GREEN LEAN SIX SIGMA ESSENTIALS FOR CAPACITY WASTE REDUCTION IN MANUFACTURING SECTOR

A Thesis

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By

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Transforming Education Transforming India

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DECLARATION

I declare that the thesis entitled "Green Lean Six Sigma Essentials for Capacity Waste Reduction in Manufacturing Sector" 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 “Green Lean Six Sigma Essentials for Capacity Waste Reduction in Manufacturing Sector”, which is being submitted by Mr. Mahender Singh Kaswan 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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ABSTRACT

Competitive landscape, learned customers and rigorous regulations have forced manufacturing industries to emphasis on operational excellence along with sustainability measures in the past few decades. Green Lean Six Sigma (GLS) is one of the inclusive approaches that reduce variations and wastes in the system and at the same time decreases negative environmental impacts. But, in order to implement a comprehensive GLS approach, it is indispensable to look at the enablers that consequently lead to the success of this strategy. The main theme of present study is to test the efficacy of GLS approach in manufacturing environment. For this, present research work also deals with identification and modelling of GLS enablers using Interpretive Structural Modelling to meticulously adjudicate interactions among the enablers. Moreover, as the industry cannot adopt all enablers, so it imperative to prioritize enablers, for this, present research illustrates prioritization of GLS enablers through a novel decision- making approach named Best Worst Method. The study depicts that the top three ranked enablers are 'organizational readiness for Green Lean Six Sigma measures together with competence for green product and process', 'top management commitment toward sustainable performance improvement' and, the integration of GLS with the business objectives' with weights 0.4055, 0.1745 and 0.1288 respectively. Moreover, to strengthen pursuits for GLS execution, it is indispensable to integrate individual Green, Lean, and Six Sigma approaches under the umbrella of GLS. Also, there exists no GLS framework that can be applied irrespective of the size, type, and culture of the organization. So, the present research work also deals with the integration and development of the GLS framework. The integration of the GLS has been proposed based on theoretical elements, and the framework has been developed based on DMAIC approach. It has been found that enablers, toolset, and implementation methods supplement the integration of GLS. Besides, to strengthen the assessment of environmental impact in manufacturing, this study investigates barriers to execute life cycle assessment and also proposes a dedicated framework of life cycle assessment. The present study considers case of a manufacturing industry to realize the competence of GLS for improvement in all dimensions of the sustainability together with reduction in capacity waste. The result exhibits that proposed framework considerably improve sustainability dynamics, e.g., GLS project leads in a saving of $43,000, environmental impact reduces by 26.4%., and capacity waste condenses by 18.16%. The present study will facilitate the organizations to have readiness for the implementation of a sustainable GLS approach through a detailed understanding of enablers, barriers, integration and framework of GLS. Moreover, study provides measures to industrial organization to enhance the social sustainability matrix through incorporation of active involvement and conglomerates in the community organizations. The present study also provides a guiding reference for practitioners and academicians to undertake similar improvement projects and identifies opportunities to expand this research on integrated GLS methodology into other industrial sectors.

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TABLE OF CONTENTS

DECLARATION	**ii**
CERTIFICATE	**iii**
ABSTRACT	**iv**
ACKNOWLEDGEMENT	**vi**
TABLE OF CONTENTS	**vii**
LIST OF TABLES	**xii**
LIST OF FIGURES	**xv**
LIST OF ABBREVATIONS	**xvii**
1. Introduction	**1**
1.1 Pretext	1
1.2 Challenges to Manufacturing Sector	2
1.3 Green technology	4
1.3.1 Green manufacturing development procedure	4
1.3.1.1 Identification of the current state of the system under consideration	4
1.3.1.2 Develop the improvement plan	5
1.3.1.3 Apply the implementation plan	6
1.3.1.4 Maintain	6
1.4 Lean manufacturing	7
1.5 Green Lean interactions	8
1.6 Constraints of Green Lean as an integrated approach	10
1.7 Six Sigma	10
1.7.1 DMAIC Methodology	11

1.8 Green Lean Six Sigma 12
1.9 Capacity and capacity waste 13
1.9.1 Concept of capacity 14
1.9.2 Capacity utilization: concept and significance 14
1.9.3 Estimation of capacity waste 15
1.10 Motivation for the present work 17
1.11 Thesis outline 17
2. Literature review **20**
2.1 Methodology adopted for literature review 20
2.2 Exploration of Green Lean Six Sigma articles 22
2.2.1 Descriptive analysis of Green Lean Six Sigma articles 22
2.3 Green Lean Six Sigma development 26
2.4 Literature review of Green Lean Six Sigma enablers and barriers 29
2.5 Literature review of Green Lean Six Sigma framework 30
2.6 Literature review of Life Cycle Assessment 35
2.7 Literature review of capacity 37
2.8 Research gaps 40
2.9 Research Objectives 41
3. Research Methodology and Framework **42**
3.1 Problem Formulation 42
3.2 Research methodology 42
3.3 Integration measure and model of Green Lean Six Sigma 45
3.4 Proposed framework of Green Lean Six Sigma 47
3.5 GLS integral measure and tools 51
4. Green Lean Six Sigma Enablers **56**
4.1 Introduction 56
4.2 Green Lean Six Sigma Enablers for all industrial sectors 57
4.2.1 Exploration of Green Lean Six Sigma enablers 57
4.2.2 Research approach adopted and analysis of Green Lean Six Sigma enablers pertains to all sectors 59
4.2.2.1 Interpretive Structural Modeling of GLS enablers 60

4.2.2.2 MICMAC analysis of Green Lean Six Sigma enablers 66
4.3 Green Lean Six Sigma enablers pertain to manufacturing 67
4.3.1 Methodology adopted and analysis of GLS enablers pertains to manufacturing 67
4.3.2 Best Worst Method 70
4.3.3 Practical case and analysis of Green Lean Six Sigma enablers pertain to manufacturing 72
4.4 Discussion on findings pertains to Green Lean Six Sigma enablers pertains to all sectors 75
4.5 Discussion on findings pertains to Green Lean Six Sigma enablers dedicated to manufacturing 77
4.6 Implications for practitioners, researchers, and industrial managers 81
4.7 Inferences drawn 82

5. Green Lean Six Sigma Barriers 83
5.1 Introduction 83
5.2 Research approach and Barriers of Green Lean Six Sigma 84
5.2.1 Environmental barriers 92
5.2.2 Management-related barriers 92
5.2.3 Knowledge base barriers 93
5.2.4 Training related barriers 93
5.2.5 Organizational related barriers 93
5.2.6 Continuous improvement barriers 93
5.3 Analysis of Green Lean Six Sigma barriers with practical case 100
5.4 Sensitivity analysis 108
5.5 Discussion on findings 109
5.5.1 Removal of barriers 110
5.6 Practical and theoretical implications 112
5.7 Inferences drawn 113

6. Life Cycle Assessment: Barriers and Framework 115
6.1 Introduction 115

6.2 Research approach and barriers of lifecycle assessment 116
6.3 Analysis of Life Cycle Assessment barriers: Practical case 123
6.3.1 Computational steps of Grey Relational Analysis for analysis of Life Cycle Assessment barriers 124
6.3.2 Computational steps of Best Worst Method 127
Validation of ranks of Life Cycle Assessment barriers 127
6.3.3 Sensitivity Analysis 128
6.4 Discussion on findings pertains to Life Cycle Assessment barriers 129
6.5 Life cycle assessment framework 131
6.5.1 Goal definition 131
6.5.2 Scope definition 132
6.5.3 Life cycle inventory analysis 134
6.6 Implications 134
6.7 Inferences drawn 135

7. Implementation of Green Lean Six Sigma 137
7.1 Introduction 137
7.2 Green Lean Six Sigma Execution Plan 139
7.3 Case Implementation 140
7.3.1 Identification and outline sustainability-focused Green Lean Six Sigma project 141
7.3.1.1 Problem statement 141
7.3.1.2 Process sequence 142
7.3.1.3 Project charter 143
7.3.1.4 Identification of critical parameters for capacity waste 143
7.3.1.5 Assessment of the material handling time of shops/sections 144
7.3.2 Assessment of the current state of the system 145
7.3.2.1 Environmental value stream mapping 145
7.3.2.2 Assessment of environmental impact using Life Cycle Assessment 146
7.3.2.3 Estimation of defects level and rework 147
7.3.2.4 Social sustainability assessment using Social Life 148

Cycle Assessment
7.3.3 Determine the root reasons for wastes and inefficiencies 151
7.3.3.1 Identification of potential causes for ineffective material handling 151
7.3.3.2 Why analysis for rework, ineffective manpower movements and space utilization 153
7.3.3.3 Assessment of reason for environmental and social sustainability 154
7.3.4 Search for better solutions and implement the same 155
7.3.4.1 7'S implementation for ineffective material handling 155
7.3.4.2 Kaizen activities 158
7.3.4.2.1 Improvements related to the cutting of raw material and lathe section 158
7.3.4.2.2 Improvements pertains to rework issues 158
7.3.4.3 Improvements to enhance societal dynamic 159
7.3.4.4 Reduction in environmental impacts 160
7.3.4.5 Layout modification to overcome unnecessary movements 161
7.3.5 Layout modification to overcome unnecessary movements 163
7.4 Results and Discussion 165
7.5 Inferences drawn 170

8. Conclusions and Future Research Agenda **172**
8.1 Conclusions 172
8.2 Future research agenda 175
BIBLIOGRAPHY **178**
LIST OF PUBLICATIONS **209**

LIST OF TABLES

1.1	Challenges to manufacturing	3
1.2	Prominent tools of Lean manufacturing	8
1.3	Lean and Green concept view’s towards wastes	9
2.1	Journal wise distribution of articles	22
2.2	Industry-wise distribution of articles	26
2.3	Comparison of various characteristics of Lean, Green and Six Sigma methodologies	27
2.4	Major studies pertains to the framework and identified limitations	32
2.5	Current status of capacity waste rate across the world	39
2.6	Capacity size v/s capacity utilization of various industrial sectors in India	40
3.1	Enablers of GLS that foster integration	51
3.2	Barriers of GLS that foster integration	52
4.1	GLS enablers	57
4.2	Statics table for GLS enablers	59
4.3	Structural self-interaction matrix	61
4.4	Initial reachability matrix	62
4.5	Final reachability matrix	63
4.6	Iteration 1	63
4.7	Final level of each GLS enabler	64
4.8	Screened GLS enablers	68
4.9	Expert panel for screening of GLS enablers	69
4.10	Pairwise comparison vector of the best enabler and worst enabler	73
4.11	Final weighted matrix of GLS enablers	74
4.12	Consistency index	74
4.13	Comparison of the rank of BWM and other decision- making approaches	75
5.1	Green Lean Six Sigma barriers	86

5.2	Characteristics and demographic background of respondents	87
5.3	Principal component analysis for grouping of barriers	90
5.4	Linguistic variables and corresponding IFS	95
5.5	Comparative scale	98
5.6	Consistency index	99
5.7	Aggregated IF decision matrix	101
5.8	Initial reachability matrix	102
5.9	Normalized direct relationship matrix	102
5.10	Total relationship matrix	103
5.11	Row wise and the column-wise sum of barriers	103
5.12	Degree and kind of relationship among barriers	103
5.13	Best to others and other to worst vector	106
5.14	Final BWM weighted matrix of GLS barriers	106
5.15	Comparative results of IF-DEMATEL against other MCDMs	107
5.16	Weights of GLS barriers using sensitivity analysis	108
5.17	Ranks of GLS barriers using sensitivity analysis	109
6.1	LCA barriers in the manufacturing environment	117
6.2	Characteristics and demographic background of respondents	120
6.3	Responses from industrial personnel	124
6.4	Normalised values	125
6.5	Deviation sequence	125
6.6	Grey relation coefficients	126
6.7	Grey relation grade and ranks of LCA barriers	126
6.8	Preference table for barriers of LCA	127
6.9	BWM weighted matrix to rank LCA barriers	128
6.10	Sensitivity Analysis	129
7.1	Project charter for GLS project	143
7.2	EVSM process metrics	146
7.3	Social sustainability indicators of case industry	149
7.4	Factors responsible for poor material handling	152
7.5	Prioritization of ineffective material handling factors using GRA	152
7.6	Prominent reasons to address for improvement in sustainability	155

7.7	7S audit sheet	157
7.8	Investigation of set up techniques	158
7.9	Actions for improvement in environmental sustainability	160
7.10	Out of control action plan	164
7.11	Process metrics before and after the execution of GLS project	166
7.12	Monetary benefits from GLS execution	167

LIST OF FIGURES

1.1	Global industrial emission of carbon dioxide	3
1.2	Assessment of current system state	5
1.3	Improvement plan	6
1.4	Improvement plan	6
1.5	Maintain the adopted green manufacturing plan	7
1.6	Effects of Green Lean on system	9
1.7	DMAIC methodology	11
1.8	Conceptual GLS model	13
1.9	Capacity Perception	16
2.1	Systematic literature review methodology	21
2.2	Years wise distribution of publications	25
2.3	Continent wise distribution of publications	25
2.4	Contribution of CU concept in Indian manufacturing	38
2.5	Distribution of published articles word wide	38
3.1	Research Methodology	43
3.2	Integration model of GLS	46
3.3	GLS framework	49
3.4	Radar chart of Green Lean Six Sigma tool	54
4.1	Research approach for analysis of GLS enablers	60
4.2	Interpretive structural model of GLS enablers	65
4.3	Driver and dependence diagram of GLS enablers	66
4.4	Research approach for prioritization GLS manufacturing enablers	69
5.1	Research approach for analysis of GLS barriers	85
5.2	Q-Q plot for GLS barriers	88
5.3	Scree plot	89
5.4	Causal diagram	105

5.5	Ranks of GLS barriers using sensitivity analysis	109
5.6	Green economy model to facilitate GLS implementation	111
6.1	Research Approach for analysis of LCA barriers	119
6.2	Q-Q plot	120
6.3	Radar chart for sensitivity analysis of LCA barriers	129
6.4	LCA framework	132
7.1	GLS framework or execution plan	140
7.2	SIPOC diagram	142
7.3	Critical parameters for high capacity waste	144
7.4	Pareto chart for material handling time of different shops/sections	145
7.5	Environmental current state value stream mapping	146
7.6	Categorized environmental impact using LCA	147
7.7	Section-wise number of parts required rework	148
7.8	Social sustainability assessment model	149
7.9	Cause and effect diagram of ineffective material handling	151
7.10	5 Why analysis for rework issue	153
7.11	5 Why analysis for ineffective space utilization	154
7.12	Assembly section before and after implementation of 7S	156
7.13	Lathe machine tool before and after incorporation of air pressure gun to remove burrs at tool workpiece interface	159
7.14	LCA after incorporation of the improvement measure	161
7.15	Existing plant layout	162
7.16	Modified plant layout	163
7.17	Future state value stream mapping	165

LIST OF ABBREVATIONS

Abbreviations	Description
3'R	Reduce Reuse Recycle
AHP	Analytical Hierarchy Process
AD	Anaerobic Digestion
ANOVA	Analysis of Variance
BWM	Best Worst Method
C&E	Cause and Effect Diagram
CAF	Contextual Adjustment Factor
CBA	Cost Benefit Analysis
CFF	Critical Failure Factors
CI	Continuous Improvement
CM	Cellular Manufacturing
CRC	Contextual Risk Class
CSO	Central Statistics Office
CU	Capacity Utilization
CW	Capacity Waste
DEMATEL	Decision Making Trial and Evaluation Laboratory
DMs	Decision makers
DOE	Design of Experiments
EDB	Electronic Databases
EIA	Environmental Impact Assessment
ER	Environmental Related
ERA	Environmental Risk Assessment

EVSM	Environmental Value Stream Mapping
FICCI	Federation of Indian Chambers of Commerce & Industry
FMEA	Failure Mode Effect Analysis
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GL	Green Lean
GLS	Green Lean Six Sigma
GM	Green Manufacturing
GRA	Grey relational analysis
IF	Intuitionistic Fuzzy
IR	Indian Rupees
ISM	Interpretive Structural Modelling
JIT	Just in Time
KB	Knowledge Base Related
LCA	Life Cycle Assessment
LSS	Lean Six Sigma
MCDM	Multiple-Criteria Decision-Making
MFA	Material Flow Analysis
MR	Management Related
MRP	Material Requirement Planning
MSMEs	Micro Small and Medium Enterprises
NCAER	National Council of Applied Economic Research
NVA	Non Value Added Activities
OCAP	Out of Control Action Plan
OR	Organization Related
PAT	Perform Achieve and Trade
PCA	Principal Component Analysis
PSRF	Product Social Risk Factor
QFD	Quality Function Deployment
RBI	Reserve Bank of India
RDF	Refuses Derived Fuel

RM	Research Methodology
SEA	Strategic Environment Assessment
SIAM	Society of Indian Automotive Manufacture
SLCA	Social Life Cycle Assessment
SLR	Systematic Literature Review
SMED	Single Minute Exchange of Dies
SPSS	Statistical Package for Social Sciences
SSIM	Structural Self-Interaction Matrix
TPM	Toyota Production System
TR	Training Related
UNEP	United Nations Environment Programme
VOB	Voice of Business
VOC	Voice of Customer
VSM	Value Stream Mapping
WRT	Waste Recycling Techniques
ZED	Zero Effect Zero Defect

1.1 Pretext

The growth of any nation mainly depends upon the advancement in operational and technological growth of industrial sectors [1] [2]. The industrial sector's growth is directly or indirectly connected with the modernization of agriculture, science, technology, urbanization, employment, high standard of living and social change, etc. [3]. These said areas will develop if the industrial sectors possess higher productivity and growth. Besides, the living standard of people and their wealth conditions will also improve along with the development of industrial sector mainly manufacturing industries [4]. The productivity and quality of manufacturing sector can be improved if industries expand their capacity or adopt advanced tools and techniques in their core business but such adoption directly increases the unit costs [5]. An alternative way to improve productivity and quality at lower unit cost is by making optimal utilization of available resources or reduce the capacity waste the industry [6]. Besides, it has been found that average earth surface temperature increased by 0.85 °C in last century [7]. The increased temperature level can be attributed to changing lifestyles, economic evolution, and the industrial revolution. The increased use of global resources, the spread of fossil-fuel-based material by industrial organizations has resulted in an increase in the level of carbon emission that leads to negative environmental impact [8][9]. Industrial organizations consume natural resources in an uncontrolled way and release a substantial proportion of pollutants into the atmosphere [10]. Moreover, these organizations are not adopting proper waste disposal measures which further add to environmental degradation [11]. Subsequently, increased carbon footprint and other associated pollutants have led to severe health issues for people [12]. The chemical and metrological changes associated with CO_2 will lead to an increased mortality rate due to increased ozone and carcinogens in the air. The increased level of GHGs will result in an upward surge of more than 20000 deaths per year per degree Celsius and many more cases of respiratory illness and asthma [13]. It has been found that previous studies pertain to manufacturing are only restricted to the environmental and fiscal dimensions of sustainability but overlooked societal aspects [14]. This approach only leads to short term gains and legs long term sustainable benefits. The consideration needed on health work environment and best labor practices, demands the inclusion of social aspects in industrial practices. Moreover, sustainable oriented demand, globalized competition, and governmental policies on climate change have enforced the industries to adopt sustainable practices [15]. For this, present study deals a novel sustainable development approach named Green Lean Six Sigma (GLS). This research work provides different measures, features, framework of GLS, and test the efficacy of GLS in a real-life industrial setting for improvement in all dimensions of the sustainability together with enhanced capacity utilization.

1.2 Challenges to Manufacturing Sector

Manufacturing industries are the prime source for the growth of any nation's economy [16]. This sector plays a significant role to generate employment, reduces inequalities in distribution of wealth that further leads to enhancement in national economy [17]. The literature reveals that a 1% increase in gross domestic product (GDP) shall result in a 0.8% reduction in poverty, whereas, in India, 1% increase in GDP has yielded only a negligible 0.3% reduction in poverty [2]. So, it is imperative to search for solutions that increase operations dynamics of the manufacturing industries.

The rapid economic growth associated with industrialization leads to an increase in capital formation, urbanization, increased utilization of natural resources, alleviation of poverty and unemployment [18]. Manufacturing sector is not deprived of challenges it faces challenges in all aspects the sustainability. It is facing a huge challenge to cope with high capacity waste that leads to the non-optimal utilization of organization resources. The prosperity of a national highly depends on the best utilization of available resources for better productivity. Moreover, manufacturing industry is facing challenges pertaining to strict governmental policies on environmental emission, sustainable product demands, and related social aspects [19]. It has been found that industry contributes nearly 21% of the global GHGs emission [27]. In 2014, the top carbon dioxide (CO_2) emitters were China, the United States, the European Union (EU), India, the Russian Federation, and

Japan [7]. China emitted nearly 30 % of the global CO_2, and the United States contributed 15%, and EU contributed 9% of the CO_2 industrial emission. Figure 1.1 depicts country-wide industrial emission of CO_2. In context of other developed nation like Japan and Russia added 5 and 4% of total CO_2 industrial emission respectively whereas India emitted 7% of total industrial CO_2 emission [7]. So, India industrial sector is contributing considerably to the global CO_2 in contrast to other developed nation. So, to mitigate current industrial emission, there is immense need to incorporate clean technologies measures in the industrial processes.

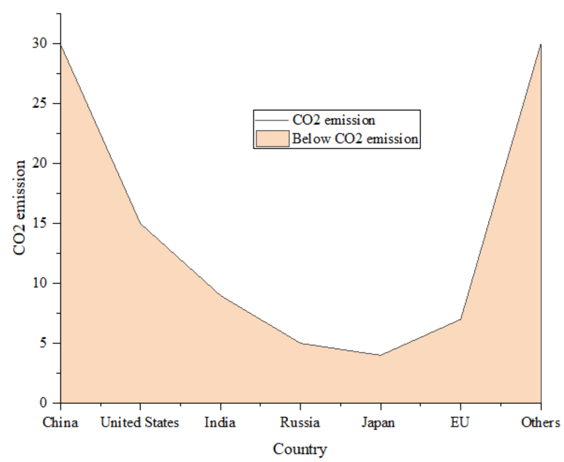

Figure 1.1 Global industrial emission of carbon dioxide

Table 1.1 depicts challenges to modern manufacturing industry in all aspects of sustainability.

Table 1.1: Challenges to manufacturing

S. No.	**Economical**	**Environmental**	**Societal**
1	Shorter product life cycle	Climate change	Aging workforce
2	Technological changes	Depletion of the natural resources	Non-availability of the skilled workforce
3	Demand fluctuation		

So, to remain competitive in market, industrial organizations must develop and implement low carbon emission technologies that not only reduce emission but also ensure optimum resource utilization. As a result, the organizations are spending enormous capital to devise sustainable methods of production and consumption. Since the last few decades, many ideas and approaches have been developed like Lean, Green, Six Sigma, etc. to produce the top quality products [20]. But, an individual approach is not able to address all the issues inclusively related to sustainability [21] [22]. Lean methodology although mitigates wastes but does not address process variations and environmental emissions [23]. Consequently, the need for Six Sigma and Green technology (GT) was felt, to produce eco-friendly products of higher specifications. GT reduces negative environmental effects such as global warming, acidification, photochemical oxidation, and eutrophication, etc. [15]. GT although addresses environmental issues, but not able to reduce variations in process, so there is a need for the Six Sigma approach to make a process with a lesser variation.

Six Sigma addresses the high rejection rate of the end product through the implementation of its well-known DMAIC methodology [24]. It reduces process variation but it cannot mitigate emission and associated wastes in the system or process [23]. So, individual approaches have their associated drawbacks which can be overcome by the inclusion of one other. So, it is imperative to integrate all three approaches in a single unique methodology termed Green Lean Six Sigma (GLS). This approach leads to organizational success through the systematic reduction of wastes, GHGs, and variation [25]. GLS addresses the modern issues of the industry through the systematic realization of associated tools and 3'R (reuse, recycle, and reduce) at different stages of the product realization [26]. It is a sustainable development approach that leads to improved productivity and profitability through the reduction of wastes, defects, and environmental emissions [27].

1.3 Green technology

Green technology is a good public spillover of Lean as it reduces waste and cuts down environmental effects [28]. It encompasses tools and techniques like Green supply chain, eco-friendly design, reverse logistics, eco-friendly building, landfill, sewage sludge for the improvement of biological inactive layers of barren land, etc. [29]. It is a sustainable technology that reduces the negative environmental effects such as global warming, acidification, photochemical oxidation, and eutrophication, etc. within the entire supply chain of the system [15]. To develop a comprehensive green technology system, it is essential to develop a green manufacturing procedure that leads to enhance capacity utilization, reduce waste, and carbon footprint.

1.3.1 Green manufacturing development procedure

There are four significant steps in the development of the green manufacturing system.

1.3.1.1 Identification of the current state of the system under consideration

The first step towards the development of the green manufacturing (GM) system is assessment of the current state of the system under consideration [30] (figure 1.2). The level of Lean and Green wastes, environmental, and other associated emissions are measured. The tools used at this stage may be a structurally designed set of questionnaires, green stream mapping (GSM), impact analysis, etc. [31]. Finally, an assessment score is calculated that determines the current level of the greenness of the system under consideration.

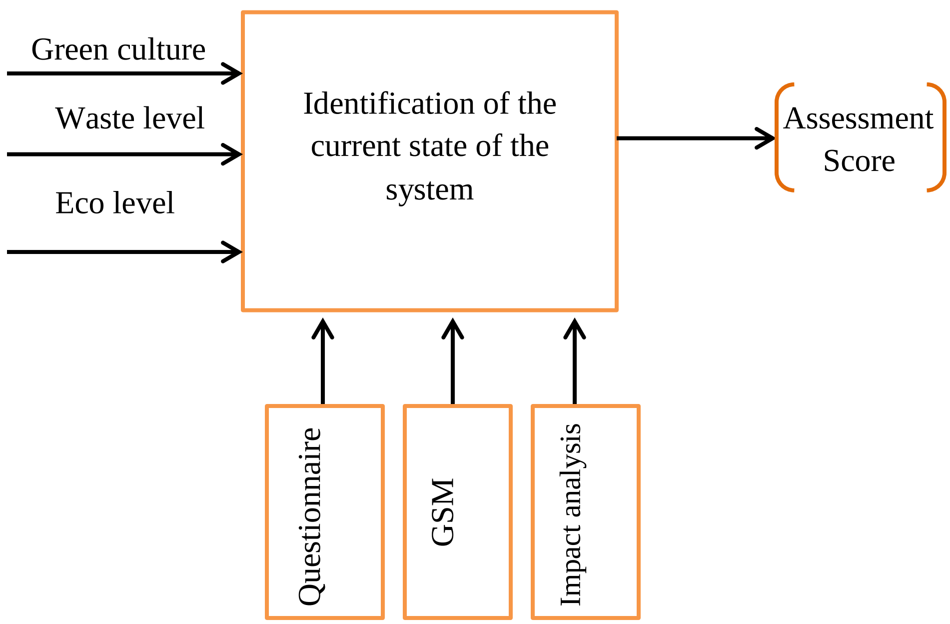

Figure 1.2: Assessment of current system state

1.3.1.2 Develop the improvement plan

The next step in the development of the GM system is the development of an improvement plan (figure 1.3). Here, based on the assessment score and production plan, improvement measures are made [31]. The optimization of the various variables is made, life cycle assessment is done, and consumption analysis is carried out to find out the best improvement plan. The plan here must make a strategic impact on all the dimensions of the sustainability of the concerned organization.

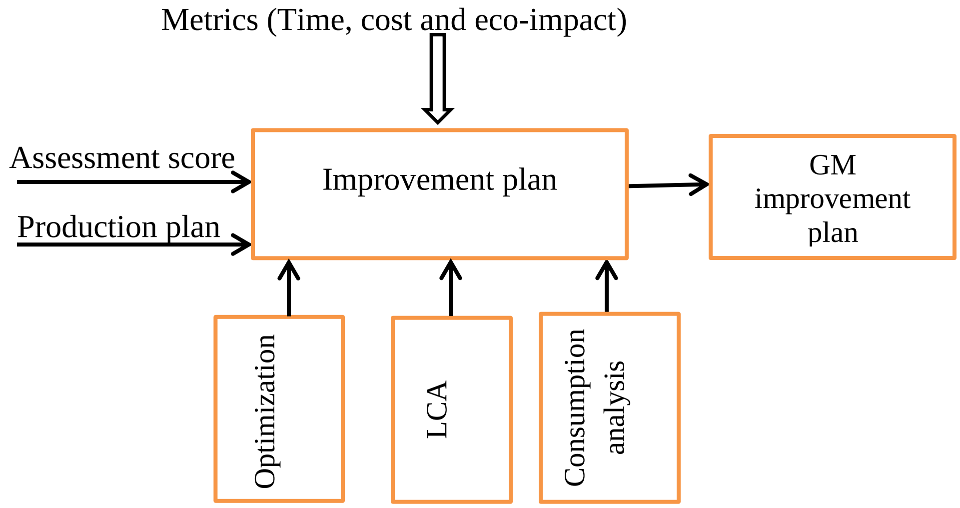

Figure 1.3: Improvement plan

1.3.1.3 Apply the implementation plan

The third step in the development of the GM system is an implementation plan (figure 1.4). The improvement plan for increased material, energy efficiency, and productivity is applied at this stage [30]. The various metrics are made for finding the sustainability content of the system under consideration.

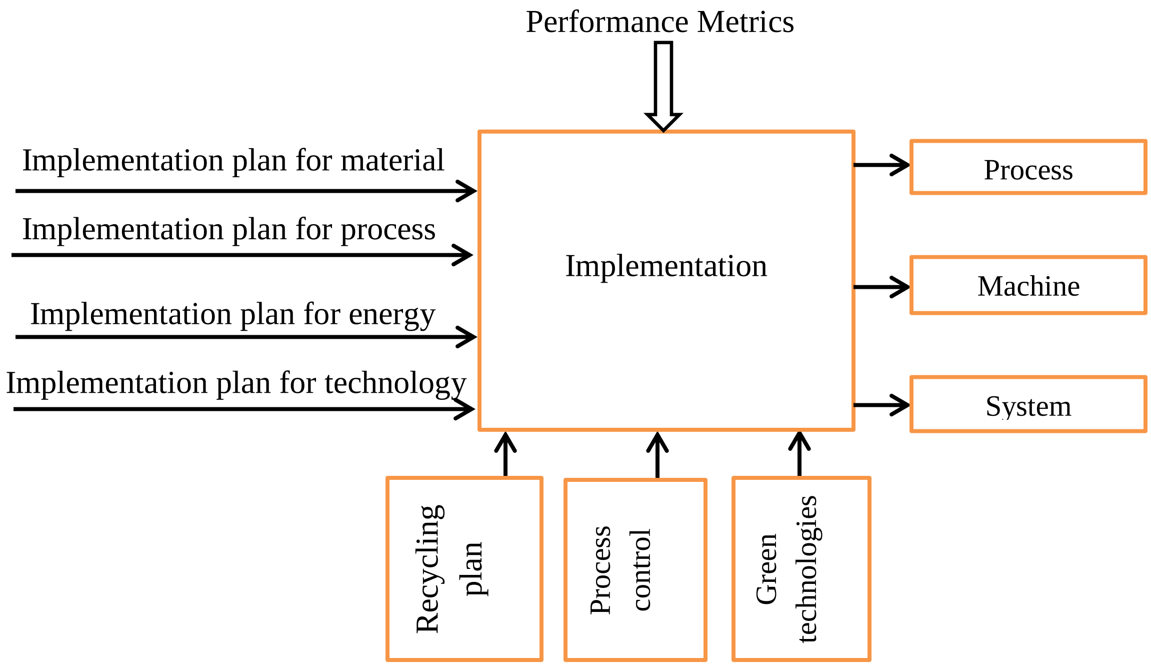

Figure 1.4: Implementation plan

1.3.1.4 Maintain

The next step in the development of a GM system is to maintain or sustain the adopted improvement plan for increased sustainability of the system being considered [30] (figure 1.5). The improvement in the system in terms of increased financial capabilities, productivity, improved level of environmental emissions are measured from time to time so that capacity of the adopted plan can be judged and if there is any distraction plan be modified accordingly [31]. Meanwhile, small pursuits are always made with the selected method for improved societal, economic, and environmental dimensions of sustainability

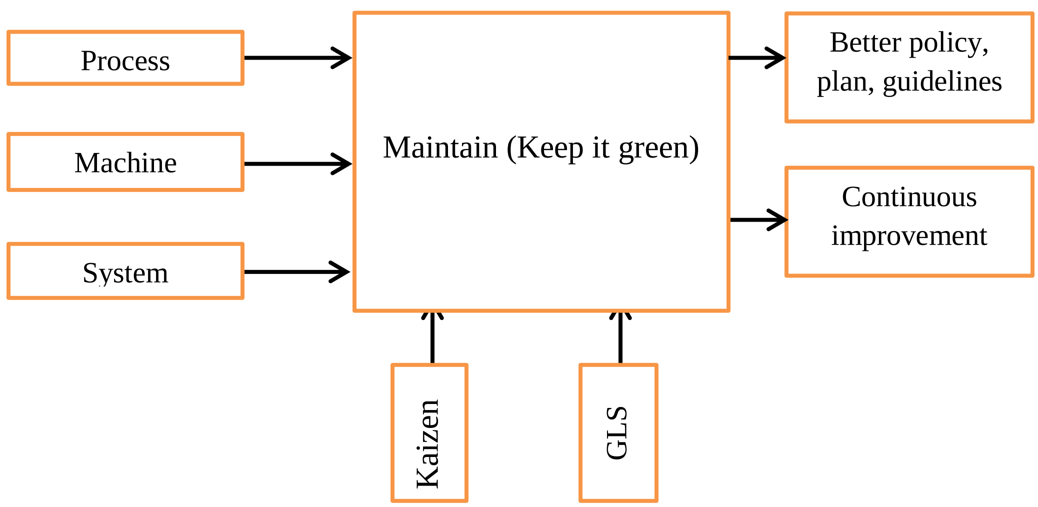

Figure 1.5: Maintain the adopted green manufacturing plan

GT can reduce the effect on the environment through the use of reduce, reuse and recycling techniques, but it is not able to reduce the variations in a particular process, so there is a need for a Six Sigma approach to make a process with less variation [20] [26].

1.4 Lean manufacturing

The lean concept was devised in Japan after the second world war when Japanese manufacturers recognized that they could not pay for the massive investment required to rebuild devastated facilities [32]. The modern concept of lean manufacturing can be traced to the Toyota Production System (TPS), pioneered by Japanese engineers Taiichi

Ohno and Shigeo Shingo [22]. Lean Manufacturing is a waste reduction technique that maximizes the value of the product through minimization of waste [33]. Lean philosophy defines value of the product/service as observed by customer [34]. It makes the flow in-line with the customer pull and striving for perfection through continuous improvement to eliminate waste by minimizing non-value-added activity (NVA). Different wastes associated with Lean are transportation, inventory, motion waiting, overproduction, over-processing, and defects. Elimination of these wastes is achieved through the successful implementation of Lean manufacturing tools (refer to table 1.2). It has been found that in literature most of the studies focused on a single aspect of lean elements, only very few focus on more than one aspect of lean elements [35]. But for inclusive implementation of lean the organization had to emphases on all aspects like value stream mapping (VSM), cellular manufacturing (CM), u-line system, etc.

Table 1.2: Prominent tools of Lean manufacturing

Tools	**Definition**
5S	Means organizing the work area, it eliminates waste that results from a poorly organized work area.
Gemba	It makes the people go out from the office and works at shop floor level where actual work takes place
Just-In-Time (JIT)	JIT means to make things in the right quality, at right time, right place with optimum cost
Kaizen	An approach where factory employees work in a group to achieve continuous improvement in the work under consideration
Kanban	A system of regulating the flow of goods both within the factory and with outside suppliers and customers.
Poka-Yoke	Poka-yoke means design error detection and prevention into production processes to achieve zero defects.

1.5 Green Lean interactions

Increasing environmental concerns have changed the focus of industries from traditional points like; quality, customer satisfaction to sustainability [36] [37]. Sustainability is not only to respect the bottom line of 3P (people, planet, and profit) but also, it is the harmonize resources to meet people’s desires [38] [39]. Many industries use the Lean concept to reduce waste and others use Green to reduce energy consumption and emphasize waste recycling techniques (WRT). Whenever, organizations give more value to social, economic, and institutional sustainability, they will invest more and focus on Green initiatives [41]. Industries enhance profitability dynamics by reducing energy, resources, pollution abetment through comprehensive learning of environmental technologies like Green Lean (GL) [42]. The customers want to purchase the goods that are of utmost quality, available at reasonable prices, and most desirable are available on time. GL approach emphasizes the minimum utilization of resources through waste reduction, reduces the negative environmental impact through the reduction of harmful gases. Consequently, the combined GL approach leads to saving in the capital, better environmental conditions and brings social equity in the organization as a whole. Figure 1.6 represents the effects of using the Green Lean approach.

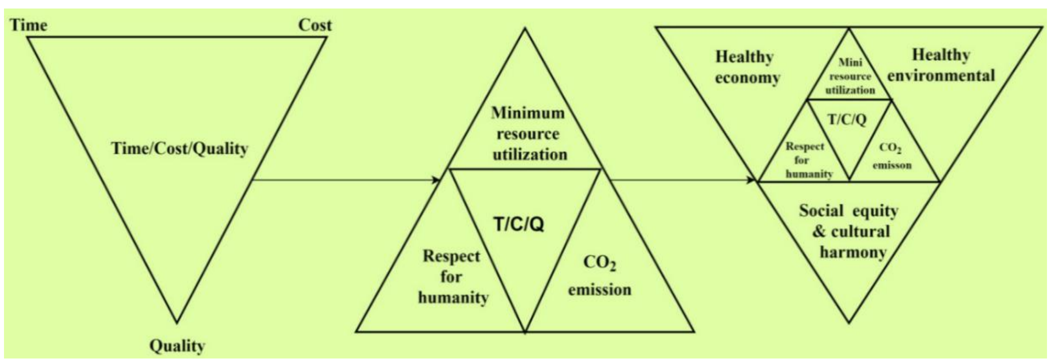

Figure 1.6: Effects of Green Lean on system

There is a good deal of similarity between the two approaches on the ground of waste reduction techniques, management practices, and business results [43] [44]. Table 1.3 indicates the relationship among various Lean wastes with the Green approach.

Table 1.3: Lean and Green concept view's towards wastes

S. No.	**Type of waste**	**Lean View**	**Green View**	**Citation**
1	Inventory	Increased inventory, hide problems, and discourage communication.	If the inventory is there, it needs storage. The store will need light/chilling that will consume energy.	[45] [46]
2	Transportation	Results in more in process inventory.	Transportation leads to the use of fossil or other forms of energy.	[47]
3	Defects	Anything not up to the specification.	The consumed raw material needs space for rework and	[46]

			recycling that leads to increased energy utilization.	
4	Overproduction	Will remain in-store as inventory.	There may be possible spoilage that will lead to an unhealthy ambiance within the industry.	[11] [48]
5	Waiting	Not utilization of full capacity.	The energy is wasted in heating, lighting during downtime.	[49] [46]
6	Over-processing	Produce more than the requirement.	The production of extra products leads to wastage of energy	[45]
7	Underutilized staff	The full potential of the team is not utilized.	Staff creativity is not harnessed to discover new ways for the reduction of wastes.	[50]

1.6 Constraints of Green Lean as an integrated approach

The research lacks practical evidence of the effectiveness of the GL approach. But still, some researchers found that if GL can be applied together, it provides operational as well as environmental success. There are also some limitations of the combined GL approach reported in the literature. It does not use statistical tools for the reduction of variation in the process although they collectively reduce wastes. The Integrated GL approach doesn't tackle the variation of product from a variable point of view but they affect the perception of the customers in attributive ways. GL approach mainly encompasses practices like Green supply chain, reverse logistics, 5'S, poka-yoke, design for the environment, and Green building, that are at all not capable to produce the product of true value even though GL produce the product up to specifications. So, from the discussion on Lean, Green, and GL it is obvious that the limitations of Lean go to Green as an inheritance, in the same way, these are forwarded to GL approach and it lacks tools to dissolve them. So, there is a huge need to devise an approach that constitutes tools and techniques to overcome these limitations [10].

1.7 Six Sigma

Six Sigma is a business enhancement approach that identifies and eliminates causes of defects, process capacity waste, etc. [51]. It was pioneered by Motorola in 1987 and with its success story in General Electric interest in Six Sigma went from a trickle to tidal [52]. This methodology in brief starts with the customer by understanding their needs and make subsequent improvements in the process to enhance customer satisfaction by using a set of statistical tools [53]. The principal idea behind Six Sigma is that if imperfections in a process can be estimated, then solution can be premeditated to eradicate them [24] . It is a highly disciplined approach used to reduce variations in process so that defects, reduced to less than 3.4 per million [54]. The Six Sigma methodology reduces, variations but it is not able to reduce the wastes and environmental damage done by process [20] [23].

1.7.1 DMAIC Methodology

The Define-Measure-Analyze-Improve-Control (DMAIC) cycle is the methodology that is used to conduct the Six Sigma approach successfully for any project. The steps of the DMAIC cycle are shown in figure 1.7.

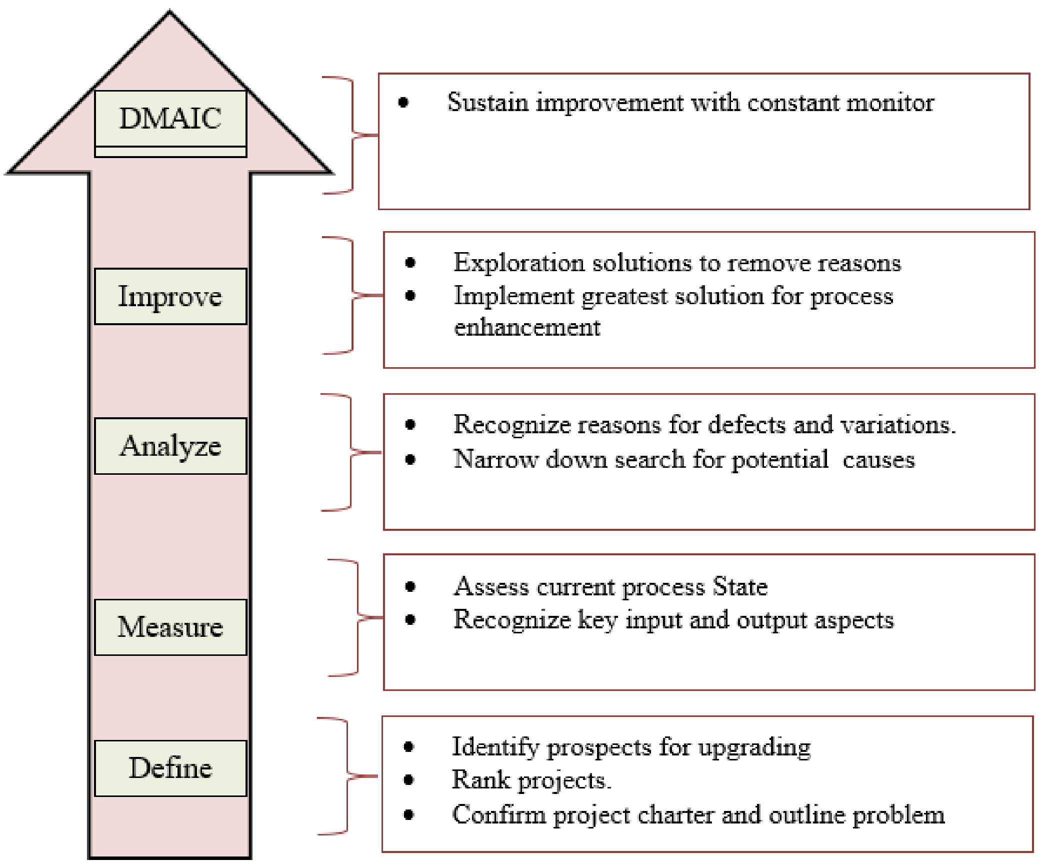

Figure 1.7: DMAIC methodology

- ✓ Define: this phase is very vital for every project because it is very necessary to select the right job or process for improvement. For successful implementation of Six Sigma, the right project selections are very important for any business organization [55].
- ✓ Measure: In the measure phase, the main objective is to evaluate current process performance and identify the potential input factors which are thought to affect the output.
- ✓ Analyze: In analyze, phase relation between input and output factors is characterized.
- ✓ Improve: Based on the conclusions of the analysis phase, improvement actions are decided and implemented. Usually, optimization is necessary to get the best out of the process.
- ✓ Control: Once the solution is implemented and validated, it is essential to ensure that improvement is sustainable.

1.8 Green Lean Six Sigma

The intense competition, shorter product life, and intergovernmental policies to cut the emission have forced the manufacturing industries to shift traditional methods to sustainable one [56]. Lean manufacturing, green technology, and Six Sigma are three different approaches developed in the time horizon to meet the demand of the customers. These entire approaches the main motto is to increase organizational productivity through the systematic removal of various non-value added activities [25]. So, different tools, commonalty adopted practices, and similarity characteristics of all three distinct approaches can be integrated under the gamut of GLS. The Integrated GLS approach improves organizational productivity and profitability through the reduction of wastes, defects, and environmental emissions [57]. Figure 1.8 presents a model of GLS.

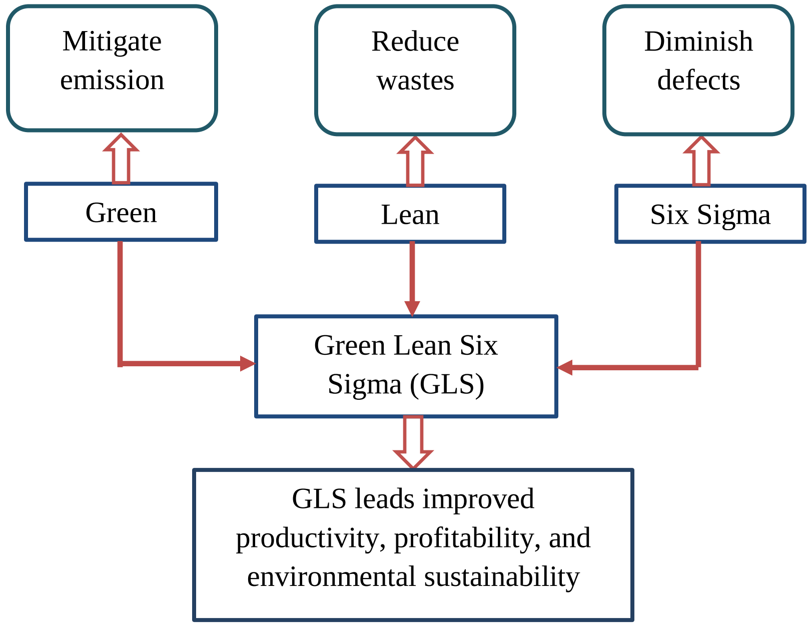

Figure 1.8: Conceptual GLS model

The simplified integrated GLS program initiates by selecting a suitable project that exhibits the highest potential to improve organizational sustainability. To measure the current state of the system, the present sigma level and eco-efficiency are measured with the associated tools [23]. Furthermore, the main cause of the problem and possible areas for improvement are identified in the next step by using tools like life cycle assessment (LCA), cause and effect diagram, etc. [58]. Thereafter, the focused area of the process is improved and optimized through the reduction in process variation and Green Lean wastes by using tools like the design of experiments, life cycle interpretation, environmental value stream mapping (EVSM), etc. Finally, the improved sigma level and associated sustainability benefits are calculated and the improvement is standardized.

1.9 Capacity and capacity waste

This section is containing the concept of capacity and capacity utilization (CU) with the importance of CU.

1.9.1 Concept of capacity

Capacity is directly related to 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 to the use of production resources [59]. The capacity concept simply relates to the level of production in any industrial unit. Capacity is the potential ability to perform and produce output without increasing input variables [60]. The capacity as output could be increased with full use of all input variables under a normal condition like without extending the working hours and considering regular holidays and machine maintenance [61]. All capacity concepts are based on the serious use of facilities and can be increased to fulfill the demand by working more days or working hours [62]. The capacity of the plant is inter-link with all facilities and types of machinery involved in producing the final product. It seems that the capacity limit is connected with the weakest link in the process used to manufacture the product [62]. Many processes in a plant may be under-utilized which may be manual or mechanical when the capacity concept is considered. The capacity can be upgraded by balancing equipment amongst the sub-processes of the plants. The capacity is subjected to the intensiveness of use of the facilities. Capacity possesses a 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.

1.9.2 Capacity utilization: concept and significance

Capacity utilization is a concept that expresses the rate at which the industry uses its available capacity. In the past era, industries did not familiar with the capacity utilization concept and its significance to enhance productivity. After 1990, Kim H. Y. proposed an index used to provide the rating to the capacity of the plant, called capacity utilization [63]. Capacity utilization is the relationship between actual output being produced with the installed setup and the potential output that could be produced if capacity was fully utilized. It is the ratio of observed output to design output of plant [64]. It is the relative index that provides the rating of the utilized capacity of the plant. If the value of this relative index is 60%, then it shows that only 60 % of the whole capacity of the plant is going to be used and the rest 40% is wastage. If resource wastage can be estimated in any unit, then it is quite easier to make a plan to reduce the wastage of resources and express the productive efficiency [64]. The organization can achieve its objective and customer satisfaction with the help of proper capacity utilization [65] [66]. Thus, capacity utilization is having a pivotal role in business success because; it is used to assign the rating to the capacity of the plant.

1.9.3 Estimation of capacity waste

The literature presents a large number of concepts and fallacies that exist in perception, measurement, and management of capacity. Figure 1.9 is presenting a framework which used to clarify the concept of capacity and is easy to understand by every concern.

In this framework, the capacity related terms are described as following:

- C_1- Theoretical Installed Capacity*:* In this perception, it assumes 365 working days with all three working shifts (i.e. 365*24 = 8760 hours per year) for each equipment, and operational time is based on collaborator's time, or established through appropriate techniques.
- C_2- Theoretical Rated Capacity: The capacity also assumes 8760 hours per year bit operational time is being considered after being downrated due to poor methods applications, faulty work measurement or low labour productivity, etc. This capacity is also called 'design capacity.
- C_3 - 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.
- C_4 - Real Capacity: This capacity refers to actual productions levels achieved after tackling breakdowns, absenteeism, power failure, material shortage, scheduling inadequacies, etc.

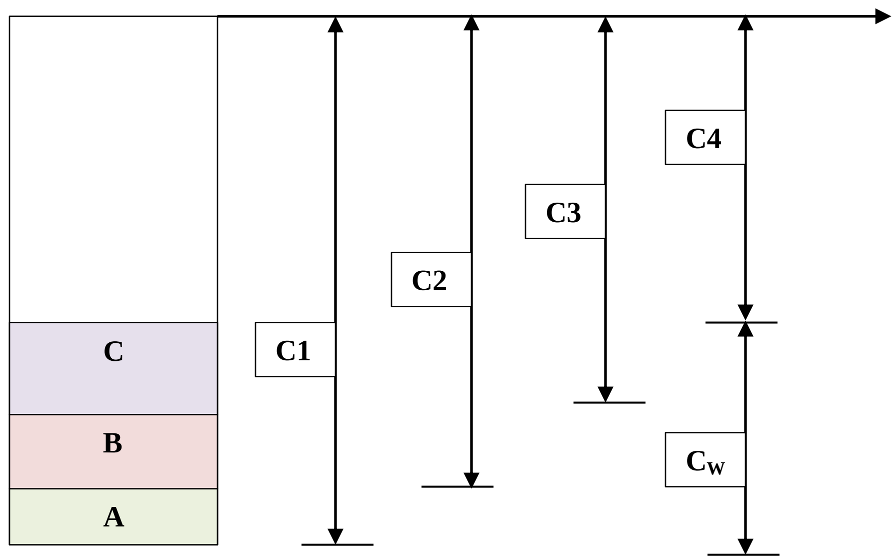

Figure 1.9: Capacity Perception [54]

Here the significance of notations is given as:

- **A** – Poor method of application, faulty work measurement, low labour productivity
- **B** – Work in fewer shifts, fewer working hours, demand trends, poor power availability, and poor input availability
- **C –** Material shortages, machine breakdowns, absenteeism, scheduling problems
- **C_W-** Capacity Waste

The relation used to estimate capacity utilization is shown in equation 1.

$$\text{Capacity utilization} = \frac{\textbf{Real Capacity}}{\textbf{Installed Capacity}} \times 100\% \qquad (1)$$

Here it can be seen that capacity utilization will be 100% if the real capacity is equal to installed capacity, but practically it's not possible due to expected and unexpected variations in the process. So, for calculating the capacity waste, equation 2 is used.

Capacity waste = 1 - Capacity utilization [54] (2)

1.10 Motivation for the present work

The increased emissions of greenhouses gases and other pollutants have led to a substantial increase in earth temperature and air-related health diseases from the last few decades [67]. The mains reasons for the same can be attributed to the traditional methods of operations adopted by the industrial organization in the majority of the world [68]. Furthermore, to remain competitive in the market and comply with environmental pacts the industrial organizations have to cut their current level of emissions by adopting sustainable practices in the business operations [56] [69]. The organizations have adopted approaches like Lean to reduce wastes and create values, Six Sigma to reduce defects and process variations [25]. Among the plethora of availed strategies green manufacturing is also being adopted by industries to suggest strategies that reduce the environmental impacts associated with the production of goods and services. But each approach i.e. Lean, Green, and Six Sigma, have their associated drawbacks that can be overcome by the possible inclusion of another approach [57]. So, the integration of these operational strategies leads to the evolution of a powerful business strategy that not only meets the modern demand of both industry and customers but leads to sustainable development. Despite the evolution of GLS, industrial managers are reluctant to apply this technique within their organizations due to lack of readiness and fear of failure. To implement a new approach the organizations, have to incorporate some suitable measures in terms of operations tools and methods called readiness measures to assure successful execution. The execution of GLS also demands the systematic framework with the associated toolset that provides a stepwise guideline for the realization of the GLS program. So, lack of integration measures, implementation framework, readiness measures, and systematic literature review pertains to GLS and its overall impact on the sustainability and contribution to Mother Nature provides motivation and direction to conduct the present study.

1.11 Thesis outline

In this thesis potential of GLS as a novel sustainable development approach has been presented. To facilitate GLS execution enablers of GLS have been found and modelled.

Moreover, barriers to GLS have been identified and removal measures were also suggested. Life cycle assessment framework along with the estimation of the environmental foot through LCA also has been presented. Integration and framework of GLS also have been presented to booster application of this new methodology. Further, to realize the full potential of the GLS, proposed framework has been tested in a real-life industrial. The outline of this thesis is as follow:

Chapter 1 presents the need for GLS, introduction to Lean manufacturing, Green technology, Six Sigma process improvement approach. Moreover, this chapter outlines the integration of Green Lean, constraints of the Green Lean approach, and presents the GLS model. This chapter also depicts the basic concept behind capacity and its significance. This chapter also enumerates the impetus for the present research work.

Chapter 2 outlines a systematic state-of-the-art literature review that pertains to GLS and capacity waste. The detailed literature review was done through the lens of systematic literature search methodology. GLS literature study leads to the development of theoretical knowledge for this study for practitioners and researchers. The comprehensive literature review reveals different grey areas that pertain to GLS that lead to the pathway for this research work.

Chapter 3 outlines problem formulation, research plan, integration measures, and the framework of GLS. Moreover, this chapter also presents tools of GLS. Besides, different multi criterion decision making techniques used in this research study were also presented.

Chapter 4 presents the identification and analysis of enablers of GLS. Enablers of GLS firstly were identified for all industrial sectors and modelled using interpretive structural modelling and further investigated using MICMAC analysis. Thereafter, GLS enablers were unearthed for the manufacturing sector and prioritized using the best-worst method (BWM). GLS enablers' facilitate practitioners and managers for the execution of the GLS execution program in the manufacturing industry.

Chapter 5 outlines barriers to GLS implementation in the manufacturing industry. Firstly barriers were recognized from the literature and further verified through expert views. To facilitate the systematic removal of barriers, it is a prerequisite to identify the most critical barriers to GLS implementation. Barriers critical to GLS were prioritized using intuitionistic fuzzy DEMATEL and further validated using BWM. Moreover, different mitigation actions for the barriers are also suggested for the manufacturing industry.

Chapter 6 presents a systematic framework of LCA for the manufacturing sector. Moreover, to estimate the current state of the process of the concerned product from the case industry systematic LCA was performed. LCA was used to estimate the environmental impact of the current system.

Chapter 7 presents practical validation of the proposed framework of GLS in a real-life industrial setting. GLS has been realized in a sequential manner using different tools of green technology, Lean manufacturing, and Six Sigma. This chapter also presents a systematic model for the assessment of sustainability of the case industry. To realize the potential of the GLS approach, different metrics pertain to wastes; inefficiencies have been estimated before realization of the GLS project and estimated same after completion of the project. GLS execution through the lens of developed framework leads to considerable saving in term of monetary values, improved environmental sustainability, and provides assessment and improvement measures of social sustainability.

Chapter 8 outlines inferences drawn from the present research work. Moreover, this chapter also depicts the future research agenda of this study for the practitioners and potential researchers.

The growing concern for environmental and social sustainability has attracted the attention of researchers from manufacturing industries and educational institutes towards GLS. Till now, a plethora of work pertains to Lean manufacturing, Six Sigma, and Lean Six Sigma exists in the literature, but scant research pertains to GLS integration, enablers, barriers, framework formulation prevail. The relevant previous work pertains to GLS, LCA, and capacity measures have been reviewed through the lens of systematic search methodology to explore the grey area for this research work. The literature that pertains to this study is organized based on the exploration of GLS articles (section 2.2), development of GLS (section 2.3), literature pertains to enablers and barriers of GLS (section 2.4), literature pertains to the framework of GL, LSS and GLS (section 2.5), literature pertains to LCA (section 2.6), and literature pertains to capacity (section 2.7). The identified research gaps and formulated research objectives are summarized in sections 2.8 and 2.9 respectively.

2.1 Methodology adopted for literature review

The systematic conduction of the literature review forms the basis for the development of theory and also uncovers potential areas for future research [23]. The systematic literature review (SLR) uses an explicit approach that includes different phases to assure that precision and transparency can be assured in the process of the literature review [70]. The SLR uses different phases starting from the questions or objectives formation, location of studies, selection of studies, and reporting of the findings [71]. Figure 2.1 depicts different phases, tools adopted, methods used in the SLR process. The pertinent research articles were searched using keywords ‘Sustainability’, ‘Lean’, ‘Green’, ‘Six Sigma’, ‘Lean Six Sigma’, and ‘Green Lean Six Sigma’, ‘Life cycle assessment, ‘Manufacturing, ‘Framework’, ‘Enablers’, ‘Barriers’, ‘Capacity’, ‘Capacity waste’, ‘Capacity waste’. The articles were accessed using the electronic databases (EDB) of Elsevier, Emerald, Springer, Taylor & Francis, Wiley, etc. These EDB were considered the main bases of information to develop and understand the notion of GLS and its effect on sustainability and capacity and to develop opinions for further research in this novel aspect. The prominent criterion for the selection of the published articles was that these had to explore the interaction of Lean with Green technology, Lean with Six Sigma, sustainability aspects adhered to Lean, Green, and Six Sigma, and articles exploring the field of GLS. From the comprehensive review of the articles, the research gaps have been identified.

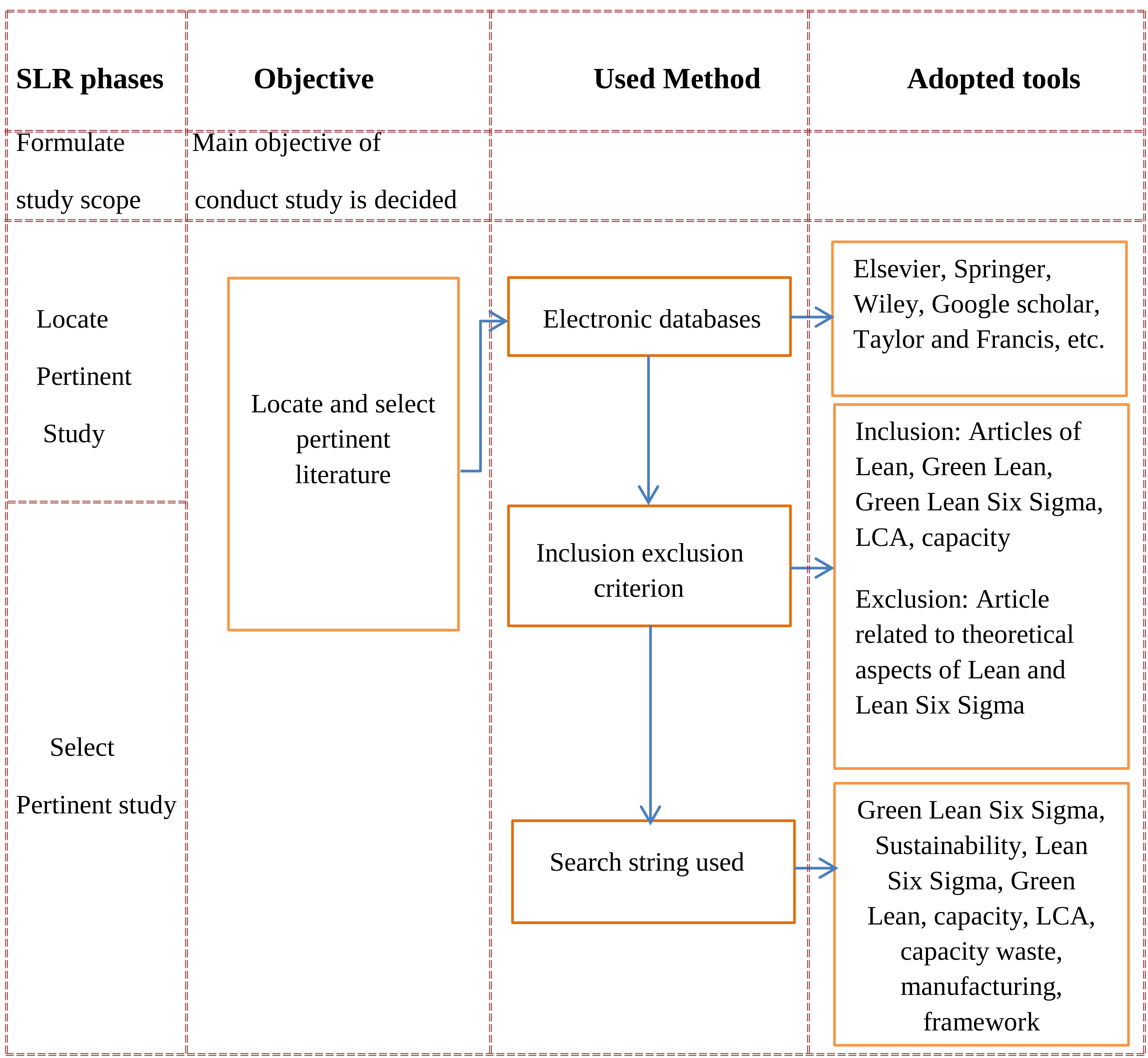

Figure 2.1: Systematic literature review methodology

2.2 Exploration of Green Lean Six Sigma articles

The SLR methodology adopted helps to select all the articles pertinent to GLS. The literature review section pertain to GLS, consists of three sub-sections. Firstly a descriptive analysis of the published articles of GLS was performed, journal-wise; year-wise; continent wise and industry-wise to explore different aspects of GLS.

2.2.1 Descriptive analysis of Green Lean Six Sigma articles

The present work covers GLS articles from 87 reputed journals/proceedings about the field of research in organizational performance improvement. A large proportion of the articles were taken from the Journal of cleaner production (13.51%) followed by the International Journal of Lean Six Sigma (11.97%). Table 2.1 depicts the journal-wise distribution of the articles.

Table 2.1: Journal wise distribution of articles

S. No.	Journal Title	No. of Articles	Percentage of Articles
1	Journal of Cleaner Production	35	13.51
2	IJLSS	31	11.97
3	Production Planning and Control	24	9.27
4	IJQRM	11	4.25
5	Total Quality Management & Business	11	4.25
6	International Journal of Productivity and Performance Management	11	4.25
7	IJSSCA	8	3.09
8	International Journal of Production Research	5	1.93
9	TQM Journal	9	3.47
10	IEEE	3	1.16
11	International Journal Lean Enterprise Research,	3	1.16
12	IJSOM	3	1.16
13	International Journal of Advanced Manufacturing and Technology	3	1.16
14	JMTM	3	1.16
15	Supply Chain Management An International Journal	3	1.16
16	TQM Magzine	3	1.16
17	Benchmarking an International Journal	3	1.16
18	Decision Science letters	2	0.77
19	European Journal Cross-Cultural Competence and Management,	2	0.77
20	Industrial Engineering Research Conference	2	0.77

21	Innovation for Reshaping Construction Practice	2	0.77
22	IJAOM	3	1.16
23	IJBE	5	1.93
24	IJSTM	2	0.77
25	International Journal of Technology Management,	2	0.77
26	International journal of operation and production management	2	0.77
27	Journal for Healthcare Quality	2	0.77
28	Journal of Industrial Engineering International	2	0.77
29	Business Process Management	1	0.39
30	Chemical Engineering Research and design	1	0.39
31	Clean Technologies and Environmental Policy	5	1.93
32	Conference for Industry and Education Collaboration	1	0.39
33	Ecological indicators	1	0.39
34	Energy, Ecology and Environment	1	0.39
35	Failure Analysis and Prevention	1	0.39
36	Growing Science	1	0.39
37	International Journal System Assurance Engineering Management	1	0.39
38	International Journal of Environmental Science Technology	1	0.39
39	International Journal of Information and Operations Management Education	1	0.39
40	International Journal Logistics Systems and Management,	1	0.39
41	International Journal Procurement Management,	1	0.39
42	International Journal Product Lifecycle Management,	1	0.39
43	International Journal Rapid Manufacturing,	1	0.39
44	International Conference on Design and Concurrent Engineering 2012	1	0.39
45	International Journal of Business and Management Invention	1	0.39
46	International Journal of Construction Management	1	0.39
47	International Journal of Industrial Engineering and Technology	1	0.39
48	International Journal of Management Science	1	0.39
49	International Journal of Physical	1	0.39
50	IJPE	1	0.39
51	IJPR	2	0.77
52	International Journal of Quality and Service Sciences	1	0.39
53	International Journal of Sustainable Development & World Ecology	1	0.39
54	IUP Journal of Operations Management	1	0.39
55	Journal of Applied Statistics	1	0.39
56	Journal of Industrial and Intelligent Information	1	0.39

57	Journal of Material Science and Mechanical Engineering	1	0.39
58	Journal of Modeling in Management	1	0.39
59	Journal of Organizational Change and Management	1	0.39
60	Journal of Purchasing & Supply Management	1	0.39
61	Journal of Sustainable Metallurgy	1	0.39
62	Management Decision	1	0.39
63	Management Science Letters	1	0.39
64	Manufacturing Systems and Technologies for the New Frontier	1	0.39
65	International Journal Productivity and Quality Management	1	0.39
66	Operations Management Research	1	0.39
67	Procedia Materials Science	1	0.39
68	Production & Manufacturing Research	1	0.39
69	Quality Engineering Journal	1	0.39
70	Quality Management Journal	1	0.39
71	Quality technology and quantitative management	1	0.39
72	Review of Managerial Science	1	0.39
73	International Journal Agile Systems and Management,	1	0.39
74	Total Quality Management & Business Excellence	1	0.39
75	Uncertain Supply Chain Management	1	0.39
76	Wiley Online Library	1	0.39
77	Work Study Journal	1	0.39
78	International Journal of Physical Distribution & Logistics Management	1	0.39
79	International Journal of Industrial Engineering & Technology	1	0.39
80	International Journal Business Continuity and Risk Management	1	0.39
81	Supply Chain Forum: An International Journal	1	0.39
82	Building and Environment	1	0.39
83	International Journal of Sustainable Engineering	1	0.39
84	Environmental Impact Assessment and Review	1	0.39
85	Sustainability	1	0.39
86	Science of Total environment	1	0.39
87	Resource Conservation and Recycling	1	0.39

In this study, articles of GLS from 2001 to 2020 have been covered. A significant rise in the number of publications of GLS has been reported in educational journals since 2007 (refer to figure 2.2). As illustrated in the line diagram, 2014 experienced a high no of articles with 26 followed by the year 2016. It has been found that from 2013 to 2019, 148 articles of GLS have published, whereas 48 articles were published from 2001 to 2008. This reveals the proclivity towards GLS has increased substantially.

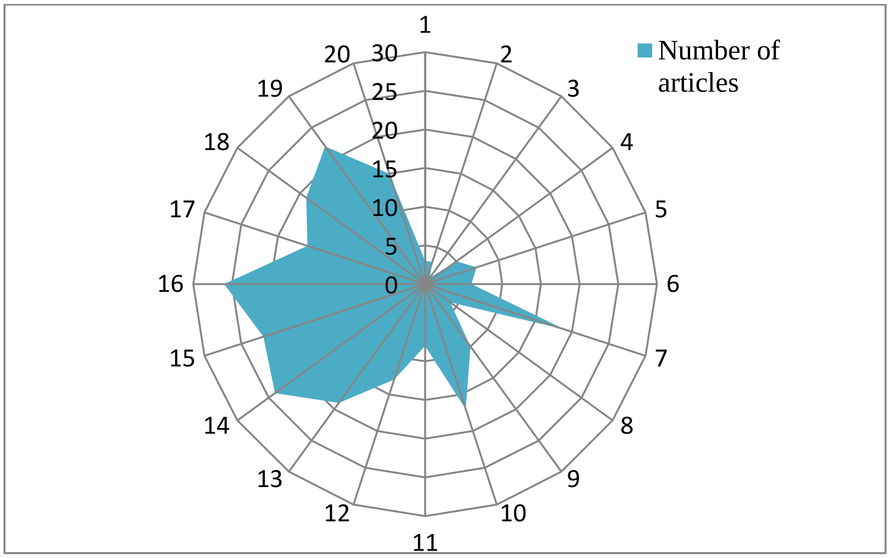

Figure 2.2: Years wise distribution of publications

Moreover, the distribution of articles of GLS was found in seven continents of our planet. Out of 259 articles, 109 were contributed by Asia, followed by Europe and North America. Figure 2.3 depicts continent-wise paper publication.

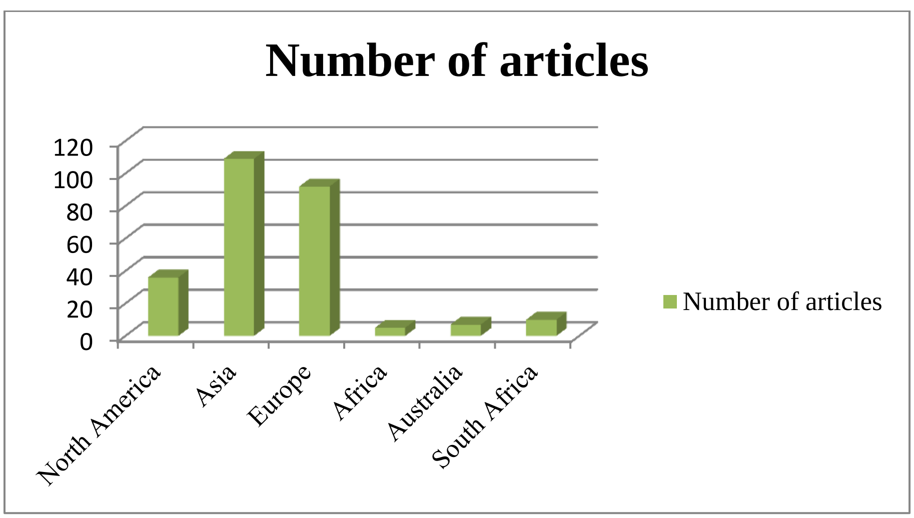

Figure 2.3: Continent wise distribution of publications

It has been found that GLS is not limited to the manufacturing domain of production, but is applicable to service also, such as banking, health care, education, etc. The frequency distribution of GLS spread in different domains of the industry has shown in table 3. It has found that most of the GLS application is in manufacturing sector (44.40%) and service sector accounts for 16.99%.of the application.

Table 2.2: Industry-wise distribution of articles

S. No.	Industry	No. of Articles	Percentage
1	Manufacturing	115	44.40
2	Conceptual and descriptive based articles	83	32.05
3	Service	44	16.99
4	Agriculture and Food Processing	13	5.02
5	Infrastructure	4	1.54

On the contrary, GLS distribution in the agriculture and food processing industry is relatively less due to a lack of exploration in these fields. In Infrastructure industries, the applications of GLS were found very less and it is challenging for the researchers to apply a comprehensive integrated approach in this sector.

2.3 Green Lean Six Sigma development

A detailed investigation of research articles was done to find the grey areas of GLS in which the research can be initiated. The development of GLS can trace back to the evolution of Lean manufacturing [72]. Lean production is a waste reduction approach that reduced the various non-value-added activities by making the system more streamlined [73]. The manufacturing industries have faced the problem of the high rejection rate of the end product, due to some assignable causes associated with the process [74]. Lean manufacturing is not able to address this challenge of manufacturing. At this stage, Six Sigma originates that reduces the defects and leads to high specifications end products [75]. It is a project-based approach that reduces defects up to 3.4 M /opportunities [5]. It was developed by the Motorola Corporation in the late 1980s. The integrated Lean Six Sigma (LSS) approach leads to reduced wastes and defects that subsequently result in increased organizational capability [3]. But the integrated LSS approach has the constraints that it is not able to mitigate the negative environmental impacts associated with the process [76]. This drawback of the LSS has been overcome by the inclusion of Green technology in the LSS. The integration of Green technology in the LSS leads to the evolution of a new sustainable development method named Green Lean Six Sigma (GLS). It reduces wastes, defects, and environmental emissions that lead to increased organizational sustainability [77]. GLS as a new approach found very limited applications in the literature. It has been applied for modelling of enablers and barriers [78], and sustainability improvement in locomotive sector [79]. In the literature, the study pertains to the synergy of Green Lean [23] [10] [80], Integrated Lean Six Sigma [81] exists. But literature lacks enough evidence for integration of the Green, Lean, Six Sigma under the umbrella of GLS. It has been identified from the comprehensive literature review that the individual Lean, Green, and Six Sigma approach have some drawbacks that can be overcome by the other approach. So, the integration of these approaches leads to the development of a new approach that will address the modern challenge of the industries in terms of reduced. Table 2.3 depicts various characteristics of GT, Lean manufacturing, and Six Sigma that foster integration of three unique approaches under the umbrella of GLS.

Table 2.3: Comparison of various characteristics of Lean, Green and Six Sigma methodologies

S. No	**Characteristic**	**Lean view**	**Green View**	**Six Sigma View**
1	Definition	Philosophy of waste reduction by the elimination of waste [82] [83] [84]	An approach to produce eco-friendly products [85] [86] [87] [88]	Statistical data-driven approach to reduce the defects in the process [89] [90] [91]
2	Pin Point	Increase profit margin and competitiveness of the organization [92] [93] [94]	To reduce the harmful environmental impact [95] [96]	Increase profit margin and competitiveness of the organization [97] [98]
3	Focus	Minimize the cost of the product through the reduction of wastages [99] [100]	Increase the utilization efficiency of energy and natural resources to improve ecological efficiency [101] [30]	Saving in cost through defective parts reduction [102] [103] [104] [105]

4	Principles	Pull system from customer to supplier; value stream mapping of the process; standardization and management of organizational resources for continuous improvement; production of utmost quality product at the lowest possible cost [106] [107] [108]	Reduction in material, energy, water, and other resources; reduction in global warming and other environmental effects; evaluation of the system from Green point of view and assessment of customer satisfaction from Green aspect [109] [110] [15] [111]	Process capability; sigma level; CTQ; Voice of Customer (VOC); DMAIC; DFSS, enhanced customer satisfaction through defects free high-quality product: reduced variation in the process [112] [113] [114]
5	Indicators	Percentage of non-value added activities; lead time of supplier and manufacturer; inventory stock; reduction in safety stock of the organization [115] [116] [117]	Life cycle assessment; CO_2 emission; energy reuse factor; Green energy coefficient; the level of recycling; reuse and remanufacturing [118]	Defects per million opportunities (DPMO); defects per million units (DPM); process capability indices; sigma level [119] [120] [121][122]
6	People	Everyone from top to bottom of the organization is responsible for the quality of the product [123] [35]	Everyone involvement from the organization [123] [124] [125] [126]	Few Green and black belts people with some project members [127]
7	Product design consideration	Limited focus on new product design, reduce the wastages and maximize the profit [128]	It considers new product design from a life cycle assessment point of view for the calculation of environmental risk and impact [129]	DFSS is used for new product design to enhance the utmost customer satisfaction [130]
8	Waste	Mainly focus on waste reduction to reduce cost [131] [132] [33]	Focus on environmental waste reduction [39] [133] [134]	Defects reduction in the process [135] [136]
9	Continuous Improvement Process	Continuous improvement process for wastage reduction from the system [137] [138]	Continuous improvement process to improve environmental performance [86]	Continuous improvement process for improvement in the sigma level of the process [139] [140]
10	Customers	Cost reduction; strong customer focus through the elimination of non-value-added activities [141] [35], [138]	People and Environment	Monetary driven approach; strong customer focus on quality [142]

11	Inventory	Consider inventory as waste and aims at the elimination of waste for cost reduction [143] [34] [144] [145]	Minimize inventory to reduce negative environmental impact [88] [146] [147]	Not a pinpoint area but process improvement leads to a reduction in inventory level
12	Supplier	Supplier involvement is key to the success of the Lean program; vendor managed inventory is key to the success of the Lean program [148] [149]	Integration of reverse information and material; collaborative approach to spread Green knowledge [150]	Due consideration to the supplier only when they impact the quality
13	Tools used	Poka-yoke; Value stream mapping (VSM), JIT, TPM, standardization; Kanban, etc. [46] [151]	Life cycle assessment; Value stream mapping etc. [96] [152]	SIPOC; Pareto Chart; DOE; brainstorming; Poka-yoke; standardization; VSM; Hypothesis testing; capability analysis etc. [153] [154]

2.4 Literature review of Green Lean Six Sigma enablers and barriers

Researchers and industrial managers are trying to recognize those features that explicate the success and failure of GLS in organizations. Enablers are the prerequisites that provide a stimulus to the organization to apply a new approach [21]. Although a lot of work has been done by researchers in past to identify the enablers of individual Lean, Green, and Six Sigma approach [155] [156] or only Green Lean concepts [157] or Lean Six Sigma concepts [158] [159]. The literature lacks much evidence of identification and modelling interactions of GLS enablers. GLS found very few applications in the manufacturing sector because of its novelty and cultural difference; the organizations have faced various challenges or barriers to implement this approach [10]. Barriers are specified as managerial and technical challenges that defer an organization to get desired targets within a particular time [89]. The GLS barriers exhibit the contextual relationship and it is imperative to understand the relationships among the barriers [78]. Based on the nature of the barriers, they can be classified into different logical groups. Parmar and Desai [160] classified 20 enablers of sustainable Lean Six Sigma (SLSS) into different groups based on expert opinions. Aboelmaged [89] classified 47 barriers of Six Sigma into groups of the knowledge base, support, sustainability, resource, customer focus, complexity, and alignment barriers using principal component analysis. Any business organization needs to identify key challenges or barriers within a particular time frame to take competitive advantages over competitors [26]. Once the failure factors have been identified, and contextual relations established then improvements measures are undertaken to overcome these barriers.

2.5 Literature review of Green Lean Six Sigma frameworks

The literature suggests that LSS implementation leads to constructive outcomes on the ecological and financial performance of the organizations. However, the inclusion and implementation of Green technology with LSS is not deprived of challenges. Lack of finance for clean technologies projects, poor organization support system, deficiency of resources, unavailability of tools and practices, and uncertain gains, further hinder the effective execution of sustainability-oriented projects [161]. The integration of sustainability with LSS has led to improvement in environmental sustainability together with traditional performance measures of quality and productivity [160]. Besseris [162] industrialized a logical model to deal with process efficacy and ecological facets together in a GL project using LSS tools. The proposed model was tested in the maritime industry and exhibited improvement in environmental, economic dimensions of sustainability together with the traditional priority of productivity. Habidin and Yusof [163] conducted an exploratory study to comprehend the contextual relationship among LSS, environmental measures, and organizational performance metrics. Statistical analysis was employed to analyze the relationship among different performance measures of LSS and environmental sustainability. The contextual relationship between GLS and management innovation for the Malaysian automotive industry was developed using interpretive structural modelling [79]. It has been determined that management innovation works as an intermediary to introduce effective GLS practices for the sustainable growth of the industry. The developed model was validated in the construction process of a pile cap installation process. It was found that lead time reduced from 54 days to 36 days and environmental effects reduced considerably through systematic kaizen events and the adoption of sustainable practices. Garza-Reyes [72] proposed a new business strategy Green LSS that integrates GL with Six Sigma methodology and pinpoint achieving financial sustainability through systematic reduction of wastes, defects, and emission measures. The proposed insights contributed to the theoretical knowledge base which helps in the development of business strategies coupled with environmental facets. Kumar et al. [164] developed a systematic framework for the merger of Green technology with Lean and Six Sigma. They also prioritized the enablers and performance measures based on the responses from the industrial personnel which facilitate effective execution of the integrated approach. Fatemi et al. [163] investigated the application of sustainable Lean and Green strategies with the Six Sigma approach (SGLS) for the reduction of wastes and emissions in the manufacturing industry. Cherraffi et al. [165] conducted a state of the art literature study on the possible integration of three management systems, i.e. Lean production, Six Sigma, and Sustainability. The authors' unearthed various challenges and opportunities for their integration and recommended future research direction for the inclusive growth of the industry. Kumar et al. [78] framed a hierarchical structural model of barriers of GLS in the product development process using interpretive structural modelling (ISM). It was found that a lack of management commitment is one of the key barriers to the successful execution of the sustainable GLS program during the product development process. To understand the interactions and interdependencies among the barriers, the authors performed a MICMAC analysis for the systematic removal of barriers in the execution of GLS. Sagnak and Kazancoglu [10] revealed the limitations of the GL approach and proposed a systematic model to overcome the same through the inclusion of Six Sigma. They found that variation in processes that cannot be overcome by GL can be overpowered by Six Sigma through the application of measurement system analyses and gage control. A VSM-DMAIC based LSS model with environmental facets to assess ecological impacts in the food processing industry of Norway was presented [166]. They found that the systematic adoption of the proposed model in the raw material processing, bottling and packaging section leads to a considerable reduction in wastes and associated environmental footprints. Ruben et al.

[161] proposed a DMAIC based LSS framework with environmental aspects to reduce defects and carbon footprint in the automotive industry. They found that the effective deployment of the framework led to a reduction in defects level from 16000 ppm to 6000 ppm while ecological effects were reduced considerably. Caiado et al. [167] provided a systematic integration of Green technology and LSS and formulated an implementation framework to institutionalize GLS in service industries. Pandey et al. [21] analyzed and prioritized enablers of GLS using a multi-criterion decision making (MCDM) approach for the smooth execution of the GLS program. The researchers made pursuits for the facilitation of GLS execution in different industrial sectors. Kaswan and Rathi [27] critically examined GLS enablers for manufacturing industries. A systematic method for the removal of different barriers in the execution of the GLS program was developed in the construction sector [26]. Kaswan and Rathi [57] developed integral measures for GLS and developed a generalized framework for the business sector based on the Six Sigma based DMAIC methodology. So, it is observed from the available literature that no study pertains to GLS framework exists in the manufacturing environment that leads to social, economic, and environmental sustainability and that also embed different tools of Green, Lean and Six Sigma. Table 2.4 depicts different studies of frameworks that have attempted to integrate Green technology with LSS as well as their major contribution and limitations.

Table 2.4: Major studies pertains to the framework and identified limitations

Authors	**Contribution**	**Limitations**	**Use of LSS tools**	**Use of environmental mgt. tools**	**Operational benefits**	**Sustainable benefits**	**Practical case implementation**
Banawi and Bilec [37]	Formulated framework for the adoption of integrated Green, Lean, and Six Sigma for the construction industry to improve process performance through	The major limitation of this study was that the adopted framework focused only on the construction sector. The integral measures of Green, Lean, and Six	👍	👍	👍	👍	👍

	retrospective diagnosis. The developed framework estimates environmental impacts and assists contractors to measure the impacts of their traditional methods and improve the corresponding efficiency.	Sigma were also not provided.					
Sony and Naik [37]	Developed a sustainability-oriented GLS framework for reducing dust and graphite pollution in the mining industry.	The developed framework exhibited limited application of Six Sigma tools and the adopted method was only applicable to the mining sector.	👍	👍	👍	👍	👍
Kaswan and Rathi [57]	The researchers proposed integration based on theoretical measures and formulated a DMAIC based GLS implementation framework.	The framework developed was not validated within a case organization.	👍	👍	-	👍	-
Ruben et al. [161]	Formulated a generic framework of LSS with environmental facets and realized the same with a case of an automotive organization.	Developed framework more inclined towards the LSS measures the aspects of social sustainability was not explored to full throttle.	👍	👍	👍	👍	👍
Siegel et al. [56]	Presented a systematic model to integrate and implement GL for manufacturing SMEs.	Six Sigma potential along with social sustainability aspects was not explored to improve organizational productivity and social performance.	👍	👍	👍	-	-
Cherrafi et al. [165]	Developed a five stages based framework to implement LSS with environmental facets. It has been found that the case industry reduced material and cost of energy through the inclusive implementation of the adopted framework.	The framework has not explored reduction in defects level, assessment of different environmental and social metrics.	👍	👍	👍	-	👍
Erdil et al. [168]	The formulated model framework to redefine the LSS (DMAIC) cycle for the incorporation of	The main limitation of the present study was that the developed model was not tested in	👍	👍	👍	👍	-

	the sustainability measures in any LSS project based on the current practices.	a real-life industrial setting to validate the results.					
Ruben et al. [123]	Based on the insights gained from the literature study developed an environmental focused LSS framework using benign LSS tools.	The developed framework was not tested practically and also did not incorporated societal aspects of the sustainability	👍	👍	👍	-	-
Caiado et al. [167]	Proposed an integrated framework of GL and Six Sigma to enhance the sustainability of the service sector based on critical factors.	The developed model was not tested pragmatically and it was solely developed for the service sector.	👍	👍	👍	-	-
Sagnak and Kazancoglu, [10]	Developed an integrated framework of GLS based on commonality characteristics that coexist among individual approach.	The study lacks practical validation of integrated framework and did consider social aspects of the sustainability	👍	👍	👍	-	👍
Gohlami et al. [169]	Proposed and implemented GLS framework to enhance organizational sustainability based on DMAIC approach	The proposed have not considered the application of the Lean. Six Sigma tools, and also not address the societal dimension of the sustainability	👍	👍	👍	-	👍
Talapatra, and Gaine [170]	Proposed and implemented GLS framework for jute industry to reduced defects, carbon footprints and energy usage.	The said framework was entirely focused on jute industry and did not incorporate societal metrics.	👍	👍	👍	-	👍
Ershadi et al. [77]	GLS project selection was made based on the integral aspects of the data envelopment analysis (DEA) and technology readiness level (TRL).	Researchers did not address that how GLS works, how it can enhance the societal dimension of the industry.	👍	👍	👍	-	-

2.6 Literature review of Life Cycle Assessment

Life cycle assessment (LCA) is a tool that supports decision-makers to develop the solution to the problem meanwhile taking into considerations all the dimensions of sustainability [171]. It is a tool that assesses an environmental load of a process, product or any activity from its initial stage to the disposal. It provides a detailed environmental analysis of a system consisting of different unit processes [172]. The quantification and investigation of wastes from a system using LCA further lead to the identification of major reasons for these non-value-added activities [173]. Once potential reasons for the source of wastes have been identified, they can be eradicated from the system. The success of green technology implementation is directly related to the effective execution of LCA as it is the main driving force to quantify or measure wastes [78]. The LCA comes into the picture in the 1960s due to increased concern about the ecological degradation and depletion of natural sources of energy [174]. LCA had its first application in packaging studies and in the early stages of its development mainly focused on energy and emissions [175]. There have been numerous efforts to develop LCA methodology since the 1970s, but it has received much consideration from researchers of environmental science since the 1990s. The term LCA was coined in the 1990s, earlier it was known by the names of life cycle oriented methods and Resource and Environmental Profile Analysis (REPA), eco-balancing resource and cradle-to-grave assessment [176]. The earlier development of LCA primarily took place in northern America and Europe. In earlier methods of LCA, material and energy accounting were predominately considered. There was no uniformity of the applied methods in the early years of LCA development because ecological concerns addressed by the methods tended to change with public anxieties. Earlier impact assessment method represented the amount of water and pollutants needed to dilute up to the safe levels [177].

In the early 1990s very impact assessment method was developed: CML 92, EPS method and Eco indicator-99 [178]. The early 1990s also show the birth of many inventory databases managed by different institutions to cover a wide spectrum of the process. The data set managed were different for even the same type of process results in the discrepancy of the final results. To overcome this difficulty consistent data standard v.1.01 was released [179]. In the 20^{th} century, impact assessment methodologies have been developed and refined. Globalization led to increased attention on bio-based products in LCA and a slew of activities regarding impact assessment of land and water used have been reported in the literature [180]. The inclusion of social dimensions in sustainability leads to the development of life cycle sustainability assessment to take into consideration each dimension of sustainability.

LCA is a tool to evaluate ecological impacts, support policy development, and making decisions [181]. It is a new discipline with 50 years of history and 30 years of intense development in the areas of food processing, agriculture construction. The main aim of the life cycle initiative (International life cycle partnership) an initiative of the United Nations Environment Programme (UNEP) is to maintain ecological balance with the support of better indicators, data set and practical procedures [182]. The researchers in the past have focused only on the carbon study of global warming whereas other potential parameters (eutrophication, acidification, ecotoxicity, human toxicity) of sustainable development were not considered [183]. The inclusion of all these parameters needs a lot of data set and the evaluation of these parameters. So, there is great potential to develop a systematic way and procedure to explore these other parameters to evaluate sustainability through LCA. Moreover, the industrial organizations are incorporating LCA in their due to environmental regulations or due to the changed perceptions of customers about environmentally friendly products. Therefore the industrial managers and practitioners are focusing on a decision support system to identify the environmental hot spots in the entire supply chain. The identifications of the environmental hot spots in the entire supply chain is a cumbersome and challenging task as it needs a real-time database of all the inventory of the supply chain and measurements of various inputs and outputs(energy water, material) at the intermediate stage of the supply chain. Despite LCA comprehensive adoption in developed nations, the Indian manufacturing sector lags LCA execution to estimate different metrics due to a lack of systematic framework and barriers in the path of LCA deployment [184]. So, it is imperative to identify and remove LCA barriers and develop a framework of LCA dedicated to manufacturing pertain to the Indian nation.

2.7 Literature review of capacity

The growth of any developing country mainly depends upon the growth of its industrial sector [2]. The growth of Indian's gross domestic product (GDP) mainly depends upon the manufacturing and service sector as these sectors majorly contribute to GDP [185]. The manufacturing sector plays a vital role in improving the health of the economy, as they have a direct impact on the country's inflation and employment. It has been found that in India,1% increase in GDP has yielded only a negligible 0.3% reduction in poverty [4]. The reason for the same can be attributed to traditional methods of operation and improper utilization of available resources or capacity [2] [6]. So, there is a need to be more focused on the development of the manufacturing sector. According to CSO 2008 report, the manufacturing sector is classified in automotive, heavy industry, and MSMEs. The automotive and heavy industries are having sufficient funds and strategies to managing their existing resources results improving the overall productivity of the plant at the lowest manufacturing cost of the product. But MSMEs are still struggling in an area in terms of capacity utilization, implement the quality tool, improving productivity without increasing input, etc. [5]; [186]. The literature presents that the CU concept has been successfully implemented in automotive (40%) and heavy industries (48%) rather than MSMEs (12%) as evident from figure 2.4.

The MSMEs are lagging due to unawareness about the capacity concept, no standard framework availability to estimate capacity, not aware of tangible and intangible benefits of capacity management, etc. [187]. According to market demand, the overall productivity of the MSMEs sector could be enhanced without increasing new resources just by properly utilizing the available resources within the plant. So, the productivity and quality of the industrial sector can be improved if industries expand their capacity or adopt advanced tools and techniques in their core business but such adoption directly increases the unit costs [5].

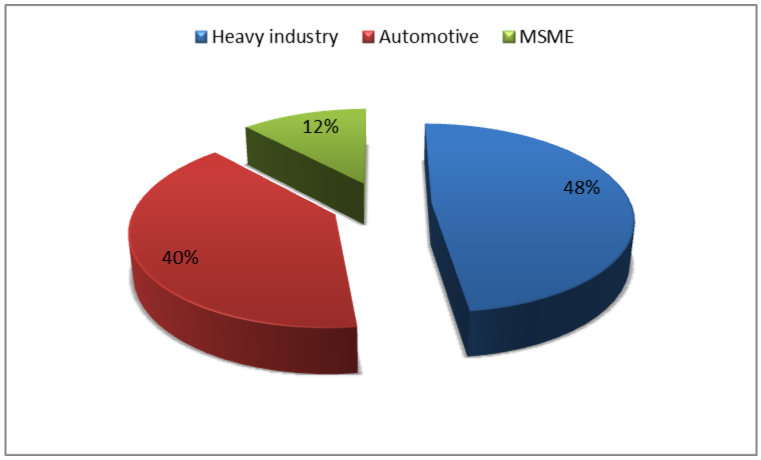

Figure 2.4: Contribution of CU concept in Indian manufacturing

Figure 2.5 is representing the active participation of countries towards the research on capacity and capacity utilization rate. It shows that the USA is the leading country in research on capacity management throughout the world. India is lying in the second position in this research area after the USA.

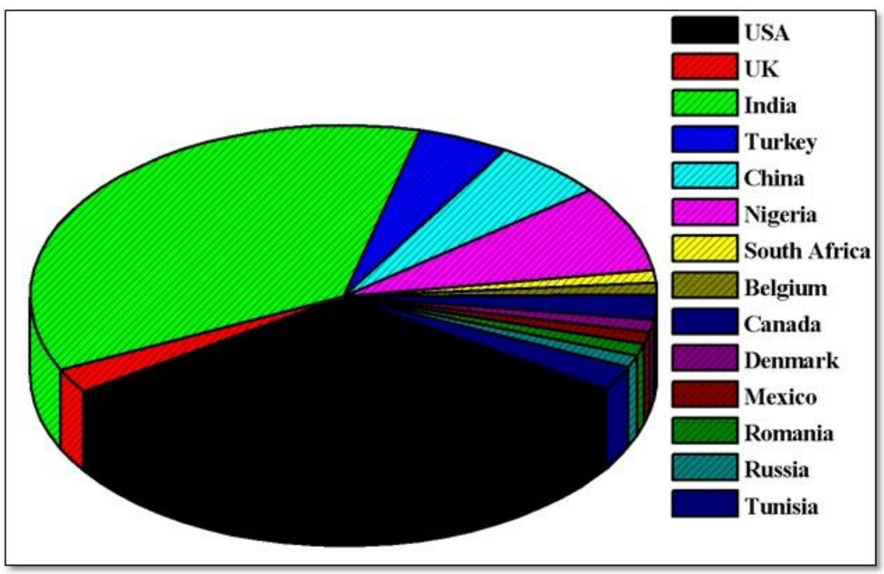

Figure 2.5: Distribution of published articles worldwide

Even the researchers are doing huge research on capacity and capacity waste in India, but the capacity utilization rate of Indian industries is 74.10% [188] lesser than USA industries capacity utilization rate (78%). Furthermore, China, Turkey, South Africa are active countries related to the research on the capacity and capacity utilization rate of industries in these countries are 76.80%, 77.10%, and 81.10%, respectively [189]. The current status of research on capacity and its management are highlighting that India is still struggling in the reduction of capacity waste (CW) rate (refer to table 2.5). So it is an alarming situation for the Indian industrial sector to grow up and participate in the growth in GDP of India.

Table 2.5: Capacity waste status across the world

Country	**Capacity waste rate**
Canada	13.90
UK	17.70
Mexico	18.40
South Africa	18.90
Denmark	19.30
Belgium	20.00
Tunisia	21.60
USA	22.00
Turkey	22.90
China	23.20
Romania	23.80
India	28.20

Although a lot of research had carried out on capacity management in India, still Indian industries are struggling with their low capacity utilization level as compared to major productive nations worldwide. The literature shows that the capacity utilization aspect has gained much attention in the last decade. One of the earliest estimations of CU rates was presented by researchers i.e. Budin and Paul based on monthly statistics of production [190]. Furthermore, government and non-government agencies are responsible for capacity estimation in India like the Reserve Bank of India (RBI), the Federation of Indian Chambers of Commerce & Industry (FICCI) and the National Council of Applied Economic Research (NCAER), Society of Indian Automotive Manufacture (SIAM). These agencies provide the capacity estimation data based on the complete sector level as shown in table 2.6. As reported in table 2.6, CW rate of the manufacturing sector is around 72%. This is most likely goes down when it comes to Micro Small and Medium Enterprises (MSMEs), i.e. about 57%. This report exhibits that resource under-utilization among MSMEs is the major issue for low productivity. As per the associated chambers of commerce and industry of India report, 79 small industries are turning financially unviable in India every day. As per the FICCI report, MSMEs are in a turbulent phase with a CU rate of about 55%, whereas in the manufacturing sector is about 75%.

Table 2.6: Capacity size v/s capacity utilization of various industrial sectors in India

S.N.	Indian industrial sector	Capacity Size	Capacity Utilization	References
1	Manufacturing	US$ 2334.60 billion	72%	[191]
2	Automotive	7 million	78%	[54]
3	MSME	US$ 765 billion	57%	[192]
4	Paper industry	18.6 million ton	88.40%	[193]
5	Healthcare	US$ 487.7 billion	75.95%	[193]
6	Education	US$ 101.1 billion	83.20%	[194]
7	Food industry	US$ 894.98 billion	78%	[195]
8	Textile	US$ 108 billion	75.48%	[195]

Based on the above state of the art literature study that pertains to capacity, it can be deduced that the Indian manufacturing sector is facing one of the prime challenges pertains to capacity waste. So, it is high time to devise techniques that enhance the organization's social, economic, and environmental performance through the reduction of waste, emission, defects, and capacity waste.

2.8 Research gaps

Based on the inferences drawn from the systematic state of the art literature review, the following research gaps have been identified.

- There is a wide gap between the installed and actual capacity of Indian manufacturing industries as reported in the literature. To achieve the target set by the NMP-2025 (Government of India), the serious problem of capacity waste of manufacturing firms is to be analyzed at the utmost priority.

- There is no evidence of a concrete process as well as environmental improvement strategy through life cycle assessment for productive capacity improvement in the manufacturing sector.
- As per the environmental regulation pact (Koyoto Protocol, Paris Pact) shop floor improvement strategies need to be integrated with green indices but the literature lacks such initiatives.
- There is not much evidence of the integration of Green, Lean and Six Sigma approach for the performance improvement of the organization, in term of lesser environmental degradation and improved quality levels. There is also a lack of clarity for the embedment of Green and Lean with Six Sigma for sustainable development.
- The major challenge with organizations is that there is no standard toolset available for improving the green efficiency and reduction of capacity waste in terms of lesser energy and other associated wastes.

2.9 Research Objectives

Based on the available literature and research gaps mentioned above, the following objectives are formulated.

- To investigate and model the enablers of Green Lean Six Sigma for performance improvement in the manufacturing sector.
- To estimate Green and Lean measures of the current process through life cycle assessment for the reduction in the capacity waste of the system.
- To develop and implement a comprehensive GLS framework for the manufacturing sector within the ambit of the environmental regulation pact.
- With a case study, to evaluate the competence of GLS for capacity waste reduction in terms of various capability and green measures.

Research Methodology (RM) is the study of various steps that are usually implemented by a researcher in studying his research problem along with the rationality behind them. This chapter outlines problem formulation, research methodology, GLS integral measure, and framework of GLS.

3.1 Problem formulation

Based on the identified research gaps from the available literature problem to be undertaken was formulated. The problem pertains to check the efficacy of Green Lean Six Sigma to reduce capacity waste, lean waste, defects, and the environmental footprint was formulated. To undertake the problem under consideration firstly enablers and barriers were identified for effective implementation of GLS. Thereafter, to access environmental impact LCA execution barriers were identified, and the LCA framework was developed. To execute GLS for addressing issues pertains to present research a comprehensive framework was developed and its pragmatic validation was tested within a manufacturing industry.

3.2 Research methodology

The present research work follows a systematic research methodology starting from a systematic literature review through the lens of SLR to realize the objectives of the study. SLR uses an explicit approach that includes different phases to assure that precision and transparency can be assured in the process of the literature review [70]. Based on the state of art literature survey grey areas pertain to GLS were identified and research objectives were formulated. Based on the identified gaps and objectives a research problem to address the challenge of manufacturing was formulated. Despite the evolution of GLS, industrial managers are reluctant to apply this technique within their organizations due to a lack of readiness and fear of failure. Enablers are the readiness measures that formulate an organization to implement any new approach.

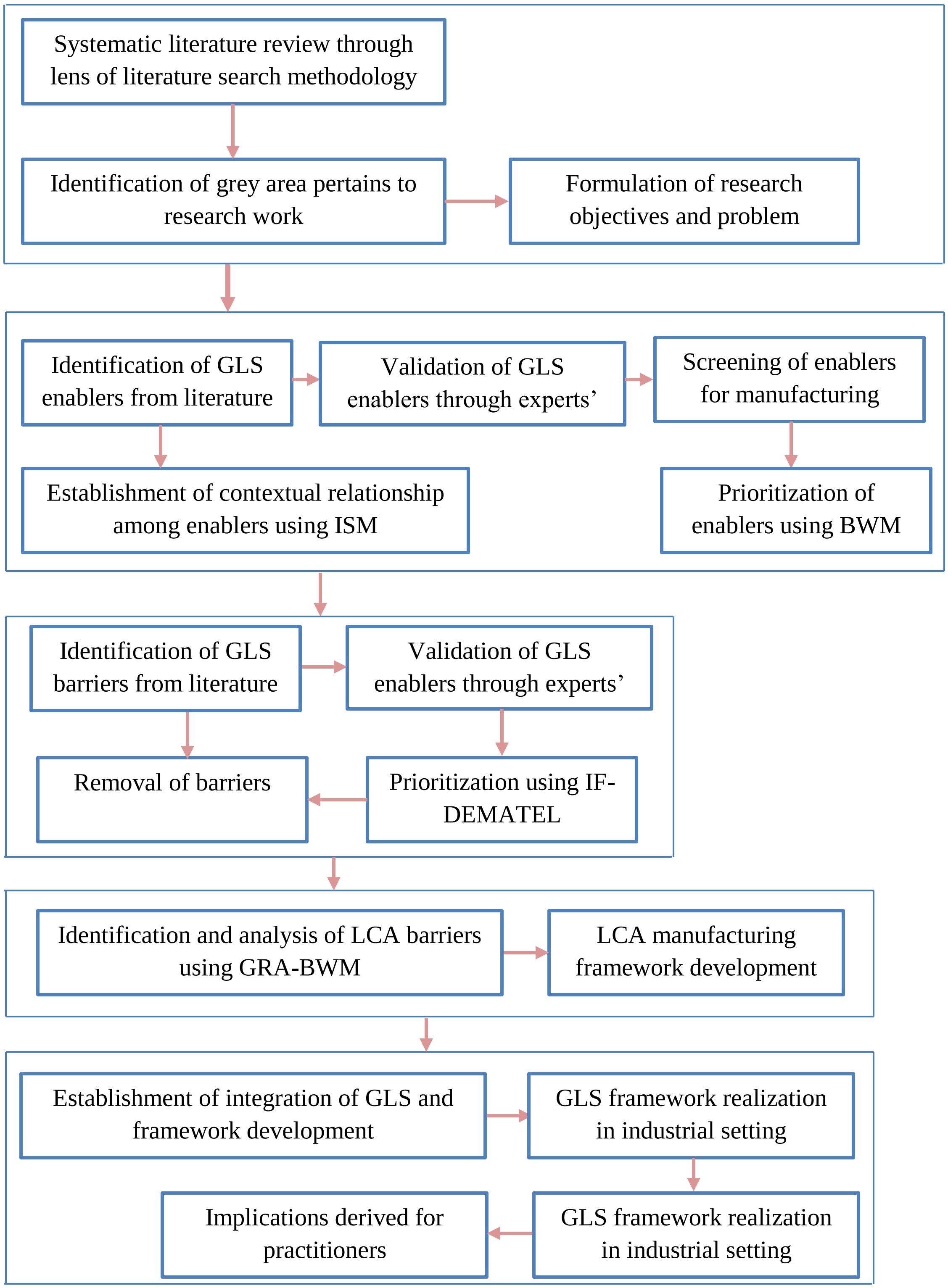

Figure 3.1: Research Methodology

These enablers not only affect the effective implementation of GLS within the organization but influence each other also. So, it is vital to identify a mutual relationship among enablers for the identification of the driver and driven enablers. For this, GLS enablers have been identified firstly for all sectors using literature review and further validated using expert opinion. To identify the contextual relationship among enablers interpretive structural modelling (ISM) had been used in this research. Thereafter, enablers were screened for the manufacturing sector from identified enablers of GLS using experts' opinions. The literature also reveals that 40% of Six Sigma projects have failed due to inappropriate project selection [196]. So, to circumvent GLS failure, it is imperative to find and rank the enablers that propel GLS implementation in the manufacturing environment. The GLS enablers exhibit very much interdependency, therefore it is much needed to recognize which enablers should be put on the priority so that incremental implementation leads to inclusive and comprehensive execution [165]. In this study, best worst method (BWM) has been used to prioritize GLS enablers as it provides more consistent results [197]. Along with enablers, it is imperative to identify GLS adoption barriers, that, if get rid to the smooth execution of GLS program. GLS barriers were firstly identified through literature and further modelled into logical groups using principal component analysis (PCA). There exist interrelationship among grouped GLS adoption barriers, and it must be exhibited to decide which barriers affect other barriers. For this, the IF-DEMATEL method has been used to bifurcate grouped barriers into cause and effects barriers. The DEMATEL method clarifies the interrelation among the selected criteria through a visual depiction of the causal diagram [198] [199]. The main advantage of the DEMATEL is that it involves indirect relationships in analysis, allocating as possible as unique ranks to alternatives, and clustering alternatives in large systems [200]. IF sets enable the practitioners to model unidentified information using a degree of hesitation. So, in real-life problems, where decision-makers are not sure of their preferences IF sets would be more comparable than the normal fuzzy set to get the opinion. Once the barriers of GLS have been identified and mitigated action initiated, it is imperative to assess the metrics of environmental measures. For this firstly barriers of

LCA have been identified and then a systematic framework of LCA was established. LCA is a tool that provides a detailed environmental analysis of a system consisting of different unit processes [172]. The quantification and investigation of wastes from a system using LCA further lead to the identification of major reasons for these non-value-added activities [173]. Although the evolution of GLS, very few pursuits have made for the realization of this sustainable approach in industrial organizations. The main reasons for the same can attribute to the lack of Green, Lean, and Six Sigma integration and implementation frameworks. For this, comprehensive integration of GLS was established based on theoretical elements and GLS five facet framework embedded with different tools of Green technology, lean manufacturing, and Six Sigma was developed. Finally, to check the efficacy of GLS in estimating and improving different metrics of Green, Lean, and Six Sigma, etc., the developed framework was tested practically in a real-life industrial setting. Based on the implementation of GLS in the case industry, inferences were drawn for the practitioners, researchers, and industrial managers.

3.3 Integration measure and model of Green Lean Six Sigma

The GLS has received due attention in recent years because of its ability to enhance productivity, profitability, and mitigate environmental concerns [25]. Green, Lean, and Six Sigma are three distinct approaches, but they are synergetic as they jointly focus on waste reduction and effective utilization of resources. Consequently, the universal principles and toolsets of these approaches can be integrated under the umbrella of a single approach called Green Lean Six Sigma. GLS is a comprehensive approach that aims to achieve improvements in the process, finance, operations, and emissions [21]. The integration of the Green, Lean, and Six Sigma can be viewed as a new prospect to industrial organizations for improvement in sustainability.

Banwai and Bilec [21] found that the organizations that have applied the GLS have achieved better performances than those implemented individual approaches. In the literature, no structured and complete method for the integration of the Green, Lean, and Six Sigma has been found. The present work proposes a theoretical integration model of the GLS based on the combination of theoretical elements. Figure 3.2 depicts an integrated GLS model. The integration model's main aim is to describe the essential facts required for industrial organizations to improve sustainable performance. The proposed model represents the conceptual similarities between the three approaches. The enablers work as the key inputs that stimulate the integration of GLS while the performances in trade-off serve as output. The challenges for the GLS integration are the constraints that restrict the organizational pursuits to improve the sustainability dynamics. The tools and associated GLS frameworks are considered as the supporting mechanism that supports the integration and implementation of GLS.

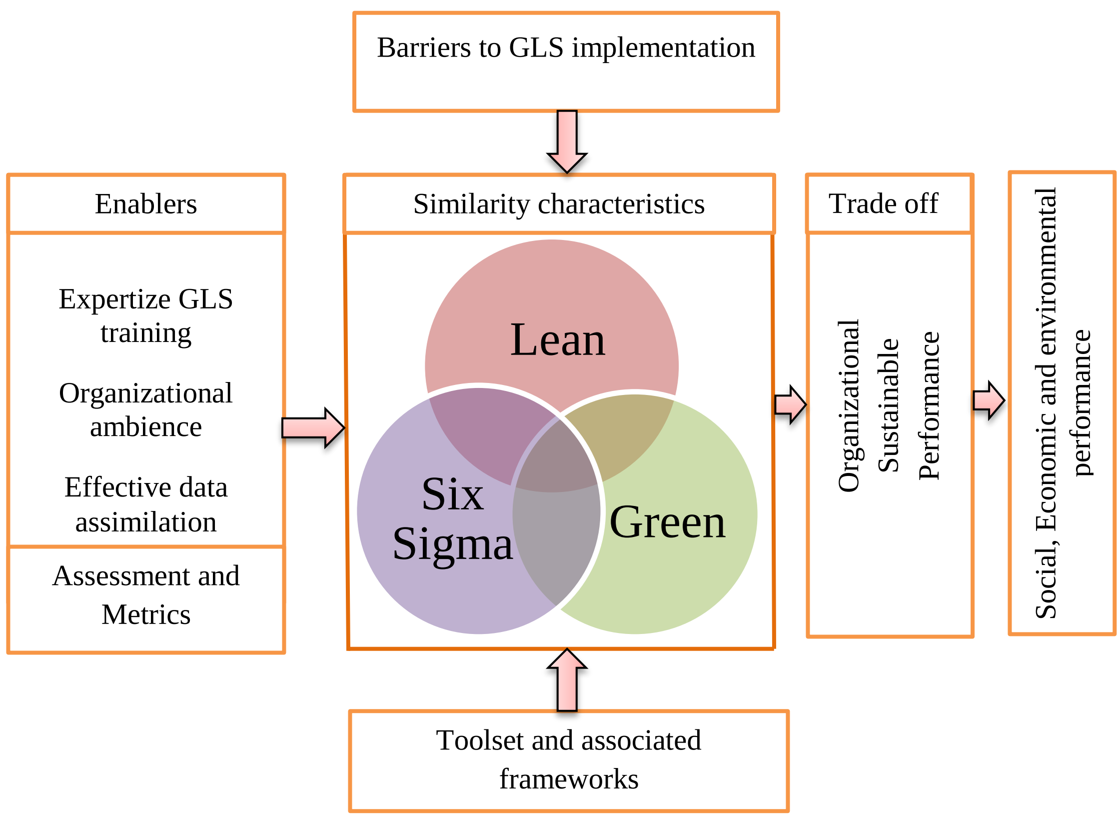

Figure 3.2: Integration model of GLS

3.4 Proposed framework of Green Lean Six Sigma

Lean and Six Sigma methodologies are being widely used by the industrial organization to reduce wastes and process variations. But, due to increased awareness about sustainability and strict government policies, the industries have to shift operation dynamics towards sustainable ones. This demand for the incorporation of the Green technology in Lean Six Sigma leads to the development of a novel approach: Green Lean Six Sigma. But to execute inclusive GLS, there is a need for a dedicated framework that provides stepwise guidelines to achieve sustainability. In the literature, no study has found to GLS framework that can be adopted by both service and manufacturing organizations. The present study depicts a DMAIC based GLS framework (figure 3.3) that can be adopted by all business organizations. The proposed GLS framework has been executed through the following five steps:

Step 1: Green Lean Six Sigma project identification

The first step of the GLS framework is to select an appropriate project based on the level of wastes, defects, environmental-related emissions, and voice of customers. GLS is a project-based approach and is executed project by project in an incremental way by covering each department or section individually. The project is classified as a particular section or division that is selected for the initiation of GLS. The literature also reveals that 40% of six sigma projects have failed due to inappropriate project selection [21]. The execution of GLS demands substantial investment and structural changes in the organization. So, it is imperative to select an appropriate GLS project that exhibits the highest scope for sustainability improvement. For this, a comprehensive study of the various sections of the industry is conducted. The detailed study of the entire industry provides wastes, defects, and associated environmental emission levels that pertain to different segments of the industry. The matrices are formulated for wastes levels, defects, and different emissions corresponding to the various sections. The prioritization of different matrices is done in the next sub-step to select a project that exhibits the highest potential for sustainability improvement. Eco QFD and critical to quality (CTQ) tools translate sustainably oriented customer demands in technical and environmental attributes that serve as a vital tool for project selection. So, based on the current needs of customers, together with business and environmental concerns, an appropriate project is selected. After the identification of a proper project, a charter is prepared based on the scope, schedule, and team members of the identified project.

Step 2: Assessment of the current level of the project

The second step of the GLS framework deals with the estimation of the current level of the system or project under consideration. Here the performance of the selected GLS project is measured against the several indices of Green, Lean, and Six Sigma. Based on the collected data and facts, the standard deviation, sigma level, and C_{pk} of the project are estimated using statistical tools. Besides, the estimation of CO_2 consumption, green energy coefficient, material consumption, etc. is made using Green technology tools like life cycle assessment (LCA). To assess the current level of various associated wastes, value stream mapping (VSM) serves as a useful lean tool. VSM provides an estimate of cycle time and material consumption across the different stages and provides a check against normal consumption of time and money. It has a notable feature of the data table that organizes process-related data like time, material, money, etc. Furthermore, life cycle assessment (LCA) is used in the measurement process to evaluate the environmental impact of each subprocess in different environmental impact categories. The combined VSM and LCA lead to the quantification of various lean and green wastes that provides the source for further improvement.

Step 3: Root out the leading causes of problem or inefficiency

The next stage of the GLS framework pertains to find out the leading causes related to high-level wastes, emissions, and defects in the selected project. In this step, first, value-added and non-value-added activities are identified both from the customers and business point of view. After that, the process cycle efficiency is determined to compare with world-class benchmarks to find out how much improvement is needed. Meanwhile, the complete analysis of the project is made to identify bottlenecks points and constraints in the selected project. After the comprehensive, detailed analysis of the project under consideration, then the possible reasons for the wastes, emission, variations, and defec

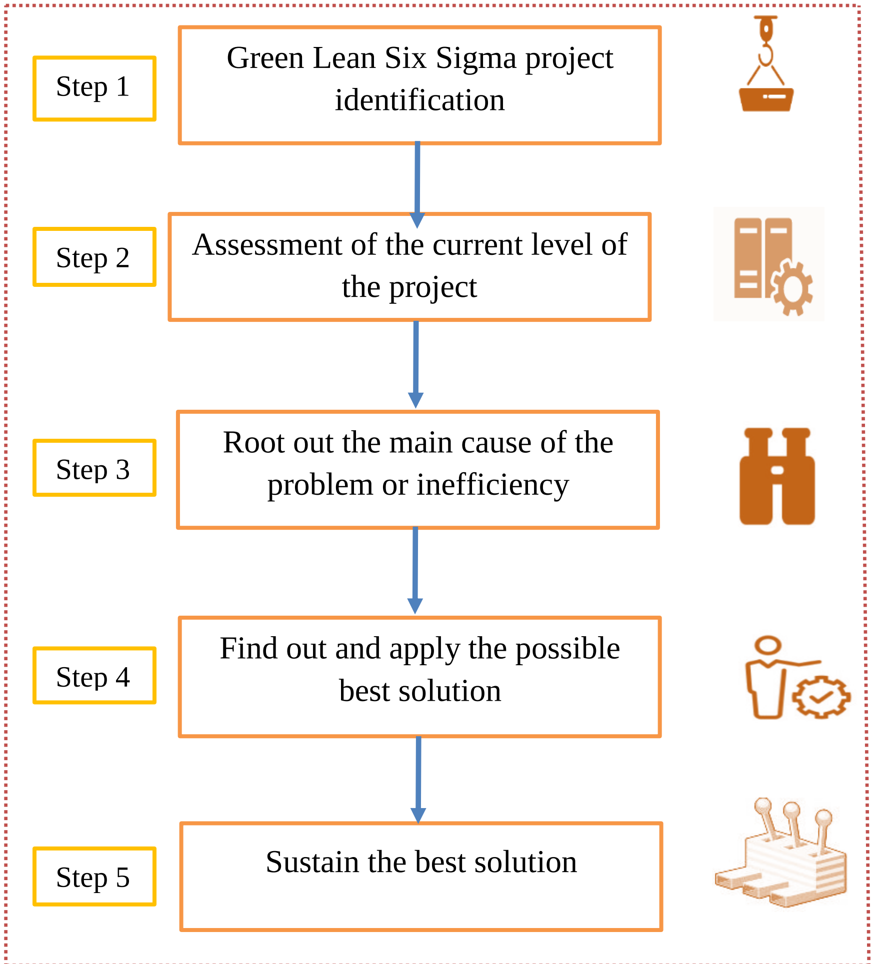

Figure 3.3: GLS framework

are found out. Tools like failure mode effect analysis (FMEA), five whys analysis, life cycle impact assessment, etc. are used at this juncture to find out the potential causes for the observed defects. Once the possible causes have been explored, the search is now confined to find out the few prominent reasons for project inefficiencies. The tools like Pareto chart, hypothesis testing, principal component analysis (PCA), regression analysis, and brainstorming are used at this point to find the critical root causes. So, this step results in the exploration of the leading causes of inefficiencies that need to undertake for improving the current project or system under consideration.

Step 4: Find and implement the best possible solution

Once the leading causes for wastes and inefficiency have been found out, potential solutions are proposed, tested, and the best solution is applied to ride out the prominent reasons. The confirmed cause and effect relationship (from analyzing phase) is used at this stage to find a wide spectrum of potential solutions. The solutions provided at this stage may be upcycling, anaerobic digestion (AD), refuses derived fuel (RDF), recirculation or recycling of water, etc. In this step, high creativity is desired from the organizational personnel. The potential solutions (alternatives) are fleshed out, criteria are developed, and the solutions are evaluated to search for the best solution. All the sources of information like a stakeholder, customers, project sponsors, and staff are used to determine the evaluation criteria. The criteria like CTQs, business-related, regulatory, and others are considered at this juncture. To evaluate the solutions against criteria tools like solution matrix, pugh matrix, and design of experiments (DOE), LCA, etc. are used. The pugh matrix determines the strengths and weaknesses of the potential solutions so that strengths can be preserved and deficiencies addressed. Here, the practitioner should be open to alter or combine solutions for the selection of the best solution. DOE is used in this step to find out the optimal settings for combinations of factors. After selecting the best possible solution, the existing VSM is revised to reflect what the process will look like after the changes are made. The best solution is now launched as a pilot solution. The tasks to perform are documented, and pilot participants are trained in various aspects of the best solution.

Step 5: Sustain the best solution

This step deals with sustain or controls the best solution if the substantial improvement is recorded by the existing system or process under consideration. The entire process is re-evaluated using VSM and LCA to find out the level of waste and emissions reduction. In this step, various observations, data collection, and control charts are used to re-assess the sigma level, $C_{pk,}$ water, electricity, material consumption, etc. If re-assessed performance parameters are better than in the measuring step, then the selected solution is sustained. Otherwise, the Out of Control Action Plan (OCAP) is initiated to select an appropriate solution. Once a potential solution for the pilot project has been sustained for a long duration, the same is commenced in other sections of the industry. The comprehensive implementation of GLS in the industry leads to improved sustainability and increased reputation at a global platform through the delivery of eco-friendly products.

3.5 Green Lean Six Sigma integral measure and tools

The Green Lean (GL) approach has been widely used by industrial organizations; comparatively, very few pursuits have been made for the realization of the GLS approach [37]. GLS is in its evolution phase, and the organizations are reluctant to adopt this approach due to resistive culture and fear of pragmatic shifts in their work methods. The comprehensive discussion on enablers, barriers, and toolset facilitates the integration of Green, Lean, and Six Sigma. Moreover, the presented GLS framework will assist the organization in implementing sustainable GLS for improved productivity and profitability.

Once the integration of GLS has been established cohesively, one can easily correlate the different functionality of all these modern methodologies. Enablers are readiness measures for an organization to implement a new approach [201]. The facilitators have considered change methods that lead to the successful implementation of a new strategy [202]. Table 3.1 depicts the enablers for the adoption of GLS.

Table 3.1: Enablers of GLS that foster integration

S. No.	Success Factors	Description	References
1	Customer satisfaction	Customer satisfaction is of the utmost importance for any organization to remain competitive in the market.	[22]
2	Organizational learning	Every employee should be familiar with the entire system so that one can put his/her keen efforts into organizational success.	[58]
3	Integration across the stages of the product development cycle	The concept of concurrent engineering and integration at various stages of product development is essential to develop a reliable product.	[27] [96]
4	Culture and communication	Organizational must develop a culture of continuous improvement, cooperation, and a two-way flow of information.	[97]
5	Strategic relationship with the supplier	A reliable supplier is essential so that raw material and other items have delivered within the time frame.	[56]

6	Data and metrics	Data collection and performance metrics are quintessential for the success of the GLS program as they provide a basis for comparisons.	[58]
7	Teamwork	To achieve the targets of GLS, all members of the organizations should work as a team.	[203]
8	Risk management	Champions of any business take the risk and introduce new concepts before the competitors grab any opportunity available in the market.	[56]
9	Organizational readiness to implement GLS	The enterprise must be in a position to introduce GLS in their system as it requires a haul changeover.	[165]
10	Linking GLS to business strategy	The linkage between organizational strategy and the GLS approach leads to achieving corporate sustainability.	[201]

The management commitment, a thorough understanding of the GLS tools, and useful data assimilation lead to improved sustainability through effective implementation of the GLS program. The barriers are critical failure factors (CFF) that hinder the progress or make it difficult for an organization to achieve set goals. These are specified managerial and technical challenges that hinder the organizations from achieving desired targets [89]. The organization needs to identify fundamental problems or obstacles in their way of success, within a particular time frame to take competitive advantages over competitors. Table 3.2 indicates the barriers that hinder the execution of the GLS program.

Table 3.2: Barriers of GLS that foster integration

S. No.	Barriers	Description	References
1	Inappropriate Lean and Green areas identification	Successful GLS implementation demands the selection of a particular shop/area that has the maximum potential for sustainability improvement.	[78] [204]
2	Resistance to change	Traditional practices of manufacturing are being adopted by most industries, and they exhibit resistance to the new approach.	[110] [101]
3	Lack of environmental knowledge	Comprehensive environmental knowledge, together with the effects of process parameters on ecology, is vital for GLS success.	[204] [205]
4	Wrong GLS tool section	The success of GLS highly depends on the selection of proper tools.	[56] [158]
5	Un-optimized transportation system	The un-optimized transportation system leads to more environmental emissions.	[78]

6	Lack of management support and ineffectiveness	Top management support and active participation are necessary for GLS success as the absolute authority to release the orderlies with management.	[78] [158]
7	The obliviousness of re-engineering	A complete understanding of various approaches to reengineering is quite essential for effective GLS project implementation within a particular organization.	[204]
8	Unawareness of various GLS strategies	To implement GLS, a thorough understanding of different GLS strategies and their pros and cons are indispensable.	[78] [204]
9	Lack of synergy between continuous improvement and strategic objectives of the organization	Coherence between objectives and CI is required for the GLS project so that desired results can achieve within the required time frame.	[206]
10	Poor organizational culture	The learning, ready to adopt, and continuous improvement of corporate culture facilitate GLS implementation.	[26]
11	Economic constraints	GLS implementation brings paradigm shifts in the concerned industry, so there is a need for finance to incorporate changes.	[26]
12	Lack of standardization and standard scheduling procedures	Standardization brings a specialty to the system that leads to a reduction in rework, waste, and emissions.	[37]

It has been found that lack of top management support is reported by many studies as one of the significant barriers to the GLS execution. The collaborative learning and linking of GLS to business objectives have been found as substantial initiatives for GLS success. The GLS toolset supplements the integration and implementation of GLS. The GLS tools have been considered as principles or concepts that have the potential to identify, remove wastes, and leads to optimum utilization of resources. After the analysis of thirteen research articles pertains to GLS, it has been observed that industrials organizations use different tools according to their diverse needs and their size. But, particular tools appear more than others and, therefore, are more frequently used by organizations that use this integrated GLS approach. The tools of GLS have been examined through the radar chart, as shown in figure 3.4. The SIPOC chart and environmental value stream mapping (EVSM) have been found as the most widely used with more than 90% (11/13). Besides, the other most commonly used tools found to be: process capability, reverse logistics, and cause and effect diagram (C&E). Out of the thirteen enlisted articles of GLS, the majority rely on the lean tools to achieve both lean and green objectives. Therefore the industrial organizations are mostly banking on lean tools to meet environmental concerns. To address the societal dimension of sustainability, only a few applications of community engagement and local sourcing tools have been found.

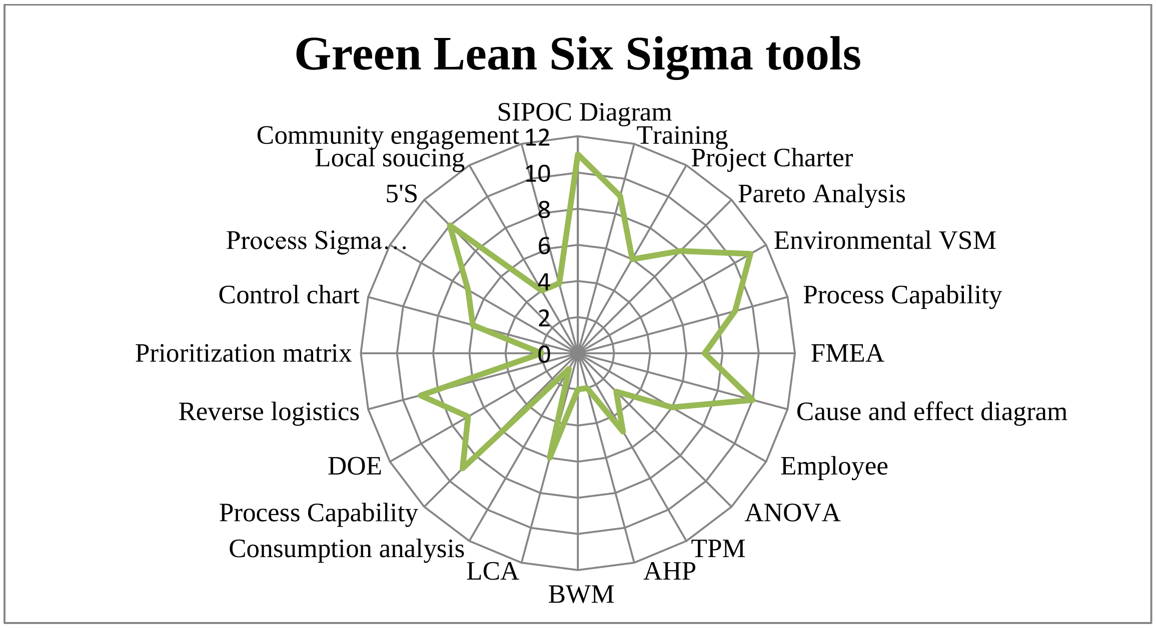

Figure 3.4: Radar chart of Green Lean Six Sigma tool

The significance of GLS is increasing continuously due to its positive effects on quality determinates like productivity, VOC, and sustainability. The literature reveals that the GLS integration not only increases productivity but also reduces negative environmental impacts. This goodwill ultimately enhances the organization's image on the global platform. But, a combination of these philosophies required considerable pursuits to identify standard tools and synergy among them. Currently, most organizations want to integrate clean technologies within their existing process improvement methods to contribute towards a healthier environment. Significant challenges with the organizations, those who wish to embed green concept within Lean Six Sigma is the non-availability of a proper road map. The researchers found that organizations are facing difficulty to implement and integrate Green, Lean, and Six Sigma for performance improvement [95]. Banwai and Bilec [37] represented a framework to improve efficiency and reduce various associated wastes. But the presented framework was confined to a particular industry together; it did not provide how it was realized through the DMAIC approach. Cherrafi et al. [95] proposed a framework of GLS for improvement in economic and environmental sustainability. But the proposed framework realization was difficult for the new industries that want to implement GLS. Cluzel et al. [207] presented an eco-friendly methodology to integrate GT and LSS, but the stepwise realization of the method followed was found to be difficult. The current research provides an integration of GLS based on the theoretical elements and provides a detailed DMAIC based framework. The proposed framework works as a pilot framework for the realization in a single section or department of the organization. The same framework can be extended within the entire organization after its successful execution as a pilot project. The authors presented a conceptual integration of Green Lean Six Sigma that guides professionals to adopt GLS culture in their organizations. The presented framework shows the combination of Lean and Green matrices at every step, which has ignored in earlier work. Lean and Green measures work as prospective areas for project selection in the first step of the GLS framework. To assess the current state of the system, in the second step of GLS implementation tools like EVSM, LCA is used. The potential causes for wastes are found in the third step of the framework using tools like LCA and conventional statistical tools. To find out the possible solutions in the improvement phase of framework tools like life cycle interpretation, environmental VSM, 5'S, kaizen, etc. are used. In the last step of the GLS implementation, VSM and LCA are used to measure the improvement made. The adopted GLS implementation method is sustained for a longer duration if the gains made are substantial than the previous state of the system or project under contemplation.

Enablers are the readiness measures that make an organization ready to execute a new approach or methodology. This chapter outlines enablers of GLS and contextual relationship among the enablers using ISM and MICMAC analysis. Secondly, identified GLS enablers have been further screened using expert opinion and prioritized using BWM.

4.1 Introduction

Green Lean Six Sigma (GLS) is an approach of sustainable development that minimizes the generation of waste through the reduction in process variation and using the Green concept of 3'R (recycle, reuse, reduce). Researchers and industrial managers are trying to recognize those features that explicate the success and failure of GLS in organizations. Enablers are the prerequisites that provide a stimulus to the organization to apply a new approach [21]. Although a lot of work has been done by researchers in past to identify the enablers of individual Lean, Green and Six Sigma approach [208] or only Lean and Green concepts [157] or Lean and Six Sigma concepts [159]. The literature lacks much evidence of identification and modelling interactions of GLS enablers. Modelling of extracted enablers is very essential for the success of the GLS strategy because it provides the linkage between different enablers at different levels which is a challenging task. So, it is vital to estimate the optimal solution in terms of modelling the interactions among GLS enablers using a robust technique. In this context, ISM has used to analyze and modelling GLS enablers that results in high gain to business. Furthermore, grouping of these enablers into different categories, like driver, dependent, linkage and autonomous has been done using MICMAC approach.

Once the enablers of GLS have been identified, enablers were further screened for manufacturing sector using expert opinion. As GLS adoption seems easy but shifts from traditional to GLS environment is a substantial task as in numerous cases it did not succeed at earlier stages of execution [159]. So, to circumvent GLS failure, it is imperative to find and rank the enablers or foundation blocks that propel GLS implementation in the manufacturing environment. The GLS enablers exhibit very much interdependency, therefore it is much needed to recognize which enablers should be put on the priority so that incremental implementation leads to inclusive and comprehensive execution [165]. The ranking of GLS enablers should be done with the Multiple-Criteria Decision-Making (MCDM) approach that unveils the hidden facts of GLS enablers. GLS barriers pertain to manufacturing have been ranked using BWM and further validated using other decision-making techniques by considering the case of a real-life industrial setting.

4.2 Green Lean Six Sigma Enablers for all industrial sectors

The effective execution of GLS depends on few vital factors, known as enablers of GLS. Enablers are those characteristics that are crucial to achieve organizational objectives. These factors are useful from inception to the maturity of GLS implementation within the organization.

4.2.1 Exploration of GLS enablers

An inclusive literature study was done, for factors identification related to the successful execution of GLS. Moreover, screening of enablers is done with the aid of experts from industry and academic backgrounds and finally, 12 enablers were listed (refer to table 4.1).

Table 4.1: GLS enablers

S. No.	Caption	Enablers
1	E1	Organizational readiness for GLS measures together with competence for green product and process.
2	E2	Effective data assimilation and Lean Green matrices identification.
3	E3	Top management commitment toward sustainable performance improvement.
4	E4	Integration of Green, Lean and Six Sigma across all the stages of product development cycle.
5	E5	Thorough understanding of green technology and statistical tools
6	E6	Expertise training in GLS
7	E7	Organizational ambience
8	E8	Team effort
9	E9	Availability of funds with the organization
10	E10	Organizational learning through human resource development

11	E11	Effective performance and feedback measure both at upstream and downstream
12	E12	Linking of GLS to business objectives.

To check the validation of the enablers found through a comprehensive literature survey a questionnaire based survey was conducted and questionnaire internal consistency was checked using reliability test. Moreover, **a** questionnaire centred survey was used to develop a relationship matrix for initializing modelling of GLS enables. Moreover, the Reliability test (Cronbach's alpha) was used to check the questionnaire internal consistency using Statistical Package for Social Sciences version 17 for windows (SPSS). The target population for this survey was expertise Green, Lean, and Six Sigma personnel of Indian industries. The respondents were selected based on data from internet sources, Six Sigma experts, and other direct/indirect linkages with industrial personnel. All the respondents were conversant with the GLS aspects and they are using the basic principles of Lean/green/Six Sigma in their manufacturing, service or product design processes. In total 125 questionnaires were sent, out of that 115 completed questionnaires were received back and further selected for analysis.

To check the internal consistency of scale or questionnaire, reliability test was performed on the data set using SPSS. Alpha is an important concept in the evaluation of assessments and questionnaires in statistical and medical sciences. Alpha was developed by Lee Cronbach in 1951 [209]. The SPSS depicts a high value of alpha if there is high internal consistency among the items [210]. The high value of alpha is also attributed to a lesser error in measurement, a large number of items/questions, and homogeneity of constructs. The value of alpha 0.70 to 0.90 is recommended for better internal consistency [211].

Table 4.2: Statics table for GLS enablers

Enablers	Mean	Std. Deviation	Number of sample
E1	3.87	0.720	115
E2	4.36	0.740	115
E3	4.21	0.811	115
E4	3.69	0.765	115
E5	4.52	0.693	115
E6	4.02	0.868	115
E7	3.52	0.765	115
E8	4.08	0.860	115
E9	3.93	0.998	115
E10	4.03	0.903	115
E11	4.02	0.878	115
E12	3.98	0.898	115

The value of Cronbach's Alpha for the present problem as calculated by SPSS was found 0.830 which is quite good for internal consistency of the questionnaire or instrument considered. The formula for Cronbach's alpha is

$$N^2 \times M\ (COV) / SUM\ (VAR/COV) \quad (4.1)$$

The mean value of all the enablers as found by equation ii was reported pretty high (refer to table 4.2), which designates proper selections of the enablers in the questionnaire.

$$\text{Mean value} = \frac{\sum Responses\ given\ by\ individual\ respondents}{no\ of\ respondents} \quad (4.2)$$

4.2.2 Research approach adopted and analysis of GLS enablers pertains to all sectors

To achieve the objectives of the present research ISM and MICMAC analysis have been used as research approaches. ISM has been used to develop the relationship among the identified enablers and MICMAC has been used to find various categories of enablers.

4.2.2.1 Interpretive Structural Modeling of GLS enablers

ISM is a logical research approach, executed sequentially (refer to figure 4.1).

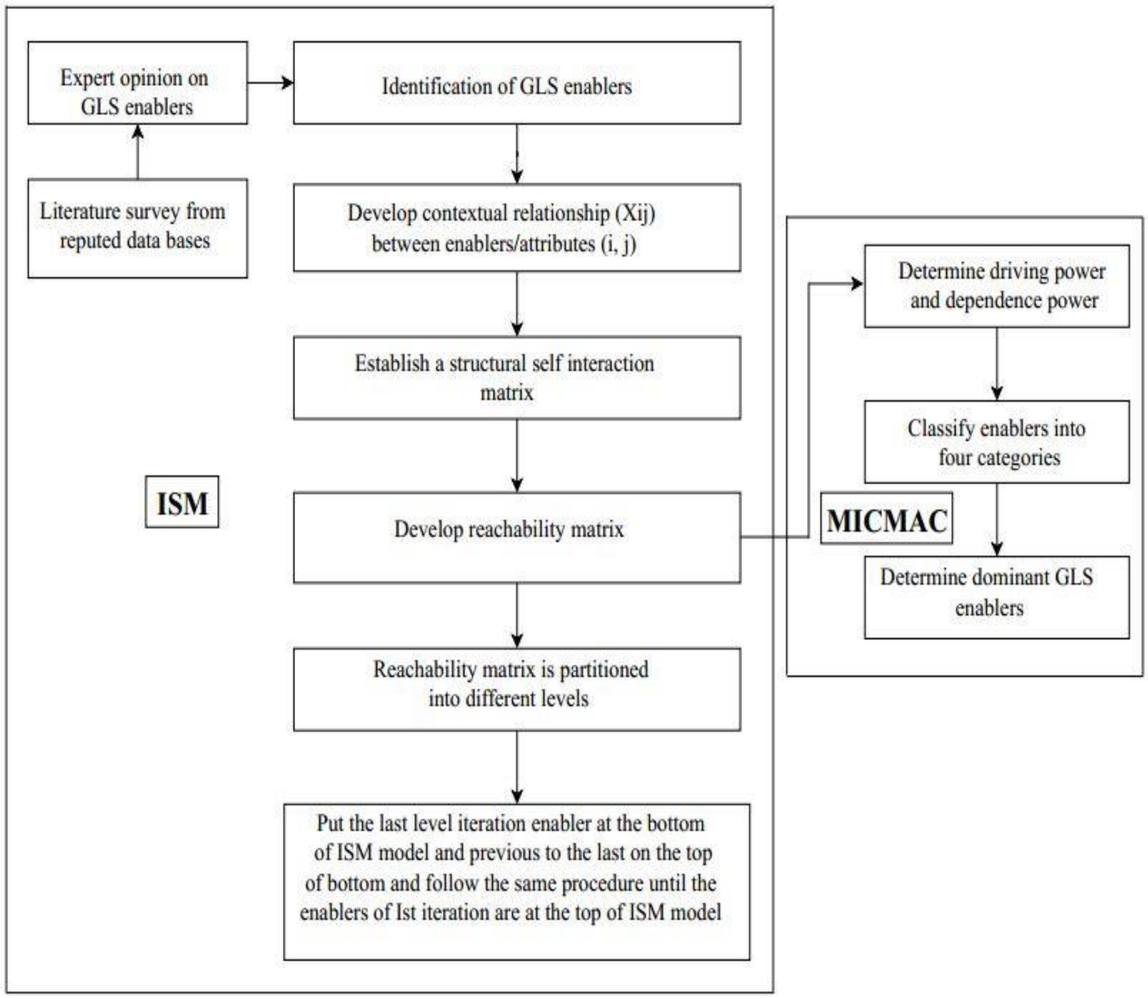

Figure 4.1: Research approach for analysis of GLS enablers

The numerous steps of interpretive structure modelling are as follows:

STEP 1: Identification of various GLS enablers

The enablers of GLS were identified through literature and discussion with GLS experts. In the present case, 12 enablers of GLS have been identified from a comprehensive literature survey and through expert opinions.

STEP 2: Development of structural self-interaction matrix

Based on contextual relationships among identified enablers, a Structural Self-Interaction Matrix (SSIM) was developed (Table 4.3). To represent the directional relationship between two enablers (i, j) four symbols were used. P: is used if enabler "i" influences or reaches to barrier "j". A: is used if enabler "j" reaches to enabler "i". X: is used if "i" and "j" reaches to each other. O: is used if both enablers are unrelated. The following testimonials exhibit the usage of symbols in SSIM.

- To cell (4, 5), symbol A is allocated because enabler E5 reaches to enabler E4.
- To cell (4, 9), symbol O is assigned because enabler E4 and E9 are isolated.
- To cell (4, 7), symbol X is allocated because enablers E4 and E7 both have directional relationships.
- To cell (3, 11), symbol P is allotted because enabler E3 alleviates E11.

Table 4.3: Structural self-interaction matrix

Enablers	**E12**	**E11**	**E10**	**E9**	**E8**	**E7**	**E6**	**E5**	**E4**	**E3**	**E2**
E1	P	P	P	O	O	A	P	X	O	P	P
E2	O	O	A	O	X	X	A	A	A	A	
E3	P	P	P	X	P	P	P	P	P		
E4	X	X	O	O	X	X	A	A			
E5	P	P	P	O	X	P	O				
E6	A	P	P	X	P	P					
E7	A	A	P	O	X						
E8	A	X	X	O							
E9	O	O	P								
E10	O	A									
E11	A										

STEP 3: Reachability matrix

The initial reachability matrix is made by altering each entry of the SSIM into 1s and 0s (refer table 4.4)

Table 4.4: Initial reachability matrix

Enablers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1	1	1	1	0	1	1	0	0	0	1	1	1
E2	0	1	0	0	0	0	1	1	0	0	0	0
E3	0	1	1	1	1	1	1	1	1	1	1	1
E4	0	1	0	1	0	0	1	1	0	0	1	1
E5	1	1	0	1	1	0	1	1	0	1	1	1
E6	0	1	0	1	0	1	1	1	1	1	1	0
E7	1	1	0	1	0	0	1	1	0	1	0	0
E8	0	1	0	1	1	0	1	0	1	1	1	0
E9	0	0	1	0	0	1	0	0	1	1	0	0
E10	0	1	0	0	0	0	0	1	0	1	0	0
E11	0	0	0	1	0	0	1	1	0	1	1	0
E12	0	0	0	1	0	1	1	1	0	0	1	1

Following rules are followed for incorporation of binary entries.

- For (i, j) entry, if it is P in SSIM then corresponding (i, j) entry in reachability matrix becomes “1” and (j, i) becomes “0”.
- For (i, j) entry, if it is A in SSIM then corresponding (i, j) entry in reachability matrix becomes “0” and (j, i) becomes “1”.
- For (i, j) entry, if it is X in SSIM then corresponding (i, j) entry in reachability matrix becomes “1” and (j, i) becomes “1”.
- For (i, j) entry, if it is O in SSIM then corresponding (i, j) entry in reachability matrix becomes “0” and (j, i) becomes “0”.

The 1^* entry is incorporated in the initial reachability matrix to bridge the judgmental gap if any prevail after the collection of experts’ opinion. Table 4.5 represents final reachability matrix obtained by incorporating transitivity.

Table 4.5: Final reachability matrix (Conical matrix showing driving and dependence power)

Enablers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	Driving Power
E1	1	1	1	0	1	1	1*	0	0	1	1	1	9
E2	1*	1	0	0	1*	0	1	1	0	0	0	0	5
E3	0	1	1	1	1	1	1	1	1	1	1	1	11
E4	0	1	0	1	0	0	1	1	0	0	1	1	6
E5	1	1	1*	1	1	0	1	1	0	1	1	1	10
E6	1*	1	1*	1	0	1	1	1	1	1	1	0	10
E7	1	1	0	1	0	0	1	1	1*	1	1*	0	8
E8	0	1	0	1	1	1*	1	0	1	1	1	0	8
E9	0	0	1	1*	0	1	1*	0	1	1	1*	0	7
E10	0	1	0	0	1*	1*	0	1	0	1	0	0	5
E11	1*	0	0	1	1*	0	1	1	0	1	1	0	7
E12	0	1*	0	1	1*	1	1	1	0	1*	1	1	9
Dependence	6	10	5	9	8	7	11	9	5	10	10	5	

STEP 4: Level Partitions

The reachability matrix obtained in the previous step was partitioned into different levels. The reachability and antecedent set for each enabler [212] were found from the final reachability matrix (Table 4.5). The reachability set for a said enabler consists of itself and the other enablers which it may help to achieve. If the reachability set and the intersection set for a given enabler is the same, then that enabler is considered to be in level I and is given the top position in the ISM hierarchy [213]. With this partition, iteration 1 is completed (refer to table 4.6).

Table 4.6: Iteration 1

Enablers	Reachability Set	Antecedent Set	Intersection set	Level
E1	1, 2, 3, 5, 6, 7, 10, 11, 12	1, 2, 5, 6, 7, 11	1, 2, 5, 6, 7, 11	
E2	1, 2, 5, 7, 8	1, 2, 3, 4, 5, 6, 7, 8, 10, 12	1, 2, 5, 7, 8	I
E3	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 3, 5, 6, 9	3, 5, 6, 9	
E4	2, 4, 7, 8, 11, 12	3, 4, 5, 6, 7, 8, 9, 11, 12	4, 7, 8, 11, 12	
E5	1, 2, 3, 4, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 8, 10, 11	1, 2, 3, 5, 8, 10, 11	
E6	1, 2, 3, 4, 6, 7, 8, 9, 10, 11	1, 3, 6, 8, 9, 10, 12	1, 3, 6, 8, 9, 10	
E7	1, 2, 4, 7, 8, 9, 10, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12	1, 2, 4, 7, 8, 9, 11	

E8	2, 4, 5, 6, 7, 8, 9, 10, 11	2, 3, 4, 5, 6, 7, 8, 10, 11, 12	2, 4, 5, 6, 7, 8, 10, 11	
E9	3, 4, 6, 7, 8, 9, 10, 11	3, 6, 7, 8, 9	3, 6, 7, 8, 9	
E10	2, 5, 6, 8, 10	1, 3, 5, 6, 7, 8, 9, 10, 11, 12	5, 6, 8, 10	
E11	1, 4, 5, 7, 8, 10, 11	1, 3, 4, 5, 6, 7, 8, 9, 11, 12	1, 4, 5, 7, 8, 11	
E12	2, 4, 6, 7, 8, 10, 11, 12	1, 3, 4, 5, 12	4, 12	

After the first iteration, the enablers forming level I are discarded and with the remaining enablers, the above-stated procedure is continued in iteration 2. These iterations are continued until the level of each enabler has been found. Table 4.7 depicts the level of each enabler of GLS.

Table 4.7: Final level of each GLS enabler

Enablers	**Reachability set**	**Antecedent set**	**Intersection set**	**Level**
E1	1	1	1	VIII
E2	1, 2, 5, 7, 8	1, 2, 3, 4, 5, 6, 7, 8, 10, 12	1, 2, 5, 7, 8	I
E3	3, 5	1, 3, 5	3, 5	VII
E4	4, 7, 8, 11, 12	3, 4, 5, 6, 7, 8, 9, 11, 12	4, 7, 8, 11, 12	II
E5	1, 3, 5	1, 3, 5	1, 3, 5	VII
E6	1, 3, 6, 8, 9	1, 3, 6, 8, 9, 12	1, 3, 6, 8, 9	IV
E7	1, 7, 8, 9, 11	1, 3, 5, 6, 7, 8, 9, 11, 12	1, 7, 8, 9, 11	III
E8	5, 8	3, 5, 8, 12	5, 8	V
E9	3, 6, 8, 9	3, 6, 8, 9	3, 6, 8, 9	IV
E10	5, 6, 8, 10	1, 3, 5, 6, 7, 8, 9, 10, 11, 12	5, 6, 8, 10	II
E11	1, 5, 7, 8, 11	1, 3, 5, 6, 7, 8, 9, 11, 12	1, 5, 7, 8, 11	III
E12	12	1, 3, 5, 12	12	VI

The enabler, effective data assimilation, and lean green matrices identification (E2) is positioned at level I and forms the top level in ISM hierarchy. Integration of Green, Lean and Six Sigma across all the stages of the product development cycle (E4) and organizational learning through human resource development (E10) are placed at level II; organizational ambience (E7) and Effective performance and feedback measure both at upstream and downstream (E11) are positioned at level III; Expertise training in GLS (E6) and availability of funds with the organization (E9) are positioned at level IV; team effort (E8) and Linking of GLS to business objectives (E12) are placed at level V and VI respectively; top management commitment toward sustainable performance improvement (E3) and thorough understanding of green technology and statistical tools (E5) is placed at level VII; Organizational readiness for GLS measures together with competence for green product and process (E1) is positioned at last level of ISM hierarchy.

STEP 5: Formation of ISM model

The ISM model for various important enablers of GLS was developed with the help of level of each enabler table 4.7 Figure 4.2 represents interpretive structural model for GLS enablers.

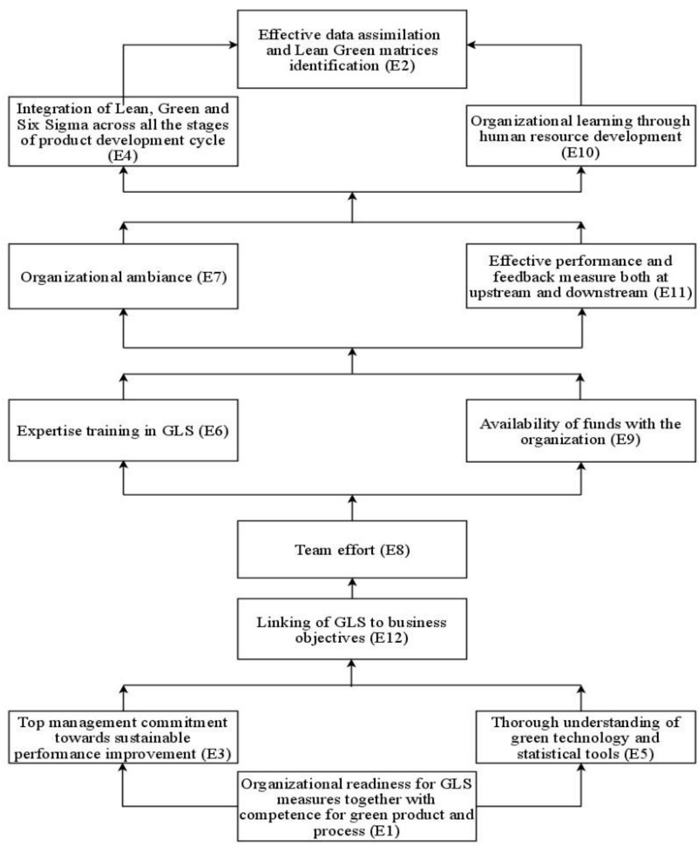

Figure 4.2: Interpretive structural model of GLS enablers

4.2.2.2 MICMAC analysis of GLS enablers

MICMAC analysis, an approach to classify enablers executed in step by step process as indicated in figure 4.1. The numerous steps of MICMAC algorithm are:

STEP 1: Determine driving and dependency power of each enabler summation of the row wise and column-wise entry of binary number '1' is done respectively in final reachability matrix (refer Table 5).

STEP 2: Classify the enablers into different categories depending on the driving and dependence power.

STEP 3: Determination of dominant GLS enablers based on their classification.

The first quadrant comprises of dependent enablers that exhibit weak driving as well as weak dependency. The second quadrant comprises of autonomous enablers that have weak driving power and dependence. The third quadrant comprises of the driving enablers that have strong driving but less dependency Moreover, the fourth quadrant designates linkage enablers that show strong driving as well as strong dependency (refer figure 4.3).

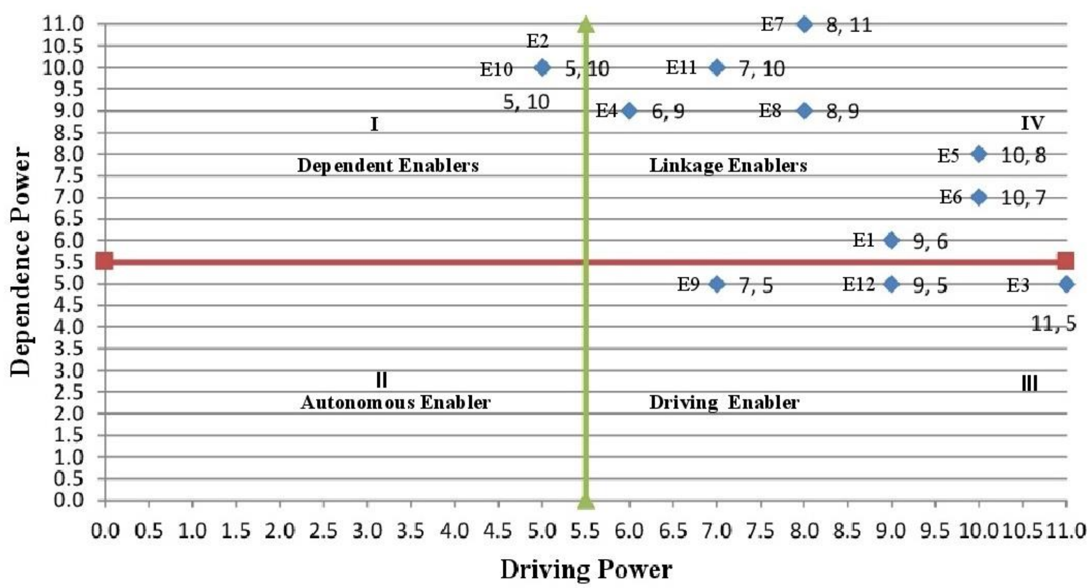

Figure 4.3: Driver and dependence diagram of GLS enablers

- From figure 4.3, it has found that there is no autonomous enabler reported during the study of GLS implementation.

- Enablers, organizational readiness for GLS measures together with competence for green product and process (E1), integration of Green, Lean and Six Sigma across all the stages of product development cycle (E4), thorough understanding of green technology and statistical tools (E5), expertise training in GLS (E6), organizational ambience (E7), team effort (E8), effective performance and feedback measure both at upstream and downstream (E11) are linkage enablers.
- Enablers, effective data assimilation and Lean Green matrices identification (E2) and organizational learning through human resource development (E10) are dependent enablers.
- The enablers top management commitment toward sustainable performance improvement (E3), availability of funds with the organization (E9) and linking of GLS to business objectives (E12) are driving enablers.

4.3 Green Lean Six Sigma enablers pertain to manufacturing

Once the enablers of GLS have been identified for all sectors, then the enablers were shortlisted for the manufacturing sector. To circumvent GLS failure, it is imperative to find and rank the enablers or foundation blocks that propel GLS implementation in the manufacturing environment. The GLS enablers exhibit very much interdependency, therefore it is much needed to recognize which enablers should be put on the priority so that incremental implementation leads to inclusive and comprehensive execution [165]. The ranking of GLS enablers has been done in this research work using BWM and further validated using other decision-making techniques.

4.3.1 Methodology adopted and analysis of GLS enablers pertains to manufacturing

This section represents a three-phase methodology for prioritization and analysis of GLS enablers: (i) screening of prominent GLS enablers (ii) ranking of GLS enablers (iii) validation of identified ranks through numerous decision making approaches. The initial phase of methodology comprises the screening of GLS enabler from the enablers found by authors in their earlier work [27](refer to table 4.1). To finalize the screened GLS enablers, a decision board of experts (refer to table 4.9) was formed. The questionnaire centred survey was designed to screen the GLS enablers pertain to the manufacturing industry. To select prominent enablers a questionnaire was constructed and experts were enquired to provide the importance of the enablers on a scale from "1" to "5" where "1" refers not at all important and "5 means the most important". The researchers analyzed the responses from personnel (Table 4.9) and found the average of the scores for each enabler and it has found that 7 enablers have scored more than 4.2. The screened enablers (Table 4.8) were selected for further analysis. To determine the inherent consistency of the questionnaire, a reliability test was done using the Statistical Package for Social Sciences (SPSS). The value of Alpha in the reliability test was found 0.860 (using equation 4.3) that depicts a fairly high consistency of the selected questionnaire.

$$p^2 \times q\,(cov) / sum\,(var/cov) \quad [209] \tag{4.3}$$

here, p^2 depicts the square of items considered in the scale, q (cov) is the covariance of mean inter-item and sum (var/ cov) represents the addition of entire elements in the variance/covariance matrix.

In the third stage of the study, the prioritization and interactions among the enabler of GLS have done through BWM and the identified ranks of the enablers were further validated through DEMATEL, PROMETHEE-II, Analytical Hierarchy Process (AHP) to provide more consistency and validation of the identified ranks.

Table 4.8: Screened GLS enablers

S. No.	Caption	Enablers
1	E1	Organizational readiness for GLS measures together with competence for green product and process.
2	E2	Top management commitment toward sustainable performance improvement.
3	E3	Effective performance and feedback measure both at upstream and downstream
4	E4	Organizational ambience
5	E5	Expertise training in GLS
6	E6	Linking of GLS to business objectives.
7	E7	Availability of funds with organization

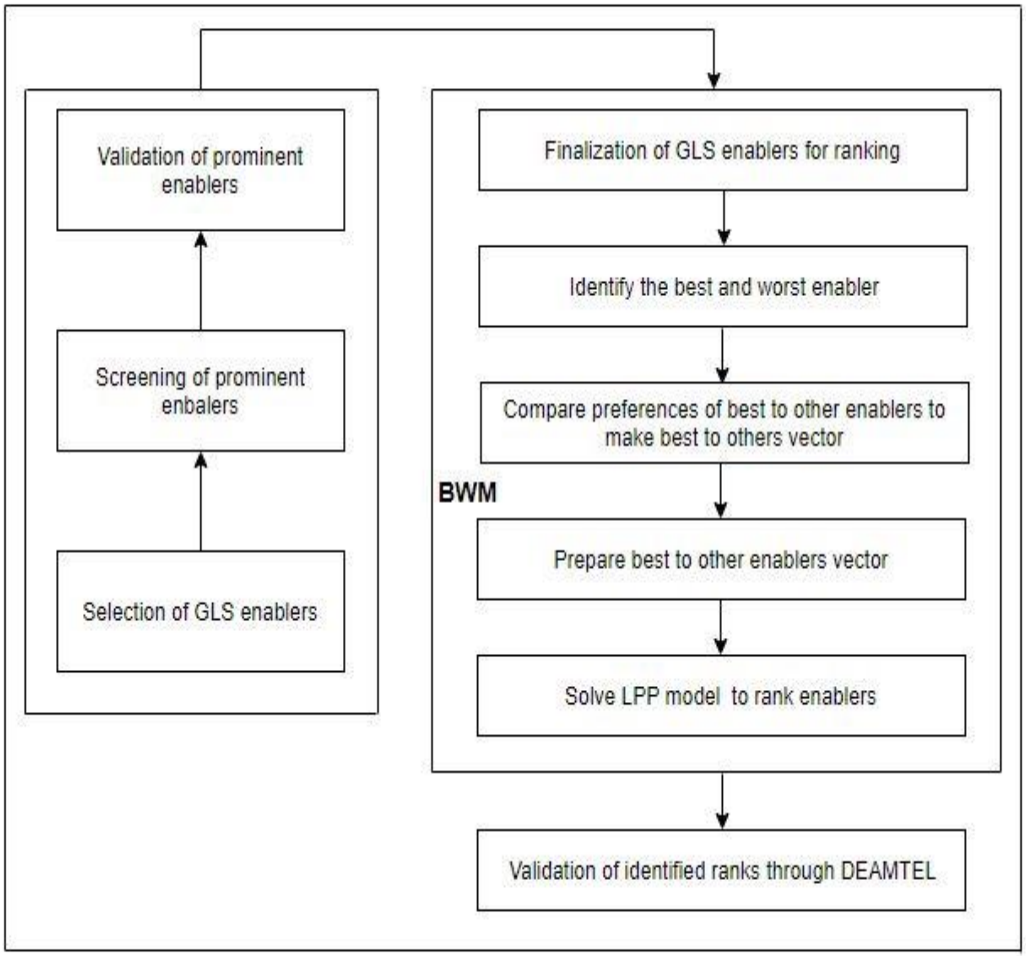

Figure 4.4: Research Methodology for GLS manufacturing enablers

Table 4.9: Expert panel for screening of GLS enablers

S. No.	Expert position	Average work experience	Number of experts
1	Senior general manager	35	1
2	General manager	30	1
3	Senior manager	25	4
4	Deputy manager	22	11
5	Engineer	8	28
6	Assistant engineer	7	44
7	Academicians	15	18

4.3.2 Best Worst Method

BWM is a pairwise assessment technique developed by Rezaei [197], to solve multi-criterion decision- making problems. It has been applied in numerous applications: selection of thermochemical conversion technology [197] [214], ranking of barriers to energy efficiency in building [214], technical assessment for treatment of urban sewage sludge [215], supplier selection [216], ranking of just in time elements in the health care sector, etc. [217]. It uses only two vectors instead of the complete pairwise matrix hence facilitate analyst and decision-maker as less data is needed. Besides, it uses a single integer scale rather than a fractional scale which makes it easier to understand. BWM uses fewer pairwise comparisons as compared to AHP and final weights derived by this method are highly reliable and consistent as compared to AHP [215].

BWM is a stepwise method executed in five steps.

Step 1: Determine of GLS enablers set for prioritization

The first step of BWM deals with the determination of GLS enablers set for prioritization. The enablers have been finalized through consultation with manufacturing personnel and finalized set of enablers are prominent to meet the future demands of the customers as well as the manufacturing sector. The six enablers have been finalized for prioritization and analysis.

Step 2: Determine the best and worst enabler

In this step, the best and worst enablers have been selected in consultation with the manufacturing personnel. The best criterion is the most needed, most favored or most imperative while the worst would be the opposite, the least needed, the least favored or the least imperative. In this step, the criteria are considered and not the values of the criteria.

Step 3: Determine the preference of best enabler to other enablers to make best to others vector

The preference of best enabler to other enablers was given by an expert panel using a number 1 to 9. The resulting best to another vector would be:

$$A_B = (a_{B1}, a_{B2}, \dots \dots, a_{Bn}), \tag{4.4}$$

where a_{Bj} indicates the preference of best enabler B over j

Step 4: Determine the preference of other enablers to worst enabler to make others to worst vector

The preferences of other enablers to worst enabler were given expert panel again between numbers 1 to 9. The resulting others to the worst vector would be

$$A_W = (a_{1w}, a_{2w}, \dots \dots, a_{nw})^T, \quad (4.5)$$

Here, a_{jw} indicates the preference of enabler j over the worst enabler W. It is clear that the value

for $a_{ww} = 1$

Step 5: Calculate optimal weights to estimate the rank of GLS enablers

In this step, the optimal weights for the enablers are found. The optimal weight for enabler is one where for each pair of w_B/w_j and w_j/w_w, we have $w_B/w_j = a_{Bj}$ and

$w_j/w_w = a_{jW}$. To meet all these conditions for j, where the maximum absolute

differences, $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_w} - a_{jW}\right|$ for all j is minimized. Considering the non-negativity constraint and sum condition for the weights, the following problem has resulted:

$$\left\{ \begin{array}{c} \min_j max\left\{\left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_w} - a_{jW}\right|\right\} \\ \sum_j w_j = 1 \\ w_j \geq 1 \text{ for all j} = 1 \end{array} \right\} \quad (4.6)$$

The problem of equation (4.5) can be transferred to the following linear programming model

$$\left\{\begin{array}{l} \min \xi^{L} \\ \left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi \text{ for all j} \\ \left|\frac{w_j}{w_w} - a_{jW}\right| \leq \xi \text{ for all j} \\ \sum_j w_j = 1 \\ w_j \geq 1 \text{ for all j} = 1 \end{array}\right\} \quad (4.7)$$

The above- mentioned problem is linear and has a unique solution. The optimal weights $(w_1^*, w_2^*, \ldots \ldots \ldots \ldots, w_n^*)$ and the optimal value of ξ called ξ^* are obtained. With the help of the consistency index, the consistency ratio is estimated using equation 4.8.

$$Consistency\ ratio = \frac{\xi^*}{consistency\ index} \quad (4.8)$$

The value of consistency ratio varies between 0 and 1 and the value of consistency ratio close to “0” exhibits more persistent comparisons.

4.3.3 Practical case and analysis of GLS enablers pertain to manufacturing

The current research work was carried out in an original equipment manufacturing industry with annual revenue of around 28 Million US dollars (2000 Million INR). It is the vendor of one of the prominent automobile industry of India and supplies original parts. The product of the enterprise exhibits negative ecological impacts and there after use is a main concern for the organization. The manufacturing organization is not able to sustain a balance between financial and ecological performance. In place of, that organization has decided to adopt sustainable measures that make harmony among social, economic and environmental dimensions of sustainability. So, the organization is planning to adopt GLS, a sustainable development approach to reduce the adverse ecological impact through reuse, recycle and reduce. The inclusive execution of GLS approach rests on a few prominent foundation blocks, acknowledged as enablers.

Therefore, the organization has to identify the enablers of GLS with their respective importance. Moreover, each enabler does not exhibit equal share to implement GLS and it is not possible to focus on each enabler due to lack of time and resources. So, it was imperative to identify the relative weights of the enablers. The screened enablers by the researchers were formulated in another questionnaire and responses were collected from the seven industrial personnel of the case industry (senior general manager, general manager, senior manager, deputy manager, two engineers and assistant engineer) to perform the BWM. The BWM has been applied to the responses collected for each industrial personnel of the case industry. The final weights of the GLS enablers are the average weights obtained from BWM on the individual responses of the case industry personnel. The unique application of BWM has been used in this study to solve complex decision-making problems of prioritization and analysis of GLS enablers. The complete procedure to calculate and rank GLS enablers by the BWM method was described to the said organization to sensitize them about the study. The top management organization seemed to be agreed upon to initiate the current research work with their valuable inputs and support in the concerned industry.

The BWM method starts with the identification of the best enabler and the worst enabler among the screened GLS enablers. The best and worst enablers were selected through consultation with industrial organization personnel. The enabler organizational readiness for GLS (E1) has been identified as the best enabler and enabler organizational ambience (E4) as the worst or least desirable enablers among the screened. Subsequently, the preference of best enabler over all other enablers and the preference of all other enablers over the worst enabler has been determined and labelled in pairwise comparison vector of the best enabler and pairwise comparison vector of the worst enabler (table 4.10).

Table 4.10: Pairwise comparison vector of the best enabler and worst enabler

Enabler	E1	E2	E3	E4	E5	E6	E7
Best enabler: E1	1	2	5	8	7	3	4

Henceforth, to rank the screened enablers GLS enablers the optimal weights $(w_1^*, w_2^* \dots \dots \dots w_7^*)$ has been found by the formulated linear programming model of equation 4.7. The weights of GLS enablers initially were found individually by using the responses for each industrial personnel of the case industry. The final weights of GLS enablers are the average of weights obtained from the individual experts. To find the optimal weights of GLS enablers different values of the ξ were considered and finally at the optimal value of ξ i.e. ξ^*, the optimal weights of enablers were considered (refer to table 4.11). To check the consistency, consistency ratio is found using the equation 4.8 and the consistency ratio was found as 0.0308 i.e. 3.08%, which depicts the high consistency in the results. Table 4.12 represents the consistency index table.

Table 4.11: Final weighted matrix of GLS enablers

S. No.	**Enablers**	**Weights expert 1**	**Weights expert 2**	**Weights expert 3**	**Weights expert 4**	**Weights expert 5**	**Weights expert 6**	**Weights Expert 7**	**Final BWM weights**	**Ranks**
1	E1	0.4255	0.3982	0.382	0.3978	0.3995	0.4054	0.4304	0.4055	1
2	E2	0.2016	0.1878	0.1806	0.1278	0.1902	0.1304	0.203	0.1745	2
3	E3	0.0697	0.0778	0.0747	0.0967	0.0783	0.0664	0.0703	0.0763	5
4	E4	0.0467	0.0559	0.0537	0.0436	0.0493	0.0499	0.0471	0.0495	7
5	E5	0.0697	0.0559	0.0537	0.0491	0.0563	0.057	0.0604	0.0574	6
6	E6	0.1036	0.0968	0.1806	0.1883	0.1289	0.0987	0.1044	0.1288	3
7	E7	0.0832	0.1276	0.0747	0.0967	0.0975	0.1922	0.084	0.1080	4

Table 4.12: Consistency index

aBW	1	2	3	4	5	6	7	8	9
Consistency Index	0	0.44	1	1.63	2.3	3	3.73	4.47	5.23

Finally, the ranks of GLS enablers identified through BWM have been further validated by using DEMATEL, AHP methods. Furthermore, the ranking was validated by the PROMITHEE II approach. Table 4.13 reveals the comparison of ranks of enablers by various prioritization approaches, the ranks are much similar and this validates the adoption of the selected method for the prioritization of GLS enablers.

Table 4.13: Comparison of the rank of BWM and other decision- making approaches

S. No.	Enabler	BWM weights	BWM rank	AHP weights	AHP rank	Importance of Enabler	DEMETAL rank	Leaving-entry flow	PROMETHEE II rank
1	E1	0.40061	1	0.2266	1	6.1446	1	0.67903	1
2	E2	0.1894	2	0.1912	2	5.9564	2	0.27083	2
3	E3	0.07832	5	0.1032	5	5.145	5	0.34179	6
4	E4	0.04936	7	0.0969	6	5.0768	6	0.17477	5
5	E5	0.05642	6	0.075	7	4.2259	7	0.45825	7
6	E6	0.1286	3	0.1944	3	5.4456	3	0.241517	3
7	E7	0.09735	4	0.1127	4	5.2947	4	0.095917	4

4.4 Discussion on findings pertains to GLS enablers pertains to all sectors

Integration of Green technology with shop floor improvement strategies like Lean and Six Sigma leads to a new improvement approach: Green Lean Six Sigma mitigates carbon emission and delivers the products of true value [164]. Researchers, in the past, proposed a framework of GLS but only the framework is not a panacea to execute a new strategy successfully within an organization [218]. Many new approaches fail at the early stages of implementation due to a lack of substantial preparedness [219]. Therefore, the immense need for the readiness measures of an approach was felt that propel an organization to implement the approach comprehensively from inception to last. The enablers of GLS are foundations for the success of any project because they are preambles and necessities to implement the comprehensive program. Pandey et al. [21] presented some enablers of GLS, but not analyzed the interactions among them. Only enablers' identification is not sufficient for gain in business, also their mutual interaction needs to be analyzed at utmost priority [220]. For this, in the present work, 12 enablers have been identified through a systematic literature review and further validated through experts' opinions. Furthermore, all enablers were modeled through ISM and classified into different categories by MICMAC analysis. ISM results reveal that 'Organizational readiness for GLS measures together with competence for green product and process' has been found as the most prominent driving enabler of GLS that founds the bottom position in ISM model (refer to figure 4.2). This enabler is the most significant in terms of execution of the GLS program because organizations have to be ready to adopt Green, lean and Six measures as a standard practice. The present work also exhibits, top management commitment; through understanding of green and statistical tools and linking of GLS to business objectives the most prominent driving enablers in ISM hierarchy. Top management commitment motivates organizational members to achieve GLS linked organizational objectives by thorough understanding of Green technology and other associated Lean Six Sigma tools. Enablers like organizational ambience effective performance and feedback measure both at upstream and downstream are middle level enablers (refer to figure 4.2). The GLS culture in an organization develop an ambience of less waste, reduce, reuse, recycle and reduction in variation of the process that leads to optimal use of the organizational resources. Further, expertise training in GLS requires investment in training and education of the organizational personnel that sensitize the human resources with new technology for sustainable development. Effective training offers more opportunities to develop GLS culture in the organization that leads to success execution of GLS. The top level enablers like integration of Lean, Green and Six Sigma across all the stages of product development cycle can only be achieved when their expert personnel and feedback measures are available at upstream and downstream of the processes (refer figure 4.2). The integration of GLS in product development together with better data gathering and Green measures and sensitized work force leads to the products that generate less carbon emission, waste and will be of closer specifications. Moreover, performance of middle level enablers can be improved when the improvement in bottom level enablers have achieved. Improvement in middle level enablers helps to achieve top level enablers. Improved level of top level enablers makes the execution of GLS in an organization easier. Similarly, in a study conducted by Soti et al. [221], top management commitment is the most significant bottom level enabler who also cited expertise training and funds availability as the next level enablers for effective six sigma implementation. Yadav and Desai [220] also depicted management engagement, financial resources, training of employee as dominant enablers of Lean Six Sigma in their study.

Further, from MICMAC analysis, it has been found that there is no autonomous enabler among all extracted enablers which exhibits all the considered enablers play a substantial role for the success of GLS `project (refer to figure 4.3). Autonomous enablers have weak driving power and weak dependency and so exhibit less influence on the system [222]. The dependent enablers (E2, E10) have relatively weak driving power but show strong dependency on other enablers. The linkage enablers (E1, E4, E5, E6, E7, E8 and E11) possess high driving as well as a dependency (refer to figure 4.4). The driver enablers (E3, E9 and E12) exhibit high driving power for the execution of the GLS program.

The organization to implement an inclusive GLS program must be ready to incorporate these enablers as the first line of preparedness. The systematic understanding of the enablers and their reciprocal interaction incorporate comprehensive learning of the realistic approach that facilitates organizational managers to recognize various pinholes in GLS implementation. The systematic procedure to incorporate GLS in the organization requires a strong commitment from every personnel, continual motivation and empowerment to learn, organization goal-oriented GLS objectives, and patience to realize efforts into gains.

4.5 Discussion on findings pertains to GLS enablers dedicated to manufacturing

In the present work, the enablers of GLS have been screened through the expert's opinion (manager, project manager, plant head). The internal consistency of the screened enablers has been tested through Cronbach alpha and the value of alpha (0.850) was calculated using SPSS. The screened enablers of GLS were ranked using a novel BWM approach and further, the identified rank was validated using DEMATEL, AHP, PROMETHEE-II.

The enabler organizational readiness for GLS (E1) has got the first rank in the prioritization of screened enablers. To implement a comprehensive GLS approach, preparedness in terms of various Green and Lean measures in product and process has to be determined inconsistent with current and future demands of the products. Simultaneously, have to cope with competitors in terms of the development of a green process which leads to lesser carbon emission in the environment. The enhanced planning, coordination, and control lead to the execution of the GLS program effectively and that is also in other words organization readiness.

Moreover, top management commitment toward sustainable performance improvement has found the second rank among enlisted enablers. The contribution, patronage, and vision of the management play a vital role in implementing sustainability concepts in organizations [223]. The top management commitment is the degree to which it encourages employees, contributes towards sustainable performance measures (in terms of alternative sources of energy and waste reduction measures), and allocation of essential resources for the production of goods and services within an organization [224]. Moreover, effective management practices motivate the employee to work in coordination with the team for the implementation of GLS effectively [95]. Linking GLS to business objectives makes the organization members work towards the goal of sustainable development by incorporating reduce, reuse and recycle of the available resources of the organization. The industry's main motive of profit and competitiveness must be linked with the aspect of GLS in terms of producing more from less, use reused material as raw material for another process, and recycling the materials that cannot be reused [225].

The availability of funds with the organization (E7) has got 4th rank in the BWM table. The organizations must have enough funds for the acquisition of not only sustainable manufacturing methods but also for the research work to innovate and study the effect of current adopted sustainable practices on all dimensions of sustainability (social, economic, and environmental). Industrial organizations have to invest a huge capital for the training of their personnel in various aspects of GLS, to develop and procure new methods for real-time feedback measures together with effective software and equipment to measure various green aspects (carbon footprint). The performance and feedback measure is very prominent to give feedback about the process. There is a need for concrete performance measurement instruments that measure the current stage of the process and system and provide real-time databases for improvement. Moreover, expertise training in GLS (E5) makes the personnel be well versed in the various aspects of GLS.

A well-thought-out training program helps to deal with change and pursues the whole participation of employees [126]. A good training program is necessary for the inclusive implementation of GLS [58]. The training provides an atmosphere of confidence among employees and they feel motivated and work with vigour to achieve the goal of sustainable development. Furthermore, organizational ambience (E4) provides a conducive environment of reduce, reuse and recycling within the industry and develops a culture where all the organizations' members work to meet the sustainable development targets. The present research work was carried out in an original equipment manufacturing organization. The findings of the present study for the adoption of GLS may vary for the organizational culture, structure, and size. The corporate culture has positive impacts on all the indices of industrial performance [226]. Through proper bureaucratic, innovative, supportive and effective culture the industry meets its set targets, improves productivity and profitability. The organization having a culture of continuous learning will be more adept to adopt GLS, as the culture of continual learning makes the organizational personnel trained in monitoring, measuring, and analyzing Lean and Green measures as compared to the organizations that are having a culture of resistance to change. Moreover, the industries with continuous learning, in the long run, will be able to include sustainable practices in their operations as compared to the resistive type of organizations.

The organization size also affects the adoption of sustainable practices like GLS, as the large organization's strategic objectives to meet sustainable demands of customer and profitability in the long run together make it easier for them to adopt GLS in their operation. Large industries have more resources as compared to small and mid-sized organizations; the application of GLS increases the financial burden in terms of shift of operation from traditional to sustainable one and requires training of employees. Therefore it is easier for large size organizations to adopt GLS as compared to the organization of small size. The organizational structures refer to the division of work among the organizational members and coordination of activities to attain the organizational objectives [227]. The effective organizational structure facilitates proper working relationships among the units of the industry that consequently leads to the ambience of mutual learning, better communication in terms of various feedbacks both upstream and downstream of the system's process that are one of the key measures for the adoption of GLS in an organization. The obligations of top management, the readiness of the organization to adopt GLS practices, associating business objectives with GLS and financial supports are always a top priority for the industry to train and educate employees in the various aspects of GLS like identification and measurement of various Lean Green wastes, feedback measures, analyzing the current state of the system or process through life cycle assessment and eco value stream mapping, etc.

Advanced manufacturing practices are defined as well-known model adoption by the industrial organizations in their operations to achieve the organization's goals [228]. The advanced manufacturing practices include Material Requirement Planning (MRP), Just in Time (JIT), Lean production, concurrent engineering, Six Sigma, etc. The present study provides useful insights towards the inclusion of GLS practices in manufacturing organizations through the analysis and prioritization of the enablers. The inclusion of Green and Lean practice of GLS will make the process of manufacturing more environmentally centred as Green Manufacturing approaches like rapid prototyping and dry machining leads to a lesser carbon footprint and Lean reduces various associated wastes. The adoption of GLS will provide a strategic approach to the management of the organization that leads to a substantial improvement in all the dimensions of sustainability. The comprehensive study and detailed analysis of GLS enablers provide sustainably oriented insights to the managers of the manufacturing enterprises that through expertise training, linking of GLS to organizational objectives, investment in green practices, and measurement tools like life cycle assessment and eco value stream mapping will lead to an ambience of sustainable development within the organization.

4.6 Implications for practitioners, researchers, and industrial managers

The present study encourages industrial managers and practitioners to adopt GLS sustainable development practice through comprehensive understanding and analyzing enablers of this eco-friendly approach. The major implication of the present research lies in suggesting a direction to industrial managers and practitioners through investigation of relationship among different enablers that gives a systematic way to initiate and implement GLS program. The prioritization of GLS enablers provides an impetus to the organization that for the inception of sustainable GLS practice the organisation must focus on the most prominent enablers at the start and subsequently shift to other enablers. The enablers can be categorized into different categories depending on their relative impacts on social economic and environmental dimensions of sustainability. Furthermore, the BWM can be applied to explore the hidden facts of GLS within a manufacturing organization: barriers for the execution of the GLS program; analyzing the various metrics of Lean and Green; integrating factors of individual Lean, Green, and Six Sigma in GLS.

All the enablers of GLS are not equally important for the induction of GLS within an industrial organization and the organizations cannot focus on all the enablers due to lack of resources and financial constraints. The present work provides relative weights of the GLS enablers that facilitate practitioners which particular enablers should be focused on with utmost importance. The enablers with less relative weights would be given lesser attention as compared to enablers with more weights during the incremental application. This research will facilitate the industrialist and environmentalist to induct the approach of sustainable business practice as GLS leads to lesser environmental degradation, wastes, and variation in the process through the reduction reuse and recycle of the organizational resources. Globally, society will be benefitted from the present research as the lesser ecological damage in terms of reduced GHGs emission and reduced wastes through comprehensive learning and implementation of a sustainable GLS approach.

4.7 Inferences drawn

The GLS has been identified as a comprehensive approach that mitigates negative environmental effects and at the same time delivers high specification products. To meet the environmental regulations and customer perception of quality, the organizations need to understand the characteristics and interrelationship of GLS enablers. Twelve enablers pertain to GLS implementation have been found suitable to be modelled and analyzed. The ISM decision making approach serves as a suitable tool for establishing the relationship among different enablers of GLS. 'Effective data assimilation and Lean Green matrices identification' form the topmost level of ISM model and 'Organizational readiness for GLS measures together with competence for green product and process' rest at the bottom of ISM model. Modelling of GLS enablers facilitates the organizational managers to understand the mutual relationship and linkage of various enablers and that will penultimate results in a successful execution of GLS program. MICMAC analysis has helped to classify these enablers into the driver, dependent, linkage enablers that will facilitate the practitioners and managers to full fill the goal of sustainable development. Seven enablers are found as linkage enablers whereas three as driver enablers. Two enablers are found as dependent and no enabler is classified as autonomous.

However, in developing countries like India, the implementation of GLS in the manufacturing environment is difficult due to the lack of alternate technology and resistance of the organization to a new approach. With this in mind, the researchers screened GLS enablers in the manufacturing environment and further rank them using the BWM approach so that organizations may pay attention to high- rank enablers at the initial stage of the GLS implementation. The present research work provides a pathway to industrial organizations (especially mid-sized) for the adoption and implementation of the GLS in a logical manner.

Chapter 5 Green Lean Six Sigma Barriers

Barriers are the hurdles or path-breakers that prevent an organization from executing a new approach. This chapter outlines firstly barriers of GLS pertains to manufacturing. The barriers have been identified from the literature and grouped into logical groups through expert opinions using PCA. The grouped barriers were further analyzed using IF-DEMATEL and results were validated using other MCDM techniques. Finally, the mitigation actions and implications were suggested for practitioners.

5.1 Introduction

GLS is a sustainable development approach that leads to improved process performance through the reduction of wastes, variations, and environmental emissions [25]. GLS leads to improvement in material efficiency, promotes 3'R (reduce, reuse, and recycle), and makes the process more streamlined [27]. The changeover for the traditional approach of doing business to GLS is a substantial task as many GLS programs have failed during their inception stage [161]. This can be attributed due to a lack of knowledge base on Green Lean metrics, GLS tools, causes of waste and emission, GLS adoption barriers, etc. [57]. The barriers are the constraints or path-breakers that, if get rid of from a system or process, leads to the smooth execution of a program [78]. Although the study pertains to enablers or success factors, and barriers pertain to the construction sector exist. The study pertains to barriers in the product development process that exhibits the hierarchical structure of barriers that exists in the literature. But no work related to exploration, establishing the contextual relationship among GLS barriers for understanding intrigue nature of barriers exists in the literature. Moreover, no study of GLS barriers provides prioritization of barriers that facilitate the industrial managers to systematically remove the most critical barriers from the implementation point of view. So, there is an immense need to relook GLS adoption barriers in the manufacturing environment. Eighteen barriers to GLS adoption have been identified through a detailed literature survey and further categorized into six logical groups using principal component analysis (PCA) using the responses from the experts (industrial personnel and academicians). There exists interrelationship among grouped GLS adoption barriers, and it must be exhibited to decide which barriers affect other barriers. For this, IF-DEMATEL method has used to bifurcate grouped barriers into cause and effects barriers. Moreover, due to limited finance and time constraints, organizations can only focus on critical GLS barriers. So, the prioritization of the barriers was also done using IF-DEMATEL, and ranks of the barriers were further validated using Best Worst Method (BWM).

5.2 Research approach and Barriers of Green Lean Six Sigma

The research approach adopted in the present work consists of two distinct phases. Figure 5.1 demonstrates various phases of the adopted research approach. The various phases of the approach are as follows:

Phase 1: Identification and grouping of Green Lean Six Sigma barriers

In the first phase, a comprehensive literature survey was done to identify barriers to GLS in the manufacturing environment. This results in the identification of 18 barriers of GLS that hinders its implementation (table 5.1). A well-defined questionnaire was prepared and to check the internal consistency and reliability of the questionnaire Cronbach's alpha test was performed. The value of the alpha is 0.83 that depicts the high reliability of the formulated questionnaire. The questionnaire was sent to the practitioners at the mid and high levels of management in the manufacturing industry, LSS personnel (LSS green belt and black belt, this LSS personnel comes from an industrial and academic background (Industry/ Academia) as some of them belong to academia and other are actively engaged with LSS projects in industries), and academicians from academic institutions (106 respondents). Table 5.2 depicts the characteristics and demographic background of respondents.

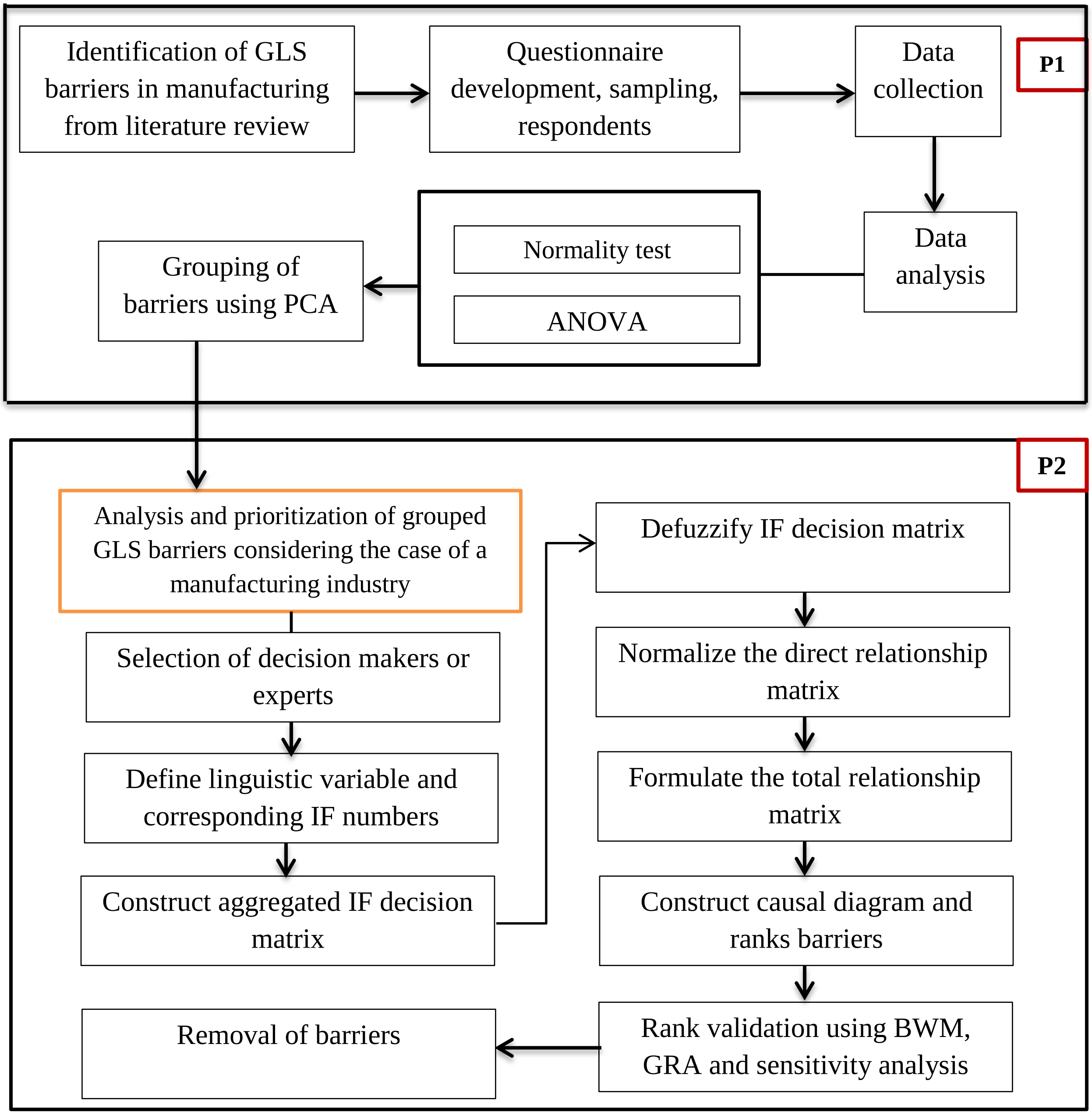

Figure 5.1: Research approach for analysis of GLS barriers

Table 5.1: Green Lean Six Sigma barriers

S. No.	Barriers	Description	References
1	Lack of understanding of different types of voice of customers	The selection of the GLS project rests on the customer's view; many times, organizations have failed in the past to convert VOC into desired results.	[158] [46]
2	Inappropriate Lean and Green areas identification	Successful GLS projects demand identification of a particular shop/ section of the industry that has maximum effects on organizational sustainability.	[47]
3	Lack of continuous improvement (CI) thinking	A positive mindset with constant improvement thinking is key to the success of the GLS project within an organization. Lack of CI thinking makes the system on a standstill, and the industry will not be able to compete in the global market.	[47]
4	Resistance to change	Traditional practices are being adopted by industries operated for a very long time; managers have resistance to change it.	[101]
5	Inadequate regulatory framework	The deficient of the monitoring framework to direct the firms for high productivity and eco-friendly performance hinders the implementation of GLS.	[229]
6	Lack of environmental knowledge	Comprehensive environmental knowledge, together with the understanding of the effect of various process parameters on ecology, is considered vital for GLS success.	[204] [205]
7	Wrong GLS tool section	The success of GLS highly depends on the selection of proper tools during various phases of implementation; the wrong choice leads to the failure of the GLS project.	[26]
8	Un-optimized transportation system	The un-optimized transportation system leads to wastage of movement, money, and energy.	[78] [36]
9	Lack of management support	Top management support is necessary for GLS success as an absolute authority to release the orderlies with it.	[158]
10	The obliviousness of re-engineering	A complete understanding of various approaches to reengineering is quite essential for effective GLS project implementation within a particular organization.	[204]
11	Unawareness of various GLS strategies	The GLS execution demands a thorough understanding of its different plans and their associated pros and cons.	[21] [47]
12	Lack of synergy between continuous improvement and strategic objectives of the organization	Coherence between objectives and CI is required for the GLS project so that desired results can be achieved within a particular time frame.	[158] [95] [47]
13	Deficiency of experienced GLS personnel	Experienced persons are well versed with the process of the organization; their skills play a focal role in indecisive time.	[230]
14	Lack of training	GLS requires comprehensive training of each employee and their full and timely participation. The organization must invest in the training and education of its employees.	[231]
15	Poor organizational culture	GLS implementation leads to a shift in the culture of the organization from the traditional to a sustainable one. So, the culture of continuous learning and cooperation is necessary.	[231]

16	Economic constraints	GLS implementation within the organization will bring some paradigm shifts in the concerned industry, so investment is needed to incorporate these changes.	[205]
17	Lack of standardization and standard scheduling procedures	Standardization brings a specialty in the system that leads to less rework and wastes.	[37]
18	Cultural fragmentation	GLS implementation leads to the shift in the culture of the organization from the traditional one. The organizations' members, show resistance to change towards a sustainable culture.	[231]

Table 5.2: Characteristics and demographic background of respondents

S. No.	Work profile	Number of person	Percentage	Industry/Academia
1	Senior Manager	28	26.42	Industry
2	Manager	24	22.64	Industry
3	LSS Green belt	22	20.75	Industry/Academia
4	LSS Black belt	17	16.04	Industry/Academia
5	Professor	15	14.15	Academia

The dataset received from all respondents was checked for normality using the Shapiro-Wilk test and Q-Q plot in the statistical package for social sciences version 20 (SPSS 20). The value "p" of the Shapiro-Wilk test ($p \geq 0.05$) and data points distributed along the line in the Q-Q plot designate that data is normally distributed [232] [233]. The p-value was found as 0.087 all the data distributed along the line in the Q-Q plot (Figure 5.2).

Analysis of Variance (ANOVA) was developed by Professor Ronald A. Fisher in 1921 for validating the collected data and also used to compare the mean of more than two groups. It is a collection of a slew of statistical paradigm and associated methods to analyze the difference among different groups. The analysis of variance (ANOVA) test was performed for the extracted factor to check whether the sample means differ for different groups is significant or not. It is an important tool for testing homogeneity, comparing means among different groups of data [217]. The ANOVA test was performed with the null hypothesis (H_0) that there is no significant difference among the sample means of different groups. The p-value after conducting the ANOVA test was found to be 0.046, which is less than 0.05, which implies that H_0 is rejected and H_A prevails [234]. So, there is a significant difference among sample means of different groups. It is obvious from the ANOVA that there is a significant difference among the different groups' barriers as a whole.

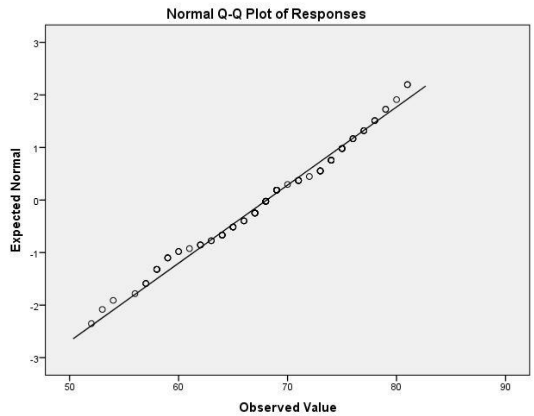

Figure 5.2: Q-Q plot for GLS barriers

The Tukey post hoc test was conducted to depict which group differs from others. From the multiple comparisons post hoc test the p-value of environmental (ER) set of barriers against continuous improvement (CI) barriers was found to be 0.36, which states that there is a significant difference in the sample means between ER and CI barriers. This infers the importance of removal of the ER barriers high as compared to the CI barriers. The p value training related (TR) barriers against knowledge (KB) barriers was found as 0.784, which depicts that there is no substantial difference among sample means for these two sets of barriers. This implies that these set of barriers have the nearly same significance of removal for the execution of the GLS program. The Tukey post hoc test p-value for management (MR) barriers against organizational barriers (OR) was found as 0.635, which depicts there is no substantial difference among sample means for these two sets of barriers. The managerial functionality and top management support are essential for organizational operations and decisions. This implies that these two sets of barriers have not much difference in the priority list for removal of barriers.

The exploratory factor analysis's principal component analysis (PCA) was used to fit the barriers into a manageable number of groups. PCA provides information about the common hidden pattern that exists in a particular set of data [235]. It is one of the most widely used and accepted techniques for forming logical groups among a large number of factors of a data set [236]. Before the PCA analysis, Kaiser-Meyer- Olkin and Bartlett's test of sphericity were performed to help assess the factorability of the dataset and sample adequacy respectively. The value recommended for Kaiser-Meyer- Olkin should be greater than 0.5 and Bartlett's test of sphericity's $p \leq 0.05$ (Field, 2000). It has been found that the KMO test value found to be 0.052 and Bartlett's test of sphericity was high at with chi-square 301.885 and p-value 0.000 Afterwards, the eigenvalue and percentage of variance approach of PCA were used to represent the GLS barriers into different groups of same characteristics. The extracted factors or group must account for at least 60% of the total variance for the authenticity of the number of groups. The PCA shows that six grouped GLS barriers account for 60.687 % of the total variance explained with the average of the item loading 0.657 (table 5.3). Moreover, it obvious from the scree plot (figure 5.3) those barriers have to be grouped into six groups as with an eigenvalue greater than one has to be retained.

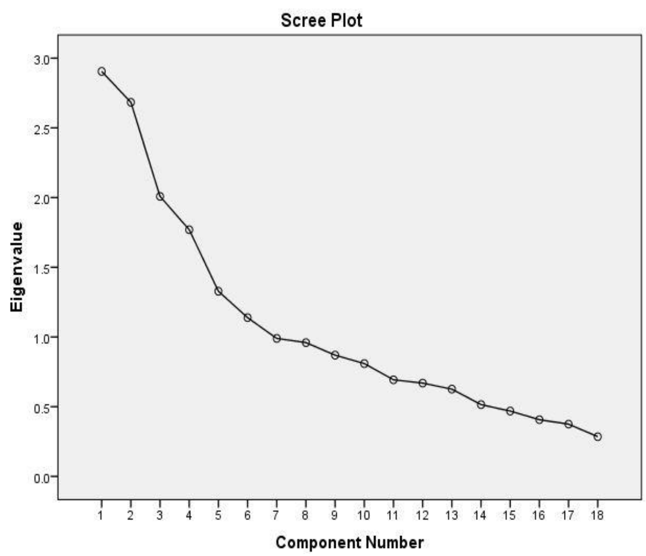

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Figure 5.3: Scree plot

Table 5.3: Principal component analysis for grouping of barriers

Grouped Barriers	Barriers	Factor loading	Interitem correlation	Rotation	Variance explained	Cumulative variance
Environmental barrier	Unawareness of various GLS strategies (B11)	0.625	0.654	.680	10.853	10.853
	Lack of environmental knowledge (B6)	0.731	0.686	.667		
	Wrong GLS tool section (B7)	0.618	0.314	.560		
	Inappropriate Lean and Green areas identification (B2)	0.513	0.562	.522		
	Deficiency of experienced GLS personnel (B13)	0.726	0.649	.521		
Management related barriers	Lack of management support (B9)	0.631	0.529	.759	10.086	20.938
	Poor organizational culture (B15)	0.652	0.494	.689		
	Resistance to change (B4)	0.541	0.629	-.504		
Knowledge base barriers	Lack of understanding of different types of voice of customers (VOC) (B1)	0.634	0.583	.773	11.718	32.657
	Un-optimized transportation system (B8)	0.56	0.678	.691		
Training related barriers	Lack of training (B14)	0.713	0.664	.504	8.272	40.929
	Lack of standardization and standard scheduling procedures (B17)	0.639	0.582	.681		
	Inadequate regulatory framework (B5)	0.691	0.621	.599		
Organization related	Cultural fragmentation (B18)	0.711	0.715	.659	9.336	50.265
	Economic constraints (B16)	0.545	0.429	-.644		
	Lack of synergy between continuous improvement and strategic objectives of the organization (B12)	0.812	0.626	.573		
Continuous improvement barriers	Lack of continuous improvement (CI) thinking (B3)	0.821	0.492	.777	10.442	60.687
	The obliviousness of re-engineering (B10)	0.679	0.642	-.630		

GLS is a project-based approach and its success primarily lies with appropriate project selection that covers all the three dimensions of sustainability [79]. The project where the opportunities exist to improve environmental sustainability through a proper area of Green Lean identification must be set at the top of the priority list. The project selection demands the experienced personnel of GLS, through experience in GSL tools, proper knowledge on different aspects of environmental aspects. The manufacturing organization to implement GLS faces difficulty in terms of improper area identification, experienced persons with knowledge of GLS strategies and tools, intrigue nature of environmental sustainability. So, these all barriers discussed here if removed will lead to improved organizational sustainability, hence they are clubbed under the head of the environmental barriers. Top management support is the most essential for the realization of any new strategy within an organization [78]. Management serves as the motivating force for the development of continuous learning culture, the establishment of confidence among the organizations' members for shifting resistive culture to continuous improvement culture. So, management lack of support, resistance to change, and poor organisational culture has been put under the umbrella of management barriers. GLS project selection is made based on different aspects of VOC, understanding VOC, different facets of the transportation system, and material handling is essential for effective GLS execution. There the barriers pertain to, lack of understanding of VOC, unoptimized transportation have been put under the group of knowledge base barriers. The training of employee in different strategies of GLS and toolset is essential to tap the full potential of this sustainable development approach [26]. Lack of training leads to inappropriate application of tools and GL areas selection that subsequently leads to a potential failure of the GSL project. The training in GLS aspects makes organization members aware of different GLS and regulatory framework, standard operating procedures for improving organizational performance. So the barriers of training, lack of standardization, and regulatory framework have been put under the umbrella of training related barriers. The linking of organization objectives with GLS, making everyone responsible for the sustainability of the organization, and financial assistance are predominant factors for GSL success [57]. Organization look forward culture makes everyone responsible for the incorporation of sustainability measures, the realization of the pursuits to ensure social and environmental sustainability to sustain in the global market. So, the barriers of lack of synergy of organization and GLS objectives, cultural fragmentation, and economic constraints have been put under the group of organization barriers. The continuous improvement thinking generates opportunities of 3'R (reduce, reuse, and recycle) in the organization that are essential for incorporation of sustainable development culture within an organization. So, the barriers of obviousness of re-engineering and lack of continuous improvement thinking have been put in the group of continuous improvement barriers.

5.2.1 Environmental barriers

The barriers that hinder environmental performance or sustainability improvement of the organizations are termed environmental barriers. This group of barriers encompasses five barriers: unawareness of various GLS strategies, lack of environmental knowledge, wrong GLS tool section, inappropriate lean and green areas identification, and deficiency of experienced GLS personnel. This group of barriers is termed environmental barriers and it accounted for 10.853 % of the total variance. The comprehensive knowledge base of Green and Lean metrics and environmental aspects associated with the process is indispensable for the success of the GLS program.

5.2.2 Management-related barriers

The barriers which are related to lack of support and functionality of the management are termed as management barriers. This group of barriers includes lack of management support, poor organizational culture, and resistance to change and accounted for 10.086% of the total variance. The management commitment, adaptation to clean technologies, and go-forward culture is demanded the incorporation of sustainability aspects in the organization.

5.2.3 Knowledge base barriers

The barriers that are related to the development of background to understand the voice of customers (VOC), the voice of business, and different aspects that pertain to transportation and material handling are termed as knowledge base barriers. This group includes barriers like lack of understanding of different types of VOC and un-optimized transportation systems.

5.2.4 Training related barriers

The barriers that restrain the sustainability of the organization due to lack of training or exercise on GLS tools, standard practices, metrics, adoption methods are named as training-related barriers. This set of barriers includes; lack of training, lack of standardization and standard scheduling procedures, and inadequate regulatory framework and it accounts for 8.272 of the total variance explained. The training of the organizational personnel in different aspects of GLS implementation is needed to tap the full throttle of this sustainable approach.

5.2.5 Organizational related barriers

The barriers which are related to the lack of organizational functionality on part of developing the culture of mutual learning, generation of finance for incorporation of clean technologies, and embedment of green culture in the organization objectives are termed as organizational barriers. This set of barriers accounts for 9.336% of the total variance explained and represents barriers of cultural differences, economic constraints, and synergetic differences among continuous improvement methods and strategic objectives of the organization.

5.2.6 Continuous improvement barriers

The barriers that restrict the organizational capability to adopt continuous learning, improvement and adoption of re-engineering methods are named continuous improvement barriers. This grouped barrier accounts for 10.442% of the total variance and is loaded with barriers to continuous improvement thinking and adoption of sustainable recycling approaches.

Phase 2: Classification and Prioritization of GLS barriers

The second phase of the methodology is related to the classification of the grouped barriers into the cause and effect barriers using IF- DEMATEL along with the prioritization of the grouped barriers. Moreover, the results of the study were primarily validated using BWM and then GRA. The sensitivity analysis was also performed to ensure the robustness of the results. The steps associated with IF-DEMATEL execution are:

Step 1: Linguistic data collection from the DMs

In the decision-making problem of the multi-criteria, responses from a group of DMs are mainly focused on the opinion of the DMs regarding the rating of the identified criteria. The DMs are requested to provide the linguistic assessment by rating the criteria, here grouped barriers using the five linguistic scales ranging from 'no influence' to very 'high influence'. In the IF-DEMATEL method, a set of proper linguistic variables and their corresponding IFS are required to compare each grouped barrier with another. The IFS in a finite set X can be written as

$$A = \{\langle x, \mu_A(x), v_A(x)\rangle | x \in X|\}$$

Here, $\mu_A(x), v_A(x)$: $X \to [0, 1]$ are defines as membership and non-membership function such that

$$0 \leq \mu_A(x) + v_A(x) \leq 1 \quad (5.1)$$

The third member of the IFS, $\pi_A(x)$ called a hesitation degree and denotes that whether *x* belongs to *A* or not.

$$\pi_A(x) = 1 - \mu_A(x) - v_A(x) \quad (5.2)$$

If $\pi_A(x)$ is small the knowledge about x is more certain and if it is large then knowledge about x is more uncertain. Linguistic variables and corresponding IFS were adopted from Boran et al.. (2009) (table 5.4). For example, here for the linguistic variable 'No influence', $\mu_A(x)$ = 0.1, $v_A(x)$ =0.8, and $\pi_A(x) = 0.1$

Table 5.4: Linguistic variables and corresponding IFS Boran et al. [237]

S. No.	Linguistic Variable	Linguistic Preference Scale	IFS
1	No influence	NI	0.1,0.8, 0.1
2	Very low influence	VL	0.25,0.6,0.15
3	Low influence	L	0.5, 0.4,0.1
4	High influence	HI	0.75, 0.2, 0.05
5	Very high influence	VH	0.9, 0.05,0.05

Step 2: Find the weights of DMs

The weights of the DMs are calculated in the 2nd step of execution of IF-DEMATEL. Let l is the number of DMs, and $D_k = [u_k, v_k, \pi_k]$ is defined as an intuitionistic fuzzy number (IFN) for weighting rating of kth DM. The weightage of the kth DM is calculated using equation (5.3) [238].

$$(\lambda_k) = \frac{\left(u_k + \pi_k\left(\frac{u_k}{u_k+v_k}\right)\right)}{\sum_{k=1}^{l}\left(u_k + \pi_k\left(\frac{u_k}{u_k+v_k}\right)\right)} \quad ; \; \sum_{k=1}^{l} \lambda_k = 1 \tag{5.3}$$

Step 3: Construct aggregated IF decision matrix

In this step, the aggregated IF decision matrix is made based on the responses of the DMs. Let $R^k = \left(r_{ij}^{k}\right)_{mxn}$ is the IF decision matrix of each DM, and $\sum_{k=1}^{l} \lambda_k = 1$, $\lambda_k \in [0,1]$. In a group decision-making process, each decision-maker's opinions need to be merged into a group opinion to constructing an aggregated IF decision matrix. For this, the subsequent operator suggested by Xu [239], named intuitionistic fuzzy weighted averaging (IFWA) operator is used. This subsequently generates the initial reachability matrix A

$$r_{ij} = IFWA_{\lambda}\left(r_{ij}^{(1)}, r_{ij}^{(2)}, , , , , , , r_{ij}^{(l)}\right)$$

$$r_{ij} = \left[1 - \prod_{k=1}^{l}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1 - v_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{l}\left(1 - v_{ij}^{(k)}\right)^{\lambda_k}\right]$$

Here $r_{ij} = \left(u_{A_i}(x_j),\; v_{A_i}(x_j),\; \pi_{A_i}(x_j)\right) (i = 1,2,3, \dots \dots m; j = 1,2,3 \dots \dots n)$ (5.4)

The aggregated IF decision matrix is represented as:

$R =$

$$\begin{bmatrix} u_{A_1}(x_1), v_{A_1}(x_1), \pi_{A_1}(x_1) & u_{A_1}(x_2), v_{A_1}(x_2), \pi_{A_1}(x_2) \dots & u_{A_1}(x_n), v_{A_1}(x_n), \pi_{A_1}(x_n) \\ u_{A_2}(x_1), v_{A_2}(x_1), \pi_{A_2}(x_1) & u_{A_2}(x_2), v_{A_2}(x_2), \pi_{A_2}(x_2) \dots & u_{A_2}(x_n), v_{A_2}(x_n), \pi_{A_2}(x_n) \\ \vdots & \vdots & \vdots \\ u_{A_m}(x_1), v_{A_m}(x_1), \pi_{A_m}(x_1) & u_{A_m}(x_2), v_{A_m}(x_2), \pi_{A_m}(x_2) \dots & u_{A_m}(x_n), v_{A_m}(x_n), \pi_{A_m}(x_n) \end{bmatrix}$$

Step 4: Obtain the crisp value of the initial reachability matrix

Defuzzification is a method of converting the fuzzy output into a crisp value. It is executed to get a crisp value of each grouped barrier corresponding to another. In this procedure, the input is a cumulative set, and output is a single number. This offers the qualitative value for the linguistics variables and fuzzy numbers allotted based on the opinions of DMs. The equation proposed by Karaşan and Kahrama [240] is used to get the crisp value and formulate the initial direct relationship matrix for further processing of the DEMATEL method.

$$P = \frac{u_A(x)+v_A(x)+\pi_A(x)}{3} + \frac{u_A(x)+v_A(x)+\pi_A(x)}{\pi_A} \quad (5.5)$$

Here, P is the crisp value of the one grouped barrier against the other barrier. From the crisp values, initial reachability matrix A is formulated.

Step 5: Normalizing the direct relationship matrix

The normalized direct relationship matrix has been obtained using equation (5.6).

$$Z = A/s \quad (5.6)$$

where $s = \frac{1}{max \sum_{j=1}^{m} a_{ij}}$ and a_{ij} are the elements of the initial reachability matrix A.

In this step, the row-wise summation of each element of the direct relationship matrix has been done. After that, each element of the direct relationship matrix has divided by the maximum sum value among the row-wise sum to get the final normalized direct relationship matrix.

Step 6: Formulate total relationship matrix

In this step, the total relationship matrix (T) has computed by using equation (5.7) [241], where "I" represents the identity matrix. The said equation has been solved in MATLAB.

$$T = Z(I - Z)^{-1} \quad (5.7)$$

Step 7: Compute D, R, D-R, and D+ R

The sum of rows and columns of the total relationship matrix (T) has been computed in this step to construct (D+R) and (D-R) vectors [30]. The basic notations used to conduct this step are:

R = sum of column of the matrix T, c_j represents direct and indirect effects on factor or barrier j by the other factors or barriers

D = sum of row of the matrix T, r_i represents direct and indirect effects given by factor i to the other factor.

$d_i + r_j$ = the importance of factor i.

$d_i - r_j$ = the net effect of factor i.

Based on these vectors, the GLS barriers were ranked and cause and effect diagram was made. (D+R) is a horizontal axis vector that represents the degree of relationship of each grouped barrier with another. The barrier, which represents the highest value of (D+R) is the most important. The (D+R) values of grouped barriers depict the ranks of the same. (D-R) is the vertical axis vector that exhibits the kind of relationship among the barriers. The grouped barriers with positive (D-R) is called cause group or dispatcher, whereas the barriers with negative (D-R) is called an effect group or receiver [31]. The ranks of the barriers found through the IF-DEMATEL were further validated using primarily with BWM. The steps associated with the BWM are as follows:

Step 1: Determine the best and worst grouped barrier

The first step of BWM is to determine, the best and the worst criteria or barrier, denoted by 'P and 'F', respectively. Here, in this method, the most important and the least important criterion or barriers are found to calculate the relative weights of the criteria [62].

Step 2: Construct best to others and other to worst vector

The second step of BWM is to determine the comparative preferences of the most important criterion or barrier over all the other criteria and that of other criteria over the least important criterion, see table 5.5. Then, the best to others (A_P) vector and the others to worst (A_F) vector can be found, as depicted in equations (5.8) and (5.9), respectively.

Table 5.5: Comparative scale of Saaty method [242]

S. No.	Scale	Definition	Description
1	1	same important	i is equally important to j
2	3	moderate important	i is moderately important to j
3	5	essentially important	i is essentially important to j
4	7	very strong important	i is very strong important to j
5	9	absolute important	i is important to j
6	2,4,6,8	intermediate value	the relative importance e of i to j to adjacent judgment

$$A_P = (a_{P1}, a_{P2}, \dots \dots, a_{Pn}), \quad (5.8)$$

where a_{pj} indicates the preference of best barrier "*P*" over j

$$A_F = (a_{1F}, a_{2F}, \dots \dots, a_{nF})^t, \quad (5.9)$$

Here, a_{jF} indicates the preference of barrier j over the worst barrier "*F*". It is clear that the value

for $a_{FF} = 1$

Step 3: Calculate optimal weights to estimate the rank of GLS barriers

The optimal weight for a barrier is the one where for each pair of w_P/w_j and w_j/w_F, $w_P/w_j = a_{Pj}$ and $w_j/w_F = a_{jF}$. To meet all these conditions for *j*, where the maximum absolute differences, $\left|\frac{w_P}{w_j} - a_{Pj}\right|$ and $\left|\frac{w_j}{w_F} - a_{jF}\right|$ for all *j* is minimized. Considering the non-negativity and sum condition for the weights, the following problem has resulted

$$\left\{ \begin{array}{c} \min_j \max \left\{ \left|\frac{w_P}{w_j} - a_{Pj}\right|, \left|\frac{w_j}{w_F} - a_{jF}\right| \right\} \\ \sum_j w_j = 1 \\ w_j \geq 1 \text{ for all } j = 1 \end{array} \right\} \quad (5.10)$$

The problem of equation (5.10) can be transferred to the following linear programming (LP) model shown in equation (5.11).

min ξ^L

$$\left\{ \begin{array}{l} \left|\frac{w_P}{w_j} - a_{Pj}\right| \leq \xi \text{ for all } j \\ \left|\frac{w_j}{w_F} - a_{jF}\right| \leq \xi \text{ for all } j \\ \\ \sum_j w_j = 1 \\ w_j \geq 1 \text{ for all } j = 1 \end{array} \right\} \tag{5.11}$$

Here, W_P and W_F represent the weight of the best and worst criterion respectively. W_j depicts the weight of the jth criterion or barriers. 'ξ' is the value of the objective function in the LP and ξ^* is the value of the programing function under the optimal weight conditions. The optimal weights and the optimal value of ξ called ξ^* have been found for the above-mentioned LP problem.

Step 4: To ensure the consistency of the adopted BWM method, similar to other decision making approaches the consistency ratio is calculated using equation (5.12). The value of the consistency ratio varies between "0" and "1" and closeness to "0" exhibit more consistent comparisons. The consistency index has been given in table 5.6.

$$Consistency\ ratio\ (CR) = \frac{\xi}{Consistency\ Index\ (CI)} \tag{5.12}$$

Table 5.6: Consistency index

$\mathbf{a_{PF}}$	1	2	3	4	5	6	7	8	9
Consistency index (maximum ξ)	0	0.441	1	1.63	2.3	3	3.73	4.47	5.23

To further strengthen the findings the ranks of the GLS barriers found through the IF-DEMATEL and BWM were further validated using GRA. Moreover, to make the result more reliable the sensitivity analysis was also performed for the ranks found through the BWM.

5.3 Analysis of Green Lean Six Sigma barriers with practical case

The present work considers the case of a manufacturing organization in India for clustering and ranking of grouped barriers. The DMs evolved in this study belong to the case industry. The organization is in the business run for more than 40 years, and its annual turnover is more than INR 5000 M. The foremost apprehension for the concerned industry is the negative environmental impacts from the process of product generation. So, the organization is planning to adopt an environmentally friendly approach in its business process. GLS is an inclusive approach that reduces the negative environmental impacts and at the same time, maintains social and economic harmony. The inclusion of GLS within an organization is challenging as it deals with significant overhauls, and a lot of factors called barriers hinder its implementation. So, the concerned organization has to identify the barriers in the path of GLS together with the logical relationship among the barriers. Moreover, the organization cannot eliminate all the barriers at one time, so it is quintessential to rank the barriers to finding the barriers which must be handled at the inception of the GLS program. IF-DEMATEL has been used in the present work to rank and bifurcate barriers into cause and effect categories. The ranks of the grouped barriers were further validated using BWM. The entire research work was discussed with the said manufacturing industry to sensitize them about the usefulness of the present work. The execution steps of the IF- DEMATEL are as follow:

Step 1: Linguistic data collection from the DMs

In this step, the appropriate linguistic variables and their corresponding IFS were defined. The linguistic variables for the barriers were provided by a team of the three DMs from the concerned industry. The team was comprised of an LSS black belt champion, general manager, and senior manager. The champion has performed different LSS projects in different industrial settings. The general manager and senior manager were top management representatives and were posed with a different set of skills in numerous organizational aspects.

Step 2: Find the weights of DMs

The linguistic variables defined with their corresponding IFNs are used to find the weights of DMs. The IFS set for three DMs: LSS black belt champion, general manager and senior manager were considered for linguistic variable of the very important, important, and medium as [0.9, 0.05, 0.05], [0.75, 0.2, 0.05], and [0.5, 0.4, 0.1] respectively. The weights of the DMs have found using equation (5.3)

$$\lambda_1 = \frac{\left(0.9+0.05\,\frac{0.9}{0.95}\right)}{\left(0.9+0.05\frac{0.9}{0.95}\right)+\left(0.75+0.05\frac{0.75}{0.95}\right)+\left(0.5+0.1\,\frac{0.5}{0.9}\right)} = 0.4133$$

The weights of other DMs: λ_2, and λ_3 were found similarly. The weights of three DMs have been found to be 0.4133, 0.3444, and 0.2423.

Step 3: Construct aggregated IF decision matrix

The DMs preferences are aggregated using the IFWA operator as shown in equation (5.4) to formulate the initial reachability matrix *A.* For example, the computation of KB barriers affects barrier ER is shown as = [0.3105, 0.5515, 0.1378].

Table 5.7: Aggregated IF decision matrix

Barriers	**KB**	**ER**	**TR**	**OR**	**MR**	**CI**
KB	0.1,0.8,0.1	0.3105,0.5515 ,.01378	0.5,0.4,0.1	0.4394,0.4484 ,0.1121	0.4139,0.4688 ,0.1172	0.7863,0.1636 ,0.05
ER	0.75,0.2,0.0 5	0.1,0.8,0.1	0.8380,0.1119 ,0.05	0.8483,0.1016 ,0.05	0.8636,0.0863 ,0.05	0.75,0.2,0.05
TR	0.3105,0.55 15,0.1378	0.4394,0.4484 ,0.1121	0.1,0.8.,0.1	0.5,0.4,0.1	0.5,0.4,0.1	0.9,0.05,0.05
OR	0.7863,0.16 36,0.05	0.3105,0.551, 0.1378	0.9,0.05,0.05	0.1,0.8.,0.1	0.7863,0.1636 ,0.05	0.8483,0.1016 ,0.05
MR	0.8380,0.11 19,0.05	0.7863,0.1636 ,0.05	0.8016,0.1483 ,0.05	0.8380,0.1119 ,0.05	0.1,0.8,0.1	0.4394,0.4484 ,0.1121
CI	0.5,0.4.0.1	0.4139,0.4688 ,0.1172	0.3361,0.5311 , 0.1327	0.3533,0.5173	0.5,0.4,0.1	0.1,0.8,0.1

Step 4: Obtain the crisp value of the initial reachability matrix

The aggregated IF decision matric values for each barrier against another was converted into their corresponding crisp value using equation (5.5) that also serves as an initial reachability matrix for DEMATEL. Table 5.8 depicts the ultimate initial reachability matrix.

Table 5.8: Initial reachability matrix

Barriers	KB	ER	TR	OR	MR	CI
KB	10.3333	7.5858	9.3000	8.2154	7.8643	19.3333
ER	19.3333	10.3333	19.3333	19.3333	20.3333	20.3333
TR	7.5858	8.2527	10.3333	9.3333	9.3333	19.3333
OR	20.3333	6.5858	19.3333	10.3333	19.3333	20.3333
MR	19.3333	20.3333	19.3333	20.3333	10.3333	8.2527
CI	9.3333	7.8643	6.8646	8.0652	10.3333	10.3333

Step 5: Normalizing the direct relationship matrix

In this step, the row-wise summation of all the elements of the initial reachability matrix (*A*) was done, After that, all the elements of the matrix were divided by the maximum value among the entire row-wise sum to get the normalized direct relationship matrix *Z* (table 5.9)

Table 5.9: Normalized direct relationship matrix

Barriers	KB	ER	TR	OR	MR	CI
KB	0.0948	0.0696	0.0853	0.0754	0.0721	0.1774
ER	0.1774	0.0948	0.1774	0.1774	0.1865	0.1865
TR	0.0696	0.0757	0.0948	0.0856	0.0856	0.1774
OR	0.1865	0.0604	0.1774	0.0948	0.1774	0.1865
MR	0.1774	0.1865	0.1774	0.1865	0.0948	0.0757
CI	0.0856	0.0721	0.0630	0.0740	0.0948	0.0948

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Step 6: Formulate total relationship matrix

The total relationship matrix has been formulated from the normalized direct relationship matrix by solving the function $Z\ (1\text{-}Z)^{-1}$ in MATLAB. Table 5.10 depicts the total relationship matrix.

Table 5.10: Total relationship matrix

Barriers	KB	ER	TR	OR	MR	CI
KB	0.3371	0.2454	0.3195	0.2872	0.2917	0.4588
ER	0.621	0.4168	0.6095	0.5641	0.5828	0.6981
TR	0.324	0.2603	0.3413	0.3084	0.316	0.4699
OR	0.5602	0.3381	0.5414	0.4247	0.5098	0.6218
MR	0.5946	0.4802	0.5858	0.549	0.4734	0.5666
CI	0.3066	0.2322	0.2777	0.2675	0.292	0.3466

Step 7: Compute D, R, D-R, and D+ R

In this step, the row-wise and the column-wise sum of the total relationship matrix has done to get the R and D matrix respectively. From D matrix and R matrix, D-R, and D+ R are vector are calculated. (D+R) represents the degree of the relationship (importance or rank) among the barriers, whereas (D-R) represents the kind of relationship among the barriers (cause and effect). Table 5.12 depicts the degree of relationship and type of relationship among the barriers.

Table 5.11: Row wise and the column-wise sum of barriers

Barriers	KB	ER	TR	OR	MR	CI	D
KB	0.3371	0.2454	0.3195	0.2872	0.2917	0.4588	1.9397
ER	0.621	0.4168	0.6095	0.5641	0.5828	0.6981	3.4923
TR	0.324	0.2603	0.3413	0.3084	0.316	0.4699	2.0199
OR	0.5602	0.3381	0.5414	0.4247	0.5098	0.6218	2.996
MR	0.5946	0.4802	0.5858	0.549	0.4734	0.5666	3.2496
CI	0.3066	0.2322	0.2777	0.2675	0.292	0.3466	1.7226
R	2.7435	1.973	2.6752	2.4009	2.4657	3.1618	

Table 5.12: Degree and kind of relationship among barriers

Barriers	D	R	D+R	D-R
KB	1.9397	2.7435	4.6832	-0.8038
ER	3.4923	1.973	5.4653	1.5193
TR	2.0199	2.6752	4.6951	-0.6553
OR	2.996	2.4009	5.3969	0.5951

MR	3.2496	2.4657	5.7153	0.7839
CI	1.7226	3.1618	4.5844	-1.4392

The barrier MR and ER the most influential barrier among the identified six barriers with (D+ R) values 5.7153 and 5.4653, respectively. The cause and effect diagram (figure 5.4) was constructed by mapping the outcome of (D+R) and (D- R). In the causal diagram, the barriers above the horizontal baseline belong to the cause group, whereas barriers below the horizontal baseline depict the effect group of GLS barriers. The (D+R) also represents the ranks of the grouped GLS barriers. It has found the barrier MR has found the top rank with (D+R) score of 5.7154. The barriers ER and OR have found the 2^{nd} and 3^{rd} rank with (D+R) scores 5.4653 and 5.3969, respectively. The barrier is considered to be the cause group if (D-R) is positive, and in the case of negative of (D-R), the barrier attributes it to the effect group. The findings reveal that knowledge base related (KB), training related (TR), and continuous improvement (CI) were classified into effect group that tends to be affected by the other barriers as their (D-R) is negative. These barriers exhibit low influential impact (D) than the influenced impact (R). Contrary to these barriers, management related (MR), organizational related (OR), and environmental-related (ER) found the cause group. These barriers affect the entire system and special attention should be given to remove the same as they affect the final attainment of the organizational goals. The barriers of the cause group reveal a more influential impact (D) than the influenced impact (R). The (D+ R) value represents the relative significance of a barrier. The management-related barriers (MR) exhibit the highest (D+R) score and hence should be given the most priority in the removal of the barriers.

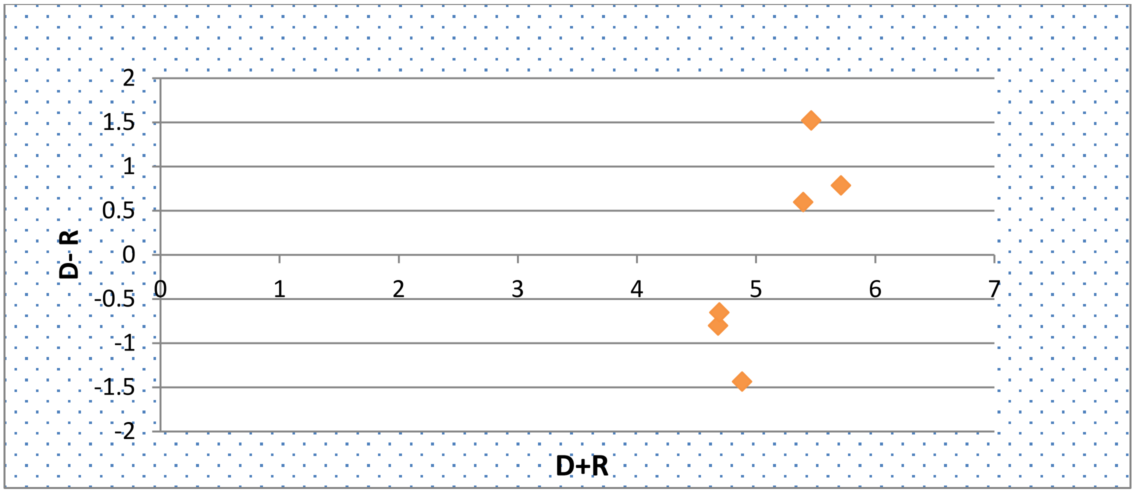


Figure 5.4: Causal diagram

Environmental related (ER), organizational related, knowledge base related (KB) rank after management related barriers (MR) in (D+R) scores respectively. The barriers continuous improvement (CI) has the lowest (D- R) score, - 1.4392, and hence obviously impacted by all other barriers. The results of the study have been found compatible with Cherrafi et al. [165] where 'environmental barrier' was found as one of the most prominent barriers that hinder the implementation of the Green Lean (GL) within an organization. Also, Aboelmaged [165] found that the 'management barrier' is the most influential barriers for the implementation of the Six Sigma approach in industrial settings. The empirical research of Singh et al. [243] also signified that 'lack of management support' and 'lack of training' as the most critical barriers for GL implementation within the industrial organization. Hence the findings of Singh et al. [243] support the research results which revealed that management-related and environmental-related barriers are the first and second, most critical barriers for the GLS execution.

To validate the ranks of GLS barriers in the present work advanced decision-making approach, BWM has been used. The steps associated with BWM are:

Step 1: Determine the best and worst grouped barrier

To determine these (the best and worst) two barriers a focus group meeting was held with DMs of the case industry. The comprehensive discussion and mutual consensus lead to management-related (MR) as the most significant barrier, and continuous improvement (CI) was recognized as the least significant among six barriers.

Step 2: Construct best to others and other to worst vector

The best to others vector in which the relative preference of the best barrier over the other barriers was also determined based on the mutual consensus from DMs of the case industry. For instance, the relative preference of the best barrier MR to others OR barrier was recognized as essentially important (corresponding to 5). Similarly, the relative importance of the best barrier (MR) over the other was found. Meanwhile, the relative importance of other barriers over the worst barrier has also been formulated. For instance, the relative preference of the barrier OR over the worst barrier CI is of very strong importance (corresponding to 7). Similarly, the preference of the other barrier over the worst barrier was formulated through a comprehensive discussion with DMs of the case industry

Table 5.13: Best to others and other to worst vector

S. No.	Barriers	Best Barrier	Worst barrier: CI
1	KB	8	3
2	OR	5	7
3	TR	7	5
4	MR	1	9
5	ER	3	7
6	CI	9	1

Step 3: Calculate optimal weights to estimate the rank of GLS barriers

In this step, the optimal weights of the barriers have been found. The linear programming (LP) model formulated in equation (5.11) has been formulated into LP model. The solution of the LP model results in the final weighted matrix (table 5.14) that depicts the weights of the GLS barriers

Table 5.14: Final BWM weighted matrix of GLS barriers

S. No.	Barriers	Label	Weights
1	Knowledge base barriers	KB	0.0653
2	Organizational related barriers	OR	0.1035

3	Training related barriers	TR	0.0744
4	Management-related barriers	MR	0.5283
5	Environmental related barriers	ER	0.1704
6	Continuous improvement barriers	CI	0.0581

Step 4: The optimal value of ξ called ξ^* was found as 0.11. The consistency ratio, as calculated using equation (5.12), has been found as 0.0210. The low value of the consistency ratio signifies that the results are more significant and reliable. The results of the IF-DEMATEL for the ranking of the GLS barriers were validated firstly BWM and further through the GRA method. Table 5.15 depicts the ranks of the GLS barriers found through the different multi-criterion decision making approaches.

Table 5.15: Comparative results of IF-DEMATEL against other MCDMs

Barriers	**Label**	**D+ R**	**IF-**	**Weights**	**BWM**	**GRG**	**GRA**
Knowledge base barriers	KB	4.6832	5	0.0653	5	0.1889	5
Environmental related barriers	ER	5.4653	2	0.1704	2	0.3561	2
Training related barriers	TR	4.6951	4	0.0744	4	0.3159	4
Organizational related barriers	OR	5.3969	3	0.1035	3	0.3186	3
Management-related barriers	MR	5.7153	1	0.5283	1	0.3889	1
Continuous improvement barriers	CI	4.5844	6	0.0581	6	0.1825	6

The management-related barriers have got the highest weight (0.5283); consequently, it is 1st ranked barrier of GLS in the manufacturing sector. Similarly, environmental-related barriers got 0.1704 weights, and it was observed at the 2nd position of BWM ranking. The continuous improvement barriers got the final rank in the BWM ranking of GLS barriers in the manufacturing sector with 0.0581 weights. It has been found that ranks of GLS grouped barriers are similar to as observed by the IF- DEMATEL. Moreover, ranks of the barriers were further validated with GRA and it has been found that ranks of the GLS barriers found through IF- DEMATEL are consistent with the results of the BWM. So, it can be deduced from the comparative analysis with different MCDMs methods that the ranks of barriers are highly consistent, and the results found are reliable.

5.4 Sensitivity analysis

Sensitivity analysis is an effective tool to check the robustness of the results found through MCDM techniques [244]. In the present study an effective MCDM technique, IF-DEMATEL was used to analyze the GLS implementation barriers. Moreover, to validate the results advanced decision-making tool, BWM was employed. But to have more robustness in the results found through BWM or to check the biasness, sensitivity analysis was performed. This analysis is executed by varying the weights of the top-ranked criterion and noting the changes in the weights of other criteria [245] [246]. Table 5.16 depicts the changing weights of the other barriers while changing the weight of the management barrier (MR) with an interval of 0.2.

Table 5.16: Weights of GLS barriers using sensitivity analysis

Barriers	**Normal**	**Preference weight value for selected barrier**				
		0.1	**0.3**	**0.5**	**0.7**	**0.9**
KB	0.0653	0.081	0.073	0.0646	0.0214	0.0053
ER	0.1704	0.4851	0.2443	0.1871	0.1154	0.041
TR	0.0744	0.1124	0.1242	0.1123	0.0527	0.0209
OR	0.1035	0.1842	0.2151	0.1057	0.0986	0.0247
MR	0.5283	0.1	0.3	0.5	0.7	0.9
CI	0.0581	0.0373	0.0434	0.0303	0.0119	0.0081

It had found that the ranking of the GLS barriers did not change considerably during sensitivity analysis. Table 5.17 depicts the ranks of GLS barriers during the different run of the sensitivity analysis. The variations in the ranks of barriers are shown in figure 5.5. From table 5.16 it is obvious that by changing the weight of the top-ranked the weights of other barriers change considerably. It has been found that the ranks of the barriers did not change significantly during the test. The outermost layer in figure 5.5 presents the ranks of barrier 'KB' with changing the weight of 'MR'. It is obvious from table 5.16 that other weights change together with the weight change of barrier 'MR'. Hence the results of table 5.17 will also exhibit the same nature of trend as shown in figure 5.5. So, ranks of the GLS barriers did not change considerably which is a characteristic of a consistent system. So, it can be deduced that the results of the study are found to be consistent.

Table 5.17: Ranks of GLS barriers using sensitivity analysis

Barriers	Normal	0.1	0.3	0.5	0.7	0.9
KB	5	5	5	5	5	5
ER	2	1	2	2	2	2
TR	4	3	4	3	4	4
OR	3	2	3	4	3	3
MR	1	4	1	1	1	1
CI	6	6	6	6	6	6

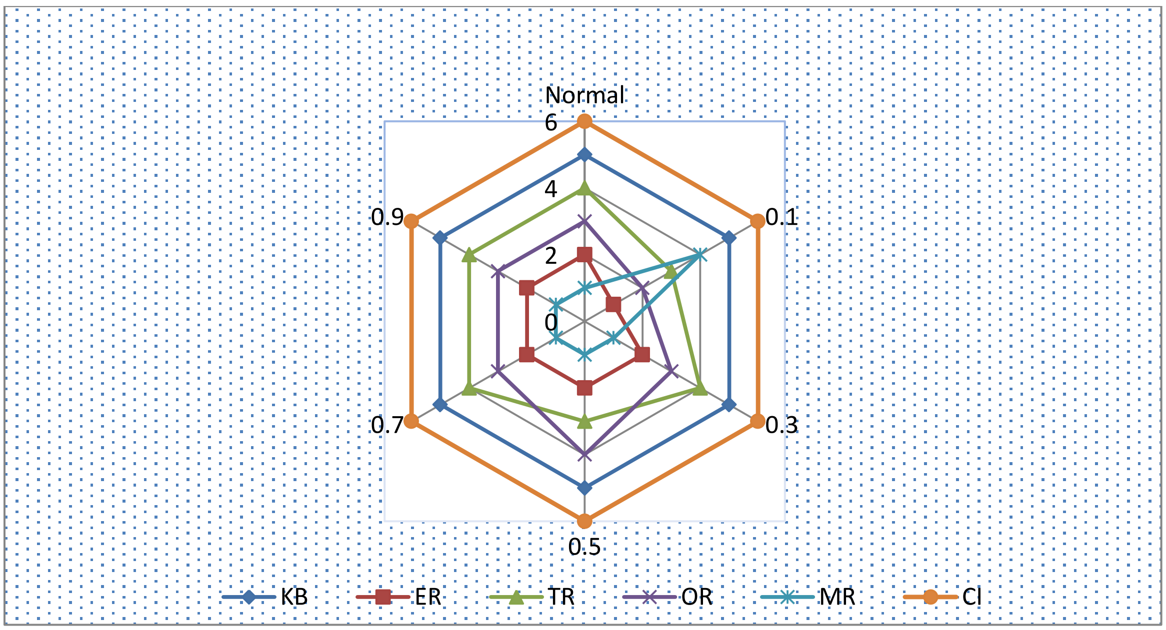


Figure 5.5: Sensitivity analysis of Green Lean Six Sigma barriers

5.5 Discussion on findings

The changed customer perception towards quality and government regulations to cut carbon emission has forced industrial organizations to shift their operations towards green technologies [56]. The inclusion of Green technology in Lean Six Sigma results in an integrated approach: Green Lean Six Sigma. GLS increases organizational sustainability through the reduction of wastes, variability in the process, and using 3’ R (reduce, reuse, and recycle).

The IF-DEMATEL analysis of GLS barriers reveals that management-related (MR) barriers are the most significant barriers among all barriers with (D+R) score of 5.85. The

MR barriers are the most prominent because management propels organizational members to execute and realize any performance improvement strategy [78]. The organizational-related (OR) barriers and environmental-related (ER) barriers have also been found within the cause or driver barriers with (D+R) score of 5.68 and 5.83, respectively. The environmental barriers like the wrong selection of GLS toolset and inappropriate Green Lean areas identification hinder the execution of GLS within the organization. The manufacturing organization would not be able to eradicate barriers until and unless its members don't know various practices and aspects of GLS.

Moreover, the organizational barriers (OR) have also found as the cause barriers because the organization provides an ambience of continuous improvement and connects corporate objectives with the GLS. The barriers, training related, knowledge base, and constant improvement have been recognized as the effect barriers. The implementation of GLS needs comprehensive knowledge and training in the field of identification and measurement of various metrics of carbon footprint. Furthermore, from the prioritization of GLS barriers, it has been recognized that management-related (MR) barriers rest at the top. The contribution, patronage, and vision of the management play a vital role in implementing the GLS concept in the manufacturing sector [247]. The environmental-related barriers influence the organization's pursuits for sustainable development. But comprehensive training in various aspects of GLS provides an ambience of mutual learning and recognizing new insights into sustainability. The organizational constraints like lack of availability of funds and linkage of continuous improvement pursuits can be mitigated by making a consensus about the adoption benefits of GLS. GLS in the organization not only reduces the negative environmental impacts but in the long run, it enhances the organization's reputation in the globalized market.

5.5.1 Removal of barriers

In this section, a few general actions to mitigate barriers that hinder GLS implementations are suggested. These removal measures will facilitate industrial managers to implement GLS for superior operational and sustainable performance.

Barrier mitigation action 1: 'Lack of environmental knowledge base', 'Inappropriate GL area identification', 'Wrong GLS tool selection', 'lack of synergy between CI and strategic objectives of the organization' can be overcome by the development of the green economy [248]. Figure 5.6 depicts the mission, strategy, and vision of the green economy that affects positively the GLS implementation.

Barrier mitigation action 2: The barrier of 'economic constraint' can be overcome by setting up financial institutions so that credit access makes it easier for industrial settings that want to implement the GLS program. The supportive government fiscal policies will facilitate banks about probable risks involved in releasing funds to GLS adopting organizations.

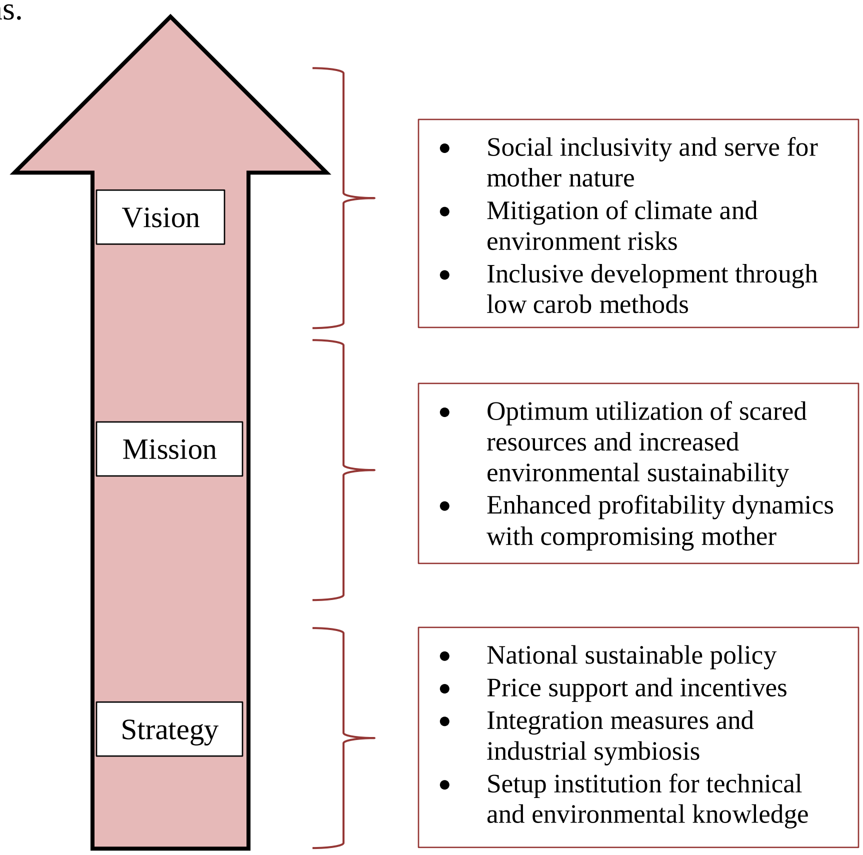


Figure 5.6: Green economy model to facilitate GLS implementation

Barrier mitigation action 3: The inclusive implementation of GLS demands expert training in different facets of this sustainable approach [164]. The comprehensive training of the GLS toolset, project selection, and environmental aspects is essential for the middle and top levels of the industry to ensure commitment in the realization of this eco-friendly approach. The industry can use different types of plans to enhance its internal competencies to execute GLS. The organization should develop a memorandum of understanding with environmental centered organizations, academic and research institutes to get opportunities for finance, technical knowledge, and capacity enhancement through the training programs. This collaborative strategy will lead to a reduction in the organization's expenses that otherwise go in vain by providing training from the outer agencies. The agencies like the UN climate change learning partnership (UNCC: Learn) and US environmental protection agencies provide free resources for climate literacy, mitigation action for carbon footprint, and guide industrial organizations to become more sustainable through the adaptation of Lean and climate-resilient practices (uncceleam.org). The academic institutions can also help industries by initiating schemes on Green Lean practices like training, and collaborative internship, and real-life projects for students. This type of work will lead to the removal of resistive organization culture to new practices, barriers of training, lack of management supportive culture, and obliviousness of reengineering practices.

Barrier mitigation action 4: Barriers like 'Inappropriate Lean and Green area identification' can be overcome by appropriate implementation of visual/statistical control and performance monitor and measurement systems. This will enable the organizational managers to identify the problem in the existing system and process, quantify the performance of the existing best practices, and monitor the progress towards the goal set by the industry. The other barriers of GLS can be overcome by making everyone in the organization responsible for the quality, deploying the right person in the right area, and adopting the culture of 3'R (reduce, reuse, and recycle) in daily practices.

5.6 Practical and theoretical implications

The manufacturing organizations have to make rigorous pursuits for the improvement in material and energy efficiency to remain sustainable in the market. The present research work will facilitate the practitioners and managers to implement GLS through the systematic understanding of the intriguing nature of barriers and removal of the same. The IF-DEMATEL analysis of GLS barriers facilitates managers to focus on the cause barriers that eventually lead to the removal of the effect barriers. The manufacturing organizations in the developing nations lack financial resources along with time, so they cannot focus on all the barriers in the single run. The ranking of grouped barriers will facilitate industries to systematically wipe out the obstacles which are more influential in the adoption of this approach. GLS execution measures facilitate practitioners to relook operations, sources, and possible hot spots for improvement in real industrial settings. This will facilitate the practitioners to develop the possible solution measures for the increased sustainability dynamics of the industry. Moreover, the study facilitates the policymakers to incorporate clean technologies measures like GLS in the industrial organizations that will address the most urgent challenge of climate change through reduced emission of the GHGs. The policymakers can adjudicate new policies on climate change for the industries through the systematic replacement of the traditional operational dynamics with Green Lean measures. The systematic knowledge base on barriers and different hidden facets of GLS develop through insights for the practitioners to develop a comprehensive GLS framework that will make the industrial organization mitigate their current level of emissions through reduction of wastes, defects, and rework. Society will be benefited from the present work in terms of the better health and motivation of the industrial works due to reduced emissions, improved cultural aspects, and impetus for quality. Moreover, the lesser environmental emission will lead to a healthy society and a better planet for the living being.

5.7 Inferences drawn

GLS has been recognized as an inclusive approach that mitigates environmental emissions and delivers eco-friendly products. To meet the targets of regulations pacts and sustainable voice of customers, the manufacturing organizations need to understand and analyze the barriers in the implementation of GLS. Eighteen barriers pertain to GLS have been found through the comprehensive literature survey and further formulated into six logical groups. The barriers have been categorized in cause and effect through IF-

DEMATEL and also prioritized for systematic implementation of GLS within the manufacturing organization. The ranking of grouped GLS barriers was further validated using BWM. The study depicts that the cause barriers are: management-related, environmental-related, and organizational-related. The cause barriers have a consequential effect on training, knowledgebase, and continuous improvement barriers. Further, through prioritization of the GLS barriers, it can be concluded that top-ranked barriers like management-related and environmental-centered barriers should be tackled first for the incremental application of the GLS program.

Chapter 6 Life Cycle Assessment: Barriers and Framework

The need for detailed information on environmental effects leads to the development of different ecological assessment tools. The life cycle assessment (LCA) is a tool of environmental management that provides a detailed analysis of the unit process of the product system. This chapter outlines barriers to LCA implementation in the Indian manufacturing industry context and also provides a comprehensive framework of LCA.

6.1 Introduction

The changed customer perception towards environmentally friendly products, government regulations, and environmental pacts enforced the organizations to think from an ecological point of view [249]. To meet these challenges industrial organizations are incorporating various tools sets like strategic environment assessment (SEA), environmental impact assessment (EIA), environmental risk assessment (ERA), cost-benefit analysis (CBA), material flow analysis (MFA), and LCA [175]. LCA is a tool that provides a detailed environmental analysis of a system consisting of different unit processes [250]. The quantification and investigation of wastes from a system using LCA further lead to the identification of major reasons for these non-value-added activities [175]. Once potential reasons for the source of wastes have been identified, they can be eradicated from the system. The success of green technology implementation is directly related to the effective execution of LCA as it is the main driving force to quantify or measure wastes. Despite extensive study of LCA in developed nations, it found very limited applications in the manufacturing sector of India. The main reason for the same can be attributed to the barriers that hinder LCA implementation. In the literature, no study exists on prioritization and analysis of LCA barriers in the manufacturing industry in the Indian context. So, this study deals with the identification and analysis of LCA barriers in the manufacturing environment of India. The LCA barriers have been identified through the literature survey and further validated through the experts' opinions (manufacturing and academicians personnel). Industrial organizations lack financial resources and time so they cannot focus on all barriers for incremental implementation of green technologies through LCA. Hence, the present study further investigates and prioritizes LCA barriers through a novel decision-making approach: Grey relational analysis (GRA).

LCA assesses the green impact of a product and process but to conduct LCA in an industry a lot of uncertainties are evolved like the type of data set to be taken into consideration, the ambit of LCA study, the uncertainty of monetary gain, and lack of a framework to conduct LCA [15-16]. There is no evidence in the literature to establish an LCA framework about manufacturing organizations. So, a comprehensive framework for LCA also has been provided along with the analysis of critical barriers of LCA.

6.2 Research approach and barriers of life cycle assessment

The present study of LCA barrier consists of a three-phase research approach (figure 6.1). The first phase is related to the identification of barriers of LCA in manufacturing. Prioritization of LCA barriers through GRA has been performed in the second phase whereas authentication of ranks of LCA barriers has been done using BWM and sensitivity analysis in the final phase. The various phases of the adopted approach are:

Phase 1: LCA barriers identification

In the first phase, LCA barriers in the manufacturing environment of India have been found through a comprehensive literature survey. The successful adoption of green technologies depends on the measurement and analysis of various wastes that eventually depend on the effective and systematic application of LCA. An inclusive application of LCA depends on a few prominent factors known as barriers. Barriers to a tool or technology are those crucial characteristics that defer achieving the organization's objectives [57]. Table 6.1 depicts the barriers of LCA in the manufacturing environment.

Table 6.1: LCA barriers in the manufacturing environment

S. No.	Label	Barriers	Description	Referecnes
1	B1	Lack of LCA dedicated method to decide ambit and conduct of LCA study	There is not a single agreed-upon method to conduct an LCA. Moreover, users are not always clear how LCA "fits in" as associated with other available environmental management tools. The SMEs also face a dearth of methods to decide on the scope of the study or adequate representation of system boundary	[251] [252]
2	B2	Lack of LCA expertise or know-how	The absence of a knowledge base to conduct and comprehend LCA is a problem in developing economies for manufacturing enterprises. The problem to communicate potential results and benefits of LCA also exists in developing nations.	[253]
3	B3	Lack of financial resources	There is a postulation that LCA is expensive due to the wide need for records and proficiency. This is particularly correct for emerging nations and manufacturing industries. Besides, ISO requirement for the appraisal of methods and procedures can enhance the cost of LCA implementation.	[254] [255]
4	B4	Integration shop floor activities with the information system of industry	Effective integration of LCA methodology at the production shop floor level can contribute to the successful execution of LCA. The integration will assist in the collection of real-time authentic data and prompts organizations members for LCA success. In-house information sharing through the integration of activities can help to support process or product development and the formation of an effective environmental management system.	[254] [255]
5	B5	Lack of education and training of employee on environmental management	LCA investigators should have a comprehensive understanding of manufacturing process flow, environment interactions, and LCA methodology for effective implementation of this environmental impact assessment tool.	[254] [256]
6	B6	Resistive culture of the organization	The endorsement and implementation of a life cycle thinking culture in manufacturing is to a large extent also a matter of organizational and social change. By making LCA accessible and understandable on the shop floor, staff themselves are proactively included in sustainability issues so that it becomes part of working culture and continuous improvement processes. So, the resistive culture of organization's members defers the inclusion of LCA pro activities in the organizations that leads to failure of LCA on the shop floor.	[256]

7	B7	Lack of management support	The decisive power to adopt or implement a new approach lies with the top management of an organization. LCA is capital intensive, it demands purchase for new software, expert knowledge, and real-time effective data collection. So management support is highly appreciable to get effective LCA results.	[257][i]
8	B8	Link of green technologies with organizational objectives	Effective LCA execution demands implementing industry must interact effectively with internal and external resources. This can be established by embedding green technology aspects with organizational objectives. Linking the organization's objectives with green aspects prompts members to assess, collect, and estimate different wastes and environmental measures that work as an effective database for LCA.	[258]
9	B9	Lack of effective data assimilation	The quality of data and its accessibility are the major bottlenecks for LCA execution. Reporting and exchange of data even become more monotonous when a business run across different nations as the global supply chain is often more fragmented.	[252]
10	B10	Lack of team effort across supply chain partners to collect effective data	The effective management of the supply chain of the product, resource management, and real-time authentic data sharing are prerequisites to realize full throttle of LCA. This demands for effective communication, mutual trust, and ounce for LCA success among supply chain partners. This can be obtained when all partner of SC works as a team. Lack of confidence and deficiency in rigor pursuits will not realize effective LCA execution.	[180]

The questionnaire-centered survey has been used in this study to authenticate LCA barriers found through literature study. A five-point Likert scale questionnaire was formulated and experts (industrial and academics personnel) (102 experts) were asked to state the importance of enlisted barriers on the scale, 1 to 5, with '1' tallies to the weakest and '5' as the strongest barriers of LCA. To check the internal consistency of the questionnaire the reliability test (Cronbach's alpha) has been used.

The value of Chronbach's alpha for the present work was found to be 0.863 and that is quite for the internal consistency of the instrument under consideration.

$$s^2 \times t\ (cov) / sum\ (var / cov) \qquad (6.1)$$

The questionnaire was sent to the practitioners at the mid and high levels of management in the manufacturing industry and academicians (102 respondents). Table 6.2 depicts the characteristics and demographic background of respondents.

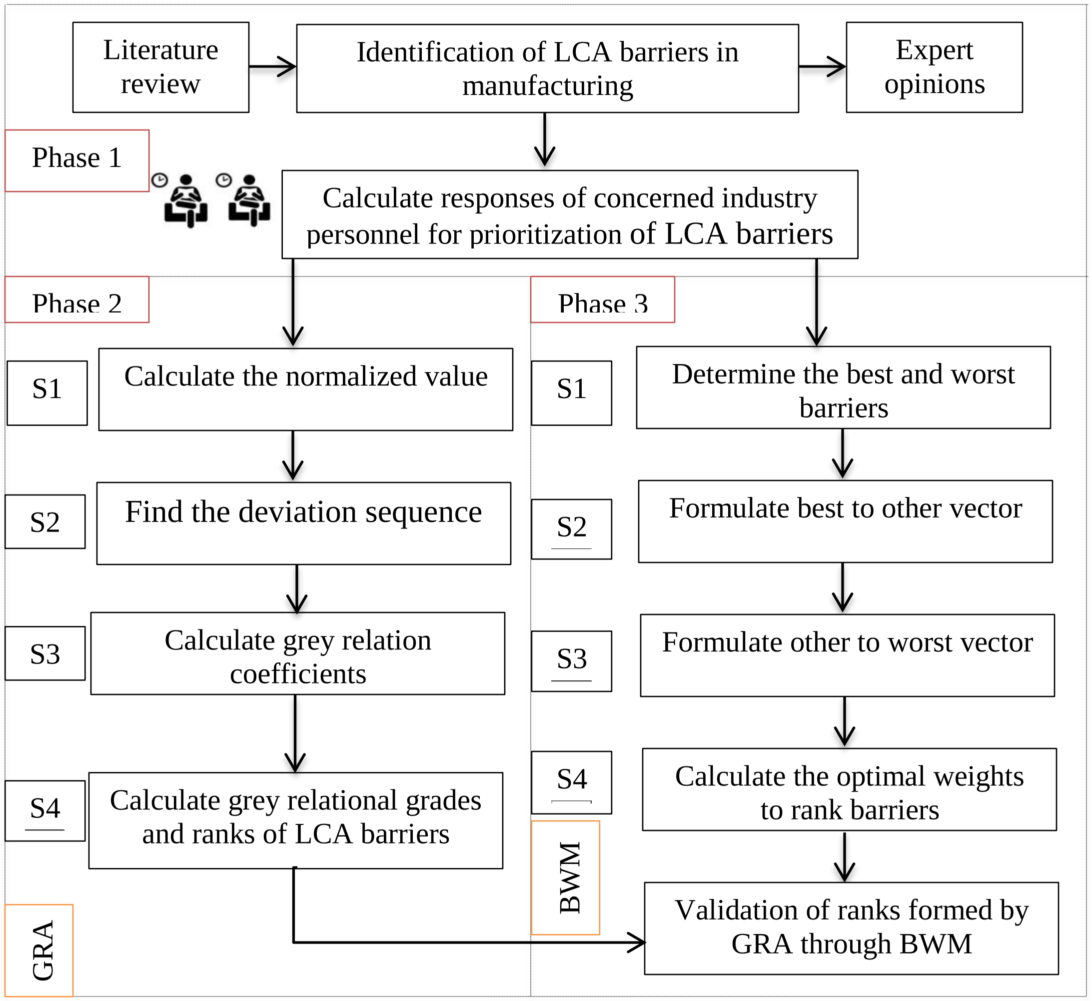


Figure 6.1: Research Approach for analysis of LCA barriers

The dataset received from all respondents was checked for normality using the Shapiro-Wilk test and Q-Q plot in the statistical package for social sciences version 20 (SPSS 20). The value "p" of the Shapiro-Wilk test ($p \geq 0.05$) and data points distributed along the line in the Q-Q plot designate that data is normally distributed The p-value was found as 0.074 for all data distributed along the line in Q-Q plot (figure 6.2).

Table 6.2: Characteristics and demographic background of respondents

S. No.	Work profile	Number of person	Percentage	Average work experience
1	Senior Manager	33	32.35	26
2	Manager	27	26.47	24
3	Deputy Manager	19	18.63	21
4	Academician	13	12.75	14
5	Senior Engineer	10	9.80	10

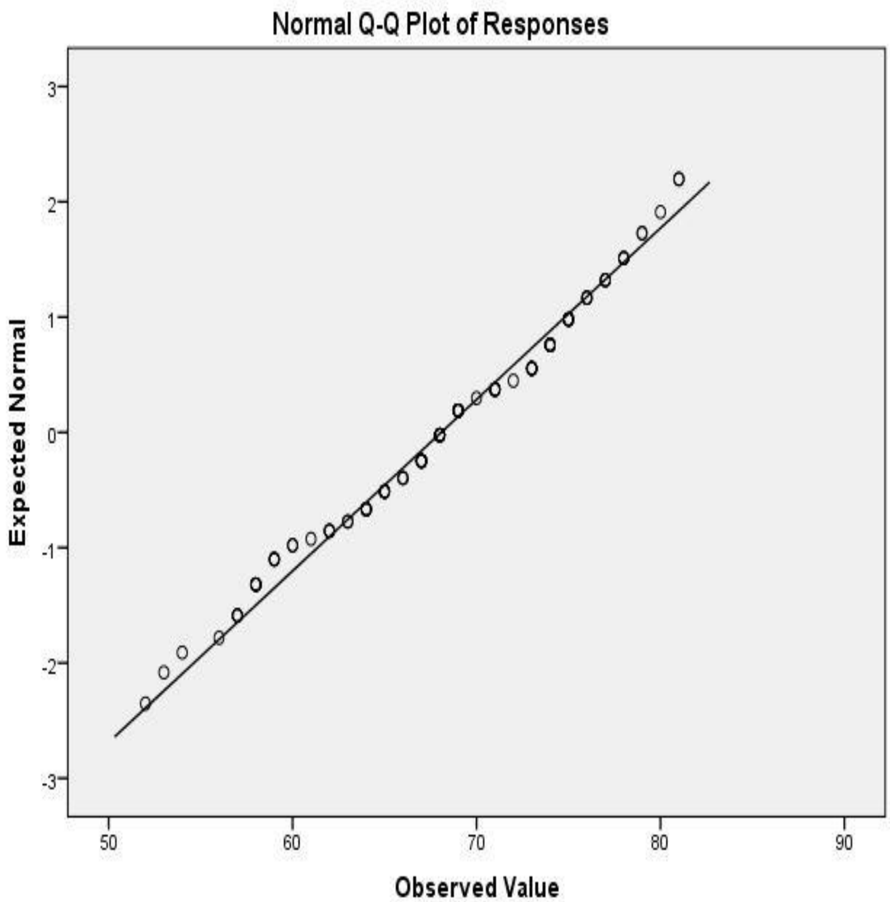


Figure 6.2: Q-Q plot for LCA barriers

To prioritize the barriers of LCA responses were collected from the coterie of the concerned manufacturing industry and these responses were further analyzed in the respective second and third phases for the prioritization of the LCA barriers using GRA and BWM.

Phase 2: Prioritization of LCA barriers through GRA

The steps of GRA are as follows:

Step 1: The first step of the GRA method is normalization or data processing. The responses collected from the personnel of the case industry against each alternative (barrier) were summed up. x_i^0, represents the sum of response of barriers "i" to personnel "o" The normalized values are obtained using equation (6.2). Here, x_i^{o*} represents the normalized value of the barriers "i" to personnel "o".

$$x_i^{o*} = \frac{x_i^0 - \min x_i^0}{max\, x_i^0 - min\, x_i^0} \tag{6.2}$$

Step 2: In the second step of the GRA the deviation sequence ($\triangle_{oi}$) is calculated using equation (6.3).

$$\triangle_{io} = \| max\, x_i^{o*} - x_i^{o*} \| \tag{6.3}$$

Step 3: In this step, the grey relational coefficients (ξ_{io}) are calculated using equation (6.4). Here, $\triangle_{min}$ represents the minimum value of the deviation sequence and $\triangle_{max}$ designates the maximum value of the deviation sequence. ξ value considered here is 0.5.

$$\xi_{io} = \frac{\triangle_{min} + \xi . \triangle_{max}}{\triangle_{oi} + \xi . \triangle_{max}} \tag{6.4}$$

Step 4: In this step, the grey relational grade (γ_{i0}) is estimated using equation (6.5). Here "n" is the number of respondent group of the case industry (in our case 5)

$$\gamma_{i0} = \frac{1}{n} \sum_{i=1}^{n} \xi_{io} \tag{6.5}$$

Phase 3: Prioritization of Life Cycle Assessment barriers through Best Worst Method

BWM is a multi-criterion decision-making method developed used to make decisions in a complex environment. The steps to execute BWM are:

Step 1: Determine the best and worst barrier

The first step of BWM is to determine, the best and the worst criteria or barrier, denoted by 'P and 'F', respectively. Here, in this method, the most important and the least important barrier are found to calculate the relative weights of barriers.

Step 2: Construct best to others and other to worst vector

The second step of BWM is to determine the comparative preferences of the most important criterion or barrier over all the other criteria and that of other criteria over the least important criterion using scales adopted by, see Table in the appendix. Then, the best to others (A_P) vector and the others to worst (A_F) vector can be found, as depicted in equations, (6.6) and (6.7) respectively.

$$A_P = (a_{P1}, a_{P2}, \dots \dots., a_{Pn}), \tag{6.6}$$

where a_{pj} indicates the preference of best barrier "P" over j

$$A_F = (a_{1F}, a_{2F}, \dots \dots., a_{nF})^T, \tag{6.7}$$

Here, a_{jF} indicates the preference of barrier j over the worst barrier "F". It is clear that the value

for $a_{FF} = 1$

<u>Step 3:</u> Calculate optimal weights to estimate the rank of LCA barriers

The optimal weight for a barrier is the one where for each pair of ${w_P}/{w_j}$ and ${w_j}/{w_F}$,

${w_P}/{w_j} = a_{Pj}$ and ${w_j}/{w_F} = a_{jF}$.

To meet all these conditions for j, where the maximum absolute differences, $\left|\frac{w_P}{w_j} - a_{Pj}\right|$ and $\left|\frac{w_j}{w_F} - a_{jF}\right|$ for all j is minimized. Considering the non-negativity and sum condition for the weights, the following problem has resulted

$$\left\{ \begin{array}{c} \min_j \max \left\{ \left|\frac{w_P}{w_j} - a_{Pj}\right|, \left|\frac{w_j}{w_F} - a_{jF}\right| \right\} \\ \sum_j w_j = 1 \\ w_j \geq 1 \text{ for all } j = 1 \end{array} \right\} \tag{6.8}$$

The problem of equation (6.8) can be transferred to the following linear programming model

$$
\left\{
\begin{array}{l}
\min \xi^{L} \\
\left|\frac{w_P}{w_j} - a_{Pj}\right| \leq \xi \text{ for all j} \\
\left|\frac{w_j}{w_F} - a_{jF}\right| \leq \xi \text{ for all j} \\
\sum_j w_j = 1 \\
w_j \geq 1 \text{ for all j} = 1
\end{array}
\right\}
\tag{6.9}
$$

The optimal weights and the optimal value of ξ called ξ^* have been found for the above-mentioned LPP problem. The consistency ratio exhibits more persistent comparisons that have been estimated using equation (6.10). The value of consistency ratio varies between "0" and "1" and closeness to "0" exhibits more consistent comparisons.

$$
\text{Consistency ratio} = \frac{\xi^*}{\text{consistency index}} \tag{6.10}
$$

6.3 Analysis of Life Cycle Assessment barriers: Practical case

The industry is the focal point for the prosperity and economic growth of any nation. Industrial organizations contribute nearly one-fourth of CO_2 emission and hence it must be the central part of clean technologies transition [259]. So, to achieve operational and environmental excellence organizations must adopt sustainable practices. The present study has been carried out in manufacturing industry in India. The foremost apprehension for case industry is negative environmental impacts from the generation of products, reuse of waste material and recycling of after-use products. So, the industry is planning to adopt an eco-friendly approach that reduces emissions and maintains a balance between societal and economic dimensions of sustainability. But effective management of an environmentally friendly approach depends on the quantification, measurement, and analysis of various environmental and lean wastes. LCA is an effective tool that measures and investigates the various non-value-added activities of the system and process. The efficacious execution of LCA within an industrial organization for a process or system is constrained by many factors called barriers. So, the said organization has to identify the barriers in the path of LCA execution. The organization cannot eliminate all the barriers at one time, so it is substantial to rank the barriers to identifying the barrier which must be handled at the inception stage of LCA execution. In this study, prominent LCA barriers have been identified through literature and further validated through industrial personnel and academicians. The identified LCA barriers have been prioritized through GRA and validated by BWM. The entire process to prioritize LCA barriers was discussed with the said manufacturing industry to sensitize them about the current research work and potential benefits.

6.3.1 Computational steps of GRA for analysis of LCA barriers

The grey relational analysis has been executed through the following steps.

Step 1: The first step of the GRA method is normalization or data processing. The responses collected from the personnel of the case industry against each alternative (barrier) have been summed up. Table 6.3 depicts the responses from five coteries of industrial personnel (40 industrial personnel of the case industry) of the case industry corresponding to each barrier. The responses from managers (M), deputy managers (DM), engineers (E), assistant engineers (AE), and supervisors (S) have been used in the present to prioritize the barriers. The normalized values x_i^{o*} have been obtained using equation (2). Table 6.4 depicts the normalized values.

Table 6.3: Responses from industrial personnel

S. No.	Label	M	DM	E	AE	S
1	B1	24	26	29	31	26
2	B2	27	34	35	30	31
3	B3	36	27	29	33	32
4	B4	28	28	31	32	31
5	B5	29	30	41	33	31
6	B6	27	29	32	37	32
7	B7	36	30	37	39	33
8	B8	28	31	32	29	31
9	B9	28	25	28	26	29
10	B10	32	33	35	29	32

Table 6.4: Normalised values

Barriers	M	DM	E	AE	S
B1	0	0.111111	0.076923	0.384615	0
B2	0.25	1	0.538462	0.307692	0.714286
B3	1	0.222222	0.076923	0.538462	0.857143
B4	0.333333	0.333333	0.230769	0.461538	0.714286
B5	0.416667	0.555556	1	0.538462	0.714286
B6	0.25	0.444444	0.307692	0.846154	0.857143
B7	1	0.555556	0.692308	1	1
B8	0.333333	0.666667	0.307692	0.230769	0.714286
B9	0.333333	0	0	0	0.428571
B10	0.666667	0.888889	0.538462	0.230769	0.857143

Step 2: In the second step of the GRA the deviation sequence ($\triangle_{oi}$) was calculated using equation (6.3). Table 6.5 depicts the deviation sequence.

Table 6.5: Deviation sequence

Barriers	M	DM	E	AE	S
B1	1	0.888889	0.923077	0.615385	1
B2	0.75	0	0.461538	0.692308	0.285714
B3	0	0.777778	0.923077	0.461538	0.142857
B4	0.666667	0.666667	0.769231	0.538462	0.285714
B5	0.583333	0.444444	0	0.461538	0.285714
B6	0.75	0.555556	0.692308	0.153846	0.142857
B7	0	0.444444	0.307692	0	0
B8	0.666667	0.333333	0.692308	0.769231	0.285714
B9	0.666667	1	1	1	0.571429
B10	0.333333	0.111111	0.461538	0.769231	0.142857

Step 3: In this step, the grey relational coefficients (ξ_{io}) are calculated using equation (4). Here, $\triangle_{min}$ represents the minimum value of the deviation sequence and $\triangle_{max}$ designates the maximum value of the deviation sequence. ξ value considered here is 0.5. Table 6.6 represents the grey relational coefficients.

Table 6.6: Grey relation coefficients

Barriers	M	DM	E	AE	S
B1	0.333333	0.36	0.351351	0.448276	0.333333
B2	0.4	1	0.52	0.419355	0.636364
B3	1	0.391304	0.351351	0.52	0.777778
B4	0.428571	0.428571	0.393939	0.481481	0.636364
B5	0.461538	0.529412	1	0.52	0.636364
B6	0.4	0.473684	0.419355	0.764706	0.777778
B7	1	0.529412	0.619048	1	1
B8	0.428571	0.6	0.419355	0.393939	0.636364
B9	0.428571	0.333333	0.333333	0.333333	0.466667
B10	0.6	0.818182	0.52	0.393939	0.777778

Step 4: In this step, grey relational grades are estimated from the grey relational coefficients using equation (6.5). The corresponding ranks were estimated from the grey relational coefficients. Table 6.7 depicts the grey relational grades and ranks of the LCA barriers in manufacturing.

Table 6.7: Grey relation grade and ranks of LCA barriers

Barriers	M	DM	E	AE	S	GRG	Rank
B1	0.3333333	0.36	0.3513514	0.4482759	0.3333333	0.3652588	10
B2	0.4	1	0.52	0.4193548	0.6363636	0.5951437	5
B3	1	0.3913043	0.3513514	0.52	0.7777778	0.6080867	4
B4	0.4285714	0.4285714	0.3939394	0.4814815	0.6363636	0.4737855	8
B5	0.4615385	0.5294118	1	0.52	0.6363636	0.6294628	2
B6	0.4	0.4736842	0.4193548	0.7647059	0.7777778	0.5671045	6
B7	1	0.5294118	0.6190476	1	1	0.8296919	1
B8	0.4285714	0.6	0.4193548	0.3939394	0.6363636	0.4956459	7
B9	0.4285714	0.3333333	0.3333333	0.3333333	0.4666667	0.3790476	9
B10	0.6	0.8181818	0.52	0.3939394	0.7777778	0.6219798	3

The ranks of LCA barriers were further validated using the advanced decision-making approach: BWM.

6.3.2 Computational steps of BWM for validation of ranks of LCA barriers

The various steps to execute BWM are:

Step 1: In the first step, best barrier and worst barrier have been identified from identified barriers through comprehensive discussion with experts of case industry. The barrier top management support (B7) has been identified as the best barrier and ambit of LCA implementation organizational ambience (B1) as the worst.

Step 2: Subsequently, preference of best barrier over all other barriers has been identified. Table 6.8 depicts best to others and others to worst preference.

Table 6.8: Preference table for barriers of LCA

Barriers	Preference of best to other	Preference of others to worst
B1	9	1
B2	4	6
B3	3	5
B4	7	4
B5	2	8
B6	5	2
B7	1	9
B8	6	4
B9	3	7
B10	8	3

Step 3: In this step, the preference of all other barriers over the worst barrier has been determined. Table 6.7 also depicts the other to worst preference.

Step 4: Henceforth, to rank LCA barriers the optimal weights $(w_1^*, w_2^* \dots \dots \dots w_{10}^*)$ has been found by solving the LPP model of equation (6.9). The LCA barrier's weight firstly has been found using different values of ξ and finally, the optimum weights have been found using the optimum value of ξ i.e. ξ^*. The consistency ratio has been found using equation (6.10) to check consistency in results. The value of consistency ratio was found to be 0.0210 i.e. 2.10%, this depicts highly consistent results. Table 6.9 represents the ranks of LCA barriers using BWM. It has found the ranks of LCA barriers found the same using GRA and BWM. So, the results of BWM have been found in agreement with the result of GRA, this states that the result found are consistent and reliable.

Table 6.9: BWM weighted matrix to rank LCA barriers

S. No.	Barriers	BWM Weight	BWM Rank	GRG	GRA Rank
1	B1	0.0358	10	0.3652588	10
2	B2	0.0788	5	0.5951437	5
3	B3	0.1034	4	0.6080867	4
4	B4	0.0458	8	0.4737855	8
5	B5	0.1534	2	0.6294628	2
6	B6	0.0635	6	0.5671045	6
7	B7	0.3232	1	0.8296919	1
8	B8	0.0528	7	0.4956459	7
9	B9	0.0394	9	0.3790476	9
10	B10	0.1039	3	0.6219798	3

6.3.3 Sensitivity Analysis

In the present study integrated GRA-BWM method has been used to analyze LCA barriers in manufacturing. Besides, to have more robustness in results authors performed a sensitivity analysis. It is an important tool to check biases in results [244]. Sensitivity analysis is performed by changing the responses of the personnel with varying percentages and noting down changes in the output parameters [245]. Table 6.10 depicts changing GRGs and ranks of the barriers during different runs of the sensitivity analysis. It has been found that for top-ranked barriers, the GRGs did not change significantly during different runs of sensitivity analysis. So, ranks of top-six rank barriers have been found the same throughout during different runs and this signifies the robustness in the results of the study. Figure 6.3 depicts ranks of LCA barriers using a radar chart for the different run of the sensitivity analysis. It has been found that for top-ranked barriers (B7, B5, B10, B3, B2, and B6) the radar chart for different degrees of responses skewed to one point that signifies that there is no variation in the ranks of the said barriers for different trials of the sensitivity analysis. The trends of the change in GRGs of barriers in table 6.10 and ranks in the radar chart present the same pattern. So, the ranks of the barriers did not change considerably, which depicts the character of a consistent system.

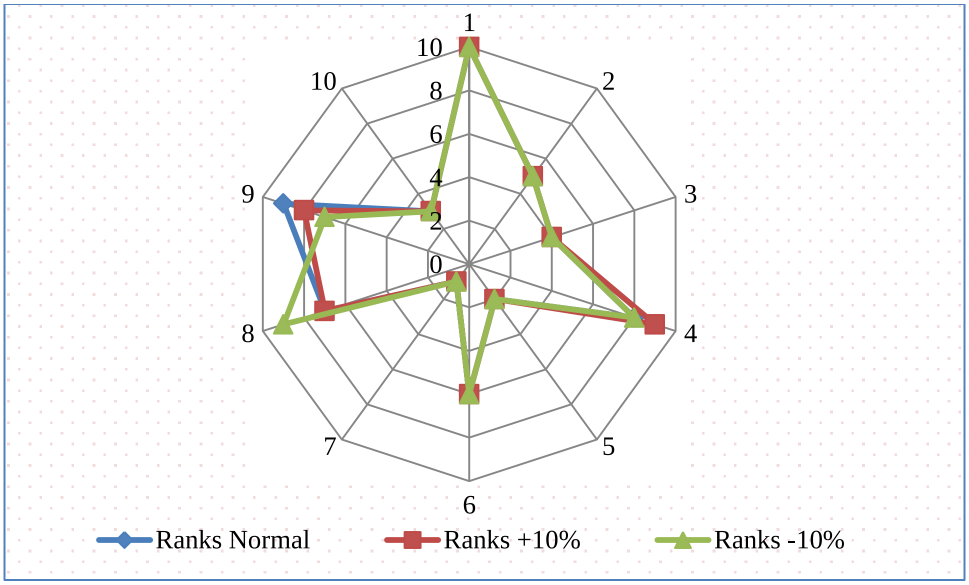


Figure 6.3: Radar chart for sensitivity analysis of LCA barriers

Table 6.10: Sensitivity Analysis

S. No.	Barriers	GRG	Rank	GRG with +10%	Rank	GRG with -10%	Rank
1	B1	0.3653	10	0.3610	10	0.3682	10
2	B2	0.5951	5	0.5655	5	0.5940	5
3	B3	0.6081	4	0.6006	4	0.6003	4
4	B4	0.4738	8	0.3772	9	0.4787	8
5	B5	0.6295	2	0.6196	2	0.6255	2
6	B6	0.5671	6	0.5419	6	0.5660	6
7	B7	0.8297	1	0.8065	1	0.8259	1
8	B8	0.4956	7	0.4904	7	0.3790	9
9	B9	0.3790	9	0.4781	8	0.4930	7
10	B10	0.6220	3	0.6038	3	0.6021	3

6.4 Discussion on findings pertains to Life Cycle Assessment barriers

Life cycle assessment is an important tool to assess the ecological impacts and resources used throughout the entire life cycle of a product [260]. It encompasses all the environmental aspects from the acquisition to disposal of the product. There has been a significant methodological development in the field of LCA from the last two decades. The LCA has been utilized in many industrial aspects like, to support corporate decision-making, managing the supply chain, optimizing the process, and making strategic marketing decisions [261]. But the execution of LCA is substantial work and bottlenecks called barriers hinder the effective execution of this sustainability assessment tool. The present study identifies and investigates the barriers to LCA execution within a manufacturing organization of India.

In this study, critical barriers to LCA execution in the manufacturing industry of India have been identified through a comprehensive literature survey and further validated through experts' survey (manufacturing and academicians personnel). The prioritization of barriers was done through GRA and further validated using BWM. It has been recognized that a lack of management support is the most significant barrier to LCA execution. The management provides comprehensive training to the industrial personnel in environmental indices, type of data set required, and interpretation of the same. The top management commitment play a vital for the adoption of a sustainable development approach through interlining organizational objectives with a new approach and building a culture of learning [262]. The inclusive management obligation, ample financial resources, and thorough training of employees lead to the build a culture of sustainability in the organizations [263].

Lack of education and training of employees on environmental management and lack of team effort across supply chain partners are also the major barriers to the success of the LCA program. Ghazilla et al. [264] also identified a lack of expertise as one of the key barriers to sustainable development adoption for SMEs. LCA needs specialized expertise knowledge or know-how and analysts of data obtained from the team through feedback measures established at the various points of a dedicated system. The LCA execution leads to a substantial financial burden on the organization for training, purchase of LCA software packages, and feedback devices. Jaramillo et al. [265] found the lack of financial capital as one of the major barriers for sustainability incorporation in SMEs. So, industrials organizations have to invest huge capital for the execution of sustainable development programs. Despite LCA evolution, there is still an absence of LCA framework that provides a systematic way for its execution in the manufacturing sector to developing nations. The manufacturing organizations to be competitive in the global market have to embrace not only clean technologies measures within operational dynamics but also in their culture.

The manufacturing organizations have to interlink clean technologies with the organizational objectives to embed sustainability in their culture. The success of LCA implementation also depends on how well you decide the ambit of the study. The extended scope demands more data and complexities increase as interrelations are amplified with the numbers of processes and systems. LCA execution depends on the effective collection of data and interpretation of the same in various indices for improvement in the current system or process. LCA considers all the aspects of sustainability (social, economic, and environmental), system, and process from a life cycle perspective. The top management assistance, proper training, effective feedback measures, proper data measures, and mining methods lead to effective LCA implementation. Moreover, embedding organizational objectives with clean technologies leads to 3' R culture (reduce, reuse, and rework) in the industry which in turn results in high material and energy efficiency.

6.5 Life Cycle Assessment framework

LCA is tool to evaluate ecological impacts, support strategic improvement and making decisions. The development LCA framework consists of five phases: Goal definition, scope definition, analysis of inventory, assessment of impact and interpretation (refer to figure 6.4).

6.5.1 Goal definition

The first phase of LCA framework is to define the goal of study. The main purpose of the study is well-defined and designated comprehensively in this phase. This phase affect much the later stages of LCA because the decisions made at the later stages of LCA must be per the goal of the study. There are generally six aspects that must be considered while defining the goal of the study. These aspects are as follow:

1. Envisioned applications from the results obtained of the study
2. Methodological choices limitations
3. Motives and decision context for conduction of the study

4. Target people
5. Revelation of proportional studies to the people
6. Representative of the work and other prominent players

To determine the envisioned applications of the LCA, results is very indispensable at the start, as it affects LCA's later stages, like drawing of boundaries of the system, tracking of inventory data set, and elucidation of results [266] [267]. The methodological choice exhibits that LCA results are dependent on the chosen method for the study. Besides, the prime motive to carry out LCA should reflect in the goal together with the intended population to whom the results of the study will affect. Moreover, the goal of the study should consider whether the results of comparison of the present work with the existing study will be made public. The goal definition should state who order the study, who supported it, the organization which will affect the study, and clearly states the LCA experts for the study.

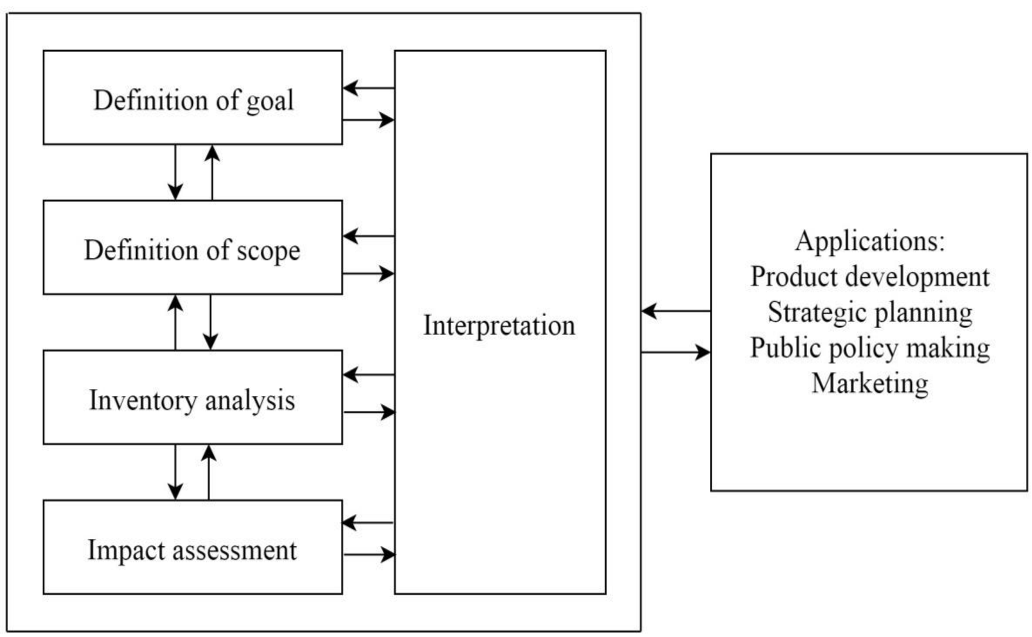


Figure 6.4 Life Cycle Assessment framework

6.5.2 Scope definition

The scope definition phase of LCA determines the system to be considered and the estimation of the system. The main purpose of the scope of the study is to confirm and document the reliability of the methods; postulation and data set together with fortifying the reproduction of the study [40]. The various elements of the scope definition are:

1. Deliverables
2. Object assessment
3. Modeling framework and multifunctional processes handling
4. System boundaries and completeness requirements
5. Interpretation of LCI
6. Readiness of The basis for the impact assessment
7. Necessities for appraisals of systems
8. Critical review need
9. Preparation for reporting of results.

The deliverables should directly replicate the results of the intended application. The ISO 14044 standard specified that LCA must comprise an impact valuation like LCI and the LCIA results. LCA considers single or multiple product systems poised of many unit processes of the product systems. The functions, functional unit and reference of the said systems must be understood for the study of the system. The scope description deals with the choice of an appropriate modeling framework of LCI and procedures to care multi-facets practices. The selections must be made in coherence with the definition of the goal, predominantly in the context of the decision. The system boundary means the periphery between the system being considered and (1) economy considered and (2) ecosphere. The unit procedures applied to designate the product system must be illustrative of the processes considered in the system. The planning of the impact assessment has been done to conform with the definition of goal. The scope definition should also include the requirements for comparisons of systems when the same function has been performed by two systems. The critical review is also done to report the credibility and quality of the study and the reflected results. Finally, to lessen the danger of improper LCA use, the report must be very perfect and translucent with an impeccable signal of what has and has not been encompassed in the study.

6.5.3 Life cycle inventory analysis

This phase is directed by goal scope goal definition and consumes a considerable period. The output of this process is the fulfilled inventory of fundamental flows that work as foundation for impact assessment of life cycle. Life cycle inventory (LCI) analysis requires a lot of effort and it is hardly pragmatically possible to collect the utmost quality data set for LCI. In LCI at first, the processes are identified thereafter panning and collection of data is done. The collection of data should be done over an extended duration, ideally, cover several production runs. The data collection is followed by the construction of the unit process and the quality of the unit process should be ensured for any error in the reported measurements. Subsequently, LCI model is constructed and each unit process works as the building block for LCI model. The inventory modeling is done by qualified software that is also capable to make product system models to connect the relevant unit processes. Finally, the LCI results are published and the sensitivity analysis is used to check the consistency and finally, the results are reported.

6.6 Implications

The increasing awareness about sustainability, intergovernmental pressure, and globalized pressure to cut carbon emissions has been forced industries to changes traditional methods to sustainable ones [268]. So, there is a need to adopt clean technologies measures that mitigate emissions and leads to a healthy work ambience. The adoption of environmentally friendly management approaches depends on the effective measurement of associated emissions and wastes in the process or system. LCA is an effective tool to estimate environmental wastes in a system. The present research work facilitates industrial organizations and managers to implement LCA through a systematic understanding of contextual relationships among the barriers.

The barrier 'Lack of financial resources' can be overcome by setting up financial institutions so that credit access makes it easier for industrial settings that want to implement LCA to access environmental performance. The supportive government fiscal policies will facilitate banks about probable risks involved in releasing funds to LCA adopting organizations. The industry can use different types of plans to enhance its internal competencies to execute LCA. The organization should develop a memorandum of understanding with environmental centered organizations, academic and research institutes to get opportunities for finance, technical knowledge, and capacity enhancement through the training programs. This collaborative strategy will lead to a reduction in the organization's expenses that otherwise go in vain by providing training from outer agencies. The agencies like the UN climate change learning partnership (UNCC: Learn) and US environmental protection agencies provide free resources for climate literacy, mitigation action for carbon footprint, and guide industrial organizations to become more sustainable through the adaptation of environment management tool like LCA. This type of work will lead to the removal of resistive organization culture to new practices like LCA, lack of education and training of employees on environmental management, lack of management support, and link of green technologies with organizational objectives. Barriers like 'lack of effective data collection' can be removed by the establishment of real-time data collection measures and electronic data interchange systems. So, LCA major barriers can be overcome by making everyone in the organization responsible for sustainability, adopting the culture of mutual learning and cooperation that helps to collect effective data, generates expertise knowledge, and identification and assessment of environmental hotspots. The manufacturing organizations in the developing nations lack financial resources and time so they cannot eradicate all the barriers in the single run. Prioritization of LCA barriers provides direction to industrial managers for the systematic removal of LCA barriers by focusing on the prominent barriers during the initial stage of the removal plan.

6.7 Inferences drawn

The LCA has been recognized as an important tool for sustainable development through assessment and analysis of the carbon footprints and associated wastes. To mitigate environmental concerns and meet the demands for sustainable products, industrial organizations need to analyze and rank the barriers to LCA implementation. Ten barriers pertain to LCA implementation in the manufacturing industry of India have been identified and prioritized through GRA and further validated through BWM. It can be concluded that top management whole hearty cooperation, comprehensive education, and training of the employee in various aspects of LCA, and culture of teamwork are the most central areas for effective execution of the LCA program in developing economies like India. The manufacturing organizations can mitigate negative environmental impacts and implement LCA by removing the barriers of effective data assimilation, feedback both upstream and downstream of the process, and linking green initiatives with the organizational objectives of the manufacturing organizations.

Moreover, it has been found that LCA framework of Saad et al. [269] of sustainable development does not address the problem of sustainable decision making, not depicts the range of data collection for material, waste, carbon emission, and lacks the interpretation of the data. The present study overcomes these issues in the development of the LCA framework for the sustainable development of the organization and includes every dimension of sustainable development and provides a rigorous approach for the assessment and interpretation of LCA indicators. The present work enables the organization to define the goal of the study and covers a wide range of aspects that should be included while goal definition. Besides, the study also facilitates organizations managers to outline scope by considering deliverable boundaries and object assessment.

In the past few decades, a competitive landscape, learned customers and rigorous regulations have forced manufacturing industries to focus on operational efficiency alongside the sustainability dimension. Scant research exists on sustainability dimensions to production frameworks through the lens of the Lean Six Sigma operational excellence methodology. The chapter outlines a systematic Green Lean Six Sigma (GLS) framework plan to fully embed sustainability and deploy it in a manufacturing environment. The framework consists of five facets where different tools of Lean, Six Sigma, and Green technology are integrated to systematically implement GLS for operational, social, and environmental excellence. The proposed framework was validated through a case study in a manufacturing company from where important inferences were derived.

7.1 Introduction

With increasing concerns about environmental impacts, industries are in the continuous run to change their operational dynamics to meet sustainably oriented customer demands [57]. This resulted in the emergence of the new paradigm of green technology. Green technology enhances ecological efficacy, reduces carbon footprints, and maintains the financial stability of organizations [72]. The integration of LSS into the green dimension has led to the development of a powerful strategy named Green Lean Six Sigma (GLS) that mitigates environmental emissions, reduces wastes, and defects [160].

Manufacturing organizations do not only have to deliver products with the shortest lead time, at less cost but also have to ensure the economic and environmental sustainability of their operations [228]. Capacity waste leads to a suboptimum utilization of the available facilities and equipment that leads to increased lead time and cost of the end product. The capacity waste of a plant or industry can be reduced by incorporations of different processes and organizational related measures (automated guided vehicles, automatic tool changers, and enhanced employee engagement, etc.)**.** Thus, to ensure the sustainable growth of the entire supply chain, organizations have to tap the full potential of their available capacity or to reduce the capacity waste. Moreover, the manufacturing industry contributes to nearly 30% of the global greenhouse gases emission [174] [270]. The increasing level of carbon footprints leads to increased earth surface temperature, adverse weather conditions, adverse effects on species, and leads to lean health of society [67]. Sector-specific technologies, cross-cutting technologies, and measures applicable in the large, small, and medium enterprise can help to mitigate the current level of emission [271]. The most effective and prominent option for waste management is reduction, followed by reuse and recycle [272]. Moreover, due to environmental regulation pacts and governmental policies on climate change, and demands for sustainable products manufacturing organizations have to adopt sustainable practices [273]. GLS is an approach that uses the concept of 3'R (reduce, reuse, and recycle), to mitigate current emission levels and deliver high specification eco-friendly products [274]. GLS is a novel approach and it is imperative to develop a comprehensive framework of this sustainable approach that facilitates the practitioners and managers for the smooth execution of this method.

Intrinsically, past studies have focused on theoretical frameworks but these have lacked empirical justification and experimental authentication. Ruben et al. [161] developed a framework of LSS with environmental facets but did not address how the developed framework can be adopted by small-scale industries. Moreover, developed LSS framework did not consider the societal aspects of sustainability. Gohlami et al. [169], used GLS to improve the operational as well as environmental aspects but the developed framework lacks practical validity in terms of use of Lean, Six Sigma tools, and LCA toolset. So, previous studies demand the research for the GLS framework that is generic, used in a different context, and incorporates all aspects of sustainability. Moreover, there is a high possibility of implementation failure of sustainable LSS frameworks in different projects [274]. So, contribute to the production literature, this research contributes to the limited body of knowledge in the Sustainability and GLS fields by proposing and implementing a novel GLS framework that can be adopted by manufacturing industries to improve performance dynamics.

7.2 Green Lean Six Sigma Execution Plan

The proposed framework was outlined in such a way that it addresses issues that relate to environmental and quality measures of the project and improves the operational dynamics of the industry. The framework incorporates environmental facets, LCA measures, and societal aspects, along with key LSS tools in different phases. Each phase of realization of GLS has different activities that reduce wastes, and associated environmental impacts. In the first phase of the GLS framework, the problem under consideration for the selected firm is elaborated as a suitable GLS project [Section 7.3.1]. Here, the project is expressed in every aspect so that a clear picture of the goals and the boundary of the project can be established. The VOC and VOB are given full consideration for the selection of the project. To understand different aspects of the considered project, a clear depiction of the entire process from supplier to the end-user is drawn through a SIPOC diagram. The project charter is drawn to demonstrate the problem, scope, objectives, and project team. In the second phase, the current state of the project under consideration is estimated in terms of different metrics using tools like EVSM, LCA, etc. [Section 7.3.2]. The data pertains to different wastes, environmental footprints; societal aspects are collected in quantitative terms. In the third phase, different causes for environmental inefficiency, wastes, and defects are found. Tools like cause and effect diagram (C&E) and 5 whys are used at this stage to find the potential causes for the reduction in environmental, operational, and social aspects of sustainability of the firm [Section 7.3.3]. In the subsequent phase, potential solutions are identified; prioritized and best-suited solutions are subsequently applied. The outcome from the implementation of solutions should be quantified in terms of quality, economic, and economic parameters to ensure sustained gains [Section 7.3.4]. In the final phase, the actions for sustainability enhancement of the industry are sustained [Section 7.3.5]. Figure 7.1 demonstrates the proposed GLS framework or execution plan for improved sustainability dynamics.

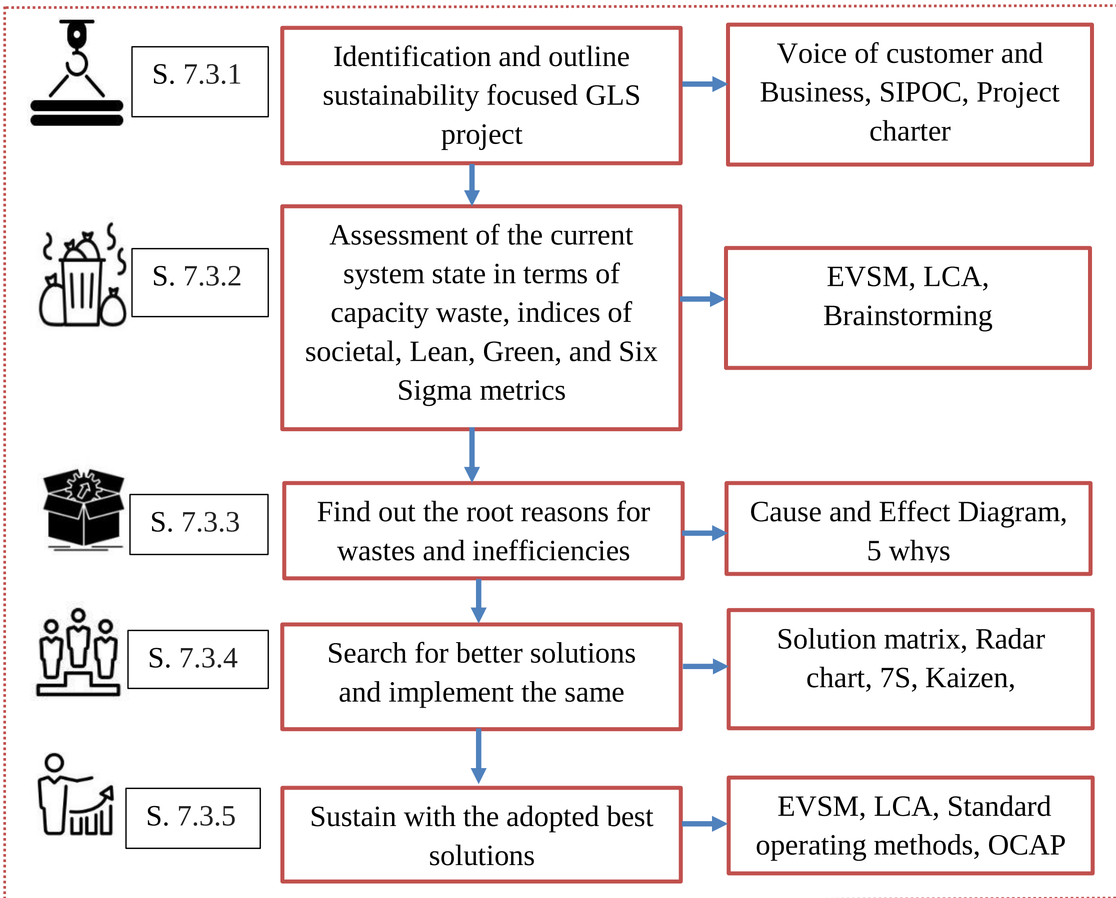


Figure 7.1: GLS framework or execution plan

7.3 Case Implementation

The case of a manufacturing firm has been considered in the present study to realize the GLS framework. The practical realization of the proposed GLS framework in the industry was performed with the subsequent steps as given below. The case organization is located in the national capital region of India and is original equipment manufacturer of fastening components. The firm is ISO: 9001.2008 and QS14001 certified and it aims to have high customer satisfaction through the delivery of high specification components. Furthermore, manufacturing industries are abided by policies on environmental regulation set by Government of India to address prestigious target of the Paris pact (2015). The case organization exhibited concern over high capacity waste, rejection, and social aspects associated with industry. So, to mitigate modern challenges of industry pertains to environmental, social, economic measures, proposed framework has been executed through following steps:

7.3.1 Identification and outline sustainability-focused GLS project

This phase of the proposed GLS framework deals with the identification and depiction of the project. The scope of the project is decided to investigate environmental, societal, and quality indices. The prerequisites and favorites for the business and customers are clearly expressed in terms of the VOC and VOB to understand the expectations from the product being made. It was identified from the VOC and VOB analysis that the industry required high customer satisfaction, capacity utilization, and employee engagement whereas customers need high-quality sustainable products. A GLS project execution needs a well-dedicated team possessing multiple skills for industrial operations. In this case, the team comprised an expert, a controller from the top management, and three organizational members. In this phase, the sequential process of manufacturing, SIPOC diagram, and project charter provide an understanding of the different facets of the project being considered.

7.3.1.1 Problem statement

The management of the case company depicted its concern for capacity waste, emission reduction for the fastening component of the fuel injection system, and assessment of the social sustainability of the organization. The firm was not only concerned about the traditional operational excellence parameters but also about how to ensure environmental and social. The firm manufactures 15,000 fastening components in a month and around 181,000 components per annum. The total installed capacity of the plant was 335,000 components per year. Based on historic data of the last three years, it was found that the company was operating at 54.7% of the total capacity, which meant that there was nearly 46% of capacity waste. The industry had a high level of environmental emission with pt 26.75, and there was no measure for the assessment of the social sustainability of the firm.

7.3.1.2 Process sequence

The manufacturing sequence of the fastening components for the fuel system starts with the arrival of material at the central location for the storage of the raw material. The parts process through different stages on shop floor and after due inspection, they are delivered to the final customer. To demonstrate a clear picture of the input materials, supplier, process flow, output, and customer of the product, a high-level SIPOC diagram was constructed (refer to figure 7.2). The details of the raw material used, power, and water consumption were also incorporated to assess environmental performance.

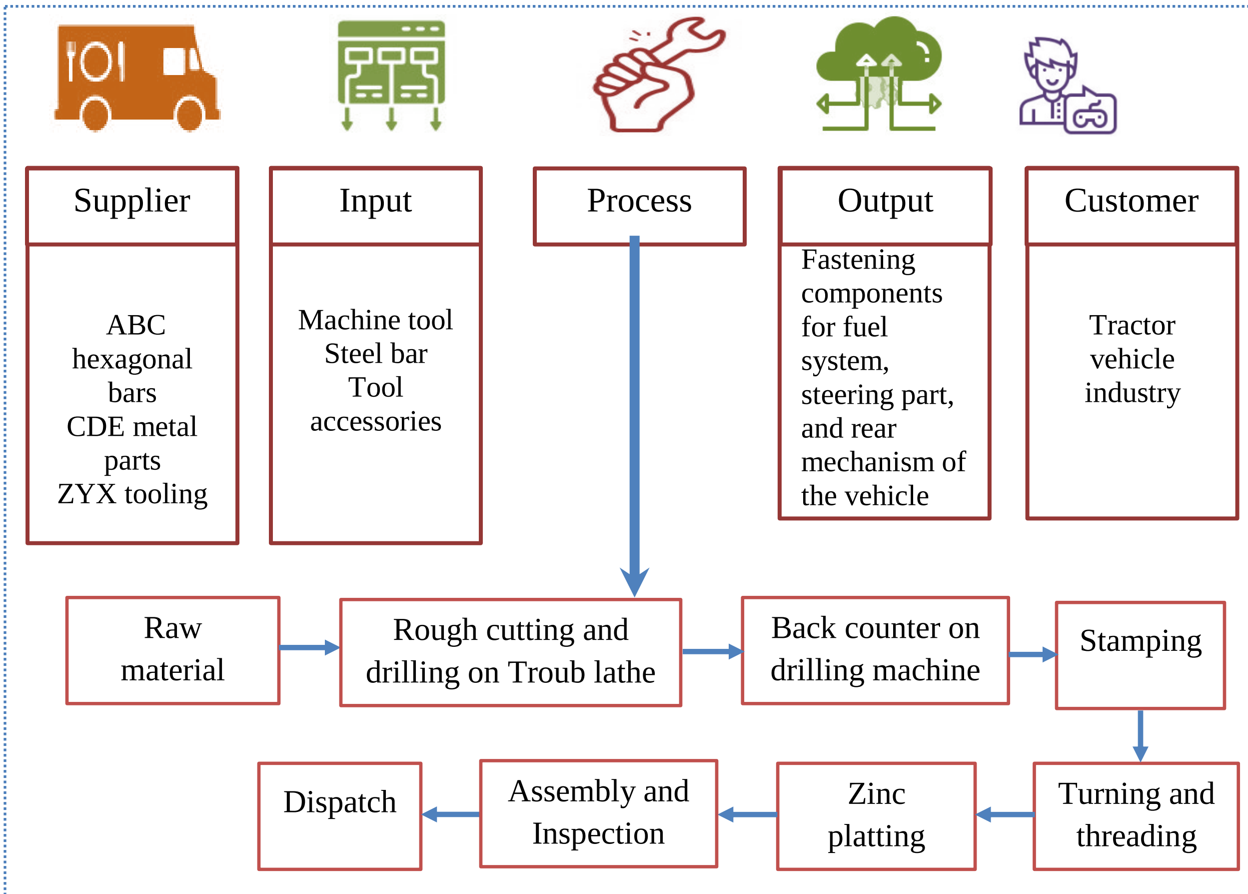


Figure 7.2: SIPOC diagram

7.3.1.3 Project charter

A project charter comprises of details that pertain to objectives, goal, scope, the problem under consideration, and project team. The project charter corresponding to the present study is shown in Table 7.1.

Table 7.1: Project charter for GLS project

Project charter	
Problem statement	**Business demand**
To enhance organizational sustainability through reduction of capacity waste, emission, rejections, rework, and efficient utilization of the available resources.	The manufacturing concern is interested to deploy GLS to reduce defects, assessment of social and environmental sustainability. The firm believes GLS adoption will bring both operational and environmental benefits.
Goal	**Scope**
To reduce defects, rejections, rework, emissions and assessment of the social Sustainability	Creates a standard data of the defects, wastes, And emissions and provide improvement measures To limit the same. The ambit of the project is limited to the fastening component of the fuel system.
Name of the firm	**Component undertaken**
XYZ manufacturer	Fastening component for fuel system
Tools deployed	**Project members**
SIPOC, LCA, EVSM, Pareto chart, 7'S, 5 Why, Cause and effect diagram, Kaizen, Spaghetti diagram, Radar chart	Expert: Mr X; Controller: Mr Z; Members: A, B, C

Project schedule		
Steps	Inception	Completion
Identification and outline the project	11 June 2019	15 September 2020
Assessment of the current system state in metrics	17 Sept. 2020	22 Jan 2020
Find out the potential reasons for wastes	25 Jan 2020	30 April 2020
Search for better solutions and implement the best ones	2 May 2020	14 August 2020
Sustain with adopted solution	16 August 2020	8 Jan 2021

7.3.1.4 Identification of critical parameters for capacity waste

In this subsection, critical parameters to high capacity waste were identified in consultation with experts and industrial visits. The radar chart depicts the percentage contribution of parameters in the capacity waste of the case organization (refer to figure 7.3). This chart depicts that ineffective material handling (37%), ineffective manpower movements and space utilization (24%), environmental issues coupled with societal issues (16%), and rework (10%) were the major contributing factors for the high capacity waste of the company. The time taken for material handling actions in different sections was investigated to identify critical sections that pertains to ineffective material handling.

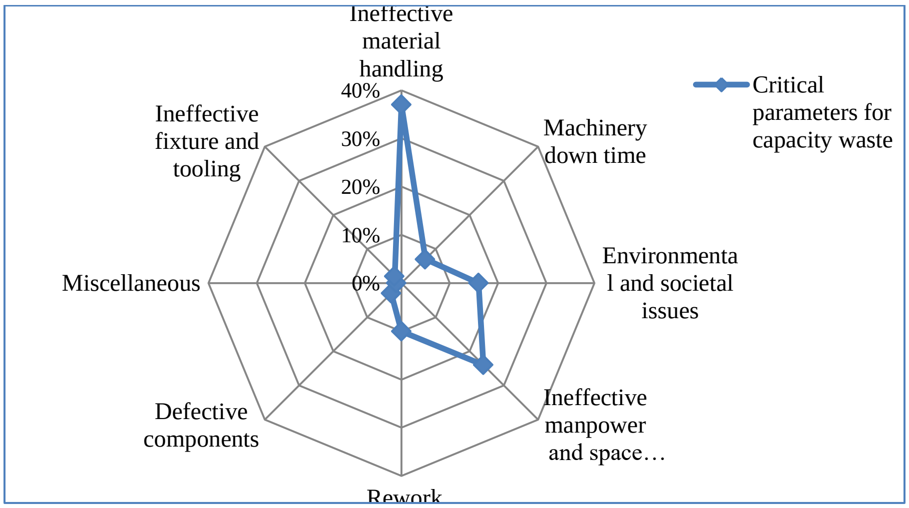


Figure 7.3: Critical parameters for high capacity waste

7.3.1.5 Assessment of the material handling time of shops/sections

In this subsection, shop-wise material handling time was analyzed to find out critical shop/section accountable for ineffective material handling. The data refers to material handling for finished and semi-finished goods, and other items were analyzed and plotted on the Pareto chart to determine the sections that were critical to high capacity waste of the firm. In the present chart, the horizontal axis depicts different shops in the company. The times evolved in the material have been represented by the different bars corresponding to each section of the case company. The adjoining bars with a cumulative frequency line determine which shop related to material handling will yield the biggest gain if addressed. The Pareto analysis suggests that the assembly section and lathe shop are the major contributors to ineffective material handling and capacity waste of the case organization.

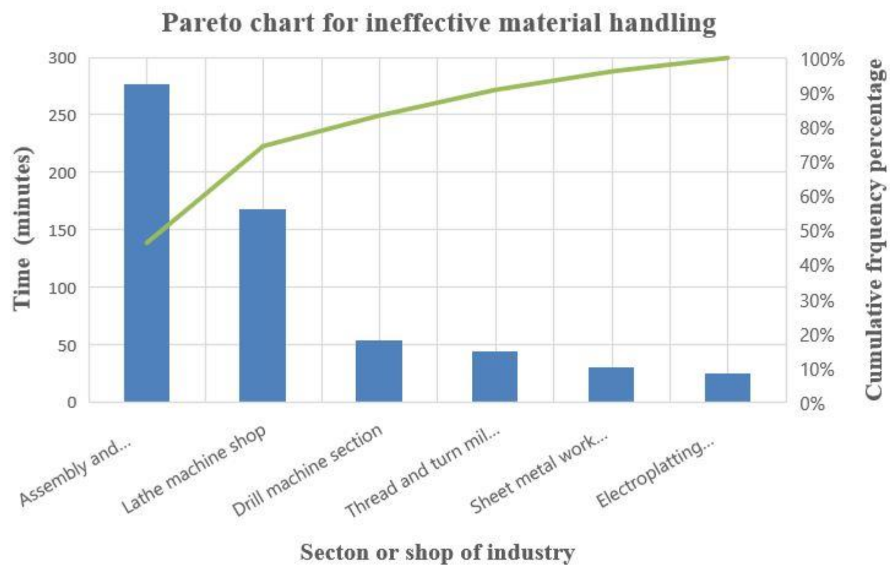


Figure 7.4: Pareto chart for material handling time of different shops/sections

7.3.2 Assessment of the current state of the system

In this section, the current state of the project under consideration was estimated to find critical measures and metrics of wastes and inefficiencies. The data collection was carried out to determine the number of defects, formulate EVSM, deploy LCA, etc. LCA was used in this step of the GLS framework to assess the current environmental impact of the process. The EVSM analysis was conducted to assess the current state of the project related to lead time, raw material, water consumption, etc. The data pertains to rework was also collected to determine the shop's critical to rework issues. Moreover, a Social Life Cycle Assessment (SLCA) was also conducted to assess the current social sustainability level of the case industry.

7.3.2.1 Environmental value stream mapping

Environmental value stream mapping (EVSM) is a practical and visual tool that can identify steps, procedures or potential hot spots that create value within the system, process, product, and supply chain [275]. Figure 7.5 depicts the current state mapping of the project under consideration while table 7.2 presents the critical process metrics.

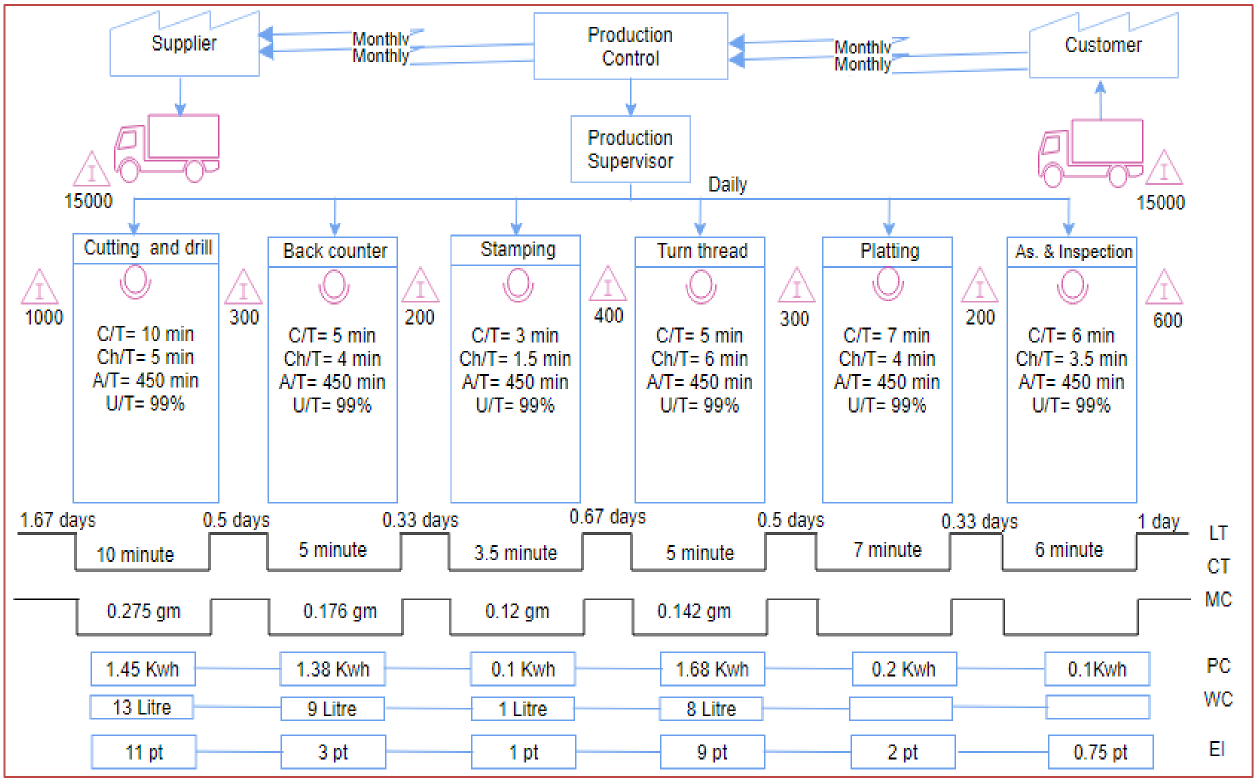


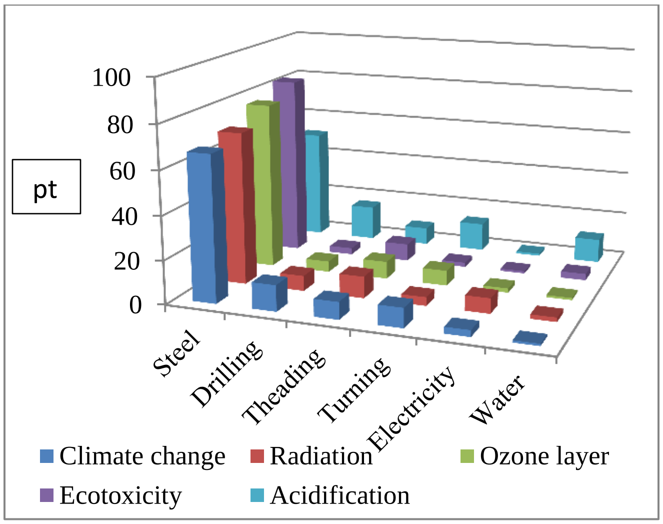
Figure 7.5: Environmental current state value stream mapping

Table 7.2: EVSM process metrics

Metrics of process	**Units**
Cycle time	36.5 minutes/lot
Lead time	5 days
Water consumption	31 liters
Power consumption	4.91 kwh

7.3.2.2 Assessment of environmental impact using Life Cycle Assessment

An open LCA was conducted to access the current environmental impact of the process under consideration. LCA measures the impact of a product on the environment throughout its entire lifespan, i.e. extraction of raw materials, manufacture, delivery, consumption, and disposal. The estimation of environmental impact was done by considering the data set of raw material, water, and power consumption. The environmental impact was expressed in a unit named Pt (point), which is a unitless number that depicts the intensity of the impact [161]. In this study, a cradle to gate LCA analysis of the product was considered to compute the environmental impact of the process. Figure 7.6 depicts the categorized environmental impacts of the case product considering all the stakeholders needed to realize it. Stakeholders considered were steel, water, electricity, turning process, drilling process, and threading process, refer to figure 7.6. The overall environmental impact for the current process considering the stakeholder was found to be 26.75 pt.



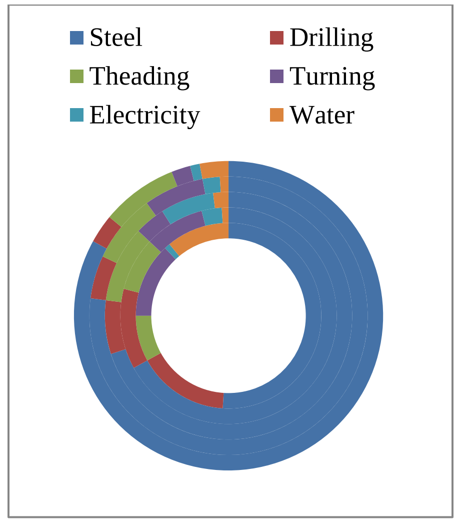


Figure 7.6: Categorized environmental impact using LCA

7.3.2.3 Estimation of defects level and rework

To estimate the sigma level of the process a sample size of 1,000 units was considered. The number of defects observed was 17 units. The defects per million opportunities (DPMO) for the mentioned number of defects were calculated as 17,000 ppm. The current sigma level of the process after matching ppm with the standard process sigma table was determined as 3.62.

The project team made a thorough analysis of the different shops/ sections of the case company to collect a monthly data set related to the number of parts requiring rework in different sections of the company. Figure 7.7 depicts a plot of the section-wise number of parts that required rework. It is obvious from Figure 7.7 that there were two crusts, i.e. lathe machine section and drill machine section. This implied that these two sections mainly contributed to reworking in the company's operations.

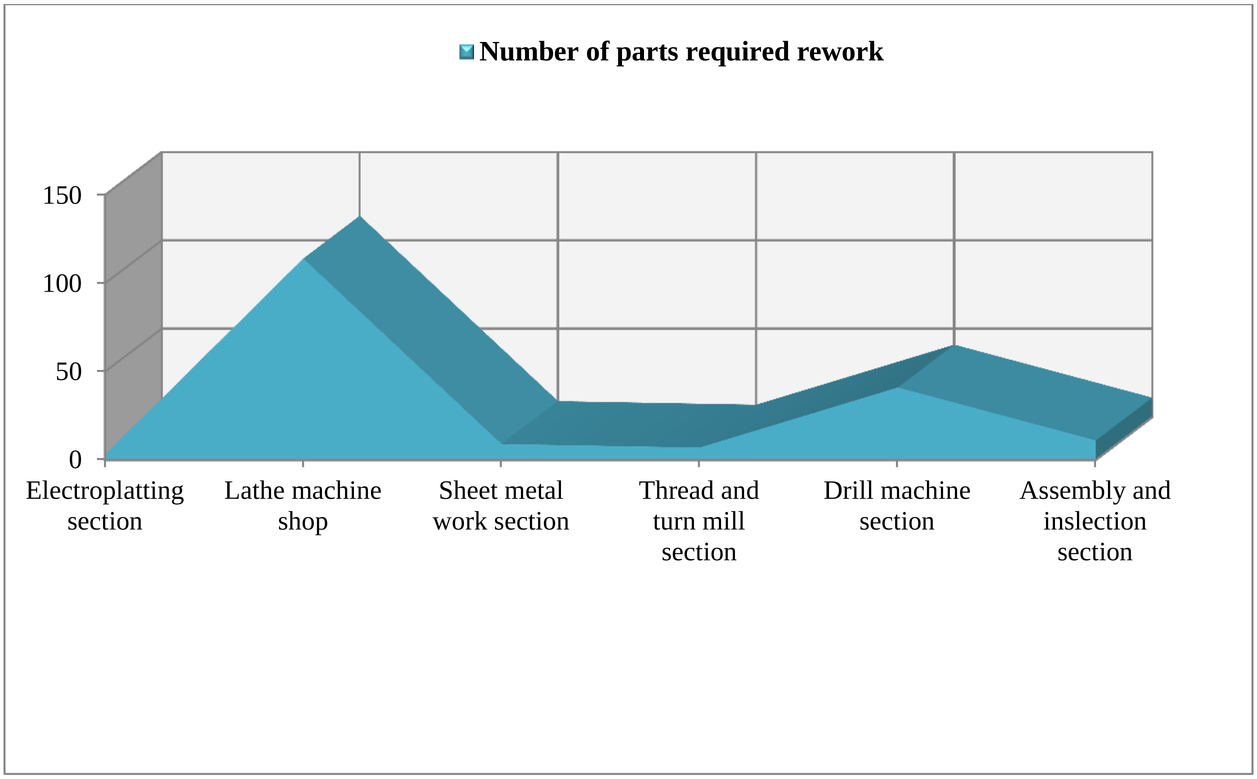


Figure 7.7: Section-wise number of parts required rework

7.3.2.4 Social sustainability assessment using S-LCA

Social sustainability is a key concern in global supply chains to protect employees from harassment and provide a healthy work environment [276]. Social sustainability assessments have been given little attention by manufacturing companies, especially in developing economies like India. In the present study, a social sustainability assessment model to assess the social sustainable performance has been presented (figure 7.8).

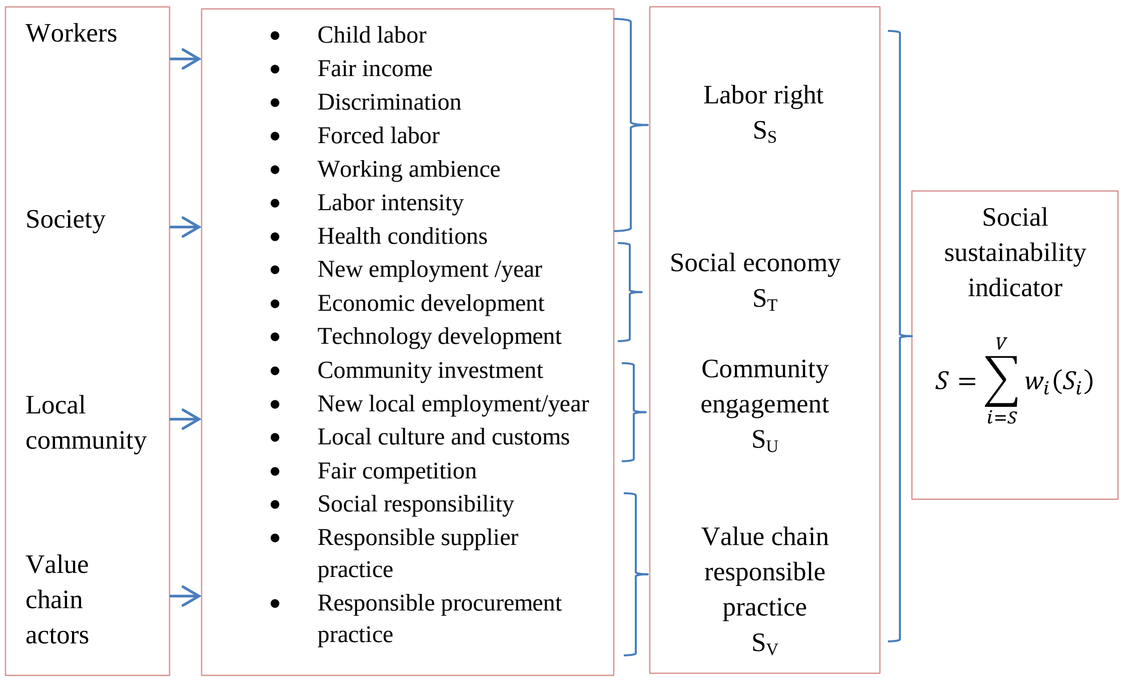


Figure 7.8: Social sustainability assessment model

In this study, original inventory social performance data was obtained through a questionnaire. The samples were collected from workers, managers, engineers. The experts (3 general managers, 2 workers, 2 academicians, and a local government officer) opinions were used to determine contextual adjustment factor (CAF), contextual risk class (CRC), product social risk factor (PSRF), and the weights of social impact categories. The social sustainability indicators of the case firm were calculated. These are presented in table 7.3.

Table 7.3: Social sustainability indicators of case industry

Category Impact	Z	ZZ	ZZZ	Z*ZZ*ZZZ	CSPS	$CSPS_{max}$	CFR	CAF	CSR	PSRF	PSRS	S_s	w	S
S1	0.7	2	2	2.8										
S2	2	0.7	1	1.4										
S3	4	1.2	1.2	5.76										

S4	0.7	2	2	2.8	46.36	112	0.58	0.4	0.23	0.6	0.16	0.84	0.2	
S5	4	2	1	8										
S6	4	1.2	2	9.6										
S7	4	2	2	16										
T1	0.7	1.2	2	1.68										
T2	4	1.2	1.2	5.76	15.44	48	0.67	0.7	0.26	0.7	0.18	0.82	0.4	81.9
T3	2	2	2	8										
U1	2	1.2	1.2	2.88										
U2	2	1	1.2	2.4	10.08	48	0.79	0.5	0.39	0.6	0.23	0.77	0.3	
U3	2	1.2	2	4.8										
V1	4	2	2	16										
V2	4	2	2	16										
V3	4	1	1.2	4.8	39.2	64	0.38	0.4	0.152	0.5	0.08	0.92	0.1	
V4	2	1	1.2	2.4										

It was found that the case company had marginal social sustainability and positively contributes to society. It is obvious from table 7.3 that the company exhibits better social performance in "labour right" and value chain responsible practice, whereas it presents a lower performance in both the social economy and community engagement categories. Thus, there is an opportunity to improve these two categories.

In this phase, the collected data and assessment of the current state in the case company provided the opportunity to identify the weak areas where further analysis was required. These areas are as follows:

- Ineffective material handling: Inspection and assembly section
- Unnecessary manpower movement and space utilization movement: entire company
- Rework: Lathe machine shop and drill section
- Environmental footprint: entire company
- Social sustainability: Society and local community parameters

The selected areas containing critical quality characteristics were further examined to identify possible causes in the subsequent phases.

7.3.3 Determine the root reasons for wastes and inefficiencies

In this phase, the root causes of different wastes and inefficiencies are identified. Based on data set of the measure phase, potential causes for rework, improper material handling, low environmental performance, and improvement in social sustainability are identified using tools like brainstorming, FMEA, DOE, cause and effect diagram (C&E), 5 whys analysis. Once the potential causes are identified, the search is narrowed down to find significant contributors to wastes and inefficiencies using tools like decision making techniques, Pareto chart, hypothesis testing, etc.

7.3.3.1 Identification of potential causes for ineffective material handling

The cause and effect diagram was initiated with the problem of interest of ineffective material handling in the assembly section of the case company (refer to figure 7.9). Six major categories: manpower, machine, material, methods, measurements, and mother nature were considered for further exploration of possible reasons. The brainstorming sessions were conducted with middle and top managers of the company.

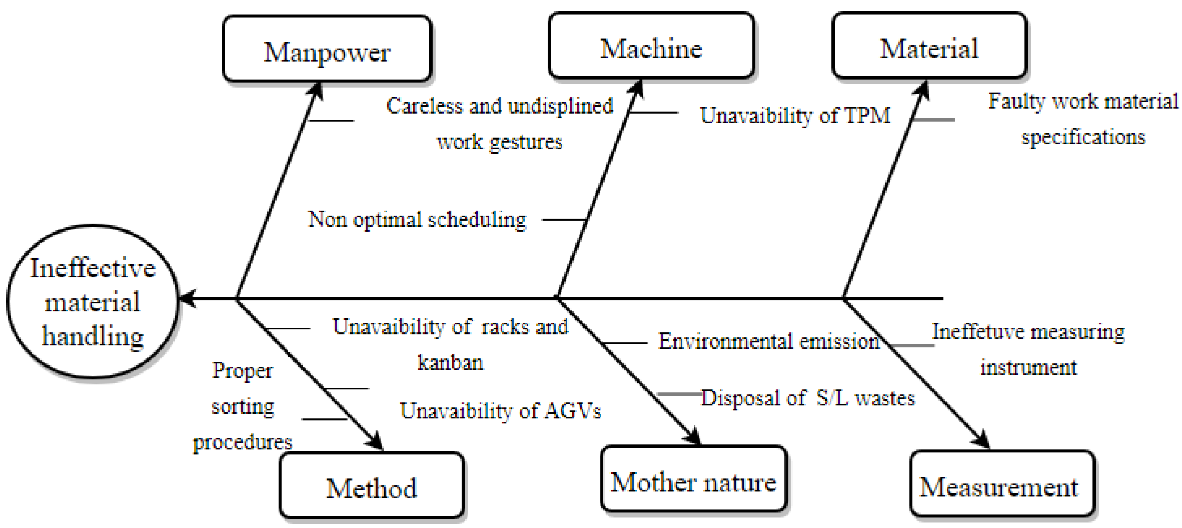


Figure 7.9: Cause and effect diagram of ineffective material handling

It was identified that ten causes/factors were responsible for poor material handling (refer to table 7.4). Further to find, critical factors among the identified factors, a grey relational analysis (GRA) was used. GRA offers distinct advantages over other methods like dynamic nature at it provides opportunities for the change in the number of parameters and transformation in computer algorithm for a quick solution [277]. Table 7.5 depicts the ranks of factors responsible for ineffective material handling. It was found through GRA that unavailability of racks and Kanban system and proper sorting procedure were the most critical factors responsible for ineffective material handling and that hence actions were needed to overcome these.

Table 7.4: Factors responsible for poor material handling

S. No.	Factor responsible for ineffective material handling	Label
1	Faulty work material specifications	FR1
2	Non-optimal scheduling	FR2
3	Unavailability of TPM	FR3
4	Unavailability of AGVs	FR4
5	Proper sorting procedures	FR5
6	Environmental emission	FR6
7	Careless and undisciplined work gestures	FR7
8	Unavailability of racks and Kanban system	FR8
9	Disposal of S/L waste	FR9
10	Ineffective measurement system	FR10

Table 7.5: Prioritization of ineffective material handling factors using GRA

Label	CR1	CR2	CR3	CR4	GRG	Rank
FR1	0.333	0.500	0.500	0.600	0.483	7
FR2	0.538	0.429	0.400	1.000	0.592	5
FR3	0.368	0.500	0.667	0.500	0.509	6
FR4	0.636	0.750	1.000	0.545	0.733	3
FR5	1.000	0.600	1.000	1.000	0.900	2
FR6	0.333	0.333	0.667	0.353	0.422	9
FR7	0.368	0.600	1.000	0.429	0.599	4
FR8	0.778	1.000	1.000	0.857	0.909	1
FR9	0.538	0.500	0.400	0.333	0.443	8
FR10	0.467	0.375	0.333	0.429	0.401	10

7.3.3.2 Why analysis for rework, ineffective manpower movements and space utilization

5Why analysis is an iterative interrogative method applied to find the root cause for a problem without any statistical analysis. The process of continually asking the question, "Why?" layers of issues and symptoms are unpeeled, which leads to the identification of root causes of the problem under consideration. The 5Why analysis was performed with considerations and the viewpoint of the section head, section supervisor, and machine operators. Figure 7.10 depicts the 5Why analysis performed to identify the root cause for the rework issue. The chips collections at the tool-workpiece interface and burr marks at work surface were identified as the root cause for rework issues in the case company.

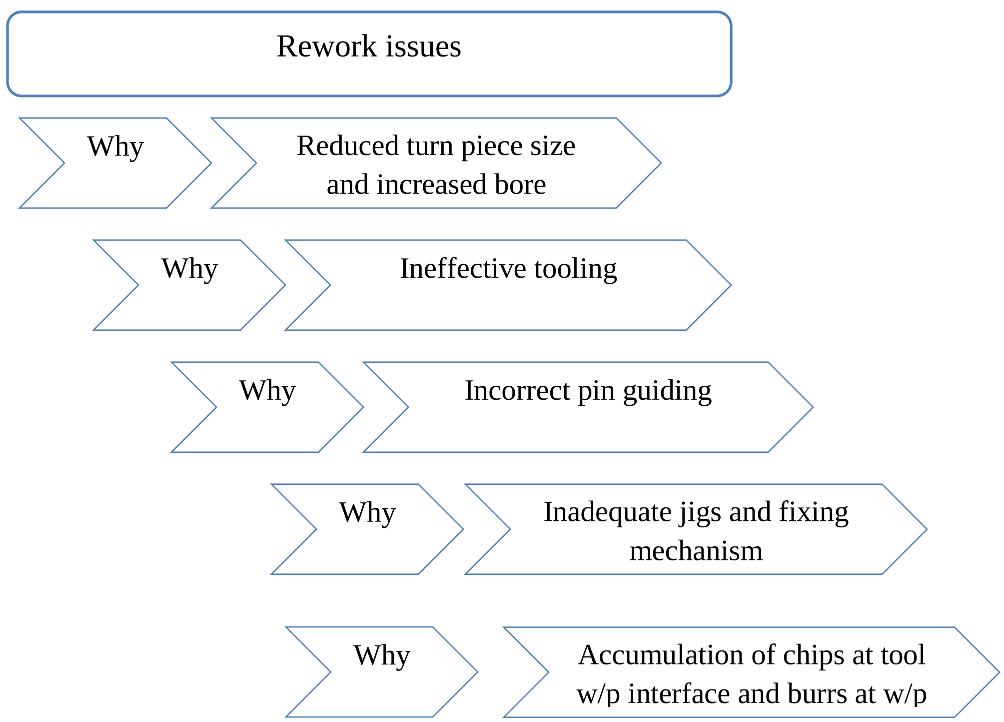


Figure 7.10: 5 Why analysis for rework issue

The project team also conducted a 5Why analysis for ineffective manpower movements and space utilization. It was determined from the analysis (Figure 7.11) that a faulty plant layout led to ineffective manpower movements as well as space utilization.

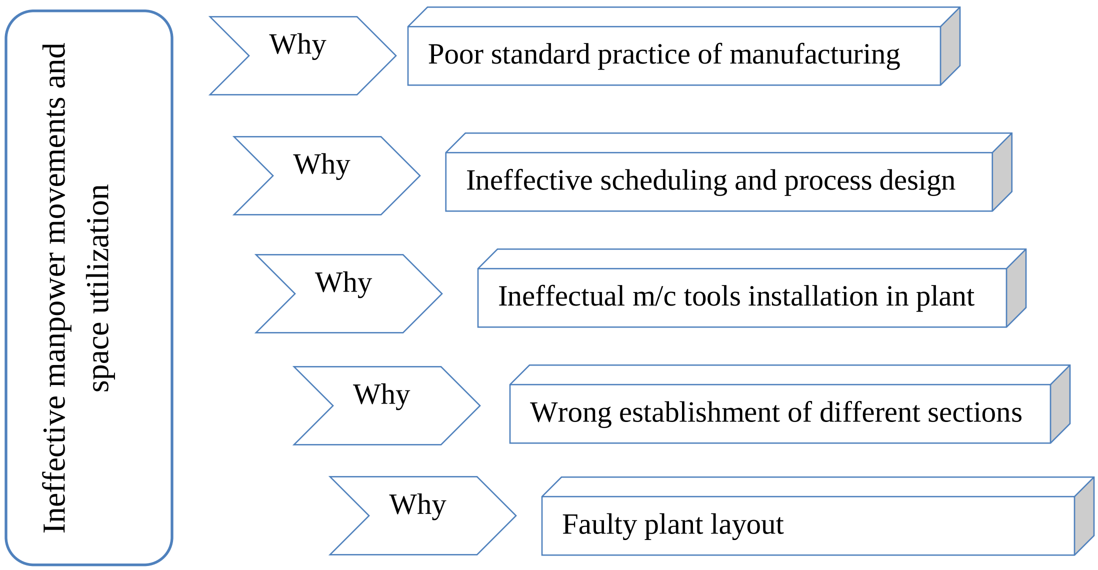


Figure 7.11: 5 Why analysis for ineffective space utilization

7.3.3.3 Assessment of reason for environmental and social sustainability

Further, project team critically investigated different sections of the case company and made different brainstorming sessions with the supervisor and working personnel, and identified excessive material, water, and power consumption as major sources for low environmental performance. It was also identified that for increased social sustainability, the case company should work on the society and local community aspects.

Table 8 presents the outcome of this phase of GLS execution and various areas and reasons that need attention to improve the sustainability dynamics of the company. In the subsequent step of the framework, various actions were implemented to improve the company's sustainability dynamics.

Table 7.6: Prominent reasons to address for improvement in sustainability

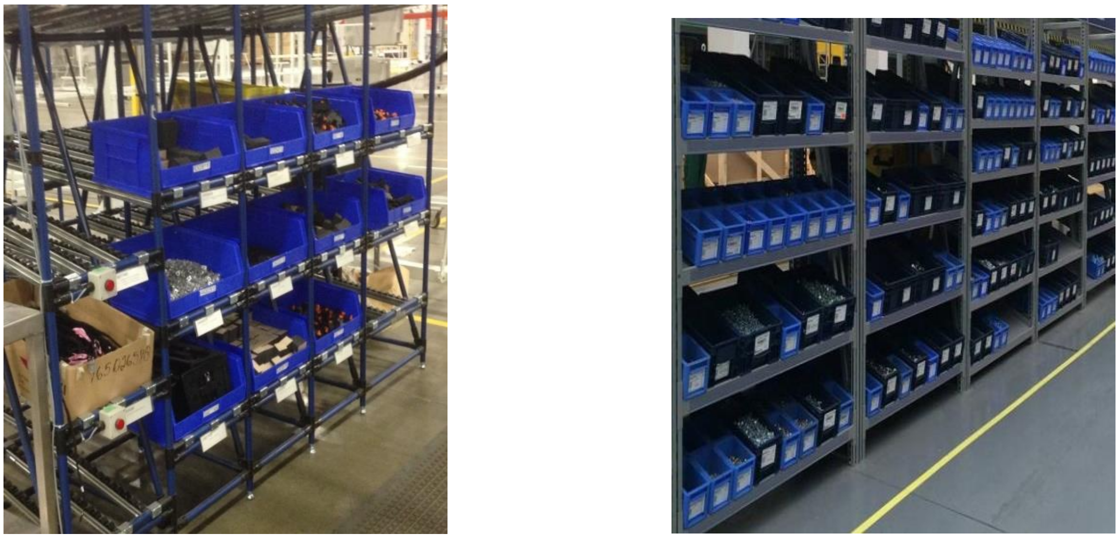
S.No.	Areas	Section/Aspects	Prominent reasons
1	Ineffective material handling	Inspection and assembly section	Unavailability of racks and Kanban, part sorting procedures, unavailability of AGVs
2	Ineffective man movement and space utilization	Overall industry	Ineffective plant layout
3	Rework	Lathe machine shop and drill machine section	Accumulation of chips at tool w/p interface and burrs at the work surface
4	Excessive raw material, water and power consumption	Overall	Incorrect machining parameters, non-availability of proper recirculation system and cleaning system, ineffective tooling
5	Social performance	Society and the local community	Community investment, new employment overall, new employment from the local community

7.3.4 Search for better solutions and implement the same

In this section, various solutions are proposed and the best solutions are identified and implemented to reduce root causes of the problem or inefficiencies.

7.3.4.1 7'S implementation for ineffective material handling

A comprehensive discussion with middle and top-level management led to a suggestion for the adoption of 7S measures in the assembly and inspection section to improve the company's sustainability dynamics. 7S (5S+ Sustainability + Safety) principles were used in this study to create an organized, clean, safe, accident-free, and environmentally friendly workplace. In the 7S implementation, during Seri, all the parts and equipment were sorted to reduce the search time. After sorting, parts were set to arrange the work items in line with the shop floor's physical workflow, and make them easy to retrieve for use. Besides, to have a conducive and clean work environment, regular cleaning of the workplace to remove dust and grim were initiated. Figure 7.12 depicts the work area of the assembly section before and after the execution of 7S. The execution of 7S led to a daily saving of nearly 120 minutes in the company's operations. The adopted work practices were standardized to create a consistent way of implementing tasks performed daily, including sort, set in order, and shine. Standardize make the process and methods more realistic and accurate to make the right things, the right way,



(a) (b)

Figure 7.12: Assembly section before and after implementation of 7S

and right every time. Visual process control systems were adopted to facilitate workers and other organizational members keeping things at designated places. The work standards for a regular check of the medical kit and regular updating of the rules on environmental sustainability according to the current regulations were regularly adopted to ensure the success of 7S. To ensure sustainability and safety in the company, apart from the practice of the 5S, checks for the removal of accidents, covering of the areas of the machine tool prone to high-temperature chip were also performed. A 7S audit sheet was constructed to collect the responses from the manufacturing personnel of the case company to eliminate wastes and associated risks at the workplace (refer to table 7.7). The different elements of the audit sheet were compared with the manufacturing environment. The elements in the response sheet were included in the questionnaire form. These had a response of either ‘Yes’ or ‘No’. The elements that got ‘No’ were checked and an action plan was initiated to convert the same into a ‘Yes’. Action plans were initiated for all 'No' responses in a sequential order starting from sort to sustainability. After the action plans implementation, the audit was checked to ensure that all the responses were in the form of 'Yes'. Finally, the documentation of the audit sheet was done and displayed in the work area. The 7S audit made the organization able to link its lean initiatives with safety measures and provided ways for constant success through sustainable profits.

Table 7.7: 7S audit sheet

7S activities	Yes	No
Sort		
Are potentially red tags items sorted and disposed of property?	✓	
Items present or walkways, stairs, fire exit etc.	✓	
Are there a Kanban system for up keeping of items	✓	
Are there proper sorting procedures to segregate according to their necessity?	✓	
Simplify		
Are the containers for material, wastes are properly stacked and sealed during nonuse?	✓	
Are material and equipment's located at the designated place and set in order of use?	✓	
Shine		
Are they any leaks from pipes, tanks, and other machine tools?	✓	
Are the supply table, bins, machine tools, tools, work floor cleaned regularly?	✓	
Is there a proper mechanism for the ventilation of fumes, and harmful gases raised during operations?	✓	
Standardize		
Are standard work procedure available and being followed?	✓	
Are all supply bin, machine tool, and kit intact?	✓	
Sustain		
Are the last audit was made less than three weeks ago?	✓	
Is the 7S board up to date? (pictures, metrics, shine, etc.)	✓	
Safety		
Are the safety valves, fire extinguish measures, primary health measures up to date and test in the last two weeks?	✓	
Are environmental, health, and safety management activities related to the work area and integrated to work methods	✓	
Sustainability		
Are the defects and wastes being reduced over a cetin length of time?	✓	
Are the environmental regulation measures as per pacts and governmental policies on climate change?	✓	
Is there continuous impetus to the employee through monetary and other recognition incentives?	✓	
Are the primary or first aid kit easily approachable in the work area?	✓	

7.3.4.2 Kaizen activities

To reduce different non-value added activities in the case company, different kaizen events were proposed and implemented. The kaizen activities were planned in such a way that these can enhance organizational productivity as well as environmental sustainability. The kaizen activities were planned to reduce work issues, setup time, and enhance the social sustainability of the organization.

7.3.4.2.1 Improvements related to the cutting of raw material and lathe section

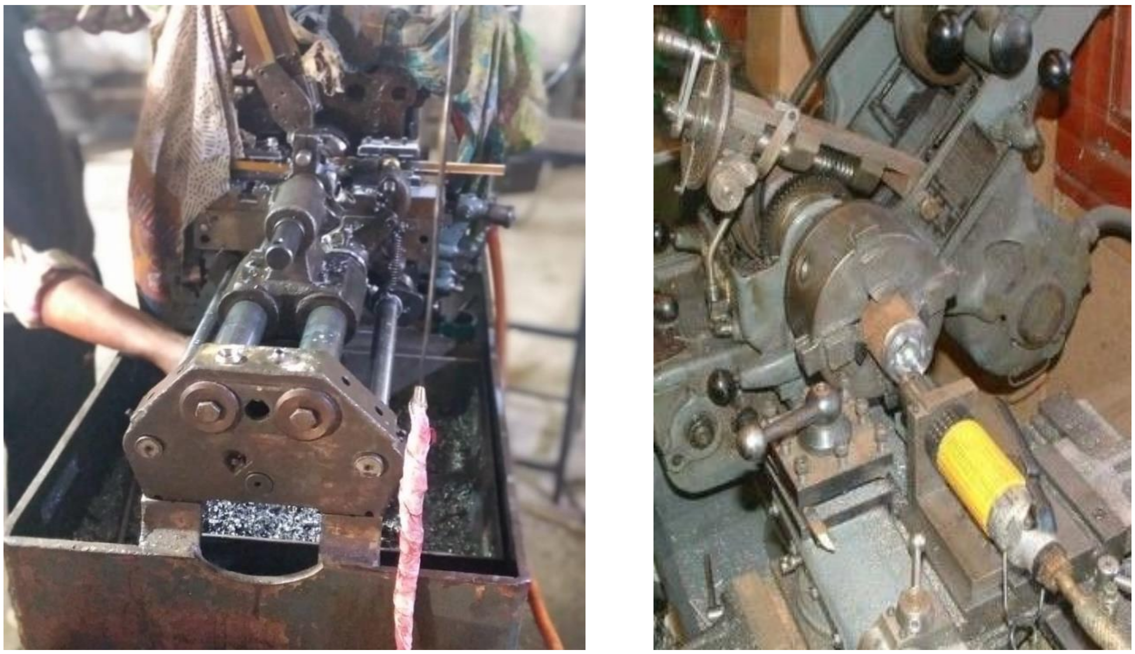
Initially, the raw materials bars were transferred with the help overhead crane system to a dedicated cutting machine in the lathe section of the company. The raw material bar was put into the dedicated fixture and then placed on the cutting machine to be cut into small parts after providing proper clamping and location. The clamping and setting work consumes considerable time as bar size changes. Thus, there was a need to provide a quick change over and reduction of set up time. For this, an investigation and feasibility analysis of three probable techniques were done. Table 7.8 depicts the analysis of set up time reduction techniques.

Table 7.8: Investigation of set up techniques

Technique	**Description**	**Adoption feasibility**
Advance part preparation	Equipped with a slew dedicated fixture to reduce changeover time	Can be used for a short duration when handling and total production cost is high
Equipment modularization	Make changes in the existing fixture to meet functional requirements	Time reduced for set up but demands quick modifications
Equipment modification	Perform redesigning of fixture and replaced existing one with modified one	High saving in setting up time through redesigning and modification of existing fixture

7.3.4.2.2 Improvements pertains to rework issues

In the previous phase, it has been identified that the accumulation of chips at tool w/p interface and burrs at w/p was a major factor behind the rework-related issues in the lathe machine section. To facilitate, proper tool conditioning the carbide tool has been replaced and locators have been provided and pins aligned properly to reduce the dislocation of the parts. To facilitate the removal of chips and burrs from the workpiece and tool interaction areas pressurized air guns have been incorporated for enhanced tool life and reduction of rework issues (figure 7.13).



(a) (b)

Figure 7.13: Lathe machine tool before and after incorporation of air pressure gun to remove burrs at tool workpiece interface

7.3.4.3 Improvements to enhance societal dynamics

Attaining excellence in environmental, health, safety, employment, and community engagement must be a part of the value creation strategy to sustain the global market. It has been found from the life cycle assessment that the case industry was lagging in the parameters of employment and community investment. Although the case industry exhibits marginal social sustainability level but to enhance the same, to a better level, the industry should incorporate measures to enhance employment and community investment aspects. As effective community performance in the long turn drives shareholder value creation, the case industry should invest more in the community towards the non-profit organization. Increasing community investment along with measurement of outcome achieved will lead to strategy enrichment, improved human resource engagement, culture building, and business generation for the case industry. The case industry should incorporate measures for training, education, and skill development as a part of corporate social responsibility. Such kind of measures will enhance the industrial organization to recruit potential talents from the local community that not only enhance social sustainability but leads to improved organizational efficacy.

7.3.4.4 Reduction in environmental impacts

The reduction in overall environmental impact has been achieved through a corresponding decrease in the use of raw material, lubricant consumption, and power usage. The improvement actions were suggested and applied for each factor. Table 7.9 depicts the implemented actions and suggested activities for each environmental factor to improved industry environmental sustainability.

Table 7.9: Actions for improvement in environmental sustainability

Factors	**Implemented actions**	**Suggested actions**
Material usage	Excess scrap material usage minimized by altering process parameters	Use a different material that leads to lesser environmental impact
	Input material consumption reduced by changing product features	
Water usage	Closed-loop water circulation system incorporated to reduce coolant consumption	Adopt conventional techniques of cleaning with the use of steam to minimize water consumption
	Reduction of water loss due to evaporation from water storage tank achieved by lining tank with a non-stick material	
Power usage	Experiment and investigation were done on lathe and drill machine tools with different feed, speed and commissioning of the electrical unit	Incorporate PMS to identify and improve energy waste.

The incorporation of power-saving measures leads to the reduction of power from 4.91 kWh to 4.06 kWh. The overall cost of the product is also reduced due to saving in the overall power consumption of the industry. The water consumption was also brought down from 31 lt to 23 lt due to the incorporation of the recirculation water system and non-sticky lining for the water tank.

From material sustainability perspective, different analysis and test were performed for the fastening component to get the optimum design. It has been found through realization with modified parameters for the product that it led to a saving of raw material consumption from 0.713gm to 0.586 gm. After the inclusion of the implementation methods, the environmental impacts were again computed using LCA and it was found to be 19.7 Pt which was 26.75Pt earlier. Figure 7.14 depicts the LCA analysis after the incorporation of the environmental impact mitigation measures. Moreover, the scope still exists for the reduction in the environmental footprint through the usage of alternate materials and reduction of material consumption.

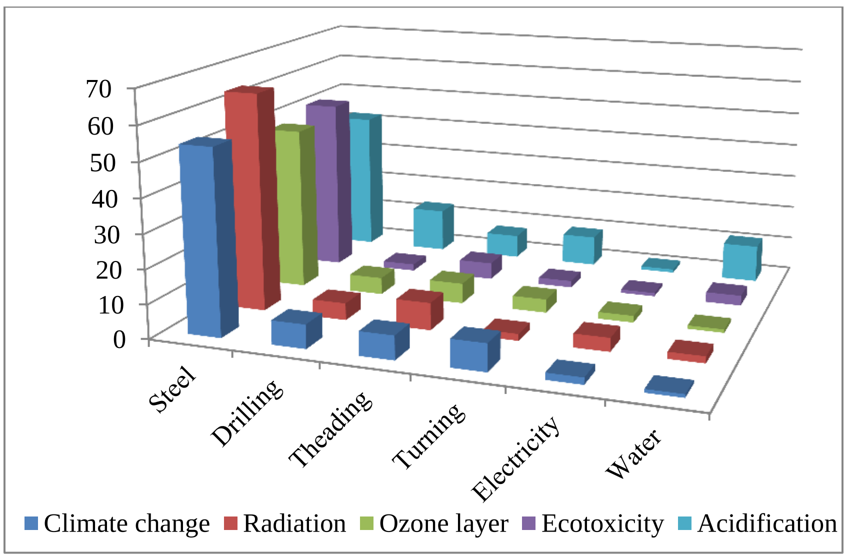


Figure 7.14: LCA after incorporation of the improvement measure

7.3.4.5 Layout modification to overcome unnecessary movements

Effective layout of the plant facilities leads to proper synchronization of the process and minimum movements of the men and materials. It has been found that the existing layout of the machines was not designed appropriately and that led to excessive movements. This improper synchronization of plant facilities leads to increased power consumption for jib crane operation and other associated material handling equipment. To modify the existing layout, firstly movements of operators were tracked with the existing layout to search for material, tools, etc. Thereafter, the movements of the semi-finished goods, raw material, and material handling equipment were also traced. Figure 7.15 depicts current layout of plant facilities. It has been found through systematic investigation of the plant that in the existing plant required floor space was not effectively organized. The probable solutions for execution were analyzed and further steps were initiated to modify the existing layout. It has been identified that in the existing layout there was not a dedicated space for storing the tools or accessories and as a part of the same operators have to move every time to search for the required tools. For this, a dedicated toolset box was incorporated on each machine tool to save time to search for tools. This has led to saving in time for operators and enhanced their overall efficacy. Moreover, the plant pressure testing machine that was initially located near the raw material bay, moved nearby to the stamping or sheet metal section that was initially occupied with scrap or worn-out materials. The resulting movement of the machine tool leads to the achievement of the U-shaped layout of the plant.

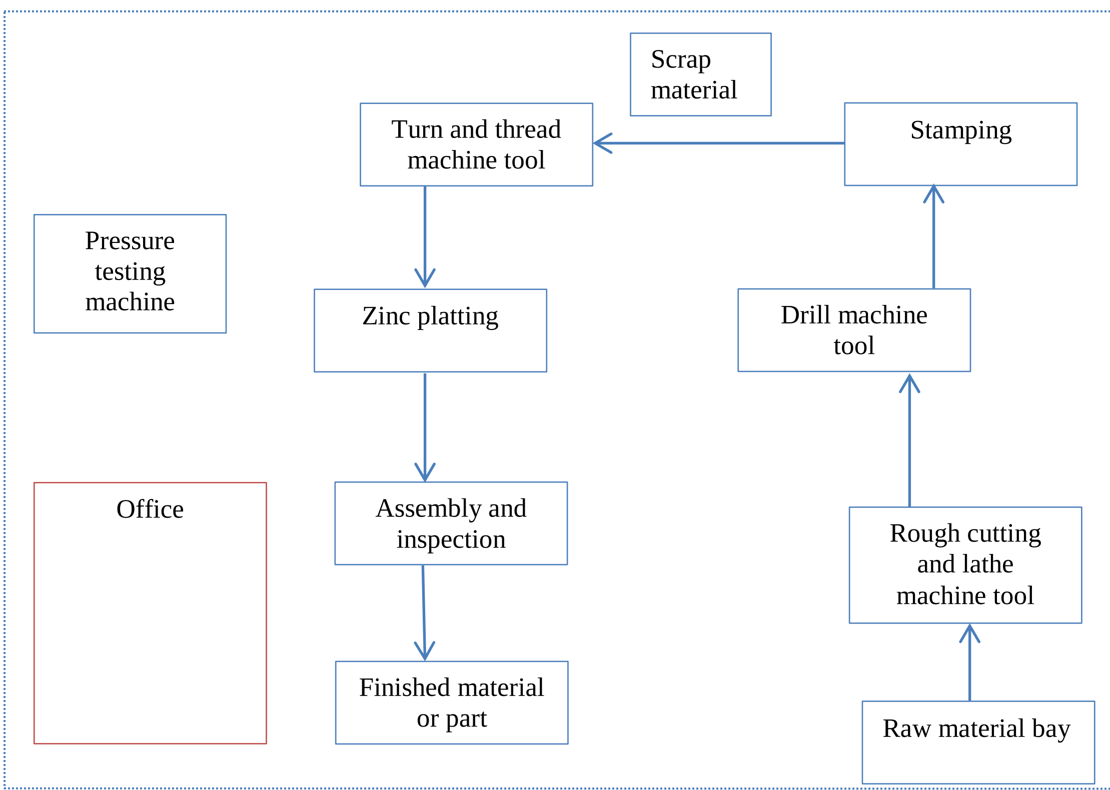


Figure 7.15: Existing plant layout

Moreover, effective floor space utilization was achieved through the removal of scrap or unwanted material and relocation of the machine tools in the plant. The existing developed facility layout helped in the achievement of the smooth workflow of material and men and subsequently leads to a reduction in waiting and power consumption for material handling equipment. The modified plant layout is illustrated in figure 7.16.

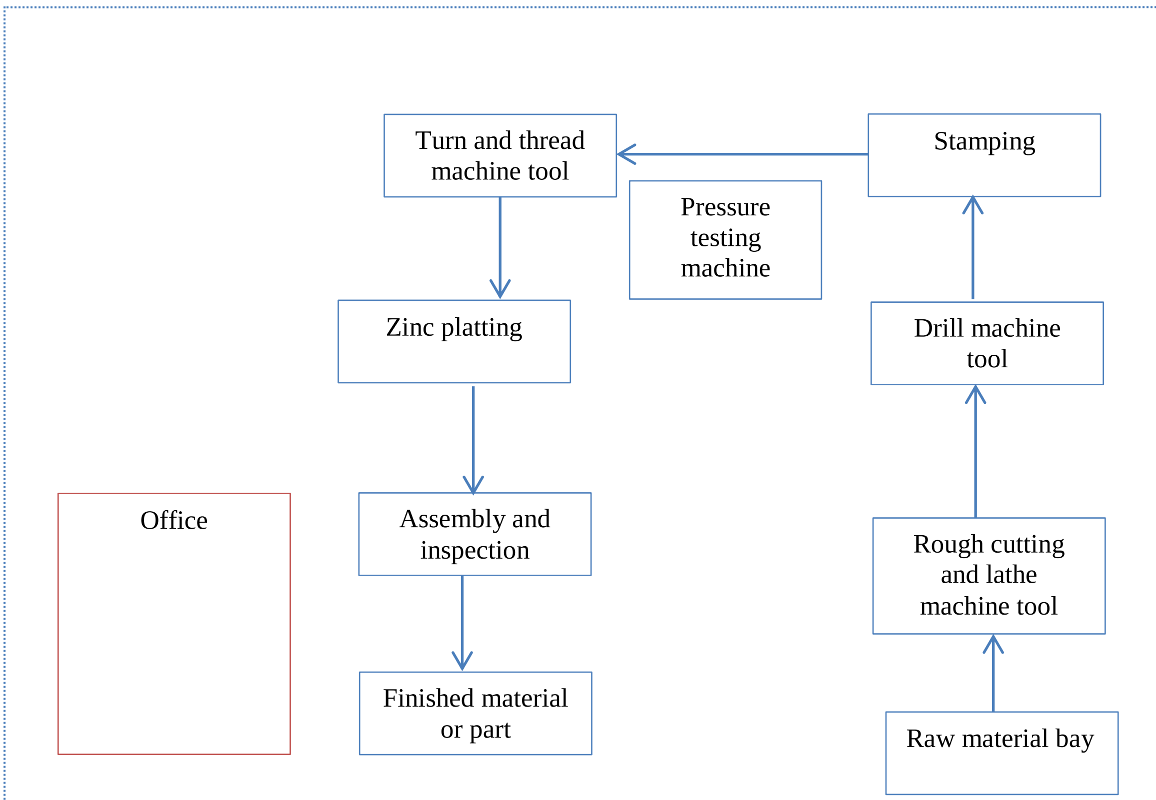


Figure 7.16: Modified plant layout

7.3.5 Sustain with adopted best solutions

In this phase of GLS execution, improvements made are documented to sustain the improvement activities. Here, the improved process is handed over to the process owner along with the complete procedure for maintaining gains. This phase ensures that gains received from the improvements made are maintained after the completion of the project. At the outset, it is essential to document and standardize the process to depict a perfect picture of the modifications made and how to sustain the modifications. After various improvement actions in the fourth step of the framework, various activities and data were noted for the next six months to check that whether improvements actions sustain for a longer duration. Different metrics pertain to wastes, environmental, and defects were assessed again to check for any deviation from the improvement phase. The gains obtained from the execution of the GLS project are communicated to all the members involved in the project and a flow chart of roles and responsibilities is prepared to sustain improvements. Table 7.10 depicts various roles and responsibilities to sustain improvements for the longer run (out of control action plan). The performance measures in terms of observation, interaction, data collection, and charting are formulated to track the performance of the system after the implementation plan.

Table 7.10: Out of control action plan

S. No.	Control item	Control Method	Responsibility	Response plan
1	Location of air gun	Visual audit	M/C operator	Train operator for proper gun location setting at tool W/P interface
2	Coolant system	Visual audit	M/C operator	Train operator for proper supply and leakage of coolant
3	Electrical system	Metric	Maintenance electrician	Every time ensure mistake proofing
4	Conveyor system	Visual audit	M/C operator	Ensure mistake-proofing and check proper maintenance of crane bearings
5	Drill machine section for drill location	Visual audit	M/C operator	Ensure proper drill location and adoption through the standard operating procedure
6	Spindle of machine tool	Audit	Maintenance section	Ensure proper lubrication and centering of machine tool spindle. Also, ensure proper sanitization of work surface and machine tool area

Based on the investigation of the current state VSM, improvement actions were planned and implemented to improve the different process metrics of the case industry. After successful execution of the suggested actions, the future state of VSM was made as illustrated in figure 7.17.

It is essential to provide sufficient training and educations to the personnel involved in the process to deal with modifications made and sustain adopted best practices. In the present case, tools like Poka Yoke, visual management, and total productive maintenance, out of control action plan have been used to provide visual aid and to control key input-output variables pertains to operational and environmental practices.

The case industry on continual following recommendations made and visual monitoring of prominent deliverables will be able to exhibit better control over the process. This will enhance the likelihood to improve the social and ecological performance of the industry.

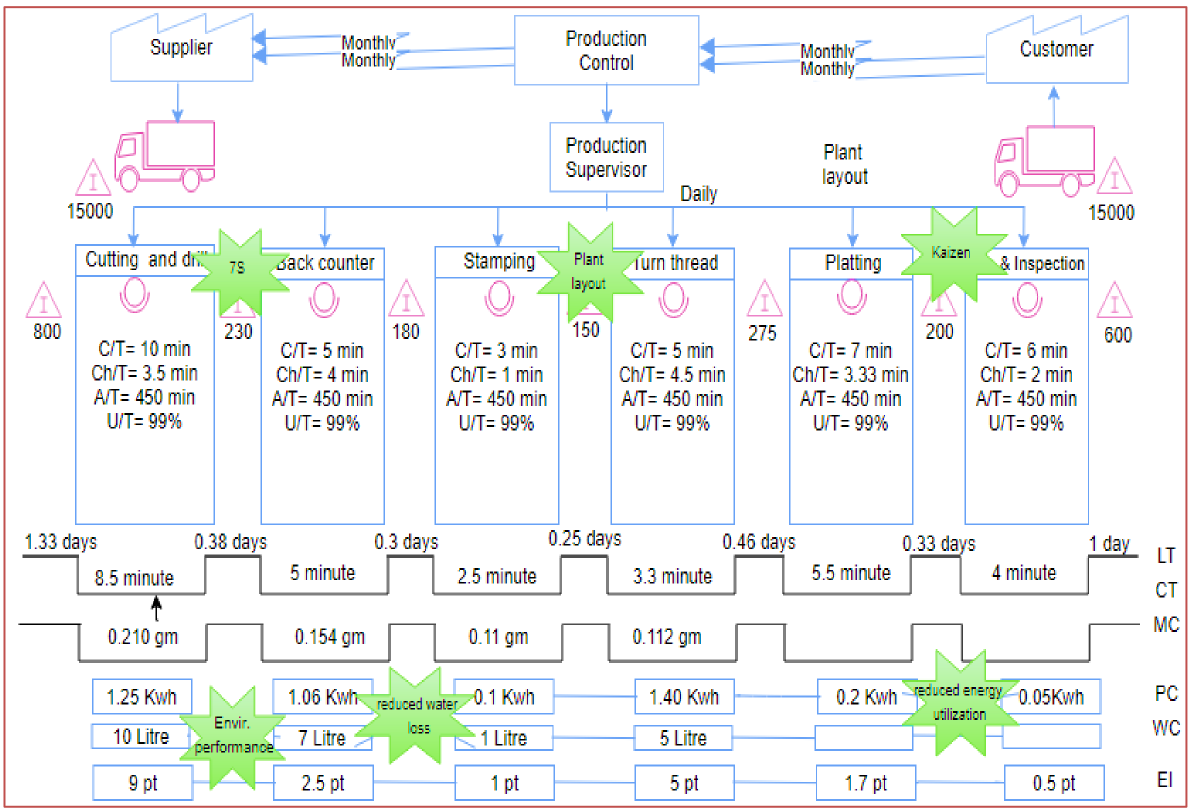


Figure 7.17: Future state value stream mapping

7.4 Results and Discussion

On successful execution of the GLS program through the adopted framework, the case company was able to improve its operational performance and environmental sustainability. Improvements were observed in the process and environmental parameters through the deployment of the proposed GLS framework. The improvements observed referred to lean metrics such as cycle time and lead time. The systematic implementation of process Kaizen, 7S, creation of effective plant layout, and Kanban resulted in a reduction of the cycle time from 36.5 minutes to 28.3 minutes (22.47%). Furthermore, lead time was also improved by 19%, which led to a considerable saving in the delay of the end product. The applied improvement actions brought a considerable improvement in the environmental metrics of raw material consumption, coolant use, energy utilization and overall environmental impact. Raw material consumption, energy utilization, and coolant consumption were reduced by 17.81%, 17.31%, and 25.81% respectively. The cumulative effect of reduction in the environmental metrics resulted in the reduction of the environmental impact by 26.40%. Moreover, the systematic application of different improvement methods brought considerable improvements in the existing capacity utilization of the plant by 18.16%. The sigma level of the company was improved considerably through a reduction in the number of components rejected. It was improved from 3.62 to 4.01 (for a sample size of 1,000 parts the number of parts found defective was 6 and it is correspondence to the DPMO 6000 that was previously 17000). Table 7.11 depicts different process metrics and the corresponding improvements before and after of the proposed GLS framework in the case company.

Table 7.11: Process metrics before and after the execution of GLS project

Process metric	**Before execution**	**After execution**	**Improvements (%) term**
Cycle time	36.5 minutes	28.3 minutes	22.47%
Lead time	5 days	4.05 days	19%
Environmental footprint	26.75	19.7Pt	26.40%
Material consumption/piece	0.713gm	0.586	17.81%
Energy utilization	4.91 kWh	4.06 kWh	17.31%
Coolant consumption	31 Litre	23 Litre	25.81%
Sigma level	3.62	4.01	10.77%
Capacity waste	46.30%	37.80%	18.16%

On other hand, improvement measures resulted in the reduction of rework parts from 2172/year to 407/year. This contributed to a saving of $ 14129/year from the rework-related issue in the case company. The comprehensive execution of the GLS project resulted in a financial gain for the company in terms of saving a net worth of

$43,000/year. Table 7.12 demonstrates the financial gains from the executed GLS project.

Table 7.12: Monetary benefits from GLS execution

Particulars	Before GLS execution	After GLS execution
Total number of components produced/month	15000	17057
No of parts rework/year	2172	407
Rework cost/ piece	$4 (297 IR)	$4 (297 IR)
Total rework cost	$17,376 (1291600 IR)	$3,256 (242030 IR)
Total revenue earned	$315,000 (23414600 IR)	$358,000 (26610860 IR)
Potential monetary saving due to GLS project execution	$43,000 (3196280 IR)	

The case company achieved considerable gains in terms of operational parameters, environmental measures through the successful execution of the GLS project. This demonstrates the capability of the proposed GLS framework to mitigate the modern challenges of the manufacturing industries.

Manufacturing companies are one of the prominent waste producers and sponsors of environmental pollution, posing a threat to environmental sustainability. Societal and ecological concerns have made a call for organizations, particularly manufacturing enterprises, to meet sustainability goals [278]. Stringent government policy on climate mitigation measures for manufacturing organizations in developing nations like India has been lead to the development of policies like perform achieve and trade (PAT), zero effect zero defect (ZED) to mitigate GHGs [279]. Through the lens of new policies for manufacturing community, manufacturing organizations have to relook operations and assessment of environmental and associated wastes. So, to mitigate environmental challenges, industrial organizations need a constructive measurement, analysis of various wastes/ emissions. GLS is sustainable approach that address modern challenges of manufacturing provide constructive measurement, analysis of wastes, emission and facilities measures to control and reduce the same.

The GLS importance is increasing constantly due to its positive effects on quality determinates environmental impacts, and the social dimension of sustainability. The Integrated GLS approach makes an organization more competitive in long run at a global platform through the delivery of high specifications and eco-friendly products. But this integration demands considerable pursuits to identify standard toolset and associated framework to realize this sustainable approach. The major challenge for industries, that want to embed green technology within LSS is the non-availability of a dedicated framework that provides comprehensive guidelines to systematically remove wastes, defects, emissions and leads to operational excellence. Intrinsically, past studies have focused on theoretical frameworks but these have lacked empirical justification and experimental authentication. So, previous studies demand the research for the GLS framework that is generic, used in a different context, and incorporates all aspects of sustainability. Moreover, there is a high possibility of implementation failure of sustainable LSS frameworks in different projects [57]. So, to contribute to the production literature by filling the above-mentioned gaps, this research developed a GLS framework as an exclusive practice.

The present research works provide a comprehensive framework of GLS along with different tools that are implemented at different stages of the execution of the GLS program. The proposed framework work can be used as a pilot framework for the realization of GLS in a single section or department of the organization. Moreover, the same framework can be extended within the entire organization after its successful execution as a pilot project. The said framework work provides insights to industrial managers and practitioners to identify sustainability-oriented GLS project that exhibits the most potential for improvement in all the aspects of sustainability. The developed framework exhibits the application of different tools of Six Sigma, Lean, and Green technology to identify and assess different metrics pertains to wastes, defects, emission, and related to the social dimension of sustainability. The framework has been developed solely for manufacturing industries and incorporates all aspects of sustainability that were not considered by researchers in the past. Ruben et al. [161] developed a framework of LSS with environmental facets but did not address how the developed framework can be adopted by small-scale industries. Moreover developed LSS framework did not consider the societal aspects of sustainability. In the existing framework, a stepwise method to identify major reasons for different wastes and inefficacy has been found using C& E diagram and 5 Why analysis. The systematic identification of the prominent causes for wastes, emissions, and other inefficacy will make the industrial professions adept in the processing for searching in continuous improvement plans in the future. Once the leading causes for wastes, environmental issues, societal issues, rework, and ineffective material handling were determined, potential solutions were proposed, tested and the best solutions implemented. In this step, high creativity is desired from organizational staff to find the best solution that will result in the utmost organizational sustainability. Based on the project team observations, and in due consultation with the stakeholders and management industries have to identify and select the best solution. This step of the adopted framework makes industries arrange different interactive sessions with people from all levels of management including shop floor workers, supervisors, etc. to unearth different notions and solutions for the problems, inefficacies and then finalize the best solution ultimately. The present framework guides manufacturing industry personnel in the execution of tools like 7'S for improved sustainability dynamics by following different rules and regulations in daily practices. Moreover, the adopted framework makes the manufacturing industry more capable to remove different non-value-added activities through the incorporation of different Lean activities to remove issues that pertain to rework, setup time, etc. This framework incorporates the application of the LCA and SLCA to identify the potential areas for improvement in the environmental and social dimensions of sustainability. Gohlami et al. used GLS to improve the operational as well as environmental but the developed framework lacks practical validity in terms of the use of Lean, Six Sigma, and Green technology tools. The systematic application and adoption of LCA and SLCA lead to the identification of different areas for improvements. The present study suggests different improvement areas and actions about environmental sustainability. These suggested areas and actions can be considered by the manufacturing industry practitioners and managers in their respective industries to make the industry more responsive towards corporate social responsibility (CSR).

The present study incorporates societal aspects and includes the LCA approach to estimate the environmental as well as social sustainability level of the organization. The step-wise realization of GLS through a practical case empowers the industrial managers to adopt GLS culture in their respective organizations. Industrial organizations must adopt and implement the proposed framework for a longer duration to sustain desired results in terms of traditional quality characteristics, social and environmental aspects. GLS adoption in the organization demands a culture of continuous learning, readiness to change, and ambience of mutual learning to realize the full potential of this sustainable approach. Thus present study unique contribution lies in assisting industries to estimate different operational, environmental, and social metrics and provide ways to improve and sustain the same for increased organization competitiveness.

The case industry is currently operating with marginal social sustainability and lagging in the area of community investment and local employment opportunities. For community investment industry needs to move from a pure “generous however no outcomes” phase to active involvement and conglomerates in the community organizations. This will enrich industry strategy for creating business opportunities, in the generation of positive and believed relations with customers, regulators and legislators. This will also enhance the organization's human resource capability to attract and retain worthy employees, boosting their morale, and enriching their leadership skill in the time frame. The community investment collaborative and outcome base model will lead to culture building in terms of shaping and incorporating core values that prompt favored employee performance. Finally, it will enhance the industry corporate image, enhance access to prominent customers, enrich the relationship, and provide a place to check for innovative practices.

7.5 Inferences drawn

GLS, environmental facets, and social considerations have been integrated with a view of reducing waste, consumption of resources, cultivating employee health, and well-being. The contribution of this research work lies two-fold, firstly, the GLS framework has been proposed to guide in carrying out the activities of execution of this approach. The proposed framework provides an opportunity to the manufacturing industries to improve environmental wastes, increased capacity utilization, handling of items, along with improvement in societal dynamics through the deployment of tools like EVSM, LCA, SLCA, Kaizen, etc. Secondly, this study demonstrates the practical benefits of using the proposed GLS through its successful implementation framework in a manufacturing setting through systematic embedment of Lean, Six Sigma, and Green technology tools. Successful execution of the proposed framework has led to a reduction in the level of rework, defects, and environmental wastes, together with improvement in operational and monetary gain. After successful execution of the GLS framework in the case industry, raw material consumption improved by 17.81%, power usage reduced by 17.31%, coolant intake reduced by 25.81%, and capacity waste reduced by 18.16%. The GLS project brings a monetary saving of $ 43000 (3196280 Indian rupees) through the successful execution of this framework. The present study assisted the industry to understand its current level of environmental impacts and enabled it to pinpoint further on reducing emissions and wastes through the incorporation of more green technology measures.

This chapter outlines the conclusions drawn from this research work. Moreover, this chapter also presents future research scopes for potential researchers, practitioners, and industrial managers.

8.1 Conclusions

The present research work tests the capability of Green Lean Six Sigma to reduce capacity wastes together with environmental emissions and enhances financial and societal aspects of sustainability for the manufacturing industry. The inferences drawn from the present research work are as follows:

- To meet the environmental regulations and customer perception of quality, the organizations need to understand the characteristics and interrelationship of GLS enablers. Twelve enablers pertain to GLS implementation have been found suitable to be modelled and analyzed using ISM and MICMAC. Modelling of GLS enablers facilitates the organizational managers to understand the mutual relationship and linkage of various enablers and that will penultimate results in the successful execution of the GLS program.
- In developing countries like India, the implementation of GLS in the manufacturing environment is difficult due to the lack of alternate technology and resistance of the organization to a new approach. With this in mind, the researchers screened GLS enablers in the manufacturing environment and further rank them using the BWM approach so that organizations may pay attention to high-rank enablers at the initial stage of the GLS execution. Based on experts' opinions, seven enablers to the implementation of GLS in the manufacturing sector were considered. The enablers ‘organizational readiness for GLS measures together with competence for green product and process (E1); ‘top management commitment toward sustainable performance improvement (E2)’ have been identified as the top ranked enablers. The manufacturing sector during the first

stage of implementation must provide a due focus on these enablers and subsequently shift focus to other enablers.

- Besides, eighteen barriers pertain to GLS have been found through comprehensive literature survey and further formulated into six logical groups using PCA. The study depicts that cause barriers are: management-related, environmental-related, and organizational related. The cause barriers have a consequential effect on training, knowledgebase, and continuous improvement barriers. Further, through prioritization of the GLS barriers, it can be concluded that top-ranked barriers like management related and environmental centered barriers should be tackled first for the incremental application of the GLS.
- LCA has been recognized as an important tool for sustainable development through the assessment and analysis of carbon footprints and associated wastes. Ten barriers pertain to LCA implementation in the manufacturing industry of India have been identified and prioritized through GRA. The manufacturing organizations can mitigate negative environmental impacts and implement LCA by removing the barriers of effective data assimilation, feedback both upstream and downstream of the process, and linking green initiatives with the organizational objectives of the manufacturing organizations. Moreover, the study provides a dedicated LCA framework and includes every dimension of sustainable development, and provides a rigorous approach for the assessment and interpretation of environmental impacts
- Organizations must understand critical elements and implementation methods of GLS to meet the sustainable oriented customer demand. The integration of the GLS has been presented based on theoretical elements: enablers, barriers, and toolset. The enablers stimulate GLS integration, and barriers work as a hindrance in the integration of GLS. The associated tools and implementation methods supplement the integration of the GLS. Moreover, to execute GLS in industrial organizations, a unique DMAIC based framework has been presented in this work. The proposed framework provides a systematic path for GLS execution

right from project identification to assessment of improvement of the system under consideration. The stepwise framework has supplemented with GLS tools that facilitate the industrial managers to execute this sustainable approach irrespective of size, type, and culture of the industry.

- Green Lean Six Sigma, environmental facets and social considerations have been integrated with a view of reducing waste, consumption of resources, cultivating employee health, and well-being. The contribution of this research work pertains to framework lies in two-fold, firstly, GLS framework has been proposed to guide in carrying out the activities of execution of this approach. The features and constituents of the framework have been modeled in such a way that it would bring the deliverables more effectually when applied to a manufacturing setting. The proposed framework provides an opportunity to the manufacturing industries to mitigate environmental wastes, increase capacity utilization, handling of items, along with improvement in societal dynamics through the deployment of tools like EVSM, LCA, SLCA, Kaizen, etc. Secondly, this study demonstrates practical benefits of using the proposed GLS framework through its successful implementation in a manufacturing setting through systematic embedment of Lean, Six Sigma, and Green technology tools. Successful execution of the proposed framework led to a reduction in the level of rework, defects, and environmental wastes, together with improvement in operational and monetary gain. After successful execution of GLS framework in case industry, raw material consumption improved by 17.81%, power usage reduced by 17.31%, coolant intake reduced by 25.81%, and capacity waste reduced by 18.16%. The GLS project brings a monetary saving of $ 43000 (3196280 Indian rupees) through successful execution of this framework. The present study assisted the industry to understand its current level of environmental impacts and enabled it to pinpoint further on reducing emissions and wastes through the incorporation of more green technology measures. The present research work contributes to the ecological balance and welfare of humanity through reduced emission, wastes, and defects by the systematic deployment of the proposed GLS framework. Moreover, the study pays towards the prestigious target of the Paris pact set by the country to mitigate GHGs through a systematic reduction in material usage, reduced energy usage, defects, reworks, etc. Besides, the study also contributes to the knowledge base of social sustainability assessment and provides measures to improve the community investment for improved social metrics.

8.2 Future research agenda

The work presented in this thesis work shows that how the limitations of Green Lean (GL) and Lean Six Sigma (LSS) can be addressed by integrating them under the umbrella of Green Lean Six Sigma. This work presents enablers, barriers, integration, and framework of GLS to enhance all aspects of sustainability of the industry. Moreover, to address the environmental and social sustainability of the manufacturing industry a dedicated LCA framework and different barriers to execution of LCA are also investigated. The findings of the present research work can be extended in the future by potential researchers, practitioners, etc. The future scopes of the present study are as follows:

- The present work considers the enablers of GLS based on experts' opinion and the proposed ISM based model of GLS enablers have not been tested statistically and practically. This shortcoming provides the direction for future work as proposed model can further be validated in the future statistically using Structural Equation Modeling and can be tested within a manufacturing industry.
- In the present study, the researchers considered twelve enlisted enablers and further screened seven prominent enablers of GLS for the manufacturing sector, but still, it cannot be deduced that no other than these enablers affect the successful implementation of GLS. So, in offing potential researchers may explore more enablers of GLS, and can also project enablers based GLS framework. Moreover, this research work emphasizes the manufacturing organization and its results may vary from industry to industry. The present work can be explored further by considering other industrial sectors like healthcare,

hospitality, food processing, education, construction, textile, etc. Moreover, in future, as literature of GLS is increasing continuously, more enablers can be found and further modeled using SEM technique.

- Given the infancy of LCA interventions in research and practice pertains to the manufacturing sector in developing nations, the analysis presented in this work was based on the expert's opinion, so the biasness in the experts' judgment may prevail. Although, it is expected that findings may have wider applicability further studies in different manufacturing industries, size, and country contexts should be undertaken to validate findings. Finally, in the present work, ten prominent barriers that hinder LCA implementation in manufacturing industries of India have been identified, but in offing, with growing literature of LCA, the list can be extended by including some other barriers that may arise from rapid organizational and technological advancements.
- Overall, this study provides useful insights into the implementation of LCA in the manufacturing environment, encouraging in these ways its application. So, it provides trustworthy evidence for practitioners and industrialists of LCA barriers that hinders its execution. Hence, empirically validation of barriers in different manufacturing industries according to size, type, and culture is a future research agenda derived from the current research work. In the future, barriers to blockchain-based LCA can also be found and an underlining relationship among the same can be adjudged using multi-criterion decision making (MCDM) approaches. In future research work, relationship model among the barriers between GLS and LCA can be established to adjudge contextual relationship among barriers.
- Future research work could focus on the wider application of the proposed framework in different industrial organizations for further validation of the framework. The developed framework is only limited to the manufacturing environment, in the future researchers can develop a framework with further modification in the steps and tools to other industrial sectors like healthcare,

textile, hospitality, etc. Future research could also consider measures to integrate mechanism and model with the existing framework for increased employee utilization, customer engagement, community investment pursuits, etc. to yield and quantify significant improvements. In offing, researchers and practitioners could explore more avenues to incorporate measures and tools for improved workforce management, better process control/monitoring health and safety of organizational members. Furthermore, the researchers and practitioners in the future can focus on grey areas in the development of GLS, like identification and measurement of metrics of green and lean, assessment of the effects of integrated GLS, and Industry 4.0 for capacity waste reduction in manufacturing organizations. Future research can also focus on the role of GLS for sustainability enhancement through industry 4.0 and modelling and investigation of barriers pertain to integrated GLS and industry 4.0 approach.

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List of Publications

1. Kaswan, M. S., & Rathi, R. (2019). Analysis and modeling the enablers of green lean six sigma implementation using interpretive structural modeling. *Journal of cleaner production*, *231*, 1182-1191.
2. Kaswan, M. S., & Rathi, R. (2020). Green Lean Six Sigma for sustainable development: Integration and framework. *Environmental impact assessment review*, *83*, 106396.
3. Kaswan, M. S., & Rathi, R. (2020). Investigating the enablers associated with implementation of Green Lean Six Sigma in manufacturing sector using Best Worst Method. *Clean Technologies and Environmental Policy*, 1-12.
4. Kaswan, M. S., & Rathi, R. (2021). Investigation of life cycle assessment barriers for sustainable development in manufacturing using grey relational analysis and best worst method. *International Journal of Sustainable Engineering*, 1-14.
5. Kaswan, M.S. & Rathi, R. (2021) An inclusive review of Green Lean Six Sigma for sustainable development: readiness measures and challenges. *Int. J. Advanced Operations Management.*
6. Yadav, V., Gahlot, P., Kaswan, M.S. and Rathi, R. (2021) Green Lean Six Sigma critical barriers: exploration and investigation for improved sustainable performance. *Int. J. Six Sigma and Competitive Advantage*.
7. Rathi, R., Vakharia, A. & Kaswan, M.S. (2021) Grey relational analysis of Green Lean Six Sigma critical success factors for improved organisational performance. *Int. J. Six Sigma and Competitive Advantage*.
8. Singh, M., Rathi, R., & Kaswan, M. S. (2021). Capacity utilization in industrial sector: a structured review and implications for future research. *World Journal of Engineering*.
9. Kaswan, M.S., Rathi, R, Garza Reyes Jose Arturo & Antony Jiju, Green Lean Six Sigma Adoption Barriers for Manufacturing Sustainability: An IF-DEMATEL and BWM Approach. *IEEE Transaction on Engineering and Management* (

Preparing Revision)

10. Kaswan, M.S., Rathi, R., Garza Reyes Jose Arturo & Antony Jiju .Green Lean Six Sigma Sustainability Oriented Project Selection and Implementation Framework for Manufacturing Industry. *International Journal of Lean Six Sigma* (Under review).
11. Kaswan, M.S., Rathi, R. & Yadav, V. Integral Measures and Framework for Green Lean Six Sigma Implementation in Manufacturing Environment. *International Journal of Sustainable Engineering.*
12. Kaswan, M.S., Rathi, R., Garza Reyes Jose Arturo & Antony Jiju. A green lean six sigma framework for improving sustainability of manufacturing industry: An empirical investigation. *Renewable and Sustainable Energy Review* (under review).
13. Kaswan, M. S., Rathi, R., & Vakharia, A. (2020). Sustainability through Green Manufacturing Systems: An Applied Approach. In *Circular Economy for the Management of Operations* (pp. 69-88). CRC Press.
14. Kaswan, M. S , Yadav, V., Gahlot, P. & Rathi, R. Sustainable Green Lean Six Sigma methodology and application status: A perspective review. *International Conference on Advanced in Sustainable Technologies.*
15. Kaswan, M. S., & Rathi, R. (2021). Prioritization of Sustainable Development Methods in the Manufacturing Sector: An Entropy TOPSIS Approach. *Advances in Industrial and Production Engineering: Select Proceedings of FLAME 2020*, 443.

APPENDIX

Steps of PROMETHEE II

	S 1: Normalize decision matrix			
E1-E2	2	0.333	0.5	0
E1-E3	1	0	0	1
E1- E4	2	0.333	0	0.5
E1-E5	2	0	0	0
E1-E6	1	0	0	0.5
E1-E7	2	0	0.5	0.5
E2-E1	0	0	0	0
E2-E3	0	0	0	1
E2- E4	0	0	0	0.5
E2-E5	0	0	0	0
E2-E6	0	0	0	0.5
E2-E7	0	0	0	0.5
E3-E1	0	0.666	0	0
E3-E2	1	1	0.5	0
E3- E4	1	1	0	0
E3-E5	1	0	0	0
E3-E6	0	0.334	0	0
E3-E7	1	0.334	0.5	0
E4-E1	0	0	0	0

E4-E2	0	0	0.5	0
E4- E3	0	0	0	0.5
E4-E5	0	0	0	0
E4-E6	0	0	0	0
E4-E7	0	0	0.5	0
E5-E1	0	0.667	0.5	0
E5-E2	0	1	1	0
E5- E3	0	0	0.5	1
E5-E4	0	1	0.5	0.5
E5-E6	0	0.334	0.5	0.5
E5-E7	0	0.334	1	0.5
E6-E1	0	0.333	0	0
E6-E2	1	0.666	0.5	0
E6- E3	0	0	0	0.5
E6-E4	1	0.666	0	0
E6-E5	1	0	0	0
E6-E7	1	0	0.5	0
E7-E1	0	0.333	0	0
E7-E2	0	0.666	0	0
E7- E3	0	0	0	0.5
E7-E4	0	0.666	0	0
E7-E5	0	0	0	0
E7-E6	0	0	0	0

S 2: Calculate evaluative difference				S3: Calculate preference function
0.8	0.0999	0.1	0	0.9999
0.4	0	0	0.15	0.55
0.8	0.0999	0	0.075	0.9749
0.8	0	0	0	0.8
0.4	0	0	0.075	0.475
0.8	0	0.1	0.075	0.975
0	0	0	0	0
0	0	0	0.15	0.15
0	0	0	0.075	0.075
0	0	0	0	0
0	0	0	0.075	0.075
0	0	0	0.075	0.075
0	0.1998	0	0	0.1998
0.4	0.3	0.1	0	0.8
0.4	0.3	0	0	0.7
0.4	0	0	0	0.4
0	0.1002	0	0	0.1002
0.4	0.1002	0.1	0	0.6002
0	0	0	0	0
0	0	0.1	0	0.1

0	0	0	0.075	0.075
0	0	0	0	0
0	0	0	0	0
0	0	0.1	0	0.1
0	0.2001	0.1	0	0.3001
0	0.3	0.2	0	0.5
0	0	0.1	0.15	0.25
0	0.3	0.1	0.075	0.475
0	0.1002	0.1	0.075	0.2752
0	0.1002	0.2	0.075	0.3752
0	0.0999	0	0	0.0999
0.4	0.1998	0.1	0	0.6998
0	0	0	0.075	0.075
0.4	0.1998	0	0	0.5998
0.4	0	0	0	0.4
0.4	0	0.1	0	0.5
0	0.0999	0	0	0.0999
0	0.1998	0	0	0.1998
0	0	0	0.075	0.075
0	0.1998	0	0	0.1998
0	0	0	0	0
0	0	0	0	0

S4: Calculate aggregated preference							
	E1	E2	E3	E4	E5	E6	E7
E1		0.999	0.55	0.9749	0.8	0.475	0.975
E2	0		0.15	0.075	0	0.075	0.075
E3	0.1998	0.8		0.7	0.4	0.1002	0.60002
E4	0	0.1	0.075		0	0	0.1
E5	0.3001	0.5	0.25	0.475		0.2752	0.3752
E6	0.0999	0.6998	0.075	0.5998	0.4		0.5
E7	0.0999	0.1998	0.075	0.1998	0	0	
Entering flow	0.116617	0.549767	0.195833	0.504083	0.266667	0.154233	0.437537

S5: Calculate net flow			S6: Calculate ranks
Outranking flow	Entering flow	Net flow	Ranks
0.79565	0.116616667	0.67903	1
0.375	0.549766667	0.27083	2
0.46667	0.195833333	0.34179	6
0.045833333	0.504083333	0.17477	5
0.362583333	0.266666667	0.45825	7
0.39575	0.154233333	0.241517	3
0.09575	0.437537	0.095917	4

Steps of AHP

Steps evolved in AHP are as follows:

STEP 1: Make comparison matrix from pairwise comparison

A Comparison matrix that is reciprocal matrix, made from pairwise comparison. Whenever we compare same element to same we assign it a value "1". Further, if the judgmental value is on the left side of "1", we put the actual judgmental value whereas if it is on the right side of "1" put the reciprocal value. The value of each element against another one was given by taking view from industrial personnel with "1" is the least important and "9" is the most important. Responses were taken from 7 industrial personnel and comparison matrix is average of all the responses

STEP 2: Sum up each column of the reciprocal matrix

In second step, summation of each column of the reciprocal matrix was carried out.

STEP 3: Divide each element of the second matrix with the sum of its column, we obtain normalized relative weight.

In this step, each element of the second matrix was divided by the sum of its column to obtain normalized relative weight.

STEP 4: Estimation of row wise sum of each row of weighted Matrix

In the next step row wise sum of each row was carried out.

STEP 5: Estimation of weighted matrix

To obtain the weighted matrix sum of last column of weighted matrix was carried out Then each element of last column was divided by summation of last column of weighted matrix to obtain the weights. The weighted matrix was

w = [0.2266, 0.1912, 0.1032, 0.0969, 0.075, 0.1944, 0.1127]

Since it is normalized, the sum of all the elements in priority vector is 1. The priority vector shows the relative weights among the factors considered.