	[209]
3	Lack of training and education	[66]
4	Unskilled human resources	[293]
5	Insufficient management commitment and involvement	[155]
6	Unclear Vision	[259]
7	Wrong tool selections	[69]
8	Lack of awareness about LSS	[52]
9	Improper project selection	[40]

10	Lack of training funds	[271]
11	Poor achievement of organization's expectation	[52]
12	High implementation cost	[294]
13	Resistance to culture change	[271]
14	Lack of roadmap for LSS implementation	[217]
15	Lack of leadership	[191]
16	Lack of total employee involvement	[185]
17	Lack of strategic thinking	[295]
18	Lack of performance measurement system	[58]
19	Poor communication among departments	[70]
20	Poor alignment between company's goal and customer demand	[58]
21	Poor selection of employee for belts training	[34]
22	Weak suppliers linkage	[295]
23	Wrong perception of LSS as a techniques, tools and practices	[57]
24	Threat of redundancy	[295]
25	Time consuming	[58]
26	Poor estimation of implementation cost	[252]

5.3 Research Approach

The main objective of the study is to identify the prime barriers of LSS implementation in Indian MSMEs. To achieve this aim, a suitable research approach has been adopted as shown in Figure 5.1. This approach consists mainly three phases as literature review, ISM steps, and MICMAC analysis. In first phase, initially 26 LSS barriers (LLSBs) have been identified through systematic literature review and screened them using experts input and reliability analysis. At the end of first phase, 22 LSSBs have been finalized for further analysis. In second phase, a model of finalized LSSBs has been constructed by using ISM approach. In third phase, MICMAC analysis was conducted for grouping the LSSBs into categories.

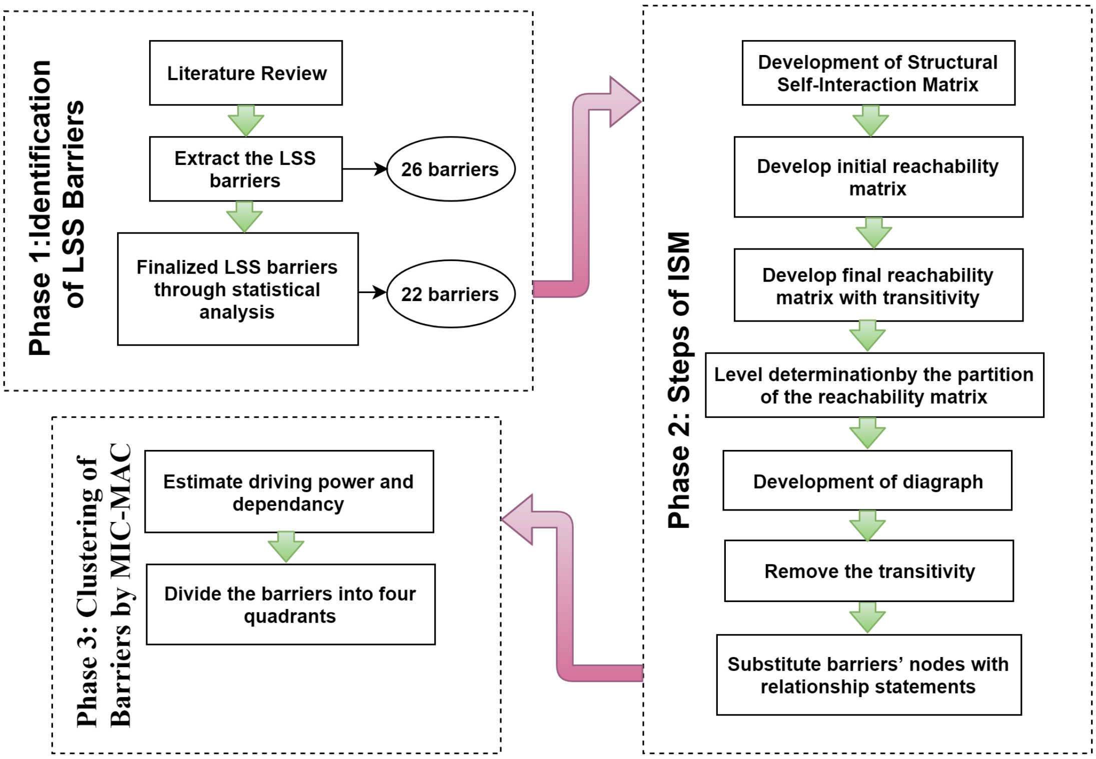

FIGURE 5.1: *Adopted research approach* .

5.3.1 Screening of LSS Barriers

The screening of identified LSSBs is carried out to make a bunch of extremely associated barriers by using statistical tool i.e. Corrected Item Minus Total Correlation (CIMTC). During CIMTC analysis, such items have been discarded for further supplementary analysis whose CIMTC value is less than 0.3. The outcomes of statistical tools have been shown in Table 5.2. The outcome discloses that CIMTC values of LSSBs named as wrong perception of LSS as a techniques, tools and practices, poor estimation of implementation cost, time consuming, and threat of redundancy were having less than 0.3, so essential to be eliminate from the final list. Rest of 22 LSSBs has been considered for further analysis in this study. The screened 22 LSSBs were having supreme standard deviation of 1.0987 and extreme value of mean (more than 3.8545), which specifies that selected LSSBs were highly significant.

TABLE 5.2: *Statistical analysis and CIMTC.*

S.N.	**Code**	**LSS Barriers in MSMEs**	**Mean**	**Standard Deviation**	**Importance Index**	**CIMTC**
1	LSSB1	Lack of resources	4.3745	0.9841	0.897	0.8102
2	LSSB2	Poor organizations capabilities	3.9074	0.7243	0.752	0.6650
3	LSSB3	Lack of training and education	4.2753	1.0120	0.805	0.7952
4	LSSB4	Unskilled human resources	3.8566	0.8915	0.687	0.7458
5	LSSB5	Insufficient management commitment and involvement	4.9053	1.007	0.907	0.8920
6	LSSB6	Unclear vision	4.1013	0.9725	0.745	0.6542
7	LSSB7	Wrong tool selections	4.2123	0.9365	0.798	0.7102
8	LSSB8	Lack of awareness about LSS	4.0341	0.8754	0.699	0.7584
9	LSSB9	Improper project selection	3.8923	0.9214	0.792	0.6258
10	LSSB10	Lack of training funds	4.2745	0.9012	0.798	0.7254

11	LSSB11	Poor achievement of organization's expectation	3.8545	1.0214	0.657	0.5421
12	LSSB12	High implementation cost	4.1589	0.9325	0.697	0.5821
13	LSSB13	Resistance to culture change	4.3510	1.0891	0.759	0.6248
14	LSSB14	Lack of roadmap for LSS implementation	4.4755	1.0741	0.785	0.6987
15	LSSB15	Lack of leadership	4.2529	0.9421	0.824	0.7559
16	LSSB16	Lack of total employee involvement	4.6725	0.9129	0.764	0.8721
17	LSSB17	Lack of strategic thinking	4.1572	0.9458	0.812	0.8102
18	LSSB18	Lack of performance measurement system	4.0542	0.9348	0.685	0.7452
19	LSSB19	Poor communication among departments	4.0892	1.0254	0.773	0.6298
20	LSSB20	Wrong perception of LSS as a techniques, tools and practices	2.9010	0.6577	0.197	0.2541

21	LSSB21	Threat of redundancy	2.1000	0.5748	0.172	0.2015
22	LSSB22	Time consuming	2.0121	0.7410	0.017	0.1750
23	LSSB23	Poor estimation of implementation cost	3.0101	0.7412	0.105	0.2148
24	LSSB24	Poor alignment between company's goal and customer demand	4.1924	1.0987	0.625	0.7235
25	LSSB25	Poor selection of employee for belts training	4.2101	0.9548	0.649	0.7648
26	LSSB26	Weak supplier's linkage	4.0122	0.9654	0.694	0.6928

5.3.2 Reliability Computation

For eliminating the biasness and validating the screened LSSBs, reliability test has been conducted on the data composed by questionnaire study.

Table 5.3: *Analysis of Reliability test.*

Cronbach's Alpha	**Cronbach's alpha when non-reliable barriers are deleted**	**No of barriers**
0.820	0.879	22

The designed questionnaire relevant to LSSBs has been shown in Appendix 1. In reliability analysis, Cronbach's alpha were computed which analyze the consistency and validity of selected barriers. It can be observed from the statistical results of reliability test that Cronbach's alpha is 0.820 as shown in Table 5.3 and it represents the good consistency among barriers.

5.3.3 Steps of ISM Approach

ISM is a coherent approach, implemented in a chronological way. The various steps of ISM are as follows:

- *Step 1: Identification of barriers:*
  Recognize and finalize the LSS barriers through extensive literature review, questionnaire survey, expert's opinion, and brainstorming session.

- *Step 2: Define the contextual relationship:*
  From the identified barriers in the first step, build the contextual relationship between barriers and construct an auxiliary Self-Interaction Matrix (SSIM) for the pair-wise examination of them. The contextual relationship is based on the structure like intend, priority, and mathematical dependence process [296].

- *Step 3: Formation of Initial and final reachability matrix:* The SSIM obtained from step 2, used further for constructing a reachability network. It is formulated through changing over the data in every cell of SSIM into binary digits (0 and 1).

- *Step 4: Partition of the final reachability matrix into different levels:*
  The obtained final reachability matrix is further divided into different levels based on reachability and antecedents sets for every barrier through a progression of cycles known as the level partitioning.

- *Step 5: Formation of the diagraph:*
  In this step, the diagraph is formed by considering the transitivity among barriers (that is if barrier A is related to barrier B and barrier B is related to barrier C, then barrier A should be related to barrier C).

- *Step 6: Development of ISM model:*
  From the obtained diagraph, remove the transitive links based on the relationships given in the reachability matrix and termed as ISM model. In this model, the variable nodes of diagraph are substituted with statements.

5.4 Result and Discussion

The present research aims to successful initiation of LSS program in MSMEs by countering the implementation barriers as per their traits and characteristics. Initially, 26 LSSBs were extracted from the literature and further screened them with the help of expert's input and statistical analysis. The statistical analysis offers a final list of 22 LSSBs in MSMEs. For industrial managers, it is very difficult to tackle all 22 barriers simultaneously due to lack of technology, poor financial resources at selected case industry. Therefore, a model of mutual interaction among screened LSSBs is constructed with the help of ISM approach and grouped them as per their appropriate traits using MICMAC analysis. The steps of ISM have been examined with the help of experts selected from case industry and academia background. The detailed explanation of ISM steps with case study are as following:

5.4.1 Investigation of LSSBs

In this step, 26 LSSBs were investigated through systematic literature review and screened them with the help of experts input and statistical analysis. Finally, 22 LLSBs found significant barriers associated with LSS implementation in MSMEs.

5.4.2 Construct Structural Self-interaction Matrix among LSSBs

The mutual relationship among screened LSSBs is formed and constructed a SSIM which is depicted in Table 5.4. Four symbols have been used to signify the directional association between two barriers (x, y).

TABLE 5.4: *Structural self -interaction matrix (SSIM).*

LSSBs	**22**	**21**	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1	A	A	A	A	A	C	A	C	A	A	A	A	C	A	A	A	A	B	A	A	A	C
2	A	A	A	A	A	B	A	B	A	A	A	A	B	C	C	A	A	B	A	C	C	
3	A	A	A	A	A	B	B	B	A	A	A	A	B	C	C	A	A	B	A	C		
4	A	B	B	C	B	B	C	B	A	A	A	A	B	B	B	B	B	B	C			
5	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	C				
6	A	C	C	A	A	B	A	B	A	C	A	A	B	B	B	C	C					
7	A	C	C	A	A	B	A	B	A	A	A	A	B	B	B	C						
8	A	A	A	A	A	B	A	B	A	A	A	A	B	C	C							
9	A	A	A	A	A	B	A	B	A	A	A	A	C	C								
10	A	A	A	A	A	C	A	C	A	A	A	A	C									
11	B	B	B	B	B	B	B	B	B	B	B	C										
12	C	B	B	B	B	B	B	B	C	B	C											
13	A	B	B	B	C	B	A	B	A	C												
14	C	B	B	B	B	B	B	B	C													
15	A	A	A	A	A	C	D	C														
16	A	B	B	B	C	B	C															
17	A	A	A	A	A	C																
18	A	B	B	B	C																	
19	A	B	B	C																		
20	A	C	C																			
21	A	C																				
22	C																					

- If barrier "x" effects to barrier "y", then symbol A is used.
- If barrier "y" influences to barrier "x", then symbol B is used.
- If "x" and "y" impacts to each other, then symbol C is used.
- If both barriers are isolated, then symbol D is used.

5.4.3 Formation of Reachability Matrix

By converting each entry of SSIM by 1 and 0, the initial reachability matrix was framed as shown in Table 5.5. Subsequent rules have been tracked for fusion of these binary entries.

TABLE 5.5: *Initial Reachability Matrix.*

Barriers	**LSS B1**	**LSS B2**	**LSS B3**	**LSS B4**	**LSS B11**	**LSS B12**	**LSS B20**	**LSS B21**	**LSS B22**
LSSB1	1	1	1	1	1	1	1	1	1
LSSB2	0	1	1	1	1	1	1	1	1
LSSB3	0	0	1	1	1	1	1	1	1
——	.....	.....	......	......	.....	.....	.....	.....	....
LSSB7	0	0	0	1	1	1	1	0	1
——	.....	.....	......	......	.....	.....	.....	.....	....
LSSB10	0	1	1	1	1	1	1	1	1
——	.....	.....	......	......	.....	.....	.....	.....	....
LSSB20	0	0	0	1	1	1	1	1	1
LSSB21	0	0	0	1	1	1	1	1	1
LSSB22	0	0	0	0	1	1	0	0	1

- The entry "A" has been converted 1 and 0 with similar to (i, j) and (j, i) barriers respectively.

- The entry "B" has been converted 0 and 1 with similar to (i, j) and (j, i) barriers respectively.
- The entry "C" has been converted 1 and 1 with similar to (i, j) and (j, i) barriers respectively.
- The entry "D" has been converted 1 and 1 with similar to (i, j) and (j, i) barriers respectively.

Further, the biasness of expert's inputs has been reduced by converting the initial reachability into final reachability matrix with integrating 1^* transitivity and shown in Table 5.6.

TABLE 5.6: *Final Reachability Matrix.*

Barriers	**LSS B1**	**LSS B2**	**LSS B3**	**LSS B4**	**LSS B11**	**LSS B12**	**LSS B20**	**LSS B21**	**LSS B22**
LSSB1	1	1	1	1	1	1	1	1	1
LSSB2	0	1	1	1	1	1	1	1	1
LSSB3	0	1*	1	1	1	1	1	1	1
——	.....	.....	......	......	.....	.....	.....	.....	....
LSSB7	0	0	0	1	1	1	1	1*	1
——	.....	.....	......	......	.....	.....	.....	.....	....
LSSB10	1*	1	1	1	1	1	1	1	1
——	.....	.....	......	......	.....	.....	.....	.....	....
LSSB20	0	0	0	1	1	1	1	1	1
LSSB21	0	0	0	1	1	1	1	1	1
LSSB22	0	0	0	0	1	1	0	0	1

5.4.4 Level Partitions

The reachability and antecedent set for all barriers are established since the final reachability matrix to procurement the level partitions. The reachability set for a screened barrier contains itself and the remaining barriers may affect other. The collection of antecedents includes the barriers themselves and the other barriers which may derive from another. The barrier exists in level I should be have similar reachability set and intersection set and a lower position in the ISM hierarchy. First iteration is accomplished by using this way. Thereafter, barriers included in level I have been discarded and with rest of LSSBs, the same procedure is repeated for constructing the iteration 2. This same procedure is being repeated until the every barrier was included in iteration and collective iterations of LSSBs are demonstrated in Table 5.7.

TABLE 5.7: *Levels of LSSBs.*

Barrier codes	**Reachability set**	**Antecedent set**	**Intersection set**	**Level**
LSSB1	1,10,15,17	1,5,10,15,17	1,10,15,17	II
LSSB2	2,3,8,9	1,2,3,5,8,9,10,15,17	2,3,8,9	III
LSSB3	2,3,8,9	1,2,3,5,8,9,10,15,17	2,3,8,9	III
LSSB4	4,16,19	1,2,3,4,5,6,7,8,9,10,13,15,16,17,18,19,20,21	4,16,19	VI
LSSB5	5	5	5	I
LSSB6	6,7,20,21	1,2,3,5,6,7,8,9,10,15,17,20,21	6,7,20,21	IV
LSSB7	6,7,20,21	1,2,3,5,6,7,8,9,10,15,17,20,21	6,7,20,21	IV
LSSB8	2,3,8,9	1,2,3,5,8,9,10,15,17	2,3,8,9	III
LSSB9	2,3,8,9	1,2,3,5,8,9,10,15,17	2,3,8,9	III
LSSB10	1,10,15,17	1,5,10,15,17	1,10,15,17	II
LSSB11	11	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22	11	VIII
LSSB12	12,14,22	1,2,3,4,5,6,7,8,9,10,12,13,14,15,16,17,18,19,20,21,22	12,14,22	VII
LSSB13	13,18	1,2,3,5,6,7,8,9,10,13,15,17,18,20,21	13,18	V

LSSB14	12,14,22	1,2,3,4,5,6,7,8,9,10,12,13, 14,15,16,17,18,19,20,21,22	12,14,22	VII
LSSB15	1,10,15,17	1,5,10,15,17	1,10,15,17	II
LSSB16	4,16,19	1,2,3,4,5,6,7,8,9,10,13,15, 16,17,18,19,20,21	4,16,19	VI
LSSB17	1,10,15,17	1,5,10,15,17	1,10,15,17	II
LSSB18	13,18	1,2,3,5,6,7,8,9,10,13,15,17,18, 20,21	13,18	VI
LSSB19	4,16,19	1,2,3,4,5,6,7,8,9,10,13,15, 16,17,18,19,20,21	4,16,19	VI
LSSB20	6,7,20,21	1,2,3,5,6,7,8,9,10,15,17,20,21	6,7,20,21	IV
LSSB21	6,7,20,21	1,2,3,5,6,7,8,9,10,15,17,20,21	6,7,20,21	IV
LSSB22	12,14,22	1,2,3,4,5,6,7,8,9,10,12,13,14, 15,16,17,18,19,20,21,22	12,14,22	VII

5.4.5 Construction of Diagraph and ISM Model

The operational model is expressed from reachability matrix and the mutual relationship among the LSSBs is shown by an arrow called as diagraph (refer to Figure 5.2). In diagraph, all possible transitivity in between the LSSBs has been shown level wise. The transitivity of LSSBs are measured as barrier i associated with j, barrier j associated with k, then barrier i is associated with k [297]. Based on diagraph, the ISM model has been framed by eliminating transitivity between the LSSBs and revealed in Figure 5.3.

This model presents that the LSSBs labeled as LSSB5, LSSB17, LSSB15, LSSB1, and LSSB3 found the most leading LSS barriers due to lying at lowest location. LSSB5 barrier as 'top management commitment and involvement' make sure the adequate human resources, best workforce for leading the project, appropriate forecasting and planning etc. If the top management does not demonstrate their full participation, then all the factors identified are lagging behind and causing the implementation of the LSS to fail. LSS leaders and champions will plan custom roadmap so that they can assist the company in adoption of procedure. Frequent statement is very crucial at various stages, including the top management, audit of project status and consumer awareness of the project. Proper training and instruction for workers is important to concentrate on teamwork and to recognize the unnecessary activities that are perceived as excess, to determine the key factors and to enable individuals to make fluctuations. Administrations must produce certain atmosphere which has consents to the recommended procedure improvements, measures, etc. It is possible only when the workers is well educated and have good view about venture. Additionally, the association among LSS and consumers-providers is important for effective implementation of LSS.

In addition, lower accomplishment of the requirements of the company, high cost of implementation, deficiency of roadmap for LSS adoption, weak link of suppliers, deficiency of worker participation, and lack of communication between top management of the established ISM model. Lack of performance assessment method, conflict to transformation of culture, poor selection of equipment, poor selection of employees for belt training poor coordination among company target and buyer claim, vague vision, poor knowledge of LSS, poor training and weak organizational skills and inadequate selection of projects lies at the middle level of the ISM model. Ultimately, this model provides engineering managers with a technique to separate their resources from important barriers (positioned in the ISM model at the bottom) to less powerful barriers (positioned in the ISM model at the top). It will help them take steps to fix LSSBs in every unit before LSS is introduced.

5.5 MICMAC Analysis

The MICMAC study is adopted to analyze both the driving power and barrier dependency [298]. Using MICMAC analysis, the barriers have been divided into four classes as dependent, independent, independent, and linkage based on their driving

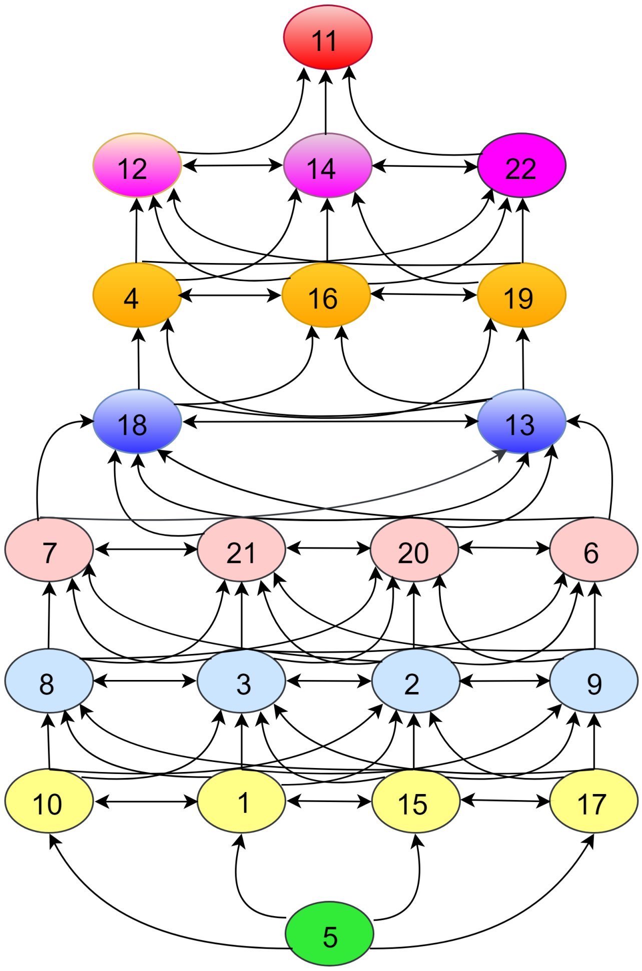

Figure 5.2: *Diagraph of LSS barriers.*

and dependency power and shown in Figure 5.4. The first quadrant contains autonomous barriers with poor driving and dependency power. The depended barriers with more dependency and lack of handling power are represented in second quadrant. The third quadrant reveals the barriers of the linkage that have appropriate power as well as heavy dependency. The fourth quadrant represents the independent barriers with extraordinary power but have least dependency on others. The grouping of primary LSSBs has helped industrial managers to concentrate on barriers with high driving power. Following are the classified barriers as per MICMAC analysis.

- No barriers identified in autonomous category in MICMAC research. Autonomous barriers show least driving power and low dependency, and thus illustrate least control on them.

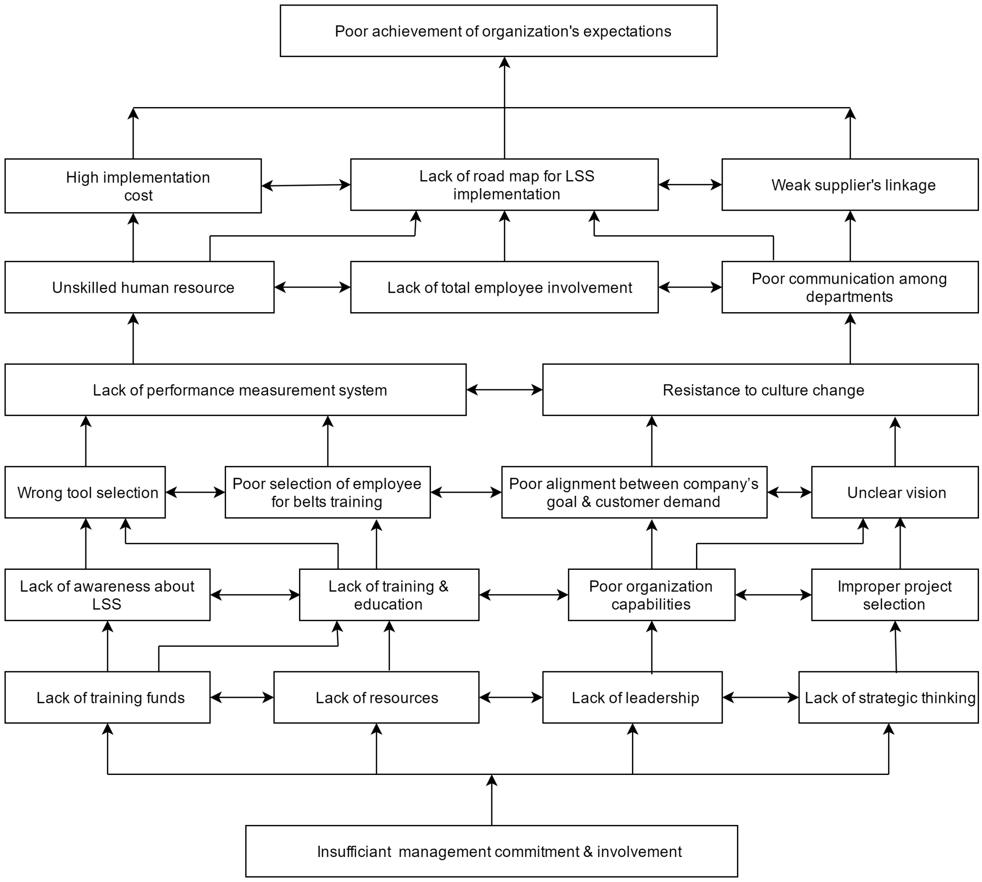

FIGURE 5.3: *ISM model of LSS barriers.*

- Barriers labelled as LSSB6, LSSB7, LSSB20 and LSSB21 are linkage barriers. Each of the barriers categorized into above having appropriate driving power and dependency.

- Barriers labelled as LSSB4, LSSB11, LSSB12, LSSB13, LSSB14, LSSB16, LSSB18, LSSB19 and LSSB22 are reliant on other barriers and these barriers contain comparatively low driving however demonstrate strongly dependence on different barriers.

- The barriers labelled as LSSB1, LSSB2, LSSB3, LSSB5, LSSB8, LSSB9, LSSB10, LSSB15 and LSSB17 are independent barriers having more driving power with least confidence on other and are being viewed as barriers to regulation.

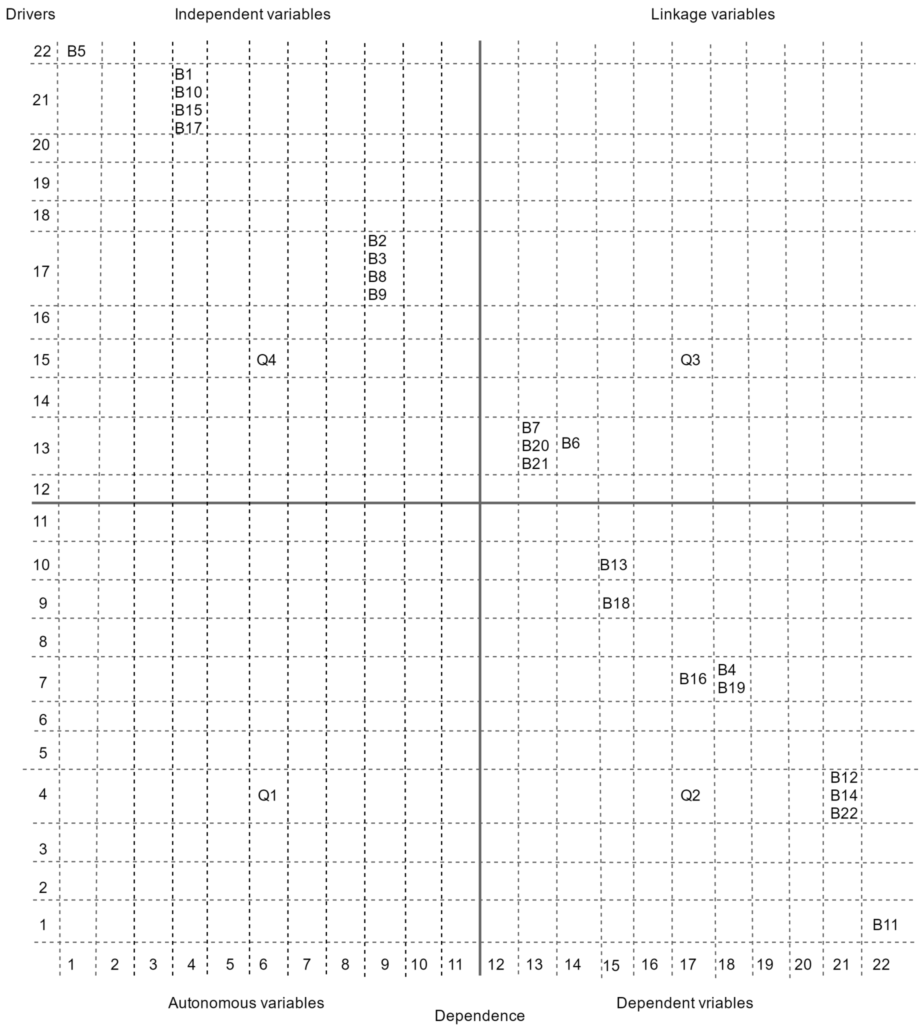

FIGURE 5.4: *Clustering of LSSBs.*

5.6 Managerial Implications

The present study inspires MSMEs managers and practitioners to adopt LSS program effectively and efficiently in their business. Consequently, the benefits of ISM stimulate LSS consultants and engineering managers as decision-makers to adopt LSS in their existing system to transform in sustainable system. All barriers are not equally important for initiation of LSS within core MSMEs. Moreover, MSMEs cannot emphasis on all barriers due to lacking of manpower and financial restrictions. The present work offers comparative ranking of LSSBs such that the engineering manager can be focused on particular barrier with utmost priority. LSS consultants should be concerned more about driving LSSBS before barriers to dependency and if they can manipulate driving barriers, then barriers to dependency will be automatically under-controlled.

The present research work discovers a few prominent research areas that can be explored by researchers in future. The barriers selected in this study can be explored more through visiting large sized and developed industries. Moreover, the present research provides motivation to the researchers to develop a framework or roadmap to LSS implementation in manufacturing environment for sustainable development.

5.7 Conclusion

This chapter presents the prime LSSBs and explores the interaction among them which helps in Indian MSMEs to successfully implement LSS. Initially, 26 LSSBs are extracted using systematic analysis of the literature and the opinions of experts. Using reliability test in SPSS software, the identified LSSBs were screened through statistical tools and CIMTC method. Finally, 22 LSSBs were screened and validated by means of a reliability test which confirms the good consistency with Cronbach's alpha of 0.820. Finally, a study of ISM and MICMAC is used to classify the relationship and clustering between screened LSSBs. ISM model results recognize the hierarchy of measures considered by technical executives which reduce the effect of LSSBs in effective implementation of LSS. The outcomes obtained via ISM model of LSS barriers are in good agreements as per the case industry's personnel. The MICMAC study shows that the LSSB clusters were developed based on driving power and reliance. The result of the MICMAC shows LSSBs have been categorized as following: 9 dependent, 9 independent, 4 existing linkage, and no autonomous. The outcome of this research will direct and aid in any organization to create a planned and deliberate judgment to switch from a traditional manufacturing structure to an efficient LSS structure.

CHAPTER 6

Implementation of Lean Six Sigma Framework in Indian MSMEs

6.1 Introduction

The "Make in India" campaign was launched by Government of India (GOI) in 2014 to deal with the issues of stagnating Indian economy and boosting the economic growth of the country. This initiative helps to creating job opportunities and converting the India into manufacturing hub of commercial products. In Indian manufacturing scenario, MSMEs contribute about 45% of total manufacturing output and 40% of total exports [249]. Additionally, the contribution of MSMEs in Indian GDP accounted for 16% and provided more than 80 M employment opportunities [250]. This indicates that the MSMEs sector is much important for Indian economic development. Despite its huge role in economic growth, it faces dynamic challenges relevant to environmental, competitiveness, and continuous improvement [251]. Even though the GOI have put extreme efforts towards the development of MSMEs sector, but due to lack of knowledge about implementation of any continuous approach, MSMEs is struggling with their lower productivity and quality. Thus, there is an immense need for such an approach that works for sustainable development and continuous improvement without compromising environmental stewardship. Literature reveals that Lean Six Sigma (LSS) is a breakthrough approach help in continuous improvement by defect reduction, waste minimization, and capacity utilization enhancement. MSMEs managers and practitioners are still hesitant in adoption to LSS strategy in their business due to lack of roadmap availability and guidelines. In this context, this chapter presents the suitable guidelines and steps of LSS framework implementation through a case study in Indian MSMEs. In this case study, LSS strategy is adopted to improve Capacity Utilization (CU)level with environmental consideration, results to enhance operational and environmental performance. The following research questions have been addressed in this chapter:

- What are the appropriate steps to implement LSS framework in manufacturing environment?
- How to implement LSS framework with environmental aspects to improve capacity utilization level in Indian MSMEs?
- What variations found in performance parameters, tangible and non-tangible benefits in case company before and after implementation of LSS?

6.2 LSS Deployment Plan

This chapter presents the implementation of LSS framework to improve capacity utilization level in Indian MSMEs. Based on the requirement of selected case company, the developed LSS framework was associated with environmental aspects for improving operational as well as environmental performance. The selected case company must be intricate in manufacturing environment where scope occurs for piloting LSS initiates. After implementation of framework in case company, the obtained results in operational and environmental perspectives are being compared with facts before implementation of the framework. Such comparisons provide the real picture of improvement and validate the developed framework. The implemented suggestions are recorded as a suitable action plan for maintaining them for longer time. The present research work adopted a case study approach for implementing the developed framework because case study approach has the likelihood to provide the exact contemporary measures and true results in-depth [299]. Case study also has capability to demonstrate the developed framework step by steps and encounter research objectives. The research methodology adopted in this study exhibits the detailed procedure right from development of the framework to its implementation to achieve business excellence. The deployment plan of LSS is developed with the role and responsibility of each member in the project and is shown in Figure 6.1.

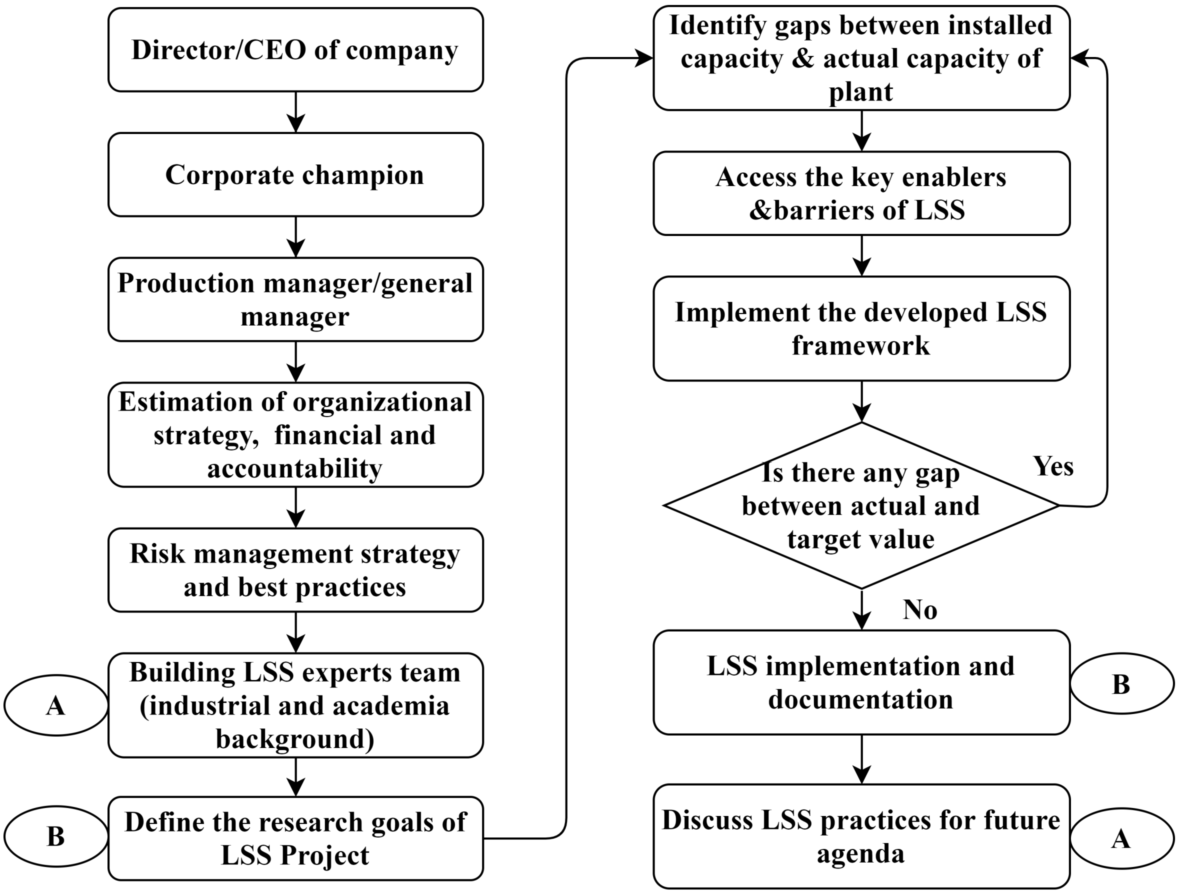

FIGURE 6.1: *LSS deployment plan.*

6.3 Case Explanation

In this chapter, the implementation of LSS approach is expressed through a case study conducted in selected MSMEs in the Indian context. During the case study, the proposed LSS framework (shown in Chapter 3) is implemented systematically to improve the CU level of the selected case industry. The detailed descriptions about the steps of case study are showing in further subsections.

6.3.1 Company Profile

The present case study was carried out at *Morbros India Private Limited* (MIPL, a unit of *Technomed India*), *Bawana industrial area, New Delhi, India.* The *Morbros India Pvt. Ltd.* is a registered as MSMEs and the leading original medical equipment manufacturer of Operation Theatre (OT) tables and operation theatre LED lights. The manufacturing plant expands across in an area of 2700 square feet and having the installed capacity to manufacture 3300 products annually. The selected unit was established in year 2008 and produces more than 17 types of OT tables and more than 10 types of LED lights. The plant comprises of advance laser cutting machine, bending machine, metal inert gas welding, Vertical Milling Center (VMC), grinding machine, buffing and painting, drilling machine, and assembly line etc. The company is certified by *ISO 9001:2008, 9002:2015* and *QS 14000* certification. All the manufacturing and assembling processes are under constant monitoring to achieve best quality, performance and economic cost for the customers. The unit has the capability to produce a wide range of medical equipment for various vendors, hospitals and exports in overseas markets like Egypt, USA, Spain, and Dubai etc.

6.3.2 Define Phase

Define phase aims to identify the problem and explore the scope of the project. In this phase, the requirement of customers are collected through Voice of Customer

(VOC) and associated with Voice of Business (VOB). A project team of three experts and two coordinators are framed. The selected experts are having the vast knowledge of Six Sigma and its implementation. The coordinators are representative to top management and having wide knowledge of LSS. The top management organized a meeting with their managers and employees to deliver the need of LSS and its benefits towards sustainability. This assisted in understanding the link between customer's requirement and business goal and also aware about environmental aspects. Table 6.1 exhibits the tools used for initialization of LSS project and clear understanding of selection process of critical project for continuous improvement.

TABLE 6.1: *Major Tools Used (Define phase).*

S.N.	Tool used
1	Pie chart
2	SIPOC
3	Project Charter
4	Pareto Chart
5	Modified TOPSIS
6	VIKOR

6.3.2.1 Project Charter

A project charter is a single picture to define the whole project work plan such as problem definition, objective, scope, limitations, benefits, team members, tools and techniques, project timelines and product detail. It also exhibits the roles and responsibility of project members and details of suppliers, stakeholders, project starting and completion date. The project charter is essential to construct for simplify the information related to project from initial to final stage. In the present case, the project charter are framed as shown in Figure 6.2.

PROJECT CHARTER	
Problem Statment	**Business Need**
To enhance the productiviy and quality by improving capacity utilization and indoor air quality level	Company is ready for adopotion of Lean Six Sigma to improve capacity utilization and indoor air quality level
Project Aim	**Project Scope**
To improve the productivity of company by increasing capacity utilization level To minimize the indoor air pollution	To estimate the capacity waste and environmental footprints that occurs within the plant and suggest substantial improvement steps for reducing the same.
Name of company	**Name of product**
Medical equipments manufacturer	OT table
Tools and techniques	**Project Team**
SIPOC, Current VSM, Pareto Chart, Process Flowchart, C&F Diagram, 6S	Expert: Mr. X, Coordinator: Mr. Y, Members: Mr. A, Mr. B and Mr. C

Project Schedule		
Activity	**Start Date**	**Completion Date**
Define	1 Oct. 2018	15 Dec. 2018
Measure	5 Jan 2019	30 May 2019
Analyze	5 June 2019	15 Aug. 2019
Improve	20 Aug. 2019	20 Dec. 2019
Control	25 Dec. 2019	15 Feb. 2020

FIGURE 6.2: *Project charter.*

6.3.2.2 SIPOC Chart

Supplier Input Process Output Customer (SIPOC) consist the significant information about supplier, input materials, customers, end product and steps intricate in manufacturing of end product. It also provides the detail of raw material consumption and energy used to tract the environmental aspects. The SIPOC chart in current case has been constructed and is revealed in Figure 6.3.

6.3.2.3 Pie Chart

The prime reasons of low CU are identified with the help of experts opinion and industrial visit and expressed their contribution towards low CU with the help of

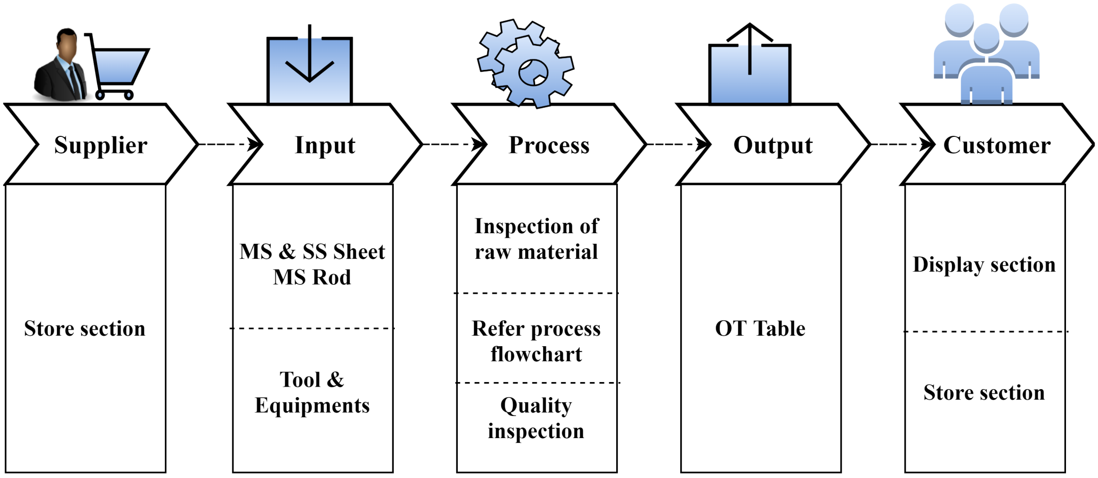

FIGURE 6.3: *SIPOC chart.*

pie chart. Figure 6.4 shows that prime reasons of low CU are poor material handling (40%), unnecessary movement (28%), environmental issues (18%), and reworks (7%).

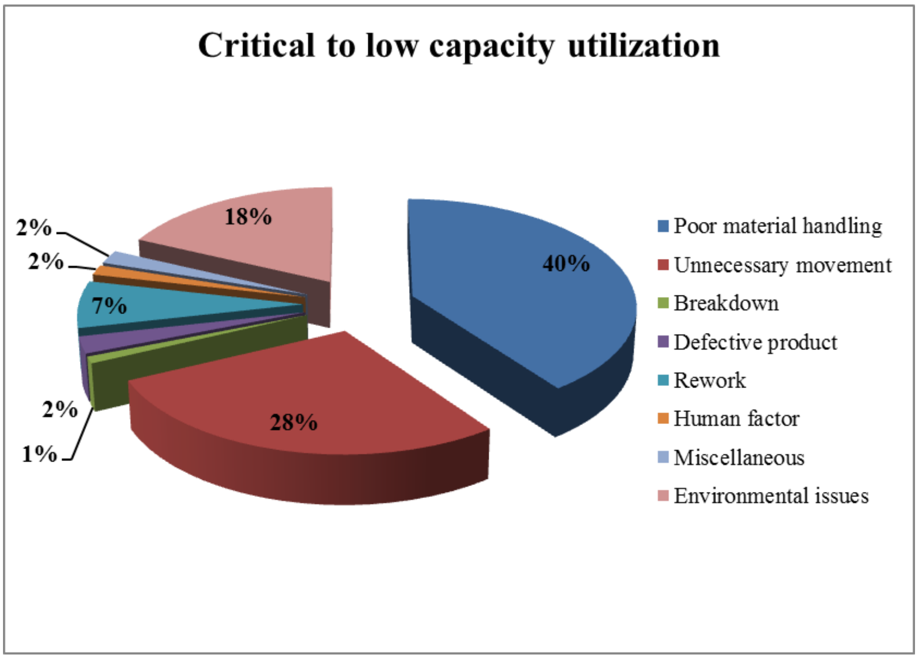

FIGURE 6.4: *Prime reasons of low CU.*

6.3.2.4 Pareto Analysis

This analysis provides a direction to select the appropriate project for CU improvement in the case company. The line joining the histogram expresses the cumulative frequency at each stage. It is quality assurance tool that positions the data categorization in the downward order from the highest possibility of occurring to lowest possibility of occurring. The past 20 months data related to time taken in searching components and equipment in various sections was collected and Pareto Chart was drawn for finding section wise maximum poor material handing time (refer Figure 6.5). The Pareto Chart reveals that assembly section has maximum time consumption in searching the components and is the prime source of low CU.

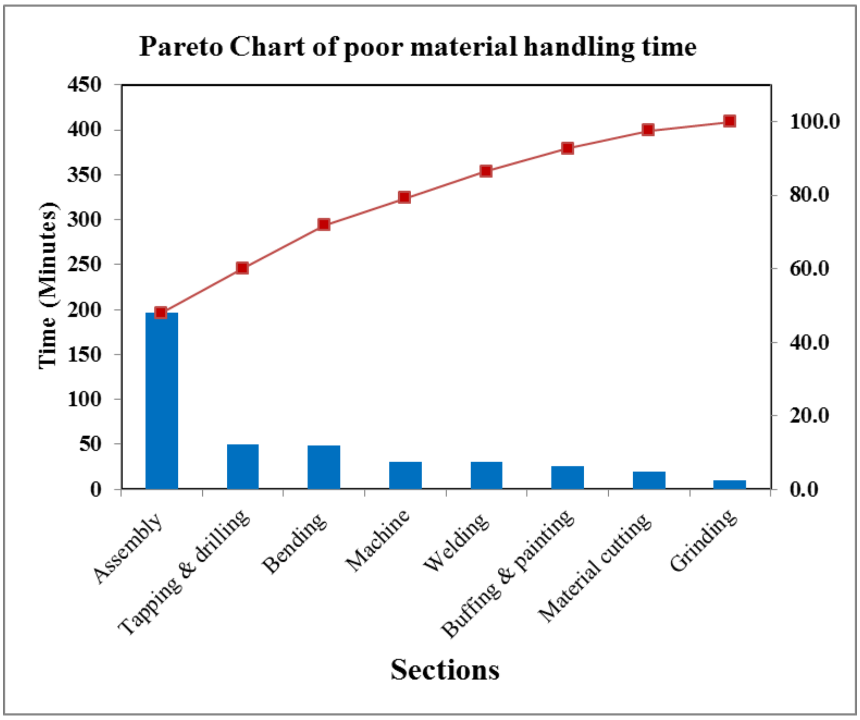

FIGURE 6.5: *Pareto Chart for poor material handling time.*

6.3.2.5 Intuitionistic Fuzzy Modified TOPSIS-VIKOR Analysis

This analysis was carried out to identify appropriate LSS project and major domain of low CU in the selected case company. For suitable LSS project selection, the decision makers (DMs) may need appropriate selection criteria to be considered. For this seven critical subjective criteria were identified at the selected MSMEs in India and shown in Table 6.2. The identified criteria were finalized after eliciting the views of various DMs like general manager, plant head, engineer, machine operators and consultant experts. Literature also reflects almost the same criteria for implementing a LSS project in medical equipment manufacturing MSMEs. All these criteria holistically represent the existing environment at the selected site and do full justice for the selection of LSS project. The alternatives for LSS project selection should be evaluated according to these established criteria and DMs preference must be exhibit by weights to given criteria.

TABLE 6.2: *Subjective criteria for LSS project selection.*

Sr. No.	**Criteria**	**Notation**	**Description**
1	Rejection	P1	It consist in-process rejection and final rejection of products.
2	Human factor	P2	Ergonomically designed work place increase the employees efficiency, results it improves the productivity.
3	Down Time Cost	P3	It includes the breakdown cost, maintenance cost and cost of activities used for its functional requisite.
4	Environmental aspects	P4	Environment aspects include minimum energy consumption, indoor air quality, and eco-friendly working environment.

5	Wastage	P5	It includes unnecessary movement of men and material, raw material wastage, time for non-value adding activity and scarp.
6	Safety	P6	Safety is the prime thing because the safe working procedure provides better way for doing work on shop floors.
7	Reliability	P7	Reliability is an important parameter for selecting reasons of breakdown in any manufacturing sites. It expresses the failure rate of each component used in particular section.

Detailed steps of methodology: The steps involved in the subjective Intuitionistic Fuzzy (IF) Modified TOPSIS-VIKOR approach for the suitable LSS project selection in MSMEs have been explained in this section. The approach uses Entropy method for getting the weightage of selected criteria followed by IF modified TOPSIS-VIKOR approach to obtain optimal alternatives. It includes following steps:

- *Step 1: Define appropriate linguistic variables, membership function, and equivalent intuitionistic fuzzy numbers.*

  A set of appropriate linguistic variables and their corresponding fuzzy numbers are required to compare all alternatives for each parameter. These selections are done with the help of DMs and responsible for inter-comparison of alternatives with each parameter.

- *Step 2: Calculate the weights of DMs*

  Assume l is the total number of DMs and their importance is considered by linguistic variables decided in IFN (Intuitionistic Fuzzy number). Let $D_k =$

$[u_k, v_k, \pi_k]$ be IFN for the rating of k^{th} DM and the weight (λ_k) can be calculated as Equation 6.1.

$$\lambda_k = \frac{(u_k + \pi_k(\frac{u_k}{u_k+v_k}))}{\sum_{(k=1)}^{l}(u_k + \pi_k(\frac{u_k}{u_k+v_k})} \quad ; \sum_{(k=1)}^{l} \lambda_k = 1 \tag{6.1}$$

- *Step 3: Construct aggregated IF decision matrix based on the opinions of DMs*
  Assume $R^k = (r_{ij}^k)_{mxn}$ is the IF decision matrix of each DM and $\sum_{(k=1)}^{l} \lambda_k = 1,\ \lambda_k \in [0,1]$. In the group decision-making process, each decision needs to be bonded into a group opinion to constructing an aggregated IF decision matrix. In this order, Equation 6.2 and 6.3 are being used [300]:

$$r_{ij} = [1 - \sum_{k-1}^{l}(1-u_{ij}^k)^{\lambda_k}, \sum_{k-1}^{l}(v_{ij}^k)^{\lambda_k}, \sum_{k-1}^{l}(1-u_{ij}^k)^{\lambda_k}, -\sum_{k-1}^{l}(v_{ij}^k)^{\lambda_k}] \tag{6.2}$$

Here $r_{ij} = (u_{A_i}(x_j), v_{A_i}(x_j), \pi_{A_i}(x_j))(i = 1, 2, 3, ..., m; j = 1, 2, 3, ..., n)$

$$R = \begin{bmatrix} (u_{A_1}(x_1), v_{A_1}(x_1), \pi_{A_1}(x_1)) & ......(u_{A_1}(x_n), v_{A_1}(x_n), \pi_{A_1}(x_n)) \\ (u_{A_2}(x_1), v_{A_2}(x_1), \pi_{A_2}(x_1)) & ......(u_{A_2}(x_n), v_{A_2}(x_n), \pi_{A_2}(x_n)) \\ ...... & ...... \\ (u_{A_m}(x_1), v_{A_m}(x_1), \pi_{A_m}(x_1)) & ......(u_{A_m}(x_n), v_{A_m}(x_n), \pi_{A_m}(x_n)) \end{bmatrix} \tag{6.3}$$

- *Step 4: Defuzzification*
  Defuzzification is a method of converting the fuzzy output into a crisp value (quantified number) in fuzzy logic by a real-valued function. It is executed to get a crisp value of each parameter corresponding to each alternative. In this procedure, the input is a cumulative set and output is a solitary number. This offers the qualitative value for the linguistics variables and fuzzy numbers allotted based on the opinions of DMs. Equation 6.4 is being used for crisp

values [301]:

$$R^*(y) = \begin{bmatrix} \leq a \;\; if \;\; y = 0 \\ a + (b-a)(y+\varepsilon)(\sqrt{\mu * (c_1 - \pounds)}) \;\; if \;\; 0 < y \leq \frac{(x-a)}{(b-a)} - \varepsilon \\ b \leq x \leq c \;\; if \;\; y = 1 - \varepsilon \\ (c-d)(y+\varepsilon) + d(\sqrt{\mu * (c_2 - \pounds)}) \;\; if \;\; 1 - \varepsilon < y < \frac{(d-x)}{(d-c)} - \varepsilon \\ \geq d \;\; if \;\; y = 0 \end{bmatrix} \tag{6.4}$$

where c_1 and c_2 are arbitrary constant and $y = \mu_A(x) + v_A(x)$.

- **Entropy Method Steps:** *Step 5: Normalize decision matrix*

$$r_{ij} = \frac{x_{ij}}{(\sum_{i=1}^{m} x_{ij})} \quad , i = 1, 2, 3, .., m \;\; ; j = 1, 2, 3, .., n \tag{6.5}$$

- *Step 6: Compute Entropy measure using following equation*

$$e_j = -h \sum_{i=1}^{m} r_{ij} ln r_{ij}, \quad j = 1, 2, 3, ..., n \tag{6.6}$$

$$h = \frac{1}{ln(m)}, m = no. \; of \; alterntives \tag{6.7}$$

- *Step 7: Calculate the divergence using the following equation*

$$d_j = 1 - e_j \tag{6.8}$$

- *Step 8: Obtain the entropy weight of criteria*

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{6.9}$$

- *Step 8: Obtain the entropy weight of criteria*

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{6.10}$$

- **Modified TOPSIS Steps:** *Step 5: Calculate the normalized decision matrix using the following equation:*

$$A_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m}(r_{ij})^2}} \quad ;\forall j \tag{6.11}$$

- *Step 6: Estimate positive ideal and negative ideal solution*
  The positive ideal solution (A_j^+) and negative ideal solution (A_j^-) are as given below:

$$A_j^+ = \{(maxA_{ij}, j \in J_1), (minnA_{ij}, j \in J_2), i = 1, 2, 3, ..., m\}, \forall j \tag{6.12}$$

$$A_j^- = \{(maxA_{ij}, j \in J_1), (minnA_{ij}, j \in J_2), i = 1, 2, 3, ..., m\}, \forall j \tag{6.13}$$

  where J_1 and J_2 represents higher best and lower best criteria respectively.

- *Step 7: Calculate the Positive Euclidean Distance and Negative Euclidean Distance*
  The Positive Euclidean Distance (D_i^+) and Negative Euclidean Distance (D_i^-) from A_j^+ and A_j^- respectively are calculated using the following equations:

$$(D_i^+) = [\sum_{(j=1)}^{n} (A_{ij} - A_j^+)^2]^{0.5} \tag{6.14}$$

$$(D_i^-) = [\sum_{(j=1)}^{n} (A_{ij} - A_j^-)^2]^{0.5} \tag{6.15}$$

- *Step 8: Estimate Collective Index* (C_i)

$$C_i = \frac{(D_i^-)}{(D_i^+ + D_i^-)} \tag{6.16}$$

- *Step 9: Rank the preference order*
  According to preference C_i values, the LSS project alternatives are ranked and

got 1^{st} rank with the highest C_i value and find the most significant project for continuous improvement.

- **VIKOR Method Steps:** *Step 5: Identify beneficial and non-beneficial criteria*

  Beneficial criteria- Whose larger value is desired

  Non-beneficial criteria- Whose smaller value is desired

- *Step 6: Find best and worst value of each criteria*

$$Best(X_i^+) = \begin{cases} max(X_{ij}) & \text{for beneficial} \\ min(X_{ij}) & \text{for non-beneficial} \end{cases} \tag{6.17}$$

$$Worst(X_i^-) = \begin{cases} min(X_{ij}) & \text{for beneficial} \\ max(X_{ij}) & \text{for non-beneficial} \end{cases} \tag{6.18}$$

- *Step 7: Compute utility measure (S_i) and regret measure (R_i)*

$$S_i = \sum_{j=1}^{m}(W_j \times \frac{(X_i^+ - X_{ij})}{(X_i^+ - X_i^-)}) \tag{6.19}$$

$$R_i = max_j(W_j \times \frac{(X_i^+ - X_{ij})}{(X_i^+ - X_i^-)}) \tag{6.20}$$

- *Step 8: Calculate VIKOR index (Q_i)*

$$Q_i = v \times \frac{(S_i - S^*)}{(S^- - S^*)} + (1 - v) \times \frac{(R_i - R^*)}{(R^- - R^*)} \tag{6.21}$$

$$S^- = max_i S_i \tag{6.22}$$

$$S^* = min_i S_i \tag{6.23}$$

$$R^- = max_i R_i \tag{6.24}$$

$$R^* = min_i R_i \tag{6.25}$$

A LSS project alternative with the least value of VIKOR index is chosen. For project assessment, a brainstorming session with DMs i.e. production managers, section head, machine operators and economic specialists have been conducted. The response of DMs about selected criteria and alternatives may vary due to different knowledge and experience level. For maintaining the uniformity in DM's opinion, the rating has been provided using linguistic variables of IF sets and weightage of DMs computed using Equation 6.1. The selected DMs provide the rating to selection criteria in the form of linguistic variables and further rating is converted into aggregate IF decision matrix using Equation 6.2. Thereafter, entropy value, divergence and weight of criteria have been computed using Eqs. (6.5) to (6.9). The final ranking of criteria are shown in Table 6.3. The parameter P5 (Wastage) is having the most dominating nature in project selection and P2 (Human factor) possesses the least role in project selection.

TABLE 6.3: *Calculated entropy measure, divergence, and weights of criteria using Entropy method.*

Measures	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
e_j	0.969753	0.986858	0.977183	0.937442	0.930097	0.975927	0.986794
d_j	0.030247	0.013142	0.022817	0.062558	0.069903	0.024073	0.013206
w_j	0.128196	0.055697	0.096704	0.265137	0.296266	0.102027	0.055972
Rank	3	7	5	2	1	4	6

The project selection in the initial phase of LSS project required high skill in decision making to select right project from all given alternatives. So a hierarchical structure are constructed using IF modified TOPSIS-VIKOR approach for the selection of right project as shown in Figure 6.6. This indicates that the selection of right LSS project depends on the seven criteria as suggested by various experts from industry and academia background. The selection of available eight alternatives depends upon the seven parameters and it shows the difficulty of the process. Therefore, the weight of selected criteria has been estimated using Entropy method. In next step, comparison among all alternatives with respect to each criteria is carried out based on IF approach. Linguistic variables were used for showing the comparison among

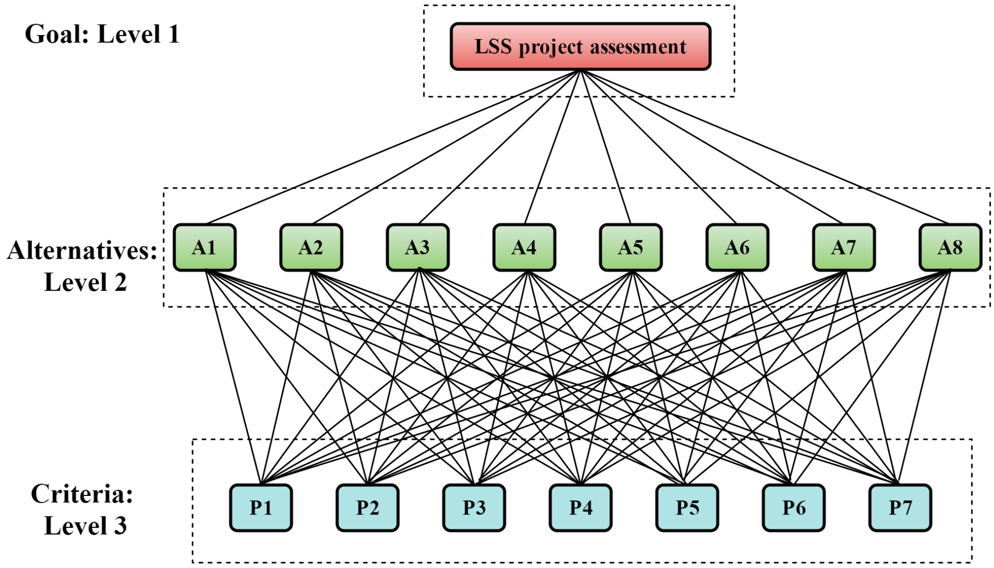

FIGURE 6.6: *Hierarchical structure for LSS project assessment.*

alternatives and conversion of linguistic variables into Intuitionistic Fuzzy Numbers (IFNs) are shown in Table 6.4. The extremely high (EH) stands for highest range and extremely low (EL) signifies the least range.

TABLE 6.4: *Linguistic variables and corresponding IFNs.*

Linguistic variables	**Notation**	**IFNs**
Extremely High	EH	1.0, 0.0
Very Very High	VVH	0.90,0.10
Very High	VH	0.80,0.10
High	H	0.70,0.20
Medium High	MH	0.60, 0.30
Medium	M	0.50,0.40
Medium Low	ML	0.40, 0.50
Low	L	0.30,0.60
Very Low	VL	0.20,0.70
Extremely Low	EL	0.10,0.90

Table 6.5: *Rating of the LSS project alternatives.*

Criteria	**Alternative**							
	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**
P1	VL	MH	VH	MH	M	VL	VL	M
P2	VH	VH	ML	VH	EH	M	H	EH
P3	H	EH	VH	MH	VL	MH	M	VH
P4	EL	M	VL	VL	VH	VH	EH	VH
P5	MH	EL	M	EL	ML	VH	VH	VH
P6	VH	VL	MH	M	VH	VH	H	EH
P7	M	MH	VH	EH	MH	EH	MH	MH

Table 6.6: *Intuitionistic Fuzzy Sets Crisp Matrix.*

Alternative	**Selection Criteria**						
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
A1	0.38333	0.98333	0.74166	0.17777	0.68333	0.9833	0.44166
A2	0.68333	0.98333	0.94444	0.44167	0.17777	0.38333	0.68333
A3	0.98333	0.68333	0.98333	0.38333	0.44166	0.68333	0.98333
A4	0.68333	0.98333	0.68333	0.38333	0.17778	0.44166	0.94444
A5	0.44166	0.94444	0.38333	0.98333	0.68333	0.98333	0.68333
A6	0.38333	0.44166	0.68333	0.9833	0.98333	0.98333	0.94444
A7	0.38333	0.74166	0.44166	0.94444	0.98333	0.74166	0.68333
A8	0.44166	0.94444	0.98333	0.98333	0.98333	0.94444	0.68333

It is a well-known fact that the pairwise comparison matrix may vary from problem to problem [302]. Hence, DMs play a very crucial role in the formation of comparison matrix. In present case, DMs provide their opinions for available alternatives and selection criteria and a decision matrix are framed as shown in Table 6.5. Further, the linguistic rating converted into a crisp matrix using Equation 6.4 and results are shown in Table 6.6.

The crisp matrix is further used for computing the positive and negative Euclidean distance using Eqs. (6.12) to (6.15). Based upon these distance, C_i values of alternatives are estimated using Equation 6.16. Besides in VIKOR method, the beneficial and non-beneficial criteria have been selected and found P1, P3, P4, and P5 are beneficial criteria and rest are non-beneficial. Using Eqs. (6.16) to (6.18) and (6.20), the unity and regret measures have computed and outcomes are shown in Table 6.7. VIKOR index is the basis of VIKOR prioritization and is estimated by using unity and regret measures with Eqs. (6.22) to (6.25).

TABLE 6.7: *Unity and regret measures (VIKOR Method).*

Alternative	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Unity measure** (S_i)	**Regret measure** (R_i)
A1	0.129	0	0.043	0.265	0.186	0.103	0	0.725	0.266
A2	0.129	0.025	0.097	0.013	0.297	0.061	0.025	0.645	0.297
A3	0.116	0.004	0	0	0.297	0.096	0.025	0.537	0.297
A4	0.129	0.056	0.054	0	0.297	0.103	0.052	0.688	0.297
A5	0.116	0.004	0	0	0.297	0.001	0.025	0.451	0.297
A6	0.065	0	0.054	0.198	0	0.011	0.052	0.378	0.198
A7	0	0.031	0	0.198	0.098	0.052	0.056	0.433	0.198
A8	0.065	0	0.007	0.179	0	0	0.025	0.275	0.179

TABLE 6.8: *Estimated Modified TOPSIS and VIKOR ranking.*

Alternatives	**Code**	**TOPSIS Index (CI)**	**Modified TOPSIS Rank**	**VIKOR Index** (Q_i)	**VIKOR Rank**
Welding Section	A1	0.345978	6	0.868079	6

Bending Section	A2	0.198383	7	0.951454	8
Machine Section	A3	0.41882	5	0.791118	5
Material Cutting Section	A4	0.155609	8	0.919193	7
Grinding Section	A5	0.743636	4	0.696154	4
Buffing and Painting Section	A6	0.856048	2	0.195458	2
Threading & Drilling Section	A7	0.805713	3	0.256946	3
Assembly Section	A8	0.912812	1	0	1

From Table 6.8, it is observed that assembly section has higher wastage, rejection, environmental aspects, downtime cost, and lower reliability, safety, and human factor. It is concluded that the outcomes obtained by using this decision making tool are almost same in nature as per the experts viewpoint. In current study, production managers have assumed a decision-making tool to decide the appropriate LSS project at an early stage of its implementation. Therefore, the selection of this section as LSS pilot project would be beneficial for the selected site in terms of overall profit gain and sustainable development.

6.3.2.6 Conclusions of Define Phase

The conclusions of Define phase are following:

- This phase identified the assembly section is the right project for LSS implementation.
- Pie chart reveals that poor material handling, unnecessary movement, environmental issues and reworks are main responsible for low CU and considered them for further improvement in the present case.
- Pareto analysis exhibits that assembly section is having maximum poor material handling time.
- SIPOC diagram designed the complete layout of plant in detail to recognize the variety of potential options to attain the desired improvement.
- Project charter interpreted the customer requirements into an appropriate problem with all possible resources existing inside the unit.
- IF Modified TOPSIS-VIKOR analysis evident that assembly section comprises of maximum wastage and is the main domain for low CU throughout the plant.

6.3.3 Measure Phase

Measure phase emphasizes the collection of data in current state of the system in documented and quantitative form. Moreover, this phase concentrates towards collection of root causes and data related to inefficiencies, low CU and defects. After extracting the possible causes of deviation from set of targets, a Pareto chart is being used to highlight the most significant cause among the listed one. For the project team, the data collection is critical task because whole project improvement and success are based on the collected baseline data. Therefore, critical to quality measures are determined from customer viewpoint and environmental perspective. The critical to quality are associated with business goal and strategy to increase CU rate of the plant and improve the productivity and eco-friendly environment. Table 6.9 exhibits the major tools used in this phase.

Table 6.9: *Major Tools Used (Measure phase).*

S.N.	**Tool used**
1	Process capability
2	Current EVSM
3	Brainstorming
4	Cause & Effect Diagram

6.3.3.1 Estimation of Current Defects Per Million Opportunities

At this stage, the current CU data of OT table is collected and analyzed statistically. Statistical results exhibit that mean of current CU data is 160 products with a standard deviation of 9.7503. The comparison is made by forming the ratio of the spread between the process specifications to the spread of the process standards. Parts Per Million (PPM) below the lower specification limit are 944015.9 based on potential performance which reveals a large number of non-conforming parts of the process lie outside the specification limits. Such non-confirming parts are further required rework during drilling operations. The Defects Per Million Opportunities (DPMO) at current CU level of OT table is computed as 309523 PPM and corresponding sigma level is observed as 1.95.

6.3.3.2 Current Environmental Value Stream Mapping.

The current Environmental Value Stream Mapping (EVSM) is drawn for visualizing the better insight of the current manufacturing process of product OT table. It helps to comprise the detailed information about critical metrics such as cycle time, lead time, change-over-time, and uptime related to each process. It also encompasses the information related to capacity waste at each section, inventory availability, and environmental impacts at each stages of the process. The development of EVSM helps to provide a clear image of the streamline flow of the manufacturing process and awareness of resource consumption. The current EVSM for the selected product is drawn as shown in Figure 6.7 and the critical process metrics are summarized in Table 6.10.

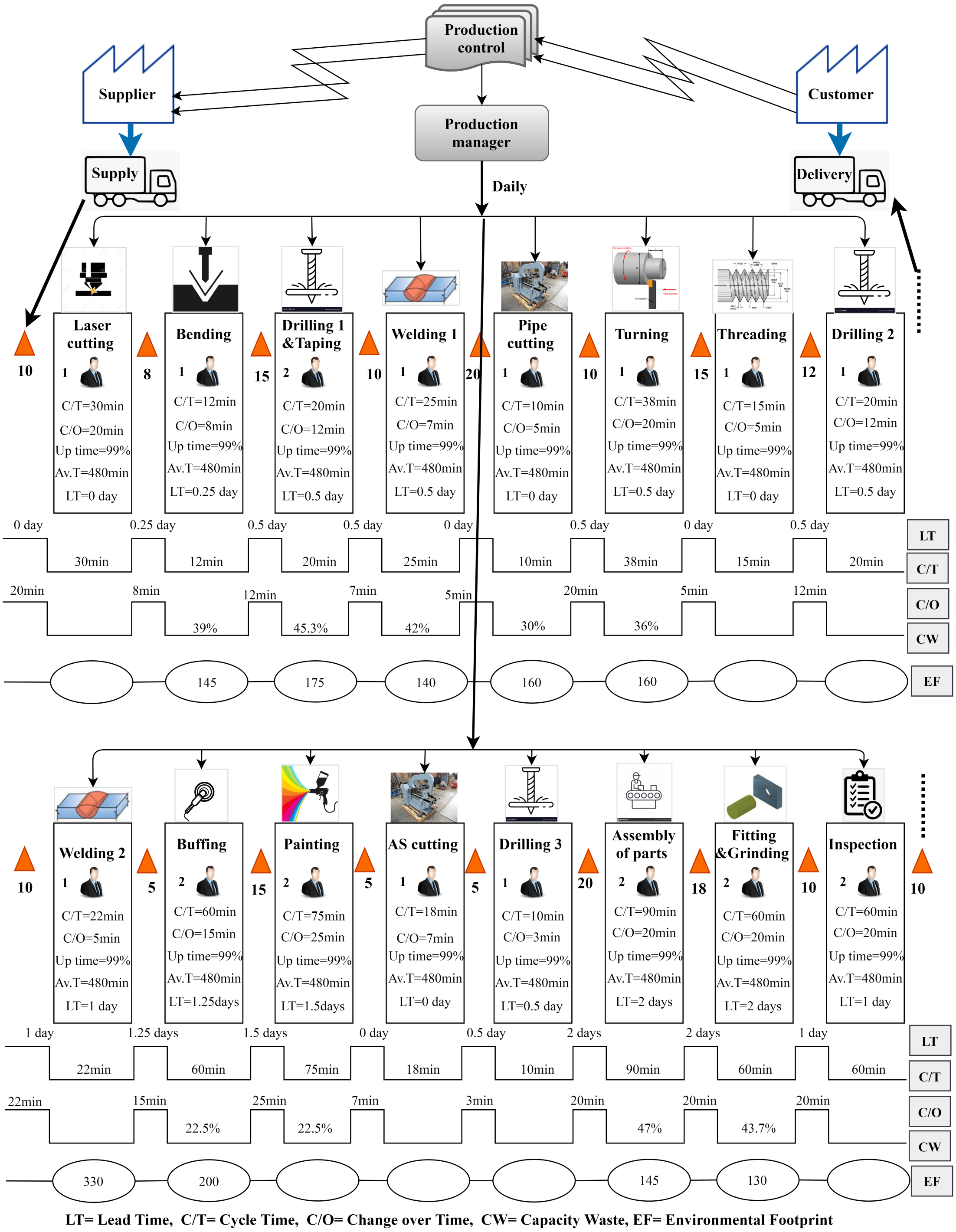

FIGURE 6.7: *Current EVSM* .

TABLE 6.10: *Current metrics of the process .*

S.N.	Process metric	Units
1	Process Lead Time	11.5 days
2	Total Cycle Time	565 minutes
3	Total Change Over Time	204 minutes
4	Average Capacity Utilization	59.25%
5	Average Indoor Air Quality	156.87 $mug\ /\ m^3$

6.3.3.3 Indoor Environmental Aspects

In the current manufacturing process of the OT table, the top management of the case company is more concerned about the indoor particulate matter and welding fumes. In selected case company, the indoor particulate matter is the complex amalgamation of solid and/or liquid particles suspended in air. The project teams are checked section-wise Indoor Air Quality (IAQ) and Carbon Monoxide Emission (CME) using PCE-RCM 15 meter and carbon monoxide detector, respectively. The measured data of IAQ and CME is recorded in a unit of $(\mu g)/\ m^3$ and PPM, respectively. The IAQ and CME of the overall plant are shown in Table 6.11. The manufacturing processes in each section are independent and hence, the weightage is assigned as per their criticality and efficacy to produce PM_{10}. As per weightage assigned with the help of LSS experts, the welding section, and buffing and painting section seems to be more critical with weightage of 0.4 and 0.20, respectively. The weighted average of IAQ level of the overall plant is found 156.25.

TABLE 6.11: *Existing status of section-wise indoor air quality level .*

Section	Operation held	IAQ (PM_{10})	Weightage	Weighted average
Welding Section	TIG, MIG, arc welding	140 CME = 33 PPM	0.4	56

Bending Section	Sheet metal bending	145	0.05	7.25
Machine Section	Turning, threading	160	0.05	8
Material Cutting Section	Cutting	160	0.10	16
Grinding Section	Major surface finishing	130	0.10	13
Buffing and Painting Section	Shining, painting	200	0.20	40
Tapping & Drilling Section	Hole making	175	0.05	8.75
Assembly Section	Assemble the parts	145	0.05	7.25
Weighted average of IAQ level of the overall plant				156.25

6.3.3.4 Section-wise Data Related to Rework

The project team members collect the section-wise data relevant to the number of parts of OT table used for rework and shown in Table 6.12. It is observed from the collected data that the tapping and drilling section holds the maximum number of parts which are required more rework. The enlargement through-hole diameter and increment in bore length are the major operations required for rework at parts.

TABLE 6.12: *Number of parts required rework in OT table.*

Section	**Operation held**	**Number of parts/-month (Rework required)**
Welding Section	Tungsten inert gas welding, metal inert gas welding, arc welding	11
Bending Section	Sheet metal bending	0
Machine Section	Turning, threading	0
Material Cutting Section	Cutting	0
Grinding Section	Major surface finishing	4
Buffing and Painting Section	Shining, painting	5
Tapping & Drilling Section	Hole making	24
Assembly Section	Assemble the parts	0
Number of parts/ month for rework at overall plant		44

6.3.3.5 Conclusions of Measure Phase

The significant conclusions of measure phase are:

- From the collected data, it has been found that DPMO at current CU level of OT table is computed as 309523 PPM.
- Table 6.12 presents that the components manufactured in tapping and drilling section required more rework steps. It observed that out of 44 numbers of defective components, 24 belongs only from tapping and drilling section.

- Estimation of indoor environmental aspects of selected case company reveals that IAQ of whole plant is 156.25 $(\mu g)/\ m^3$ and CME in welding section is found 33 PPM.

- Current EVSM of existing plant exhibits that total cycle time, total change over time, distance covered due to unnecessary movement, total lead time, and CU level found to be 565 minute, 204 minute, 325 feet, 11.5 days, and 59.25%, respectively.

6.3.4 Analyze Phase

Analyze phase elaborates the analysis of collected facts and data of existing system and outlines the possible improvement actions to enhance the overall productivity of the plant. The collected data has been analyzed through lean tools like Cause and Effect diagram and 5Why analysis. The Cause and Effect diagram is used for identifying the prime causes of Poor Material Handling (PMS) in assembly section. Further, the identified root causes are prioritized using Multi-Attribute Decision Making (MADM) approaches i.e. VIKOR and GRA under fuzzy environment. These approaches help in extracting the gaps that existing in between current and best practices in plant. The another 5Why tool is used for finding the root cause of unnecessary movement, environmental issues, and rework. The tools adopted in this phase are shown in Table 6.13.

TABLE 6.13: *Major Tools Used (Analyze phase).*

S.N.	**Tool used**
1	Cause and effect diagram
2	5Why
3	VIKOR
4	GRA

6.3.4.1 Cause and Effect Analysis

The purpose of cause and effect analysis is to perceive the number of flaws occurring in the product and define the actual source of flaws from which they transpired. With the help of managers, engineers, machine operators, and financial experts, the critical factors responsible for PMH are listed in the assembly section of case company. The possible factors are represented through the Cause and Effect diagram as shown in Figure 6.8. The causes are categorized into six areas such as man, material, method, store, environment, and personal. Each area is further explored with its conceivable sources of poor material handling and expressed in the form of a fishbone structure. The major identified zones and corresponding reasons responsible for PMH are:

- ***Machine:*** Poor space utilization, lack of maintenance.
- ***Store:*** Non-availability of rack system, bin card is not used, unavailability of bin system.
- ***Method:*** Improper flow of material, poor material testing.
- ***Environment:*** Poor indoor air quality.
- ***Material:*** Improper specifications of material.
- ***Personal:*** Violation of rules.

6.3.4.2 Critical to Poor Material Handling

The critical factors identified through Cause & Effect diagram are listed in Table 6.14 and further, prioritized them as per their criticality by using MADM approach. Ten critical to PMH are identified which are responsible for capacity waste in assembly section at selected industry. The main purpose of this section is to prioritize and estimate the critical to PMH for further improvement. An appropriate selection of critical to PMH is a crucial task due to the fact that wrong selected factors can degrade

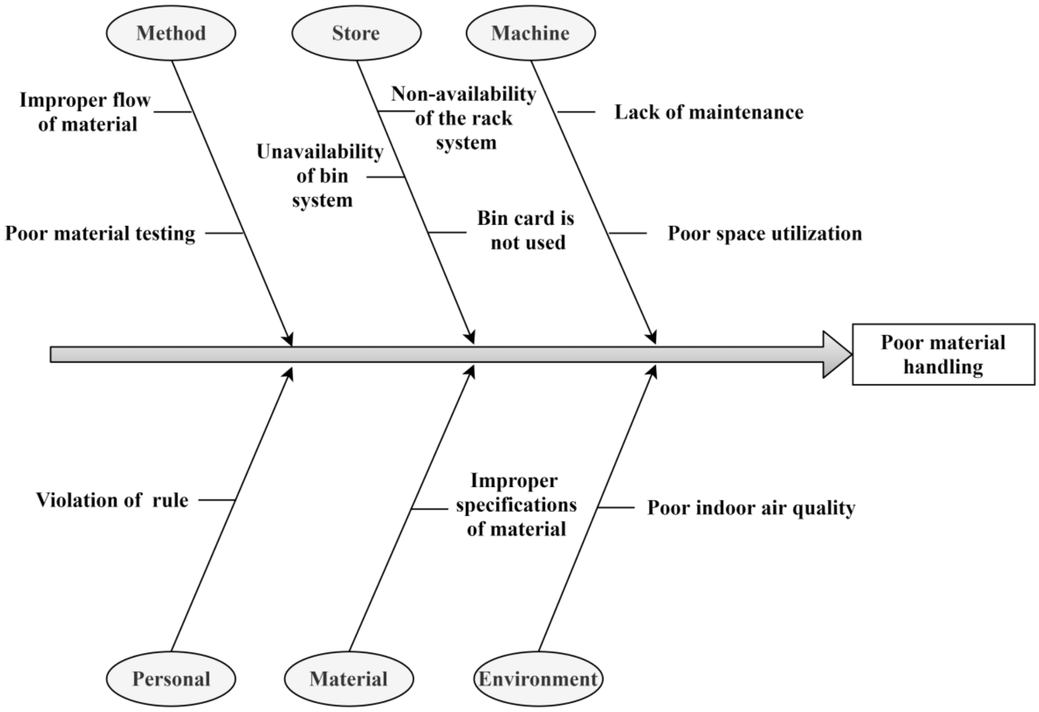

FIGURE 6.8: *Cause and effect diagram.*

the overall performance of a manufacturing system. Besides, the rate of manufacturing mostly depends on how much capacity waste arises during production runs. The selection of critical to PMH is also a time consuming and requires expertise and experience. So the process to evaluate such critical reasons can be very complex for managers, engineers, and machine operators. In such complex situation, the decision making could be a complex task and may require a large number of factors to be considered and analyzed. These issues can be effectively solved with decision making approach.

TABLE 6.14: *Critical factors to poor material handling.*

S.N.	**Critical factors to PMH**	**Abbreviation**
1	Improper flow of material	F1
2	Lack of maintenance	F2
3	Poor material testing	F3
4	Non-availability of the rack system	F4
5	Poor indoor air quality	F5

6	Unavailability of bin system	F6
7	Bin card is not used	F7
8	Improper specification of material	F8
9	Poor space utilization	F9
10	Violation of rules	F10

In this context, the key critical to PMH are identified with the help of expert's input and there is no clear harmony among the views of these decision makers. Therefore, it becomes essential to select optimum solution in terms of selecting critical factors using a MADM approach. MADM approaches are used to select the best possible factors from the large number of options for a set of selection parameters.

Table 6.15: *Evaluation Parameters for Selection of critical to PMH*

Parameters	**Notation**	**Description**
Environmental effect	C1	Environmental effect attempts to rate the work done for green concept adoption, energy used, and wastage at an assembly section. The environmental effects are significantly more incorporating than just energy. An energy efficient shop floor may not a green shop floor, but an environmental friendly shop floor will be energy efficient.
Safety	C2	Safe work station is the prime aspect because the safe way is the right way. The expenses of injuries and ill health can be unreasonably high for engineers in assembly section and machine section. Many workers are "important," who are seriously disrupted in production and efficiency and profitability by losses from injury or ill health.

Cost	C3	This includes all expenses for breakdown, repairing, preservation and other required activities, in order to fulfill other operating criteria over the entire service life. It is a key factor for examining the critical reasons of capacity waste.
Awareness	C4	Awareness provides the way to solve the critical issues on time and in accurate manner. This factor is highly responsible for selection of right critical to PMH in assembly section.
Measurement system	C5	In machine section and assembly section, the accurate measurement system helps in quality production and reduces the cost used for rework the components.

The numerous methods are reported under MADM category in literature. In this study, VIKOR and Grey Relational Analysis (GRA) methods are adopted because these can be effectively used for selecting the best alternatives. These MADM approaches mainly used in crisp decision applications and not provide accurate results in case of qualitative rating. During formation of decision matrix, human judgment of qualitative parameters is always subjective and indefinite. To overcome this issue, Fuzzy set theory could be integrated with selected approaches. The fuzzy MADM approach provides a more perfect depiction of the decision making process.

Evaluation parameters: With the help of expert's input and existing literature, five main parameters are selected for assessment of the critical to PMH in assembly section at selected industry (refer Table 6.15).

Steps of adopted methodology: In this phase, a hybrid approaches i.e. fuzzy VIKOR and fuzzy GRA are used for prioritization of critical to PMH in assembly section at selected site. The approach uses Modified Digital Logic (MDL) weights for inter-comparison among all parameters followed by fuzzy logic with VIKOR and GRA methods. The steps used in adopted methodology are as follows:

- *Step 1:* MDL weights (W_i) are estimated for all evaluation parameters. This offers the weights of different parameters. Here X_j is positive summation of each parameters and n is number of parameters.

$$W_j = \frac{X_j}{\sum_{j=1}^{n} X_j} \tag{6.26}$$

- *Step 2:* Linguistic variables and corresponding fuzzy numbers are defined. A set of fuzzy rates is required to compare the critical to PMH with respect to evaluation parameters. These fuzzy terms are allocated by the decision makers and accountable for intra parameters comparisons of the critical to PMH.

- *Step 3:* Formation of Decision Matrix
  Let assume $\mathscr{M}$ is the evaluation parameters and $\mathscr{N}$ is the critical to PMH during formation of decision matrix $\mathscr{L}$. The aggregating fuzzy rating for n parameters using k number of decision makers is represented as$\{\mathfrak{x}_{ijk} = \mathfrak{x}_{ij1}, \mathfrak{x}_{ij2}, \mathfrak{x}_{ij3}, \mathfrak{x}_{ij4}\}$. For $i = 1, 2, ..., \mathscr{M}; j = 1, 2, ..., \mathscr{N}; k = 1, 2, ..., k.\mathfrak{x}_{ijk}$ is estimated using Equation 6.27.

$$\begin{cases} \mathfrak{x}_{ij1} = minimum(k)\{\mathfrak{g}_{ijk1}\} \\ \mathfrak{x}_{ij2} = \frac{1}{k}\sum\{\mathfrak{g}_{ijk2}\} \\ \mathfrak{x}_{ij3} = \frac{1}{k}\sum\{\mathfrak{g}_{ijk3}\} \\ \mathfrak{x}_{ij4} = maximum(k)\{\mathfrak{g}_{ijk4}\} \end{cases} \tag{6.27}$$

  Hence the obtained decision matrix $\mathscr{L}$ is shown in Equation 6.28.

$$\mathscr{L} = \begin{bmatrix} \mathfrak{x}_{11} & .... & \mathfrak{x}_{1\mathscr{M}} \\ .... & .... & .... \\ \mathfrak{x}_{\mathscr{N}1} & .... & \mathfrak{x}_{\mathscr{N}\mathscr{M}} \end{bmatrix} \tag{6.28}$$

- *Step 4: Normalization of aggregating fuzzy rating*
  In this step, the aggregating fuzzy rating is normalized for making uniformity among all contrasting comparison quantities. Mathematically, the normalization

is carried out using the Eqs. (6.29) and (6.30) respectively.

$$\lambda_{ij} = (\frac{\mathfrak{r}_{ij1}}{\mathfrak{r}^{+}_{ij1}}, \frac{\mathfrak{r}_{ij2}}{\mathfrak{r}^{+}_{ij2}}, \frac{\mathfrak{r}_{ij3}}{\mathfrak{r}^{+}_{ij3}}, \frac{\mathfrak{r}_{ij4}}{\mathfrak{r}^{+}_{ij4}}) \;\; j \in \pounds \tag{6.29}$$

$$\lambda_{ij} = (\frac{\mathfrak{r}^{-}_{ij1}}{\mathfrak{r}_{ij1}}, \frac{\mathfrak{r}^{-}_{ij2}}{\mathfrak{r}_{ij2}}, \frac{\mathfrak{r}^{-}_{ij3}}{\mathfrak{r}_{ij3}}, \frac{\mathfrak{r}^{-}_{ij4}}{\mathfrak{r}_{ij4}}) \;\; j \in \pounds^{'} \tag{6.30}$$

where $\mathfrak{r}^{+}_{ij4}$ = maximum $\mathfrak{r}_{ij4}$, $j \in \pounds$; $\mathfrak{r}^{-}_{ij1}$= minimum $\mathfrak{r}_{ij1}$, $j \in \pounds^{'}$; j represents higher desired value and $\pounds^{'}$ represents lower desired value.

- *Step 5: Defuzzification*

  Defuzzification is done to get the crisp values for each parameters corresponding to each factors. This provides a quantitative value for the linguistic variables and fuzzy numbers assigned based on the verbal reasoning of the decision makers. The Equation 6.31 is used for estimation of crisp values.

$$\mathscr{N}_{ij} = Defuzz(\mathfrak{r}_{ij}) = \frac{(\int \lambda(\mathfrak{r}).\mathfrak{r}d\mathfrak{r})}{(\int \lambda(\mathfrak{r}).d\mathfrak{r})}$$

$$\mathscr{N}_{ij} = \frac{\int_{\mathfrak{r}_{ij1}}^{\mathfrak{r}_{ij2}} \{\frac{(\mathfrak{r}-\mathfrak{r}_{ij1})}{(\mathfrak{r}_{ij2}-\mathfrak{r}_{ij1})}\}.\mathfrak{r}d\mathfrak{r} + \int_{\mathfrak{r}_{ij2}}^{\mathfrak{r}_{ij3}} \mathfrak{r}d\mathfrak{r} + \int_{\mathfrak{r}_{ij3}}^{\mathfrak{r}_{ij4}} \{\frac{(\mathfrak{r}_{ij4}-\mathfrak{r})}{((\mathfrak{r}_{ij4}-\mathfrak{r}_{ij3})}\}.\mathfrak{r}d\mathfrak{r}}{\int_{\mathfrak{r}_{ij1}}^{\mathfrak{r}_{ij2}} \{\frac{(\mathfrak{r}-\mathfrak{r}_{ij1})}{(\mathfrak{r}_{ij2}-\mathfrak{r}_{ij1})}\}.d\mathfrak{r} + \int_{\mathfrak{r}_{ij2}}^{\mathfrak{r}_{ij3}} d\mathfrak{r} + \int_{\mathfrak{r}_{ij3}}^{\mathfrak{r}_{ij4}} \{\frac{(\mathfrak{r}_{ij4}-\mathfrak{r})}{((\mathfrak{r}_{ij4}-\mathfrak{r}_{ij3})}\}.d\mathfrak{r}}$$

$$\mathscr{N}_{ij} = \frac{-\mathfrak{r}_{ij1}\mathfrak{r}_{ij2} + \mathfrak{r}_{ij3}\mathfrak{r}_{ij4} + \frac{1}{3}(\mathfrak{r}_{ij4} - \mathfrak{r}_{ij3})^2 + \frac{1}{3}(\mathfrak{r}_{ij2} - \mathfrak{r}_{ij1})^2}{-\mathfrak{r}_{ij1} - \mathfrak{r}_{ij2} - \mathfrak{r}_{ij3} + \mathfrak{r}_{ij4}} \tag{6.31}$$

- **Steps of VIKOR Approach**-*Step 6: Identify beneficial and non-beneficial parameters*

  Beneficial parameter- Whose larger value is desired

  Non-beneficial parameter - Whose smaller value is desired,

- *Step 7: Find best and worst value of each parameter*

$$Best(X_i^{+}) = \begin{cases} max(X_{ij}) & \text{for beneficial} \\ min(X_{ij}) & \text{for non-beneficial} \end{cases} \tag{6.32}$$

$$Worst(X_i^-) = \begin{cases} min(X_{ij}) & \text{for beneficial} \\ max(X_{ij}) & \text{for non-beneficial} \end{cases} \tag{6.33}$$

- *Step 8: Compute utility measure* (S_i) *and regret measure* (R_i)

$$S_i = \sum_{j=1}^{m} (W_j \times \frac{(X_i^+ - X_{ij})}{(X_i^+ - X_i^-)}) \tag{6.34}$$

$$R_i = max_j(W_j \times \frac{(X_i^+ - X_{ij})}{(X_i^+ - X_i^-)}) \tag{6.35}$$

- *Step 9: Calculate VIKOR index* (Q_i)

$$Q_i = v \times \frac{(S_i - S^*)}{(S^- - S^*)} + (1 - v) \times \frac{(R_i - R^*)}{(R^- - R^*)} \tag{6.36}$$

$$S^- = max_i S_i \tag{6.37}$$

$$S^* = min_i S_i \tag{6.38}$$

$$R^- = max_i R_i \tag{6.39}$$

$$R^* = min_i R_i \tag{6.40}$$

- **Steps of GRA approach**-*Step 6: Normalization of crisp matrix*

  In this step, the obtained crisp matrix is converted into normalized matrix using Equation 6.41. Here, $\mathfrak{X}_i^*$ represents the normalized value of the critical to PMH of "i" with respect to evaluation parameter"*".

$$\mathfrak{X}_i^* = \frac{(\S_i - min(\S_i))}{(max(\S_i) - min(\S_i))} \tag{6.41}$$

- *Step 7: Formation of Deviation Sequence Matrix*

  In the second step of the grey relational analysis, the deviation sequence (Θ_i) is calculated using Equation 6.42.

$$\Theta_i = \| max(\mathfrak{X}_i^*) - \mathfrak{X}_i^* \| \tag{6.42}$$

Step 8: Estimation of grey relational coefficients

In this step, the grey relational coefficient (ϱ_i) is calculated using Equation 6.43. Here, $\Theta_m in$ represents the minimum value of the deviation sequence and $\Theta_m ax$ designates the maximum value of the deviation sequence. The value of ϱ is considered as 0.5.

$$\varrho_i = \frac{(\Theta_{min} + \varrho.\Theta_{max})}{(\Theta_i + \varrho.\Theta_{max})} \tag{6.43}$$

- *Step 9: Ranking as per grey relational grade* In this step, the grey relational grade ($\mathfrak{Y}_i$) is estimated using Equation 6.44. Here "n" is the number of evaluation parameters for selection of critical to PMH at selected case industry.

$$\mathfrak{Y}_i = \frac{1}{n \sum_{i=1}^{n} \varrho_i} \tag{6.44}$$

After selection of evaluation parameters, the next step is to prioritize these parameters, as to which of these parameters have more impact on the identified critical to PMH. MDL method is used to prioritize these parameters and in order to compare these individual parameters, numeric priority values are assigned on a scale of 1-3. The numeric value 1, 2, and 3 signifies the less, equal, and more significant parameters, respectively. Table 6.16 shows the relative decision matrix formed on the basis of pair-wise comparison and the MDL weights are calculated using Equation 6.26. The ranking of evaluation parameters exhibit that cost is the most dominant parameter for the selection of critical to PMH, while measurement system emerged as the least dominant parameter.

TABLE 6.16: *Weights of Evaluation Parameter using MDL.*

Parameters	**C1**	**C2**	**C3**	**C4**	**C5**	**MDL weight**	**Rank**
C1	2	3	1	1	3	0.2	3

C2	1	2	1	1	3	0.15	4
C3	3	3	2	3	3	0.3	1
C4	3	3	1	2	3	0.25	2
C5	1	1	1	1	2	0.1	5

Further, fuzzy hypothesis analysis is used as per suggestion of decision makers for the comparison of all critical to PMH with respect to evaluation parameters. Linguistic variables are used for this problem and further converted them into corresponding fuzzy numbers (refer Table 6.17). The highest range is termed Extremely High (EH) and the least is termed as Extremely Low (EL). During brainstorming session with decision makers, the linguistic decision matrix in context of VIKOR and GRA approaches were filled as shown in Table 6.18 and Table 6.19, respectively. Here a single decision matrix is formed rather than having a separate decision matrix for each selected decision maker. Thereafter, fuzzy values are obtained and converted into crisp values using Equation 6.31 for VIKOR and GRA approach as shown in Table 6.20 and Table 6.21, respectively.

TABLE 6.17: *Linguistic variables and corresponding fuzzy number.*

Linguistic Variable	**Fuzzy Number**
Extremely High (EH)	(0.8,0.9,1.0,1.0)
Very High (VH)	(0.7,0.8,0.8,0.9)
High (H)	(0.5,0.6,0.7,0.8)
Above Average (AA)	(0.4,0.5,0.5,0.6)
Average (A)	(0.2,0.3,0.4,0.5)
Very Low (VL)	(0.1,0.1,0.2,0.3)
Extremely Low (EL)	(0.0,0.0,0.1,0.2)

TABLE 6.18: *Linguistic Decision Matrix of critical to PMH (for VIKOR approach).*

Parameters	Critical to PMH									
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
C1	H	AA	VL	VH	H	VH	H	VL	H	EL
C2	AA	H	H	EL	A	VL	VL	VH	A	EH
C3	A	VL	VL	EH	H	VH	H	EL	AA	EL
C4	AA	AA	H	EL	VL	VL	VL	VH	A	EH
C5	AA	AA	H	EL	A	VL	VL	VH	A	VH

TABLE 6.19: *Linguistic Decision Matrix of critical to PMH (for GRA approach).*

Parameters	Critical to PMH									
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
C1	A	AA	VH	EL	A	VL	A	VH	A	EH
C2	AA	A	A	EH	H	VH	VH	VL	H	EL
C3	H	VH	VH	EL	A	VL	A	EH	AA	EH
C4	AA	AA	A	EH	VH	VH	VH	VL	H	EL
C5	AA	AA	A	EH	H	VH	VH	VL	H	VL

TABLE 6.20: *Crisp Values for Assigned Fuzzy Rates (for VIKOR approach).*

Critical to PMH	Evaluation Parameters				
	C1	**C2**	**C3**	**C4**	**C5**
F1	0.741667	0.683333	0.441667	0.683333	0.683333
F2	0.683333	0.741667	0.383333	0.683333	0.683333
F3	0.383333	0.741667	0.383333	0.741667	0.741667
F4	0.983333	0.177778	0.944444	0.177778	0.177778
F5	0.741667	0.441667	0.741667	0.383333	0.441667
F6	0.983333	0.383333	0.983333	0.383333	0.383333
F7	0.741667	0.383333	0.741667	0.383333	0.383333
F8	0.383333	0.983333	0.177778	0.983333	0.983333

F9	0.741667	0.441667	0.683333	0.441667	0.441667
F10	0.177778	0.944444	0.177778	0.944444	0.983333

Table 6.21: *Crisp Values for Assigned Fuzzy Rates (for GRA approach)* .

Critical to PMH	**Evaluation Parameters**				
	C1	**C2**	**C3**	**C4**	**C5**
F1	0.441667	0.683333	0.741667	0.683333	0.683333
F2	0.683333	0.441667	0.983333	0.683333	0.683333
F3	0.983333	0.441667	0.983333	0.441667	0.441667
F4	0.177778	0.944444	0.177778	0.944444	0.944444
F5	0.441667	0.741667	0.441667	0.983333	0.741667
F6	0.383333	0.983333	0.383333	0.983333	0.983333
F7	0.441667	0.983333	0.441667	0.983333	0.983333
F8	0.983333	0.383333	0.944444	0.383333	0.383333
F9	0.441667	0.741667	0.683333	0.741667	0.741667
F10	0.944444	0.177778	0.944444	0.177778	0.383333

The crisp values from Table 6.20, used for VIKOR approach for estimating the rank of critical to PMH using Eqs. (6.32) to (6.40). Table 6.22 exhibits the equivalent rank indices and VIKOR ranks for the critical to PMH in assembly section. Besides, the crisp values obtained from Table 6.21 used further for estimating GRA ranking of critical to PMH using Eqs. (6.41) to (6.44). Table 6.23 shows the grey rational grades and corresponding GRA ranking of the critical to PMH in assembly section.

Table 6.22: *VIKOR Ranking of critical to PMH.*

Critical to PMH	**S**	**R**	**Q**	**Ranking**
F1	0.575517	0.201724	0.618227	6
F2	0.622586	0.223448	0.680628	7
F3	0.722414	0.223448	0.732287	8

F4	0.014483	0.014483	0	1
F5	0.29569	0.09	0.277767	4
F6	0.127586	0.063793	0.144882	2
F7	0.277586	0.09	0.268399	3
F8	0.948966	0.3	0.983583	9
F9	0.335517	0.111724	0.336421	5
F10	0.98069	0.3	1	10

TABLE 6.23: *GRA Ranking of critical to PMH.*

Factors	**Evaluation Parameters**					**GRG**	**Ranking**
	C1	**C2**	**C3**	**C4**	**C5**		
F1	0.60416	0.57312	0.41666	0.57312	0.5	0.53341	6
F2	0.44342	0.42647	0.33333	0.57312	0.5	0.45527	7
F3	0.33333	0.42647	0.33333	0.42647	0.35643	0.37520	8
F4	1	0.91195	1	0.9119	0.88524	0.94182	1
F5	0.60416	0.625	0.60416	1	0.55384	0.67743	4
F6	0.6621	1	0.6621	1	1	0.8648	2
F7	0.60416	1	0.60416	1	1	0.84166	3
F8	0.33333	0.40166	0.34441	0.40166	0.33333	0.36288	9
F9	0.60416	0.625	0.44342	0.625	0.55384	0.57028	5
F10	0.34441	0.33333	0.34441	0.33333	0.33333	0.33776	10

The relative analysis of both MADM approaches shows that the results attained by VIKOR and GRA approach are precisely same. The obtained ranks of critical to PMH represent that five factors are the most critical for causing extensive capacity waste and these are shown in Table 6.24. All these factors need instant observing in the next phase.

TABLE 6.24: *Most critical factors to PMH.*

S.N.	Critical to PMH
1	Non-availability of rack system
2	Poor indoor air quality
3	No bin system used
4	Not used the bin card facility
5	Poor space utilization

6.3.4.3 5Why Analysis for Environmental Issues, Unnecessary Movement, and Rework

5Why analysis aims to simply ask the question "Why" enough times until to get all possible symptoms of the problem and down to the root cause. This tool provides in-depth analysis for finding the root cause of the problem and focuses only on concerning reasons. In the present case, the project team discusses with section heads, machine operators, and workers for exploring the root causes of environmental issues, unnecessary movement, and rework. Figure 6.9 exhibits the prime root causes of environmental issues. Here, it is observed that poor coating at the floor and non-availability of the air cleaner system are the main responsible factors for the high IAQ index inside the selected case company. The project team conducts 5Why analysis for finding the root causes of unnecessary movement issues and results are shown in Figure 6.10. In this analysis, a faulty plant layout is found as the root cause of unnecessary movement. The same analysis is also done for finding the root causes of rework and outcomes are shown in Figure 6.11. This figure reveals that the accumulation of burrs and chips founds the prime cause of rework required at the finished components. The above three issues of low CU are tackled in the improve phase by providing appropriate solutions.

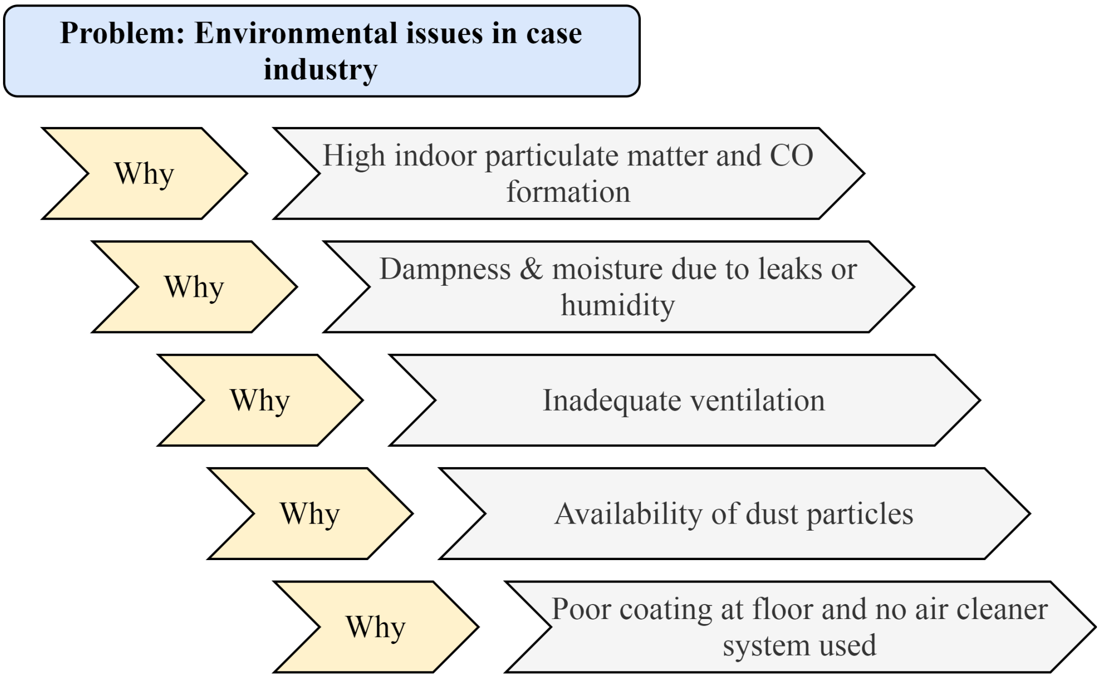

Figure 6.9: *5 Why analysis for environmental issues.*

6.3.4.4 Conclusions of Analysis Phase

- Fuzzy MADM approaches were successfully applied in this phase to prioritize the major factors responsible for PMH in the assembly section.
- After analysis phase, it became noticeable that out of ten critical to PMH, only five are the most critical to PMH (refer Table 6.20).
- Cause & Effect Diagram shows the possible reasons of PMH and found that main problem of material handling in assembly section occurs due to storage of material and equipment without rack, bin, and bin card system.
- 5 Why analysis exhibits that lack of awareness about proper space utilization is the main root of PMH in the assembly section of the plant.
- This phase provides crucial critical to PMH and these should be taken into improve phase for getting estimated breakthroughs in PMH improvement.

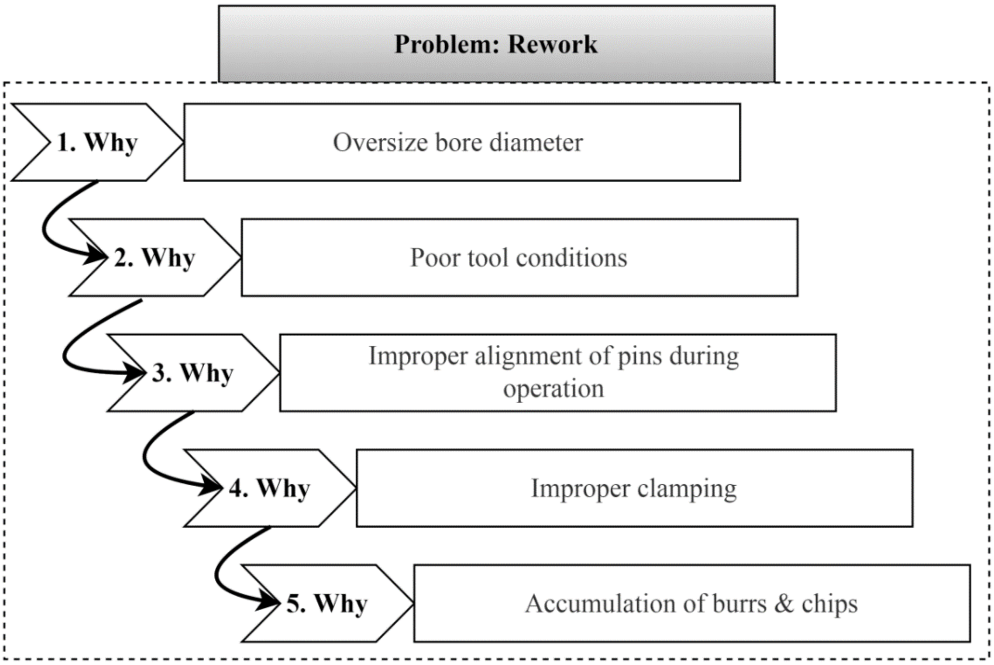

FIGURE 6.10: *5Why analysis for rework.*

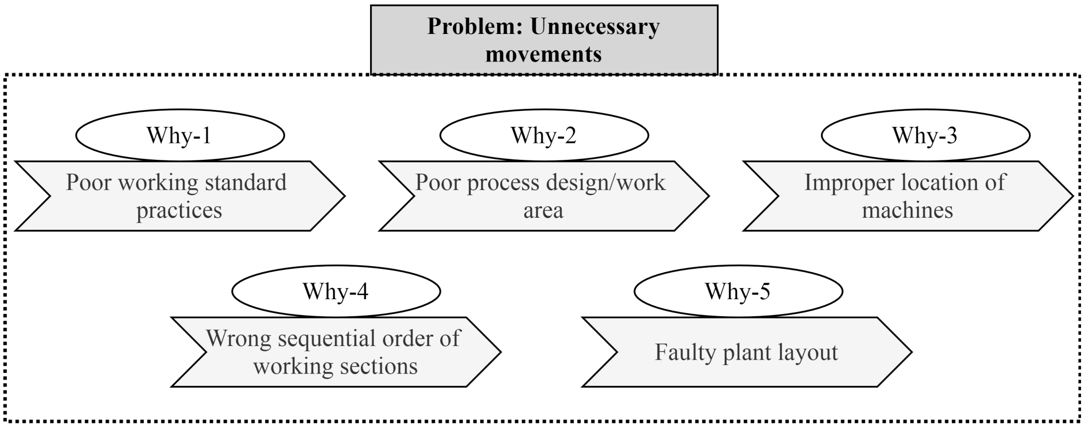

FIGURE 6.11: *5Why analysis for unnecessary movement.*

- With the help of cause & effect diagram and 5 Why analysis, the list of possible root causes of low CU level at the selected case company are shown in Table 6.25.

Table 6.25: *Identified possible root causes.*

S.N.	**Encountered problem**	**Critical areas**	**Root causes**
1	Poor material handling	Assembly section	Non-availability of the rack system No bin system used Not used the bin card facility
2	High IAQ	Overall plant and welding section	Poor coating at the floor and no air cleaner system used
3	Unnecessary movement	Overall plant	Faulty plant layout
4	Rework	Tapping & Drilling Section	Accumulation of burrs & chips and improper clamping

6.3.5 Improve Phase

In this phase, the possible solutions have been identified, implemented and tested in the plant. Each proposed solution have been implemented in such a way that a proper recording can be done to compare with past results. The required training to employee and managers has been provided time to time for successful implementation of LSS. Besides, appropriate tools like 6S, kaizen and future value stream mapping are adopted for development the improvement actions related to productivity and environmental aspects. Table 6.26 reveals the major tools used in the improve phase for identifying the suitable solutions of highlighted issues of low CU within the plant.

Table 6.26: *Major Tools Used (Improve phase).*

S.N.	**Tool used**
1	6S
2	Brainstorming
3	Kaizen
4	Before-and-after analysis

6.3.5.1 Implementation of 6S Technique in Assembly Section

The brainstorming session with experts provides suggestions to used 5S techniques for reducing the critical to PMH in the assembly section. But in the present case, with the 5S tool, sustainability was also incorporated for considering the improvement in the environmental point of view. Here 6S stands for Seri, Seiton, Seso, Seiketsu, Shitsuke, and SeJizoku kanosei which means sort, streamline, shine, standardizes, sustain, and sustainability, respectively. During Seri step, the parts and equipment are sorted out as per their used frequency. After sorting, the resetting of all parts and equipment is done to streamline the flow of material. The scenario of the assembly section before and after 6S implementation is shown in Figure 6.12. This tool helps in time-saving of 139 minutes in searching the components to assemble one product. Further, the work area is cleaned properly to make a healthy working environment and minimize air pollution. The work standards are finalized like regular checking of the first aid kit and updating the environmental rules for sustainability. Implementation of the 6S technique decreases the losses in productivity by providing a clean working environment and saves energy losses. A 6S audit sheet is prepared to collect the facts of the manufacturing company as shown in Table 6.27. In this sheet, each question is having two possible responses as YES or NO. During the evaluation of facts from the manufacturing company, if any elements obtain NO response, then more attention needs to be given towards that specific element to convert the response into YES. After implementing all the suggested action plans, it ensures that each element from S-sort to S-sustainability in the audit sheet gets the YES response.

Finally, the 6S audit sheet provides a conformation of taken lean initiatives in the company for optimal utilization of resources with sustainable benefits.

(a) (b)

FIGURE 6.12: *(a) Assembly section before 6S adoption; (b) Assembly section after 6S adoption.*

TABLE 6.27: *6S audit sheet*

6S activities	Yes	No
Sort		
Are components used frequently placed at front area in store room?	✓	
Are heavy components positioned at lower rack in storage area?	✓	
Are consumables and non-consumables items segregated properly?	✓	
Systematic arrangement		
Are all waste boxes properly covered when not in used?	✓	
Are all materials, components and equipment located at designated place in sequential order?	✓	
Shine		
Are machines and equipment free from any leakage and dust?	✓	
Are ventilation systems clean and unhindered?	✓	

Standardized		
Are standard of procedure for each job available with each machine?	✓	
Are employees aware about safety precaution in working area?	✓	
Sustain		
Are health, environment, safety and production management activities integrated with standard of procedure of job?	✓	
Sustainability		
Are the first aid kits easily available at each work station?	✓	
Are the dust particles emitted during manufacturing process estimated?	✓	
Are the environmental rule and regulations strictly followed by the organization?	✓	

6.3.5.2 Kaizen

For reducing the environmental impacts and rework, the significant kaizens are implemented in the plant as shown in Table 6.28. There was a huge emission of fumes and hazardous gases during the welding process. Besides, a lot of rework was required especially in drilling and tapping sections.

TABLE 6.28: *Adopted Kaizens for minimizing rework and environmental issues.*

Kaizen no.	Problem	Kaizen considered
1	Environmental issues (high IAQ index and CME)	Through epoxy flooring inside the plant, the problem of dust has been removed. To convert the CO into the fresh air, installed a machine called Kemper in the welding section.

2	Rework	Replace the drill bit at a specific time interval. Do proper clamping of a workpiece. Remove the chip and burr formation.

Two kaizen activities are implemented to improve the operational and environmental aspects throughout the plant. As per the implication of kaizen, the coating of epoxy material is done on the floor throughout the selected plant and provides high performance, smooth, and durable surface. It can also withstand heavy loads, impact shock, and high amplitude vibrations. Further, it helps in the reduction of downtime of machines and health issues of employees by providing a clean and safe working environment throughout the plant. The comparisons between before and after the epoxy coating on the floor are shown in Figure 6.13. To convert the high emission of CO, fumes, or gases into the fresh air in the welding section, a machine called Kemper is installed as suggested by the project team. The top management of the case company gets ready with this suggestion and implemented subsequently. This machine is having the capability to covert the welding fumes or carbon monoxide gas into fresh air resulting in environmental sustainability. The welding section before and after the implementation of Kaizen 1 is shown in Figure 6.14.

6.3.5.3 Plant Layout: Before-and-After Analysis

To find out the main reason of critical factor i.e. unnecessary movement, a brainstorming session among selected experts were held. The outcome of brainstorming session shows that faulty plant layout is the prime reason of unnecessary movement within the plant. The existing plant layout was framed and analyzed that the processes were not correctly aligned and resulted in unnecessary movement of worker and materials. The movement of worker and materials have been tracked and found that the total distance of 325 feet travelled from starting to end process steps. The tracked movement of worker included the distance in tool searching, material searching and

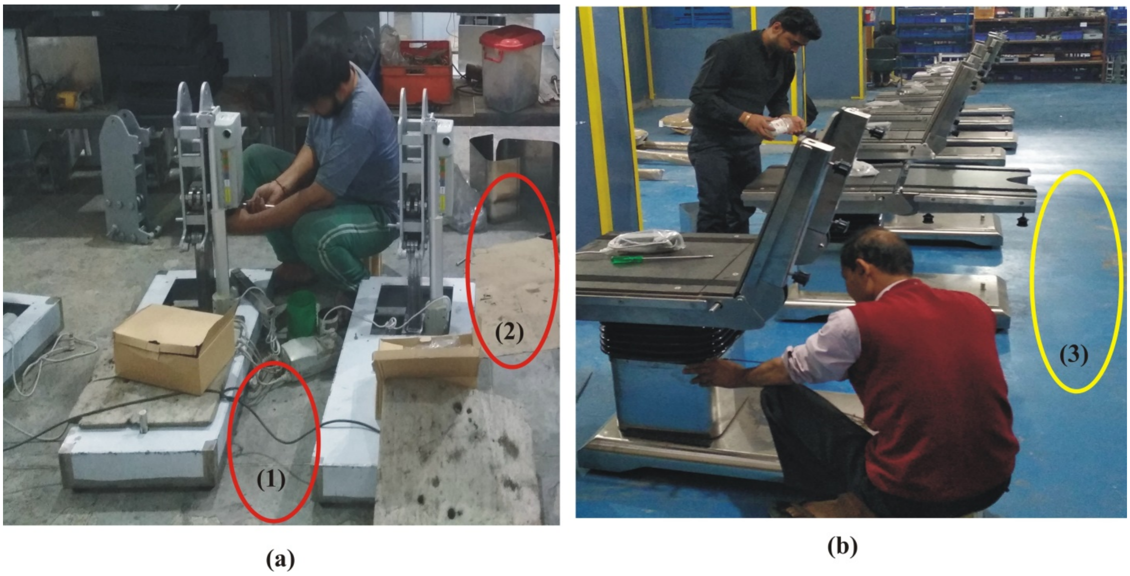

FIGURE 6.13: *(a) Plant floor before epoxy coating (b) Plant floor after epoxy coating.*

FIGURE 6.14: *(a) welding section before implementation (b) welding section after implementation.*

transporting the semi-finished components as well as raw material movements. The existing plant layout of selected case company are shown in Figure 6.15. After analyzing the existing layout, it is observed that location of individual section and machines inside them were not appropriates. The possible modification in existing layout has been done and re-locates the machines and equipment in each section. The modified plant layout is shown in Figure 6.16, which shows that the travelling distance of workers are reduced to 120 feet from 325 feet.

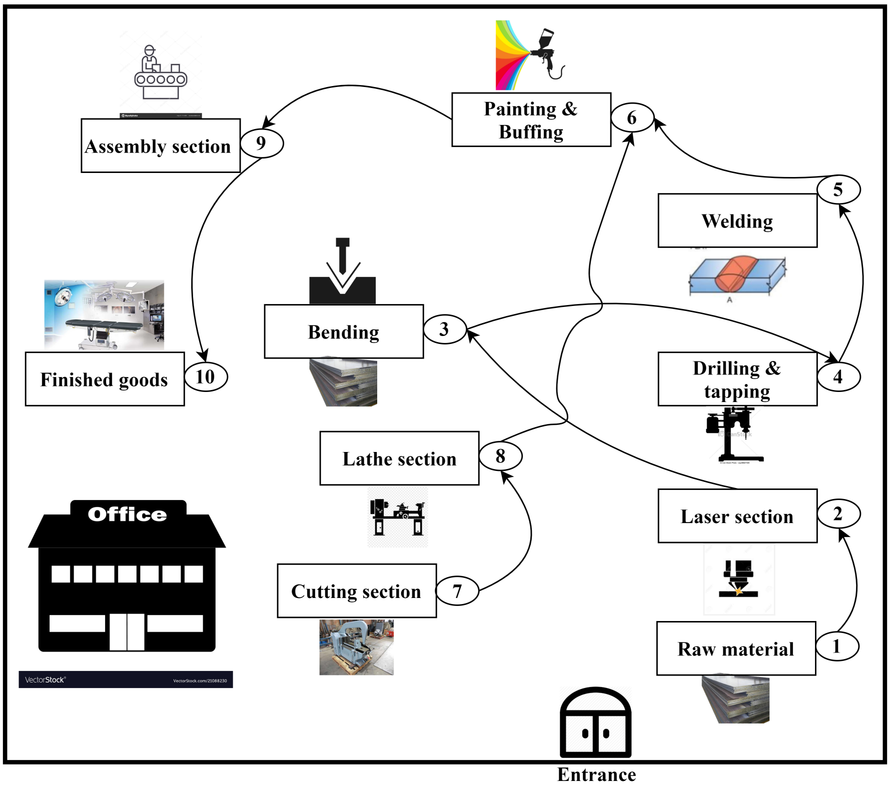

FIGURE 6.15: *Plant layout before analysis.*

6.3.5.4 Conclusions of Improve Phase

The main conclusions from improve phase are:

- To reduce the PMH in assembly section, 6S as an improvement tool is suggested and successfully installed the rack, bin and bin card system for storage of the material.
- To improve IAQ level of the plant, Brainstorming has been used as improvement tool and suggested for coating of epoxy material over the floor at whole plant.
- To minimize the high emission of CO, fumes or gases during welding process, Again Kaizen was applied for installing a machine called Kemper in welding section.
- Before-and-after analysis has been successfully applied to modify the plant layout to reduce the unnecessary movement throughout the plant.

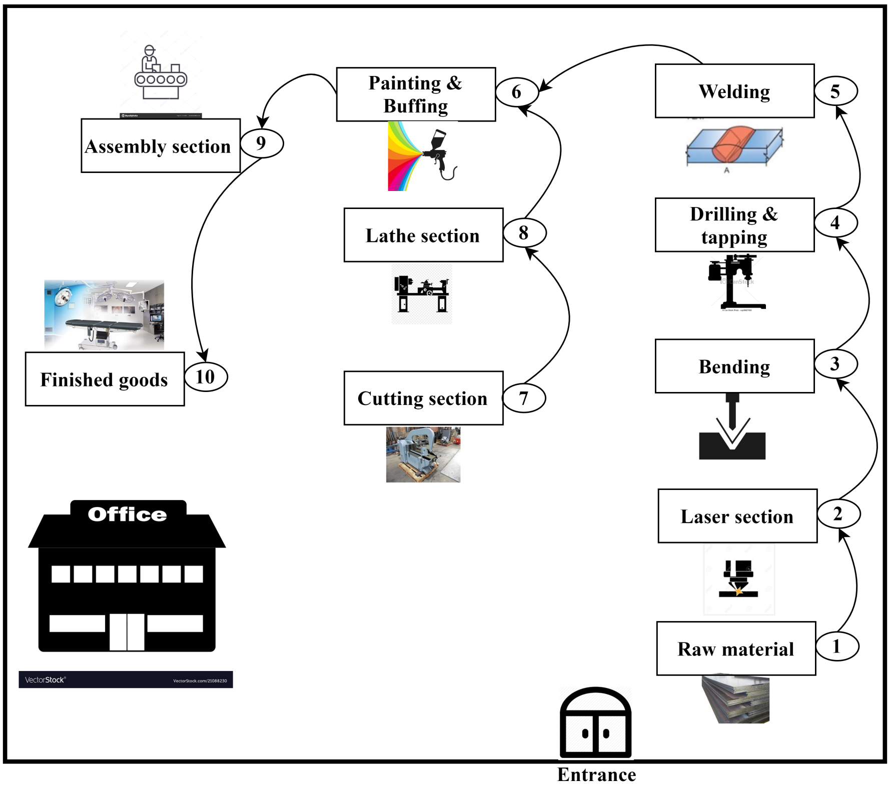

FIGURE 6.16: *Plant layout after analysis.*

- To reduce the rework and time taken in searching the components, suitable kaizen has been suggested as improvement measure and implemented successfully.

6.3.6 Control Phase

In order to support improvement activities, the changes incorporated in business must be reported. The control process also ensures that the gains acquired after the adopting improvement steps are maintained correctly after the completion of project. The improved results must be communicated to all employees who are involved during the implementation process and a flowchart is to be developed to clearly describe the role and tasks of each individual in sustaining the development. Design evaluation and performance measurement models are developed to continuously monitor the improvement activities and to track the improvements. In main housing of firm, the tools adopted in the control phase is shown in Table 6.29.

TABLE 6.29: *Major Tools Used (Control phase).*

S.N.	Tool used
1	Future EVSM
2	Revised DPMO
3	Improvement metrics

6.3.6.1 Future Environmental Value Stream Mapping

The future EVSM is the process based on convinced improvements that are identified in the current state mapping. The future EVSM ensures improvement after the successful execution of suggested solutions within the plant. It is drawn with the representation of important metrics like cycle time, uptime, lead time, environmental footprints, and capacity waste. The future EVSM of improved process of OT table is shown in Figure 6.17.

6.3.6.2 Revised of Defects Per Million Opportunities

The case industry has implemented the suggested solutions for reducing poor material handling, unnecessary movement of men and material, and improving IAQ at assembly sections as well as whole plant. After successful implementation of ELSS approach, ten months of production data of case industry are collected to authenticate the alterations made for attaining the required specifications. The mean of production data is improved to 201 products with a standard deviation of 3.5401. The DPMO at improved CU level of OT table is computed as 48951.44 PPM and corresponding sigma level also improved as 3.15. The analysis shows that variation is declined reliably and the selected process metrices improved significantly.

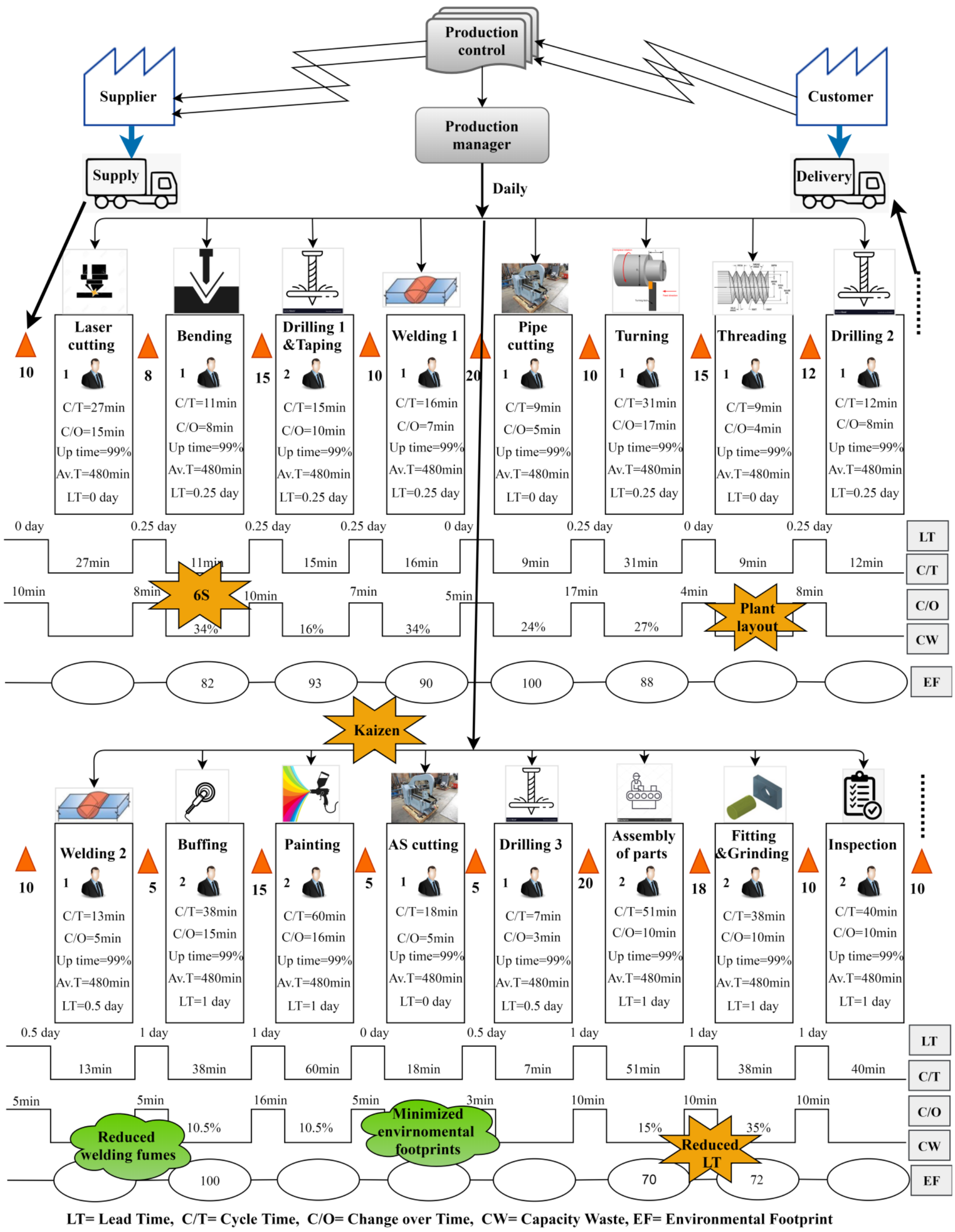

FIGURE 6.17: *Future EVSM .*

6.3.6.3 Improvement Metrics

The top management of the case organization agreed to implement the suggested solutions to improve the CU level of the plant. After ten months of implementation of the suggested solutions, again the data is collected and analyzed. The process metrics evaluation after the analysis is shown in Table 6.30. From the analysis, it is observed that the CU of the plant increased by 20.5% and unnecessary movement of men and material decreased by 63.08%. In the context of environmental aspects, performance improvement in the IAQ level, and CME is measured and noted in Table 6.31. This result shows that the IAQ index of the plant is decreased from 156.87 $(\mu g)/\ m^3$ to 86.85 $(\mu g)/\ m^3$. The re-assessed data exhibits that with an increment of CU level, DPMO and production of the plant are increased significantly (refer to Table 6.32).

TABLE 6.30: *Process metrices evaluation before and after implementation*

Process metrices	**Total Count units (Before).**	**Total Count units (After)**	**Performance improvement (%)**
Total Cycle Time	565 min.	395 min.	30.08%
Total Change over Time	204 min.	148 min.	27.45%
CU	59.25%	74.3%	20.25%
Unnecessary movement	325 feet	120 feet	63.08%
Total Lead Time	11.5 days	7.25 days	37%

TABLE 6.31: *Improvement analysis in indoor air quality level.*

Section	**Operation held**	**IAQ** (PM_{10}) **before project**	**IAQ** (PM_{10}) **after project**
Welding Section	TIG, MIG, arc welding	140 CME = 33 PPM	90 CME = 1.5 PPM
Bending Section	Sheet metal bending	145	82
Machine Section	Turning, threading	160	88

Material Cutting Section	Cutting	160	100
Grinding Section	Major surface finishing	130	72
Buffing and Painting Section	Shining, painting	200	100
Tapping & Drilling Section	Hole making	175	93
Assembly Section	Assemble the parts	145	70
IAQ of the overall plant		156.87	86.85

TABLE 6.32: *Project Gains (Before and after).*

Parameter	**Before project**	**After project**	**Improvement**
DPMO	309523	48951.44	84.18%
IAQ level at overall plant	156.87 $(\mu g)/\ m^3$	86.85 $(\mu g)/\ m^3$	44.5%
CME at welding section	33 PPM	1.5 PPM	95.45%
Production per month	160 units	201 units	15.18%

6.3.6.4 Conclusion (Control Phase)

- After completion of LSS project, the selected case company was able to enhance its productivity by minimizing rework, unnecessary movement, and PMH. The CU level of OT table is improved from 59.25% to 74.3% through effective implementation of given suggestions. Also, the rejection rate of parts dropped down to 2 units from 24 units, resulted minimize DPMO of OT table reduced from 309523 to 48951.44.

- The improvements were obtained in terms of process metrics like cycle time decreases by 30.08%, lead time decreases by 37%, 63.08% reduction in unnecessary movement, and 27.45% reduction in change over time.

- The IAQ level of overall plant has been reduced from 156.87 to 86.85 contributing 44.5% improvement and CME reduced from 33 PPM to 1.5 PPM subsidizing 95.5% improvement. Overall, the production level per annum increases by 15.18%.

6.3.6.5 Overall Result Assessment

The major results achieved during LSS implementation in selected case industry are shown in an integrated manner as following:

- In the present research, the assembly section is selected the optimal project for LSS implementation.

- IF Modified TOPSIS-VIKOR analysis evident that assembly section comprises of maximum wastage and is the main domain of low CU.

- Pie chart reveals that poor material handling, unnecessary movement, environmental issues and reworks are main responsible for low CU and they considered for further improvement in the present case.

- From the collected data, it has been found that The DPMO of OT table is improved by 84.18% (309523 PPM reduced to 48951.44 PPM).

- Current EVSM of existing plant exhibits that total cycle time, total change over time, distance covered due to unnecessary movement, total lead time, and total CU found to be 565 minute, 204 minute, 325 feet, 11.5 days, and 59.25% respectively. Also indoor air quality of whole plant is found 156.87 $(\mu g)/\ m^3$ and carbon monoxide emission in welding section founds 33 PPM.

- Fuzzy MADM approaches were successfully applied in analyze phase to prioritize the major factors responsible for critical to PMH in assembly section.

- After analysis, it became noticeable that out of ten critical to PMH, only five were actually responsible for PMH of OT table at selected case company. These were non-availability of rack system, poor indoor air quality, no bin system used, not used the bin card facility, and poor space utilization.

- To reduce the poor material handling in assembly section, 6S technique as an improvement tool is suggested and successfully installed the rack, bin and bin card system for storage of the material.

- To improve IAQ level of the plant, Brainstorming has been used as improvement tool and suggested for coating of epoxy material over the floor at whole plant.

- To minimize the high emission of CO, fumes or gases during welding process, Again Kaizen was applied for installing a machine called Kemper in welding section.

- Before-and-after analysis has been successfully applied to modify the plant layout to reduce the unnecessary movement throughout the plant.

- To reduce the rework and time taken in searching the components, appropriate Kaizens are suggested as improvement measure and implemented successfully.

- At completion of LSS project, the selected case company was able to enhance DPMO by minimizing rework, unnecessary movement, and PMH. The overall CU rate is increased from 59.25% to 74.75% through effective implementation of the given suggestions. Also, the rejection rate of parts dropped down to 2 units from 24 units, resulted minimize DPMO of OT table reduced from 309523 to 48951.44.

- The IAQ level was reduced from 156.87 to 86.85 contributing 44.5% improvement and CME reduced from 33 ppm to 1.5 ppm reflecting 95.5% improvement.

6.4 Managerial Implications

The LSS framework which is adopted in the current case study will facilitate the organizations to implement the LSS program within the organization in a practical manner. The framework is constructed with a rationale that the Lean process reduces waste and Six Sigma eliminates the process variations logically in line with environmental initiatives like decrease indoor pollutions, energy consumption, etc. During the implementation of LSS framework, the organizations should be attentive about the existing organizational culture towards environmental initiatives. The organizations may use the EVSM to draw the entire process in the quantified value sustainably. The successful implementation of the LSS framework primarily depends on top management commitment and involvement. An effective project leader and team members are required for the successful implementation of the LSS approach. The practitioners, project head, and team members are being proficient on the suitable lean tool and their association with DMAIC and environmental aspects. A training session about LSS implementation also required for workers and supervisors, so that they can participate in LSS implementation with full enthusiasm and interest.

CHAPTER 7

Conclusions and Scope for Future Research

The research was carried out for checking the efficacy of the Lean Six Sigma (LSS) approach for productive capacity utilization in Indian MSMEs. Literature had considerable evidence on LSS in the Indian context. Thus, the research work concentrated on recognizing the research gap in terms of LSS application in the Indian MSMEs sector. Based on the research gap, five objectives were proposed in this research work to facilitate the LSS adoption practically in India. In this research work, a case study was carried out in a medical equipment manufacturing industry in New Delhi, India. This chapter presents the major findings of the research work, limitations, and scope for future research.

7.1 Findings of the Research

This research comprises a mixed approach that contains a questionnaire survey, expert inputs, and brainstorming sessions with employees of the case industry to facilitate LSS implementation in Indian MSMEs. After successfully implementing the LSS approach in the selected MSMEs, the following conclusions are made:

- Investigation and prioritization of enablers associated with LSS implementation in Indian MSMEs are essentials to healthy initiation of the LSS program. To find vital enablers from the identified 22 enablers, an advanced MCDM approach i.e. BWM was adopted. The BWM result exhibits that top management of MSMEs must give due attention to strategy and environmental based enablers at the initial stage of environmental LSS implementation to get success. Under environmental regulations and customer requirements, this prioritization assists MSMEs organizations in choosing appropriate enablers for fluent implementation of the program.

- Identification of critical barriers of LSS implementation in MSMEs is essential to the fruitful initiation of this program. With the help of literature and expert's input, 26 LSSBs are identified and further 22 LSSBs screened using statistical analysis. The screened LSSBs are modeled using ISM and MICMAC analysis. ISM model presents that insufficient management commitment and involvement, lack of resources, lack of training and education are the most critical barriers and needs to tackle at upmost priority. Besides, MICMAC analysis splits the LSSBs into four clusters as per their driving power and dependency. The MICMAC results show that out of 22 LSSBs, 9 dependent, 9 independent, 4 existing linkage, and 0 autonomous barriers are existing. These results provide a clear mind-set to engineering manager for focusing more on LSS barriers with higher driving power and lower dependency.

- In the present study, a novel LSS framework with consideration of environmental aspects is developed. The developed framework is based on the DMAIC methodology with a synergy of advanced lean tools and competences to improve the capacity utilization of MSMEs. The strategy for estimating the capacity utilization of the plant is based on the actual capacity and design capacity of the selected plant.

- The optimal LSS project selection at the selected site is done by using a hybrid approach based on the Intuitionistic fuzzy Modified TOPSIS-Entropy-VIKOR approach. The hybrid approach evident that out of eight available sections, the assembly section comprises maximum wastage and the main responsible for low CU in selected MSMEs.

- During the implementation of LSS in the identified critical section, after defining and measuring the problem, 10 critical factors of low CU are identified. Further, 4 factors are shortlisted due to their high contribution towards low CU as poor material handling (40%), unnecessary movement (28%), environmental issues (18%), and reworks (7%).

- In the analysis phase, the possible reasons for shortlisted low CU factors are explored using the lean tools as cause & effect diagram and 5Why analysis as well as MADM approach i.e. Fuzzy VIKOR-GRA. The result reveals that the critical issues are non-availability of the rack, not used bin and bin card system, poor indoor air quality, CO emission during welding, and rework in drilling and tapping operation. These issues are resolved with the help of lean tools like 6S and Kaizen in the improvement phase.

- From the improve phase, it was inspiring to note that the execution of proposed solutions had a positive impact on the performance indicators like DPMO, CU, IAQ level, unnecessary movement, and production rate. These are shown in Table 7.1.

- The selected case company gets tangible benefits after LSS implementation successfully as shown in Table 7.2. The successful LSS implementation increases confidence among team members and employees with top management to be work with more dedication. Additionally, the case industry also gain several non-tangible benefits such as cultural change, employee behaviors, customer satisfaction, etc. The industry also stimulated to share its profit in Corporate Social Responsibility (CSR) activities to improve the community in the region.

Table 7.1: *Performance parameters evaluation before and after implementation*

S.N.	Parameters	Before	After	Improvement
1	DPMO	309523	48951.44	84.18%
2	IAQ level at overall plant	156.87	86.85	44.5%
3	CME at welding section	33 PPM	1.5 PPM	95.45%
4	Unnecessary movement	325 feet	120 feet	63.08%
5	Total pieces reworked per month	24	2	91.66%
6	Production per month	160 units	201 units	15.18%

Table 7.2: *Tangible benefit after LSS project*

Performance metrics	Before implementation	After implementation
Total pieces reworked per month	24	2
Total components produced per month	160	201
Reworked cost per piece	US$ 100	US$ 100
Price of component per piece	US$ 2200	US$ 2200
Total reworked cost	US$ 2400	US$ 200
Total Revenue	US$ 349600	US$ 442000
Tangible benefit due to the LSS project	US$ 92400	

7.2 Scope for Future Research

LSS as a continuous improvement approach is widely exposed in recent years to fight quality issues, waste problems, and prevail customer satisfaction. But still, its implementation for capacity utilization improvement is in the initial phase. In Indian industries concern, LSS offers a large scope for research in the future:

- In the selected MSMEs for case study, there are other sections also exists i.e. welding section, machine section, buffing and painting section etc. which running at low CU. Therefore, LSS approach can be implemented at these sections to improve CU levels, defect reduction, and waste minimization.

- The current study provides a summary of the LSS approach in the Indian MSMEs sector. The developed LSS framework is suitable for a developing country and variations in the outcomes may be occurs in context of developed countries due to the differences in culture and practices. Further LSS implementation should be done in the MSMEs of the developed countries.

- In the developed LSS framework, a comprehensive set of tools provided in each step of DMAIC methodology as per the project objective and the operating conditions of the organization. In the future, the framework can be extended with more advanced tools and techniques for further enhancement and assisting other sustainability drivers with environmental aspects.

- Apart from MSMEs sector, LSS can be implemented as improvement strategy in service sector like educational institutes, hospitals, banking, communication sector etc. in India.

- In the present study, a Quantitative model is proposed for evaluation of LSS enablers and barriers in the MSMEs sector, which can be extended to other types of industries like process, public, and service sectors.

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APPENDIX A

Appendix

QUESTIONNARIE

SECTION-A

1. **Organization Name:**
2. **Location:**
3. **Name of the Authority**
4. **Designation**
5. **Work Experience**

SECTION-B

Enablers of Lean Six Sigma (LSS)

Please tick mark at appropriate place against each enabler according to the label provided corresponding to each enabler.

1. **The weakest**
2. **Weak**
3. **Neutral**
4. **Strong**
5. **The Strongest**

TABLE A.1: *Scoring to LSS enablerss*

Sr. No.	Enablers	Score of enablers				
		1	2	3	4	5
1	Carbon reduction initiatives					
2	Environmental friendly packing of products					
3	Incentives for producing green products					
4	Practices of Green design					
5	Environmental friendly transportation					
6	Green operational practices					
7	Market demands for green products					
8	Effective project leadership					
9	Rewards and incentives for employee					
10	Top-management commitment, Involvement and support					
11	Environmental LSS supportive organizational Infrastructure					

12	Performance measurement system					
13	Consistent and accurate data collection					
14	Selection and retention of employee					
15	Team work					
16	Effective communication among departments					
17	Sufficient time to solve problems					
18	Employee empowerment					
19	Share project success stories					
20	Organizational culture and ethics					
21	Understanding of Environmental LSS methodology					
22	Project selection and prioritization					
23	LSS awareness program and training					
24	Financial benefits sharing among employees due to Environmental LSS					
25	Fund for operational expenditure					
26	Supplier relationship management					

27	Customer satisfaction and delight					
28	Understanding the customer demand					
29	Linking Environmental LSS to buyer-suppliers					
30	Linking Environmental LSS to core business processes					

TABLE A.2: *Appropriate Grouping of LSS*

Sr. No.	**Enablers**	**Tick in suitable group**				
		ELSSE	**SLSSE**	**RLSSE**	**CLSSE**	**LLSSE**
1	Carbon reduction initiatives					
2	Environmental friendly packing of Products					
3	Incentives for producing green Products					
4	Practices of Green design					
5	Environmental friendly Transportation					
6	Green operational practices					
7	Market demands for green Products					
8	Effective project leadership					
9	Rewards and incentives for Employee					
10	Top-management commitment, Involvement and support					

11	Environmental LSS supportive organizational Infrastructure					
12	Performance measurement system					
13	Consistent and accurate data Collection					
14	Selection and retention of Employee					
15	Team work					
16	Effective communication among Departments					
17	Sufficient time to solve problems					
18	Employee empowerment					
19	Share project success stories					
20	Organizational culture and ethics					
21	Understanding of Environmental LSS methodology					
22	Project selection and prioritization					
23	LSS awareness program and Training					
24	Financial benefits sharing among employees due to Environmental LSS					
25	Fund for operational expenditure					

26	Supplier relationship management					
27	Customer satisfaction and delight					
28	Understanding the customer demand					
29	Linking Environmental LSS to buyer-suppliers					
30	Linking Environmental LSS to core business processes					

The notation used in above table is described as follows:

- **ELSSE: Environmental based enablers**
  In this category, the enabler which directly related to the environment, air pollution, hazard gas emission, and noise pollution with in the industries. Such enablers are drives the system to control the factors those works against environment and stimulates the aspects those in favor of green concept and cleaner production.

- **SLSSE: Strategy based enablers**
  Strategy based enablers are those success factors which are closely related with the employees, vendors, customers, stake holders to handhold them and drives in implementing the road map of LSS approach.

- **RLSSE: Resources based enablers**
  These enablers are having ability to identify human resource needs and attract, nurture and retain capable employees. Also, it having capability to mobilize funds and sustain new strategic/business initiatives for the long term.

- **CLSSE: Culture based enablers**
  Cultural enablers are those foundational beliefs and expectations that serve as

the fence around the playground. They enable and empower employees to know exactly where the boundaries of exploration exist. For example, enablers could include expectations on ethics, innovation, empowerment, or communication oriented behaviors. Additionally, enablers include environmental factors that employees link to their ability to excel.

- **LLSSE: Linkage based enablers**

  Linkage based enablers are those which directly or indirectly make connect among supplier, vendor, industrial manager, stake holder and customer.