Development and Validation of an Integrated Framework of Lean Six Sigma and Agile Manufacturing for Indian Industries

THESIS

Submitted in partial fulfilment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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Under the Supervision of

Prof. Rajesh Prasad Mishra

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI

2023

...Dedicated

to

My Beloved Family

&

Parents...

BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE

PILANI -333031 (RAJASTHAN) INDIA

CERTIFICATE

This is to certify that the thesis entitled **"Development and Validation of an Integrated Framework of Lean Six Sigma and Agile Manufacturing for Indian Industries"** submitted by **NIDHI MUNDRA,** ID. No. **2016PHXF0101P** for the award of Ph.D. Degree of the Institute embodies the original work done by her under my supervision.

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ABSTRACT

The purpose of the study is to develop and validate Critical Success Factors (CSFs); Critical Failure Factors (CFFs) and integrated implementation framework of Lean Six Sigma (LSS) and Agile Manufacturing (AM) implementation with a focus on Indian Manufacturing Industries. This study also emphasizes the literature review of LSS, AM and their integration field to understand their evolution; integration benefits; critical success factors and critical failure factors for implementation. To achieve the objectives of the proposed study a systematic literature review of research articles of LSS, AM, Leagile (Lean-Agile) and LSS-AM, based on descriptive analysis (research methodology, author's demography, distribution of papers over time, journal and publishers, type of sector, type of approach) and content analysis (CSFs, CFFs, performance outcomes, frameworks, application in SME's and MSME's and research trends of integration of LSS/AM /Leagile with other approaches) is carried out to uncover their evolution, definition, and research gaps. Further CSFs to and CFFs for LSS-AM are identified from the vast literature review and experts' opinions. These factors are endorsed through Structural Equation Modeling (SEM). To identify the hierarchy and degree of influence of one factor over another, individual models of CSFs and CFFs are developed through Fuzzy-Total Interpretive Structural Modeling (Fuzzy-TIMS). CSFs and CFFs are categorized through MICMAC (Matrice d' Impacts Croisés-Multiplication Appliquée. un Classement) analysis. A critical review of existing LSS, AM, Leagile, and LSS-AM frameworks is carried out. Frameworks are classified based on approach, type, sources, verification and mode of verification. Further, a comparative analysis of these frameworks is performed. Based on the limitations of existing frameworks, an integrated implementation framework of LSS-AM has been developed. To validate the applicability of the proposed integrated implementation framework in the real world, an Action Research (AR) case study in eco-friendly paper products manufacturing MSME has been carried out.

It is expected that the outcome of the proposed research will be beneficial to industries managers and researchers in the field of LSS and AM. Comprehensive details about CSFs and CFFs to LSS-AM implementation will make industries managers' journey of implementation smooth. The proposed integrated framework of LSS-AM implementation will also be helpful for the industries to implement LSS-AM effectively to get a competitive advantage by improving overall performance. From the researchers'

point of view this study provides vast literature about the LSS, AM and Leagile definitions; frameworks; LSS and AM tools; types of industries and the synergy of integration.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol/Abbreviation	**Description**
AAA	Attribute Agreement Analysis
AEP	Adyah Eco Products
AGFI	Adjusted Goodness of Fit Index
AGV	Automated guided vehicle
AHP	Analytic Hierachy Process
AM	Agile Manufacturing
AMOS	Analysis of Moment Structures
ANOVA	Analysis of Variance Analysis
ANP	Analytic Network Process
AR	Action Research
AVE	Alpha Variance Explained
BB	Black Belt
BWM	Best-Worst Method
C/T	Cycle Time
C&E	Cause and Effect
C&P	Counting and Packaging
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CBA	Cost Benefit Analysis
CFA	Confirmatory Factor Analysis
CFF	Critical Failure Factor
CFI	Comparative Fit Index
CI	Continuous Improvement
CITC	Corrected Item Total Correction
CLCSS	Credit linked capital subsidy for technology upgradation
CPCB	Central Pollution Control Board
C_{PK}	Actual Process Capability (Short term)
CR	Composite Reliability
CSF	Critical Success Factor
CTQ	Critical to Quality
CVSM	Current Valuse Stream Mapping
DEMATEL	Decision Making Trial and Evaluation Laboratory

DMAIC	Define Measure Analyze Improve and Control
DOE	Design of Experiment
DOF	Degree of Freedom
DPMO	Defects per Million Opportunity
DPU	Defects per Unit
EFA	Exploratory Factor Analysis
ERP	Enterprise Resource Planning
FDA	Food and Drugs Administation
FMCG	Fast Moving Consumer
FMEA	Failure Mode and Effect Analysis
FTY	First-time yield
Gage R& R	Gage Repeatability and Reproducibility
GDP	Gross Domestic Product
GFI	Goodness of Fit Index
I-MR	Individual Moving Range
ISM	Interpretive Structural Modeling
JIT	Just in Time
KMO	Kaiser-Meyer-Oklin
KPI	Key Performance Indicator
KPIV	Key Performance Input Variable
KPOV	Key Performance Output Variable
LAMP	Lean and Agile Multi-Dimensional Process (LAMP)
Leagile	Lean-Agile
LM	Lean Manufacturing
LSS	Lean Six Sigma
MCDM	Multi-Criteria Decion-Making
MIC-MAC	Matriced Impacts Croises Multiplication Appliquesaun Classement
MIS	Management Information System
MLE	Maximum Likelihood Estimation
MMT	Million Metric Tonne
MOQ	Minimum Order Quantity
MRP	Material Resource Planning
MSA	Measurement System Analysis
MSME	Micro Small Medium Enterprise
NFI	Normed Fit Index
NVA	Non value added
OEE	Overall equipment effectiveness
PCE	Process Cycle Efficiency
PDCA	Plan-DO-Check-Act
PFMEA	Process Failure Mode and Effect Analysis

P_{PK}	Actual Process Capability (Long term)
PPM	Parts Per Million
QC	Quality Check
QFD	Quality Function Deployment
QMS	Quality Management Standards
QTT	Quality Technology Tools
RMSEA	Root Mean Square Error of Approximation
RPN	Risk Priority Number
RTY	Rolled throughput yield
SDMMAICS	Selection Define Measure Map Analyze Improve Control Sustain
SEM	Structural Equation Modeling
SIPOC	Supplier Input Process Output Control
SLR	Systematic Literature Review
SM	Straw Manufacturing
SME	Small Medium Enterprise
SMED	Single Minute Exchange of Die
SOP	Standard Operating Procedure
SPC	Statistical Process Control
SPSS	Statistical Package for Social Sciences
SRMR	Standardized Root Mean Square Residual
SS	Six Sigma
SSIM	Structural Self-Interaction Matrix
TAT	Turnaround Time
TISM	Total Interpretive Structural Modeling
TOPSIS	Technique for Order Performance by Similarity to Ideal Solution
TPM	Total Productive Maintenance
TQM	Total Quality Management
TWI	Tucker-Lewis Index
UAE	United Arab Emirates
UK	United Kingdom
USA	United States of America
VA	Value Added
VIKOR	VIekriterijumsko KOmpromisno Rangiranje
VOC	Voice of Customer
VSM	Value Stream Mapping
VUCA	Volatility Uncertainty Complexity Ambiguity
WIP	Work In Process
Z_{bench}	Sigma level

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WIP	Work In Process
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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF LEAN SIX SIGMA AND AGILE MANUFACTURING

Rapid Globalization, dynamic demands and market turbulence are compelling organizations to adopt new operational improvement initiatives to sustain in the market. Further, the Covid-19 pandemic has hit hard in every aspect of life. This pandemic has trembled up the manufacturing sector, which contributes a vital part to any nation's GDP. This pandemic has triggered volatility and cutthroat competition in the market. Furthermore, customers are more demanding than ever. To face these challenges, manufacturing industries are looking forward to new order-winning operational improvement initiatives. Deployment of strategies such as lean manufacturing (LM), Six Sigma (SS) and agile manufacturing (AM) individually has received immense attention in the past few years. Now the integration of Lean Six Sigma (LSS) and AM can be seen as a favorable operational improvement initiative to bounce back from the current situation. Therefore integration of LSS –AM is a convincing improvement initiative to foster the organizations in fulfilling dynamic demands responsively at low cost without compromising on quality.

LM is a continuous process improvement approach having a fundamental goal to eliminate waste and maximize the process flow. In other words, LM is a systematic approach to improve processes efficiently and economically by eliminating non-value-added activities and enabling the value flow continuously as per the customer pull. LM roots came from Japan’s Toyota Production System (TPS), prominently developed by two Japanese engineers i.e. Taiichi Ohno and Shigeo Shingo. LM term first came into existence from MIT’s 5 million, 5-year research study in International Motor Vehicle Program (IMVP) in 1988. This study discussed the significant difference in performance between the western and Japanese automobile manufacturing industries. However, the term “Lean” became famous after the Womack *et al*. (1990) book “Machine that the World”. Womack and Jones (1997) defined LM’s five core principles i.e. define the value, identify/map the value stream, create a continuous value flow, establish a pull system and pursue perfection. Initially, LM was implemented in the automobile sector only but in the past two decades; LM has received enormous attention in each type of sector because of its benefits such as productivity improvements and cost reductions by waste elimination.

On the other hand, Motorola launched the SS program in the mid-1980s to improve the quality by 10 times within five years. Bill Smith, an engineer at Motorola, derived the term "Six Sigma". Later in 1996, Jack Welch launched SS at GE. SS is a systematic data-driven approach, which has a prime focus to reduce variation and defects in a process to enhance quality, customer satisfaction and organizational performance. In other words, it is a metric that represents the performance of the process at 99.99967 percent on the quality scale. The core of SS is its five-phase methodology i.e. Define, Measure, Analysis, Improve and Control (DMAIC).

Nowadays the synergy of lean and SS seems to be a renowned continuous improvement (CI) operational improvement initiatives to reduce the cost, increase productivity; enhance product quality in the manufacturing sector. In 1986, George group integrated Lean and Six Sigma but this synergy received widespread popularity in the early 2000s’ when several research articles about LSS were published. This merger concealed the individuals' limitations, as SS stand-alone is incapable to eliminate all types of muda in the process whereas lean solitary is unable to reduce the variation in the process and bring it under statistical control (Antony, 2011). LSS is an operational improvement initiative, which has the main objective to bring the process into control; eliminating waste hence enriches the bottom-line results of any organization (Snee, 2010). Lean and SS complement each other by handling process inefficiency (lean) and process variation (SS) in a single effort (Arumugam *et al*. 2012). In LSS, the DMAIC approach forms the core framework for process improvement and lean five principles of lean tools are embedded in each phase.

Over a period of 22 years, LSS has been implemented in both manufacturing and service sectors immensely to get both qualitative and quantitative benefits. The majority of service sectors such as healthcare, higher education institutes, telecommunication and banking deployed LSS to improve service quality, enhance stakeholder satisfaction, reduce turnaround time (TAT), and optimize resource allocation (Su *et al*. 2006; Heuvel 2006; Koning *et al*. 2006, Kanakana *et al*. 2010, etc.). Application of LSS in various manufacturing sectors such as aerospace manufacturing, automobile and parts manufacturing, food and construction, touch panel manufacturing, reamer manufacturing small-scale furniture manufacturing, bolt manufacturing and printing SMEs have been found profoundly to improve performance matrices i.e. process capability index, (C_p and C_{pk}), rolled throughput yield (RTY), overall equipment effectiveness (OEE), defects per unit (DPU), cycle time, reduction in lead time and costs simultaneously (Chen and Lyu,2009, Wang and Chen 2012, Dora *et al.* 2015 etc.)

Despite of several advantages of LSS, it is incapable of fulfilling the customers' demand in turbulent market conditions when demands are unstable. However, neither LM nor SS addresses the total requirements demanded by the current market, which includes a simultaneous focus on efficiency and quality, as well as flexibility (Yaghoubi and Banihashem, 2010). In this scenario, AM has emerged as one of the vital weapons to give a competitive advantage to the organization in a turbulent business environment (Kumar *et al*., 2019a). The term "agile" was originated by a group of researchers at Lehigh University in 1991. Further, in 1999, Gunasekaran defined AM as burgeoning manufacturing, originating from the novel concept of LM. In philosophies, AM is defined as the ability to reconstruct and communicative adaptability to operate in unstable environments (Leite and Braz, 2016). In other words, AM is the strategy by which the industry can quickly react according to the demands and expectations of its customers. It is mutually fit with other approaches such as LM; computer-integrated manufacturing (CIM); total quality management (TQM); material requirement planning (MRP) and employee empowerment (Kidd, 1994). Delivering value to the customers, being adaptable to change, sharing information & skills sets transparently and quickly, using advanced information-sharing technologies, use of flexible or technologically advanced tools and developing virtual enterprise (to overcome one own incompetency) and quick decision-making are the core principles and practices of agility to sustain in a turbulent environment. Earlier agile was implemented in the software industry only, but the application of AM is gearing up in manufacturing sectors such as automobile, aerospace manufacturing, rotary switch manufacturing and SMEs. In these industries, AM positively improved responsiveness, flexibility, quality, and profitability by integrating resources and AM practices in a customer-driven turbulent market (Dev and Kumar, 2016, Soepardi *et al*., 2018, Kumar *et al*. 2019a).

Agility needs "Lean" as AM is considered to be the next generation advancement of LM (Potdar *et al*., 2017a). Amalgamation of Lean and Agile is known as Leagile, which has its origin in manufacturing supply chains (Katayama and Benett, 1999, Naylor *et al.*, 1999). In a Leagile supply chain, lean manufactures and agile manufacturers are joined by a decoupling point (Krishnamurthy and Yauch, 2007). Ustyugová *et al*. (2014) argued that lean and agile production are conceptually different, however together with attention to customer satisfaction and the production of high-quality goods, an elevated level of competitiveness can be achieved. According to Balkrishna *et al.* (2020), many organizations are adopting lean to eliminate waste, and shorter the lead-time. To fulfill the customized demand and product variety in a highly turbulent market, organizations are keeping their process more agile. The Leagile concept is relatively new to manufacturing industries. It has two dimension wastes elimination and responsiveness (Soltan and Mostafa, 2015). Only a few applications in automobile parts manufacturing and pump manufacturing were found to improve operational cost and time to market, minimization of time in storage and waste, which further helps in cost reduction and improvement in quality of service (Salah and Elmoselhy, 2013, Balkrishna *et al.*, 2020)

LSS and AM have their inherent limitations when implemented individually. Although AM brings responsiveness and flexibility, it is far behind LM in terms of efficiency. On the other hand, LM can't handle the dynamic market demand due to a lack of flexibility. While both LM and AM address basic improvement issues but they don't encompass a problem-solving approach, which is the core competency of Six Sigma (Yaghoubi NM, Banihashemi, 2013). So the perfect blend of LSS-AM practices can be promising business strategies to strike a balance between new competitive order-winning criteria i.e. availability of products, product customization, shorter lead-time, cost and quality.

1.2 RESEARCH MOTIVATION

From the past two years, we have been living in a world of the Covid-19 pandemic. The manufacturing sector has already been facing fierce competition and turbulence globally. The Covid-19 crisis has made the situation worse. Now the manufacturing sector is looking forward to long-term business strategies to come out of such a critical situation. Mass markets are continuously fragmenting into niche markets. As customers are demanding customized products, wider product variety at low-cost and shorter lead-time without compromising on quality. Only organizations nimble enough to react to the dynamic requirements of customers in every form can keep their foothold in the marketplace. In view of the present market scenario integration of LSS and AM can be seen as a captivating approach in the long run. AM, when applied in combination with the LSS approach, can enable an organization to offer desired products and services quickly to its customers without compromising on quality at optimum prices. For the deployment of an integrated LSS–AM operational improvement initiative in any organization, a conceptual as well as a step-by-step structured implementation framework is required. For the successful implementation of any framework, the development of Critical Success Factors (CSFs) and mitigation of Critical Failure Factors (CFFs) are prerequisites.

Although several researchers, consultants, academicians and practitioners have developed frameworks about LSS, and AM individually over a period of time, only two researchers (Shahin and Jaberi, 2011; Dibia and Onuh, 2012) have developed an integrated framework for LSS and AM implementation, significantly fewer in number. Therefore, a strong need arises to develop an integrated LSS-AM implementation framework that gives step-by-step guidelines to implement LSS-AM. Further, comprehensive lists which comprise the principles, practices, tools and techniques or constructs of LSS-AM as a whole are missing and at the same time, a structured framework which depicts these comprehensive sets of elements as a coherent whole is also not present. This indicates that the amalgamation of LSS and AM is still at a nascent stage. Hence there is a need to develop an integrated framework of LSS-AM for the manufacturing industry.

1.3 OBJECTIVES AND SCOPE OF THE STUDY

The following are the objectives that need to be fulfilled by the proposed study

- To develop Lean Six Sigma & Agile Manufacturing critical success factors and critical failure factors
- To validate Lean Six Sigma & Agile Manufacturing critical success factors and critical failure factors
- To develop an integrated implementation framework of Lean Six Sigma & Agile Manufacturing based upon the analysis of existing frameworks of LSS and AM
- To validate the developed integrated implementation framework through a case study in an Indian manufacturing industry

1.4 METHODOLOGY

To fulfill the objectives of the current study; the following steps have been carried out:

- A systematic literature review of research articles of LSS, AM, Leagile and LSS-AM, based on descriptive analysis (research methodology, author's demography, distribution of papers over time, journal and publishers, type of sector, type of approach) and content analysis (critical success factors, critical failure factors, performance outcomes, frameworks, application in SME's and MSME's and research trends of integration of LSS/AM /Leagile with other approaches) is carried out to uncover their evolution, definition, and research gaps.
- CSFs to and CFFs for LSS-AM are identified from the vast literature review and experts' opinions. These factors are endorsed through Structural Equation Modeling (SEM). Further to identify the hierarchy and degree of influence of one factor over another, individual models of CSFs and CFFs are developed through Fuzzy-Total

Interpretive Structural Modeling (Fuzzy-TIMS). CSFs and CFFs are categorized through MICMAC (Matrice d' Impacts Croisés-Multiplication Appliquée. un Classement) analysis.

- A critical review of existing LSS, AM, Leagile and LSS-AM frameworks is carried out. Frameworks are classified based on approach, type, sources, verification and its mode of verification. Further, a comparative analysis of these frameworks is performed. Based on the limitations of existing frameworks, an integrated implementation framework of LSS-AM has been developed.
- To validate the applicability of the proposed integrated implementation framework in real world, an action research (AR) case study in eco-friendly paper products manufacturing MSME has been carried out.

1.5 SIGNIFICANCE OF THE STUDY

The outcome of the proposed research will be beneficial to industry managers and researchers in the field of LSS and AM. Comprehensive details about CSFs and CFFs to LSS-AM implementation will make industries managers' journey of implementation smooth. The proposed integrated framework of LSS-AM implementation will also be helpful for the industries to implement LSS-AM effectively to get a competitive advantage by improving overall performance. From the researchers' point of view this study provides vast literature about the LSS and AM definitions; frameworks; LSS and AM tools; types of industries; the synergy of integration.

1.6 STRUCTURE OF THESIS

- Chapter 1 is an introduction to the thesis, which describes an overview of LSS and AM, research motivation, objectives scope, methodology, and the implication of the proposed study.
- Chapter 2 presents a systematic literature review of 350 papers on LSS, AM, and their integration published during 2000 to August 2022 to uncover their evolution, definition, and research trends. It exhibits and analyzes the various definitions of LSS, AM, and Leagile, reflecting the scope and goals. These articles are analyzed descriptively (journal and publishers; author's demography, distribution of papers over time, research methodology, type of sector, type of approach) and content-wise (critical success factors, critical failure factors, performance outcomes, frameworks, tools/techniques/practices; application in SMEs and SMEs and research trends of integration) to identify the research gap.
- Chapter 3 describes the identification of CSFs to and CFFs for LSS-AM implementation through literature review, validation of them through SEM approach and development of individual models of CSFs and CFFs through Fuzzy-TISM. These Fuzzy- TISM models depict a proper hierarchy of identified LSS-AM CSFs and CFFs and also present the level of influence of one factor on another in manufacturing industries. These CSFs and CFFs are further grouped into 4 clusters using MICMAC analysis. The developed Fuzzy-TISM models were statistically validated through SEM. These models offer more robust results as it allows decision-makers to evaluate the effects of system variables on each other. These models of LSS-AM CSFs and CFFs would provide step-by-step guidance to decision providers, scholars, and consultants to implement LSS-AM successfully.

- Chapter 4 presents a critical review of 41 frameworks of LSS, AM, Leagile and LSS-AM frameworks based on several taxonomies such as type; approach, source, verification and mode of verification. Further, the reviewed frameworks were compared based on abstractness, utilization of frameworks, comprehensiveness and degree of fit basis. A review of the existing articles revealed that existing frameworks are flooded with lots of shortcomings. Further comprehensive lists, which comprise the principles, practices, tools and techniques or constructs of LSS-AM collectively are not found at the same time a well-structured implementation framework of LSS-AM, is also not present. In view of this, a comprehensive list of LSS-AM practices, tools, principles, practices, tools and techniques or constructs are prepared. Further considering the strengths and mitigating the weaknesses of the existing frameworks an integrated LSS-AM implementation framework has been developed.
- Chapter 5 presents an action research case study in an eco-friendly paper product manufacturing MSME to validate the proposed implementation framework in real world. The study has shown the implementation of different phases of proposed framework in case organization, to reduce the production lead -time. The results of the case study revealed that efficiency; effectiveness and responsiveness business performance have significantly improved by eliminating different types of waste; selecting optimum parameters and implementing automation. Further for mass customization virtual enterprises have been developed to fulfill customers varying demands efficiently, effectively and quickly. By implementing the proposed framework case organization gained both tangible and intangible benefits

- Chapter 6 describes the conclusion of the proposed study, which further includes limitations and the future scope of the present study.
- The flow chart of research work is shown in the figure below:

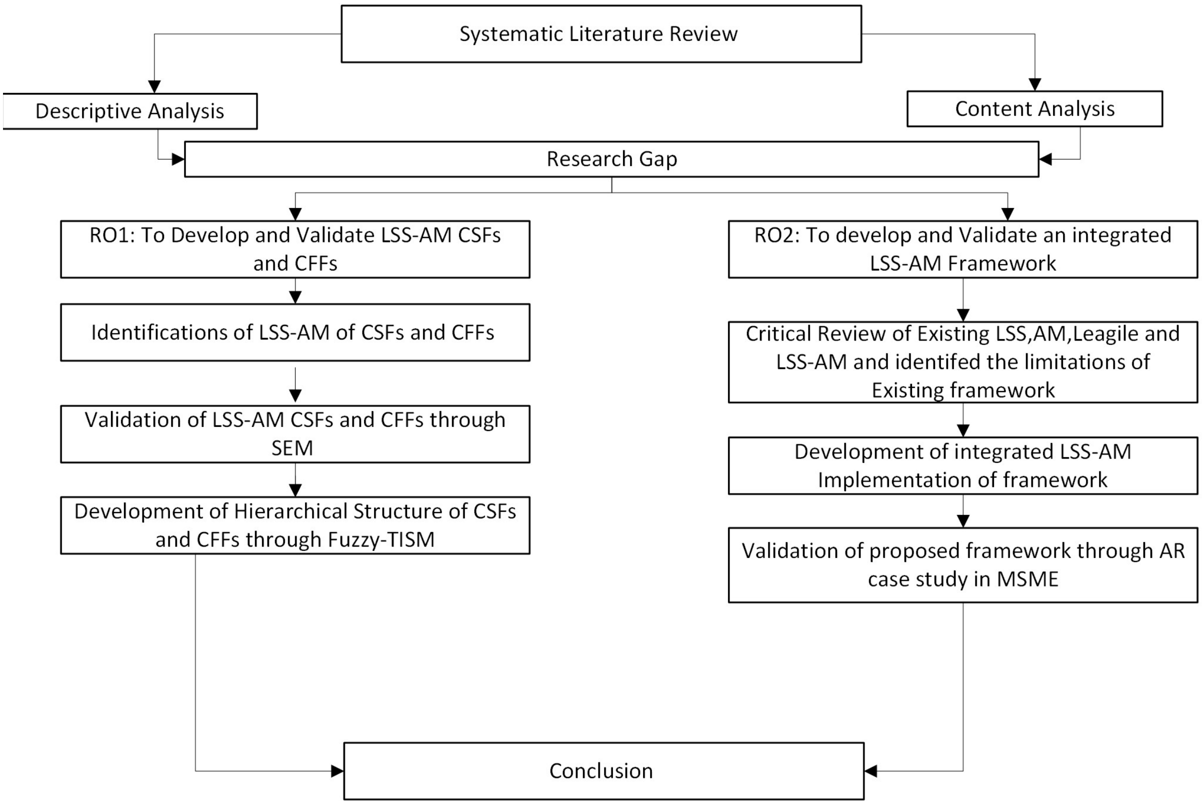

Figure 1.1 Flow Chart of Research Work

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In the 21st century, we are living in VUCA (volatility, uncertainty, complexity, and ambiguity) world, where organizations are facing immense pressure due to globalization and technological advancement. In addition, the Covid-19 pandemic has broken the backbone of the gross domestic product (GDP) of every nation over the last two years. Although the situation has improved and the economy is regaining momentum, the manufacturing sector is facing cutting-edge competition. Customers are demanding a more innovative and wide variety of products with shorter lead time, lower cost and without compromising on quality (Bhamu and Sangwan, 2014, Dubey and Gunasekaran, 2015; Rathi *et al.*, 2015, Kumar *et al.*, 2019a). To fulfill these criteria's fusion of LSS and AM can be seen as a promising business improvement strategy to get a competitive edge.

Therefore this chapter has the following two objectives:

- To study the evolution of LSS, AM, and their integration
- To explore the current state of LSS, AM and their integration from the research outlook from existing research work and identify the research gap.

To cater to the above objectives, a systematic literature review of research articles of LSS, Agile, Leagile and LSS-AM, based on descriptive analysis (research methodology, author's demography, distribution of papers over time, journal and publishers, type of sector, type of approach) and content analysis (critical success factors, critical failure factors, tools/techniques/methodologies/practices analysis, performance outcomes, frameworks, application in SME's and MSME's and research trends of integration of LSS/AM /Leagile with other approaches) has been done. This paper is organized into seven sections. Section 2.2 explains the methodology adopted for carrying out the literature review. Section 2.3 describes the brief background of LSS, AM, Leagile (lean-agile), and various definitions of LSS, AM, and Leagile reported by different authors. Section 2.4 represents the summary of existing literature articles in the domain of LSS, AM, Leagile and their integrated one. Section 2.5 presents the descriptive and content analysis of research articles. Section 2.6 discusses the conclusion and key findings, followed by section 2.7, which explains the limitations and future research issues.

2.2 SYSTEMATIC LITERATURE REVIEW

A systematic literature review (SLR) approach is adopted to analyze the research trends in LSS, AM, Leagile, and LSS-AM. A comprehensive literature review is carried out in LSS, AM, and Leagile individually to build a solid foundation regarding the LSS-AM approach. Articles published from 2000 to august 2022 are part of this literature review to learn the evolution and current trends in LSS, AM, Leagile, and amalgamation. For identification and selection of the articles, the research methodology adopted for the systematic literature review is shown in figure 2.1

The well-known database Scopus was selected for review and searched with the keywords such as "Lean Six Sigma," "Agile Manufacturing," "Lean-Agile," "Leagile," "Agile Six Sigma," "Lean Six Sigma," and "Leagile Six Sigma" in title only field. A total of 2449, number of articles appeared in the search result. Next, further articles published in the English language and Emerald, Taylor- Francis, Inderscience, Springer, IEEE, and Willey publications were included. Then, book chapters and working papers were excluded from the selection. This selection reduced the total articles count to 615. After that, low citations were excluded and based on the abstract, introduction, conclusion, and full paper reading, 350 articles were found relevant for descriptive and content analysis. For the historical background and origin of definitions, cross-references were also used.

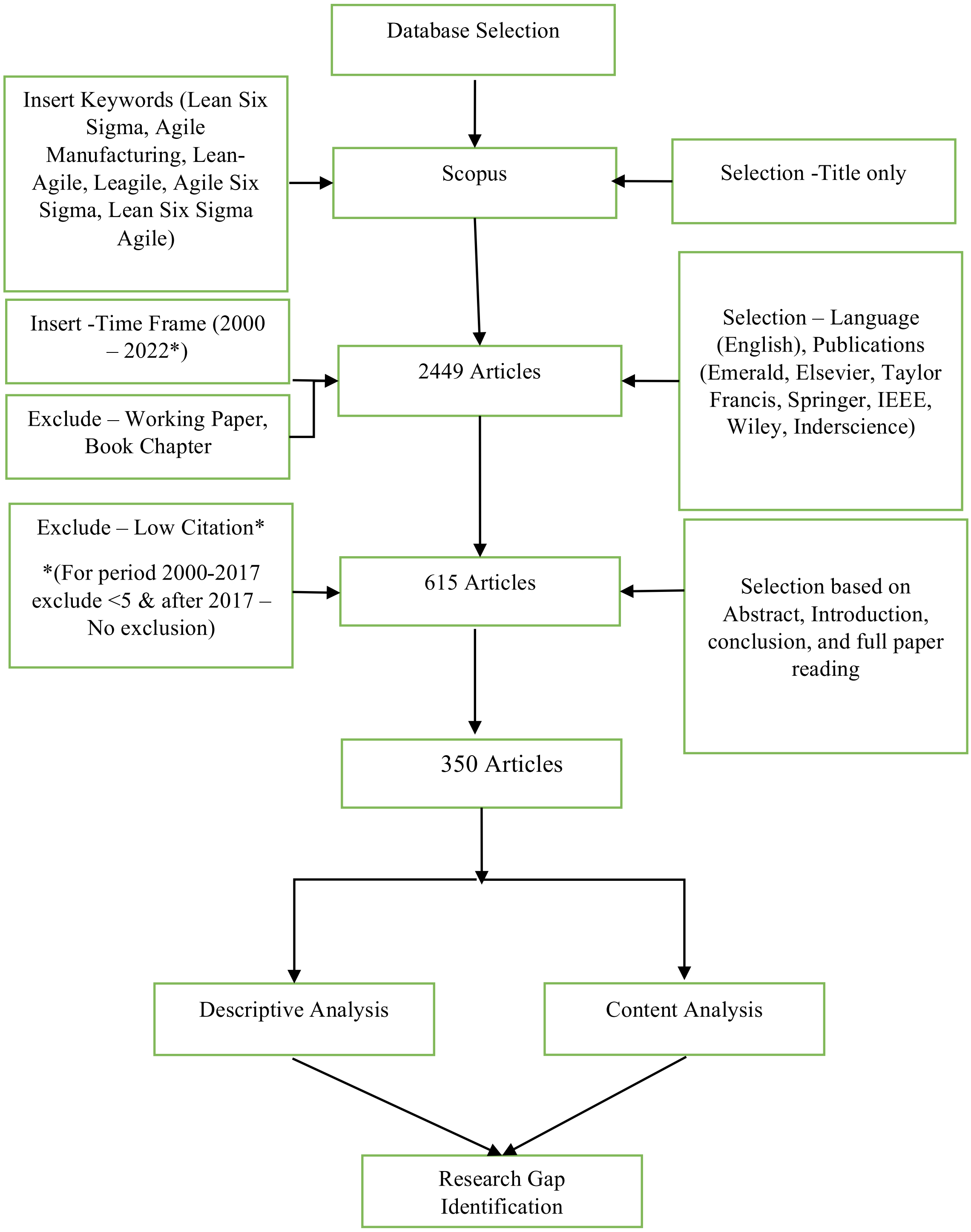

Figure 2.1: Research methodology for Systematic Literature Review

2.3 HISTORICAL OUTLINE OF LSS, AM, AND LEAGILE AND THEIR DEFINITIONS

2.3.1 Brief Background of Lean Six Sigma

Over a while, organizations have evolved and adopted numerous continuous improvement (CI) strategies, i.e., Plan-Do-Check-Act cycle (Deming cycle), Total Quality Management (TQM), Six Sigma, lean manufacturing, Total productive maintenance (TPM), and LSS for process improvement (Patel and Patel*,* 2021). As a CI approach, lean originated from Japanese practices. Lean is defined as the practice of creating an efficient, well-organized system dedicated to continuous improvement and elimination of all forms of waste (Simpson and Power, 2005). On the other hand, Motorola launched Six Sigma in early 1990. Later, GE and allied signal implemented Six Sigma in mid-1990 (Smith, 2003). Six Sigma is a well-structured data-driven business methodology to improve process performance, customer satisfaction, quality, and bottom-line savings by reducing variability in the process (Thomas *et al*., 2008). Many organizations have implemented lean and Six Sigma individually in the past century and reported huge tangible (such as reduction in cost, lead-time, cycle time, defects, and overall equipment effectiveness) and intangible benefits (such as improved employees morale, job satisfaction, effective communication among stakeholders) (Thomas *et al.*, 2008, Bhamu and Sangwan 2014, Antony *et al.,* 2017; Sahoo and Yadav, 2018).

However, sometimes deploying lean and Six Sigma in isolation does not solve all the organization's problems (Drohomeretski *et al.*, 2014) because of their limitation. As Six Sigma will eliminate defects in processes, but it will not address the question of how to optimize process flow (Antony, 2011), and lean cannot bring the process into statistically control (George *et al.*, 2003, Bhuiyan and Baghel, 2005, Corbett 2011), which is the core competency of Six Sigma. Integration of lean and Six Sigma have drawn the attention of researchers, academicians, and practitioners in the 21st century to bring out the advantages of both (Snee 2010, Prasanna and Vinod 2013). George Group in the USA made the maiden attempt to merge lean and Six Sigma in 1986 (Chakravorty and Shah, 2012; Albiwi, 2015; Sreedharan and Raju, 2016; Patel and Patel, 2021). Lean Six Sigma is a merger of two different, but complementary CI approaches, i.e., Lean and Six Sigma (De Koning *et al.*, 2008, Proudlove *et al.*, 2008, Isabel and June, 2015; Sanders and Karr, 2015, and Patel and Patel, 2021). LSS integrates Six Sigma's process variability reduction tools and techniques with lean waste, and non-value-added elimination tools and techniques to enhance an organization's process performance and bottom-line results (Kumar *et al.*, 2006, Cheng and Chang, 2012). In LSS, the five phases DMAIC (define, measure, analyse, improve, and control) approach of Six Sigma serves as a base framework and lean tools/principles embedded into each phase to reduce the waste and encountered variability of the process. LSS improves efficiency and effectiveness (precision and accuracy) in a single effort (Arumugam *et al.* 2012, Lighter 2014, Laurani and Antony 2012a, Ndaita *et al.* 2015).

2.3.1.1 Definitions of Lean Six Sigma

This section represents a compilation of definitions of LSS, with connotations reported by various research articles in different time frames. LSS as a business improvement methodology has been accepted by various production/operation managers and has been implemented successfully across many sectors. As a result, researchers and practitioners across the globe have given different definitions of LSS, which reflects how the LSS scope and objectives have changed over time. Table 2.1 represents the various definitions of LSS briefly:

Table 2.1: Definitions of LSS from literature

Author	Definition of LSS
George (2003)	"Lean Six Sigma is a methodology that maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed, and invested capital."
Antony *et al.* (2003)	"Lean Six Sigma is an integrated approach utilizing the best of Six Sigma, and lean strategies will maximize shareholder value by accomplishing dramatic improvements in customer satisfaction, cost, quality, speed, and invested capital."
Kumar *et al.* (2006)	"Lean Sigma combines the variability reduction tools and techniques from Six Sigma with the waste and non-value added elimination tools and techniques from Lean Manufacturing to generate savings to an organization's bottom line."
De Koning *et al.* (2006)	"Synthesizing Lean and Six Sigma approaches lead to an integrated program combining the best of both programs."
Byrne (2007)	"Lean Six Sigma program is not just about doing things better; it is a way of doing better things."
Shahin and Alinavaz (2008)	"Lean Six Sigma combines both provides an over-arching improvement philosophy that incorporates powerful data-driven tools to solve problems and create rapid transformational improvement at a lower cost."
Chen and Lyu (2009)	"Lean Six-Sigma technology is considered a powerful business strategy for employing a well-structured continuous improvement methodology to effectively reduce process variability and increase quality in business processes using statistical tools."
Snee (2010)	"A business strategy and methodology that increases process performance resulting in enhanced customer satisfaction and improved bottom-line results"
Delgado *et al.* (2010)	"LSS is a methodology that, by combining two of the most popular tools for improving the performance of organizations in the 1990s."
Laureani and Antony (2012a)	"Lean Six Sigma is a business improvement methodology that aims to maximize shareholders' value by improving quality, speed, customer satisfaction, and costs: it achieves this by merging tools and principles from both Lean and Six Sigma."
Pamfilie *et al.* (2012)	"Lean Six Sigma has become a business model, a symbol of excellence, to eliminate waste and reduce the defects and variations in organization's processes."
Timans *et al.* (2012)	"LSS represents the merger of two well-known improvement programs with a long history: Lean manufacturing and Six Sigma."
Antony *et al.* (2012)	"Lean Six Sigma (LSS) is a powerful methodology for achieving process efficiency and effectiveness resulting in enhanced customer satisfaction and improved bottom-line results."
Arumugam *et al.* (2012)	"Lean is about speed and efficiency, and Six Sigma is about precision and accuracy. Both are complementary, and when combined, Lean and Six Sigma tackle process inefficiency (Lean) and process variation (Six Sigma) as a single effort."
Chiarini (2012)	"Lean Six Sigma is a fusion of two important and powerful management systems."
Assarlind *et al. (*2013)	"Lean Six Sigma can refer to integration into one concept and the concurrent usage of both concepts separately."
Chiarini and Bracci (2013)	"Lean Six Sigma is a method for strategic process improvement that aims to improve operational uniformity and quality, and reduce variations and waste."
Prasanna, M. and Vinodh, S. (2013)	"Lean Six Sigma (LSS) integrates both lean and Six Sigma concepts to bring out the advantages of both."
Vinodh *et al*.,(2014)	"Lean Sigma integrates both the variability reduction waste and non-value added elimination tools and techniques for facilitating monetary savings to the organization."
Antony (2014)	"LSS is a powerful methodology for achieving process efficiency and effectiveness, resulting in enhanced customer satisfaction and improved bottom-line results. Bringing the two strategies together to an organization creates a powerful vehicle for value creation."
Albliwi *et al*., (2014)	"Lean Six Sigma (LSS) is a continuous improvement methodology that aims to reduce the costs of poor quality, improve the bottom-line results and create value for both customers and shareholders."
Bhat *et al*., (2014)	"Lean Six Sigma (LSS) is one of the business management strategies, which specifically addresses the problems related to process flow and waste while focusing on reducing variation to promote business and operational excellence."
Youssouf *et al*., (2014)	"Lean Six Sigma is a method of improving the quality and profitability based on mastering statically of process, and it is also a management style based on a highly regulated organization dedicated to managing project."
Gijo and Antony (2014)	"Lean Six Sigma is a business improvement methodology that maximizes shareholder value by improving quality, speed, customer satisfaction, and costs."

Andersson *et al.*, (2014)	"LSS joint-use strategy of Lean Six Sigma claim that it helps companies flourish in a new world, where customers expect no defects and fast delivery at a minimal cost. The Lean strategy takes care of waste across all processes and focuses on speed and time, whereas the Six Sigma strategy focuses on design, eliminating defects, driving out process variability, and reducing costs."
Lighter (2014)	"Lean targets non-value added (NVA) work to make processes more efficient, while Six Sigma focuses on "nonconformities, or defects, to eliminate errors. Thus, Lean and Six Sigma complement."
Bhat and Jnanesh (2014)	"Lean and Six Sigma share common goals and grounds in striving to achieve customer satisfaction."
Hess *et al.*, (2015)	"The processes and techniques comprising the Lean Six Sigma methodology can catalyze the meaningful change needed to ensure the continued relevance of universities in our evolving societal structure."
Douglas *et al.*, (2015)	"Lean Six Sigma describes integrating the lean philosophy and associated tools and techniques with the six sigma philosophy and its associated tools and techniques. The combined approach can simultaneously achieve cost, quality, variability, and lead-time improvements."
Sanders and Karr (2015)	"Together, these methodologies complement each other and form a synergetic and broader process improvement methodology."
Randall and Maleyeff (2015)	"LSS is the latest in a progression of quality- and productivity-related movements motivated by several industry leaders' teachings, most notably W. Edwards Deming (1900-1993)."
Cabrita *et al.* (2015)	"Lean and Six Sigma complement each other. Lean accelerates Six Sigma, delivering greater results than would typically be achieved by Lean or Six Sigma individually."
Antony *et al.*, (2016)	"LSS is a powerful methodology that increases process performance and capability, resulting in enhanced customer experience and improved bottom-line impact measured in hard-cash savings."
Sunder (2016a)	"LSS is not a statistic, but a management strategy for quality excellence by reducing waste, variation, and improving value to the customers."
Yadav *and Desai* (2016)	"LSS could be described as an amalgam process that allows companies to identify the customer desires drastically, eliminate all non-value-added activities, and reduce the variability within the production."
Thomas *et al.*, (2016)	"One that is capable of achieving greater efficiency of production while also ensuring variation reduction."
Raval and Kant (2017)	"The LSS concept materializes as a balanced approach between the Lean philosophy and Six Sigma methodology."
Sunder and Antony (2018)	"As a hybrid methodology, LSS includes the rapidness of Lean and robustness of Six Sigma."
Trehan *et al.*,(2019)	"Lean and Six Sigma are two different tools used for operational excellence. It provides a framework for waste reduction and elimination of non-value-added activities and variability reduction tools."
Costa *et al.*, (2021)	"Lean Six Sigma (LSS) is a hybrid initiative that identifies customer desires, eliminates wastes, and reduces variation."
Rathi *et al.*, (2021a)	"Lean six sigma is not just a methodology or not just having tools needed to improve, but it has mentality and psychology to make change happen."
Singh *et al.*, (2021)	"LSS is an integrated amalgam of two powerful approaches, i.e., lean and six sigma."
Citybabu and Yamini (2022)	"LSS is the combination of Lean manufacturing that focuses on streamlining the process flow, and Six Sigma is applied to reduce the defects in the production"

From the above definitions, it is revealed that there is no universal LSS definition, which is reported throughout the literature. LSS is identified as a ***business improvement / continuous improvement / process improvement/ hybrid methodology*** (George, 2003; Chen and Lyu, 2009; Laureani and Antony 2012a; Gjioa and Antony, 2014; Albliwi *et al.*, 2014; Sanders and Karr, 2015; Sunder and Antony, 2018)**,** a ***business improvement/ management strategy*** (Snee 2010; *Bhat et al., 2014; Sunder 2016*), a ***model for a symbol of excellence (***Pamfilie *et* *al*., 2012), a ***philosophy*** (Shahin and Alinavaz 2012), a ***concept*** (Assarlind *et al.,* 2013), *an* ***integrated amalgam*** **approach** (Antony *et al.* 2003, Douglas *et al.*2015, Raval and Kant 2017; Singh *et al.* 2021), a ***way*** (Byrne et al.,2007), a ***quality and productivity movement*** (Randall and Maleyeff,2015), ***a set of*** variability reduction and waste elimination ***tools and techniques*** (Kumar *et al*.,2006; Delgado *et al*.,2010; Trehan *et al*.,2019), an ***initiative***(Costa *et al.* 2021). The scope of LSS includes the elimination of waste and non-value-added work (Kumar *et al*., 2006; Pamfilie *et al*., 2012; Sunder, 2016; Chiarini and Bracci, 2013; Costa *et al*., 2021), reduction in process variation in organizations and business processes (Pamfilie *et al*., 2012, Chiarini and Bracci 2013), managing the projects (Youssouf *et al*., 2014), identify the customer need (Costa *et al*., 2021). The goals for which LSS is implemented are- to improve the process efficiency and effectiveness (Antony *et al*., 2012; Antony 2014, Thomas *et al*., 2016), to improve the cost, quality, and process speed (George 2003; Antony *et al.*, 2003; Laureani and Antony, 2012a), to enhance customer satisfaction and improve bottom-line results (Taghizadegan, 2006; Snee, 2010), to maximize shareholder value (George 2003; Antony *et al*., 2003; Laureano and Antony 2012; Albliwi *et al.*, 2014), to get operational uniformity (Chiarini and Bracci, 2013) and to improve the process (Bhat *et al*.,2014).

2.3.2 Brief Background of Agile Manufacturing

Due to globalization, digitalization, and turbulence of the market, the new order-winning criteria are cost, high quality, and high production rate, but also include responsiveness, and flexibility towards fulfilling ever-changing customers' demands for long-term sustainability (Cheng *et al*., 1998, Thilak *et al*., 2015, Kumar *et al*., 2019a, Kumar *et al.,* 2020a). Lean works effectively in a stable market environment where demands are not dynamic. However, due to its consistent and stable processes, lean manufacturing organization is generally regarded as unable to meet the challenges of shrinking product life cycles, increased customization, market fragmentation, and response to unanticipated spikes in customer preferences (Iqbal *et al*., 2020). This situation compels organizations to shift their focus from traditional manufacturing paradigms, i.e., craft, and mass production, to embrace a new advanced manufacturing paradigm, termed agile manufacturing, to meet the customer's demand (Matawale *et al.*, 2013). The term "agile" was originated by a group of researchers at Lehigh University in 1991.

Further, Gunasekaran *et al.*, (1998) defined AM as the competency to survive and flourish in a competitive environment of volatile demand by reacting responsively and effectively to fulfill the customized demands of customers. In other words, the capability of organizations known, as "agility" is the degree of quickness, flexibility, and responsiveness doomed to endure in an unstable marketplace (Matawale *et al.,* 2013). Therefore, turbulence and competitive differences are the key drivers of AM (Khalfallah and Lakhal 2020). The core principles and practices of AM are to sustain in a turbulent environment are delivering value to the customers, being adaptable to change, sharing information & skills sets transparently and quickly, using advanced information-sharing technologies, use of flexible or technologically advanced tools, and developing virtual enterprise (to overcome one own incompetency) and quick decision making (Leite and Braz, 2016; Potdar *et al.,* 2017a).

2.3.2.1 Definitions of Agile Manufacturing

Various researchers and practitioners have given different definitions of AM, reflecting how the AM scope and objectives have changed with time. Table 2.2 represents the various definition of AM briefly.

Table 2.2: Definitions of AM from litertaure

Author	Definitions
Iacocca Institute (1991)	"AM is a 21st-century manufacturing strategy capable of responding to a global economy's fast-changing market needs and manufacturing demands"
Sanchez and Nagi (2001)	"Agile manufacturing is a new strategy used to represent the ability of a producer of goods and services to thrive in the face of continuous change. These changes can occur in markets, technologies, business relationships, and all facets of the business enterprise."
Gunasekaran and Yusuf (2002)	"Agile manufacturing is a vision of manufacturing that is a natural development from the original concept of `lean manufacturing. Agile manufacturing requires enriching the customer; cooperating with competitors; organizing to manage change, uncertainty, and complexity; and leveraging people and information."
Yusuf and Adeleye (2002)	Agile manufacturing has evolved especially as a challenge to the limitations of lean production.
Jin-Hai *et al.* (2003)	"Agile manufacturing embodies the ability to cope with change by applying partners' core competencies to supply customized products. It requires the synthesis of diverse technologies within an integrated system."
Guisinger and Ghorashi (2004)	"An agile company can be defined as an enterprise capable of operating profitably in a competitive environment of continually, and unpredictably, changing customer opportunities."
Adeleye and Yusuf (2006)	"Agile manufacturing has emerged as a systematic solution to the pressures imposed by market turbulence and complexity. It seeks to leverage preceding systems of lean, time-based, and mass customization objectives to add value to the customer at no extra cost."
Ramesh and Devadasan (2007)	"AM is the capability of the manufacturing enterprise to respond to the market requirements quickly."
Nambiar (2009)	"Agile manufacturing or agile production serves as a framework that integrates lean principles with mass customization."
Vinodh and Kuttalingam (2011)	"AM is a manufacturing paradigm which encompassed all modern manufacturing and competitive strategies "
Dubey and Gunasekaran (2015)	"Agile manufacturing is one of the operational strategies organizations have adopted to beat environmental uncertainties resulting from worldwide economic recession, shortening of the product life cycle, supplier constraints and obsolete technologies."
Soltan and Mostafa (2015)	"Agile manufacturing responds to complexity brought about by constant change."
Potdar *et al.*(2017a)	"AM is alleged to be the next progression of LM and flexible manufacturing, but it is a new system of manufacturing which borrows concepts from LM and flexible manufacturing with those of supply chain management to form a new manufacturing strategy."
Potdar *et al.* (2017a)	"Agile manufacturing (AM) has evolved as a revolutionary way of manufacturing the products while managing the uncertainties, product introduction time, responsiveness, innovation, and superior quality along the supply chain to satisfy the ever-increasing customer demand and to maximize the profit"
Thilak *et al.*, (2017)	"Agile manufacturing is a paradigm that enables an organization to respond to the dynamic demands of the customers quickly."
Gunasekaran *et al.* (2018)	"As an operations strategy, agile manufacturing can be defined as a business-wide mindset that emphasizes routinely adaptable structures and infrastructures and enhanced access to global competencies to achieve greater responsiveness to rapidly changing customer requirements."
Iqbal *et al.* (2020)	"An agile organization can be defined as one whose muscles are adept enough to produce at the cost of mass production (MP), a response like time-compression manufacturing, and have the flexibility of LP. The core aim of AM is not just to produce required products but rather to attain customer satisfaction throughout the product life cycle."
Kumar *et al.*, (2019a)	"Agile manufacturing emerged as a global phenomenon that integrates strategies, available technology, and human resources to provide customer-driven products and services by beating business environment uncertainties."
Kumar *et al.* (2020a)	"Agile manufacturing characterized a unique form of industrial competition for US companies where changes may occur in customer, supplier, and competitor firms to gain the advantage of opportunities in the market to satisfy individual customer preferences."
Kumar *et al.* (2012a)	"Agile manufacturing has high potential to satisfy customers' dynamic and turbulent demands and counteract future uncertainty in market situation efficiently utilizing market knowledge and virtual corporation."
Bhamra *et al.* (2021)	"Agile manufacturing, a conceptual approach for more flexible manufacturing and supply chain operations. Agile manufacturing is a broad, strategic, market-driven approach that involves a balanced consideration of organization, people, and technology more integrative."

AM can be defined as ***a manufacturing and an operational strategy*** (Iacocca Institute 1991, Sanchez and Nagi 2001, Gunasekaran et al. 2018), a ***vision of manufacturing*** (Gunasekaran and Yusuf, 2002), a ***manufacturing paradigm*** (Vinodh and Kuttalingam 2011, Thilak *et al.,* 2017), a ***business-wide mindset*** (Gunasekaran *et al.*, 2018), a ***borrowed manufacturing system*** (Potdar *et al.*, 2017a), a ***market-driven approach*** (Bhamra *et al.*, 2021), a ***capability*** (Matawale *et al.,* 2013), a **response to complexity** (Soltan and Mostafa, 2015), a ***systematic solution*** (Adeleye and Yusuf, 2006), a ***challenge to lean limitations*** (Yusuf and Adeleye,2002), an ***integrated framework of lean and mass customization*** (Nambiar,2009) and a ***global phenomenon*** (Kumar *et al.*,2019a) to beat market uncertainty (Dubey and Gunasekaran, 2015). The scope of AM includes inflexible and modern manufacturing systems (Vinodh, and Kuttalingam 2011; Bhamra *et al.*, 2021), product development (Potdar *et al.*, 2017a), supply chain (Potdar *et al.*, 2017a, Bhamra *et al.*, 2021), market knowledge (Kumar *et al*., 2021a), technology and human resource integration (Sanchez and Nagi, 2001, Kumar *et al.*, 2019a).

The goals for which AM is implemented are- to give the capability to respond quickly (Iacocca Institute, 1991, Thilak *et al.*, 2017) and effectively (Matawale *et al.*, 2013) in the dynamic and turbulent markets (Kumar *et al*., 2021a), to produce customized product (Jin-Hai *et al.*, 2003) with cost-effectively, rapidly and continuously with superior quality (Matawale *et al*., 2013, Potdar *et al.*, 2017a), to leverage the market opportunity (Barmer, 2020), to reduce product introduction time, bring innovation (Potdar *et al.*, 2017a), to beat and counteract future uncertainty in the market situation (Dubey and Gunasekaran, 2015, Kumar *et al*., 2021), to integrate core competencies of partners, virtual enterprises, technology, infrastructure business strategy (Jin-Hai *et al.,* 2003; Gunasekaran *et al.*, 2018; Kumar *et al.*, 2019a; Kumar *et al*., 2021) and to give global competencies (Gunasekaran *et* *al.*, 2018)

2.3.3 Brief background of lean and agile (Leagile)

The integration of two manufacturing paradigms, i.e., lean and agile, has divergent views of researchers. Some researchers are in support of this amalgamation and said they could coexist (Mason-Jone, 2000; Van Hoek, 2000; Krishnamurthy and Yauch, 2007; Shahin and Jaberi, 2011; Elmoselhy, 2013; Mehrsai *et al.*, 2014; Soltan and Mostafa 2015; Mostafa *et al.*, 2016; Mostafa *et al.*, 2016; Khalfallah *et al.*, 2020; Balakrishnan *et al.,* 2020; Hemalatha *et al.*, 2021) whereas few researchers are in against of it and said that lean and agile are two mutually exclusive topics (Hallgren and Olhager*,* 2009). Iqbal *et al.* (2020) proved empirically that lean manufacturing and AM are complementary and not competing paradigms. Balakrishnan *et al.*, (2020) and Hemalatha *et al.*, (2021) have successfully implemented a leagile paradigm in the pump and boiler manufacturing industry.

Agility needs "Lean" as AM is considered to be the next-generation advancement of LM (Potdar *et al.*, 2017a), and skipping lean for AM implementation is wasteful and expensive (Revelle, 2014). Conversely, lean practices are not self-sufficient to fulfill customized demands and improve operational performance without the mediating role of AM in the turbulent market (Khalfallah, 2020). To take advantage of agile's responsiveness and lean's waste elimination ability, Naylor *et al.*, (1999) integrated these two approaches into the supply chain through a strategic decoupling point named "Leagility". This decoupling point separates the lean and agile practices upstream and downstream to fill the dynamic demand cost-effectively (Krishnamurthy and Yauch 2007). This integrated approach found applications from the supply chain to production by many researchers. This amalgamation has attracted many manufacturing industries because of its capability to handle product mix and dynamic demand responsively while simultaneously increasing profit by eliminating waste (Chan *et al.*, 2009).

2.3.3.1 Definitions of Leagile

Following are the few definitions found in the literature

Table 2.3: Definitions of Leagile from literature

Author	Definition of Leagile/leagility
Naylor *et al.*, (1999)	"They defined leagility by combining the agility and leanness in one supply chain through the strategic use of the decoupling point."
Mason-Jones *et al.*, (2000)	"Leagility combines the lean and agile paradigm within a total supply chain strategy by positioning the decoupling point to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream from the decoupling point."
Krishnamurthy and Yauch (2007)	"A Leagile system has a characteristic of both lean and agile systems (supply chain +manufacturing), acting together to exploit market opportunities cost-effectively."
Chan *et al.* (2009)	"Both the lean and agile strategies have proven their usefulness in their respective situations, but the present market scenario demands a more robust strategy that can encapsulate the salient features of both. This gave birth to a new strategy termed as"Leagile."
Shukla and Wan (2010)	"Leagility is defined as the capability of deploying lean and agile paradigms simultaneously."
Shahin and Jaberi (2011)	"Integration of agility and leanness in a supply chain via the strategic use of a decoupling point has been termed leagility."
Soltan and Mostafa (2015)	"Leagile is manufacturing strategies with two dimensions: waste removal and responsiveness."
Shahin *et al.*, (2016)	"Leagile strategy makes it possible to utilize the advantages of both strategies. The objective of the agility paradigm is to approach mass customization and responsiveness, and the objective of the lean paradigm is moving towards more effective mass production."
Virmani *et al.* (2017a)	"Leagile manufacturing paradigm is simultaneous adoption of lean and agile principles."
Virmani *et al.* (2018a)	"The leagile manufacturing systems combine the advantages of both lean and agile systems. It provides industries to remove all different types of wastes and at the same time concurrently meeting the changing needs of customers and hence helps in achieving better customer satisfaction."
Balakrishnan *et al.*, (2020)	"Leagile manufacturing has emerged as an archetypal manufacturing system. So leagile-manufacturing system has attributes of both lean as well as an agile manufacturing system."
Bhamra *et al.*, (2021)	"Leagile is an approach to managing production and supply chain excellence that combines conventional Lean and Agile thinking and methods. The combined strategy of lean manufacturing upstream and agile response downstream is commonly referred to as leagile."

Leagile is identified as a ***manufacturing paradigm*** (Balakrishnan *et al.*, 2020), a ***manufacturing strategy*** (Chan *et al.*, 2009); Shahin *et al.*, 2016), *a* ***manufacturing system*** (Krishnamurthy and Yauch, 2007; Virmani *et al.*, 2017a) and a ***hybrid approach*** **(**Bhamra *et al.*, 2021). The scope of Leagile includes level scheduling (Mason-Jones, 2000) and managing production and supply chains (Bhamra *et al.*, 2021). The goals for which Leagile is implemented are- to handle dynamic customers demand responsively and remove all different types of waste simultaneously (Soltan and Mosta, 2015; Virmani *et al.*, 2018a) in a cost-efficient manner (Krishnamurthy and Yauch, 2007), to become responsive and flexible for dynamic variation in demand (Chan *et al.*, 2009); to enhance the customer satisfaction by taking advantage of lean and agile strategies together (Shahin *et al.*, 2016)

2.4 EXISTING LITERATURE REVIEW ARTICLES IN THE FIELD OF LSS, AGILE, AND THEIR INTEGRATION

To start the review of LSS, Agile, and their integration domain, it is necessary to identify how many literature review articles have been published in the relevant area. In order to do that, Table 2.4 presents the summary of existing literature review research articles focused on LSS, AM, and Leagile individually.

Table 2.4: Existing Literature articles based on LSS/AM/Leagile

S.no.	Reference	Year	No. of Research articles Reviewed	LSS	AM	Leagile
1	Sanchez and Nagi	2001	75		State of the art review of 73 Agile manufacturing systems papers	
2	Ramesh and Devadasan	2007			Reviewed AM criteria	
3	Shahin and Alinavaz	2008		Comprehensive Reviewed LSS frameworks		
4	Sreenivasa and Devadasan	2011			Reviewed AM applications of AM in different manufacturing areas	
5	Prasanna and Vinodh	2013		Systematic Reviewed Scope of LSS in SMEs		
6	Albini *et al.*	2014		Systematic Reviewed Critical Failure Factors for LSS		
7	Yadav and Desai	2016	189	Categorized review of LSS from 58 journals published from 2001 to 2014		

8	Sreedharan and Raju	2016	253	Systematic Reviewed LSS articles published from 2003 to 2015		
9	Mostafa *et al.*	2016	62			A systematic review of Leagile articles published from 1992 to 2015
10	Yadav *et al.*	2017	26	Structured literature review of 26 frameworks of LSS, published articles from 2000 to 2017		
11	Raval *et al.*	2018(a)	190	Systematic Reviewed LSS articles published from 2000-to 2016		
12	Soepardi *et al.*	2018	228		Systematic Reviewed AM articles published from during1991 to 2015	
13	Muraliraj *et al.*	2018	261	Content Reviewed of LSS articles published from 2000-to 2017		
14	Gunasekaran *et al*.	2019			Reviewed based on the evolution of AM	
15	Patel *et al*.	2019		Systematic Reviewed LSS articles		
16	Sunder *et al*.	2020	175	Systematic Reviewed LSS articles published from 2003-to 2015		
17	Kumar *et al.*	2020(b)	37		Critically reviewed CSFs of AM articles published from 1991 to 2019	
18	Davidson *et al.*	2020		Reviewed LSS frameworks in HEI (Higher Education industries)		
19	Rathi *et al.*	2021a		Systematic Reviewed LSS articles		
20	Bhamra *et al.*	2021	53			Systematic reviewed Leagile articles
21	Potdar *et al.*	2017(a)	300		Systematic Reviewed AM articles published during1993-2016.	
22	Virmani *et al.*	2020(a)				Reviewed Existing articles based on Leagile Manufacturing
23	Patel and Patel	2021	223	Critically reviewed Lean, Six Sigma and LSS articles published from 2000-to 2019		
24	Citybabu and Yamini	2022	142	Systematic Reviewed 141 articles based on LSS in Indian context, published during 2010 to 2021		
25	Psomas *et al.*	2022	56	Performed a systematic literature		

	review of 56 research articles based on LSS applications in public administration sector published during 2010 to 2021	

2.5 RESEARCH CONTRIBUTIONS MADE BY VARIOUS CONTRIBUTORS IN LEAN SIX SIGMA, AGILE MANUFACTURING, AND INTEGRATION

This section represents the various contribution made by several authors published during 2000 to august 2022. These articles were analyzed based on descriptive and content-wise.

2.5.1 Descriptive Analysis

Descriptive analysis is a visual analysis of research articles based on the journals, author demography, methodology, sectors, and approaches. For this analysis following classification diagram (see figure 2.2) is used.

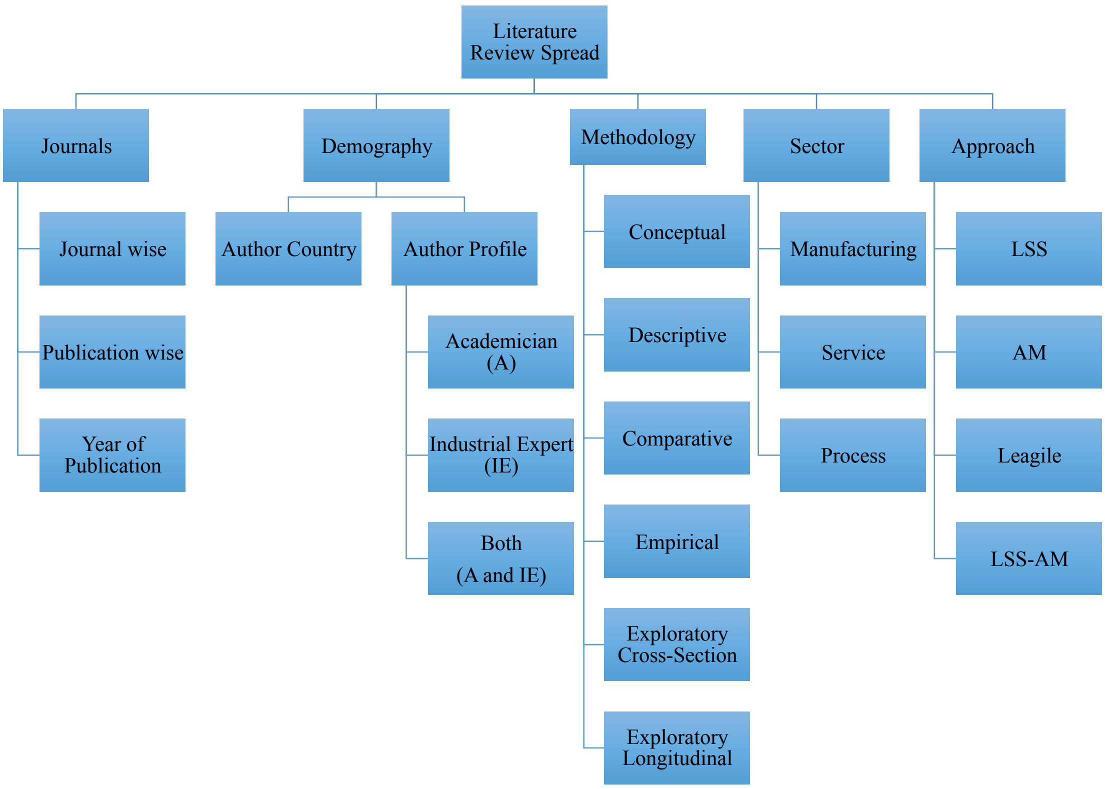

Figure: 2.2 Descriptive Analysis of articles

This section represents the review of 350 articles based on research contribution, research methodology, type of approach used, and type of sector in which LSS, AM, Leagile or integration was applied. The research articles are presented in chronological order with the author profile, and the country of the authors is also mentioned for descriptive analysis. For example, Raval *et al.*, (2018a) divided 190 articles based on empirical quantitative, empirical qualitative, desk quantitative, and desk qualitative research methodology, whereas Kumar *et al.*, (2019a) divided the AM articles based on survey and interview-based research methodology. In this chapter research methodology classification is based on the combination of classification used by Sreedharan and Raju (2016) and Bhamu and Sangwan (2014). Based on that research articles are divided into six categories: conceptual, descriptive, empirical, exploratory cross-sectional, and exploratory longitudinal and are explained as follows:

Conceptual:

Describe the fundamental concepts of LSS, AM, or Leagile Approach

Descriptive:

Describe the LSS, AM, or Leagile content or process, performance, and measurement issues.

Empirical:

Data for the study has been taken from an existing database, review, case study, taxonomy, or typological approaches.

Comparative:

Comparison between two or more practices or solutions and the evaluation of the best practice or a solution

Exploratory Cross-Sectional:

The study's objective is to become more familiar through a survey, in which information is collected at one point in time.

Exploratory Longitudinal:

Survey methodology, where data collection is done at two or more points over time in the same organization.

Total 350 research articles were reviewed and the contributions made by various authors are presented in table A.1 (See Appendix A-I)

2.5.1.1 Review Observations, Results, and Discussion based on Descriptive Analysis

In this section, observations, results and discussions based on descriptive analysis of reviewed articles are presented.

2.5.1.1.1 Distribution of Research Articles based on Journals and Conferences

Table 2.5 represents the distribution of research papers, journals, and conferences. 95.34 % of articles were published in international journals, and international conference papers contributed 4.66 % of total selected research articles.

Table 2.5 Distribution of research articles based on journals and conferences

	No.of Research Articles	Percentage (%)
(A): Journal		
International Journal of Lean Six Sigma	42	12.0
Production Planning and Control	20	5.7
The TQM Journal	21	6.0
International Journal of Quality & Reliability Management	17	4.9
International Journal of Agile Systems and Management	13	3.7
International Journal of Productivity and Performance Management	13	3.7
International Journal of Production Research	13	3.7
Benchmarking: An International Journal	12	3.4
International Journal of Six Sigma and Competitive Advantage	12	3.4
Journal of Manufacturing Technology Management	10	2.9
International Journal of Productivity and Quality Management	8	2.3
Total Quality Management & Business Excellence	7	2.0
International Journal of Operations & Production Management	7	2.0
Business Process Management Journal	5	1.4
International Journal of Production Economics	3	0.9
International Journal of Business Excellence	4	1.1
International Journal of Process Management and Benchmarking	3	0.9
International Journal of Quality and Service Sciences	3	0.9
International Journal of Services and Operations Management	3	0.9
International Journal of System Assurance Engineering and Management	3	0.9
Quality Management Journal	3	0.9
The International Journal of Advanced Manufacturing Technology	3	0.9
Transactions on Engineering Management	3	0.9
World Journal of Science, Technology and Sustainable Development	3	0.9
Others *(Two references of each Journal)	38	10.9

Others**(One reference of each Journal)	65	18.6
(B): International Conferences	16	4.6
Total	350	100.0

***European Journal of Industrial Engineering, Industrial, Management & Data Systems, International Journal of Agile Management Systems, International Journal of Construction Management, International Journal of Health Care Quality Assurance, International Journal of Industrial and Systems Engineering, International Journal of Sustainable Engineering, Journal of Manufacturing Systems, Leadership in Health Services, Measuring Business Excellence, Public Money & Management, Quality & Quantity, Quality, and Reliability Engineering International; Quality Engineering, Technovation, The TQM Magazine*

**Annals of Operations Research, Applied Ergonomics, Arabian Journal for Science and Engineering, Assembly Automation, Baltic Journal of Management, BMC Health Services Research, Chinese Journal Of Mechanical Engineering, Drug Development and Industrial Pharmacy, European journal of operational research, European Management Journal, Expert Review of Medical Devices, Expert Systems with Applications, Facilities, Flexible Automation, and Intelligent Manufacturing, Global Journal of Flexible Systems Management, International Business Innovation and Research, International Federation for Information Processing, International Journal of Business Excellence, International Journal of Industrial and Systems Engineering*
, International Journal of Advanced Operations Management, International Journal of Business Innovation and Research, International Journal of Computer Integrated Manufacturing, International Journal of Healthcare Management, International Journal of Healthcare Technology and Management, International Journal of Logistics Systems and Management, International Journal of Management Practice, International Journal of Management Science and Engineering Management, International Journal of Operational Research, International Journal of Product Development, International Journal of Technology Management, International Journal of Value Chain Management, International Journal on Interactive Design and Manufacturing, Journal for Healthcare Quality, Journal of Advances in Management Research
Journal of cleaner production, Journal of Engineering, Design and Technology, Journal of Enterprise Transformation, Journal of Facilities Management, Journal of Industrial and Systems Engineering, Journal of Industrial Information Integration, Journal of Intelligent Manufacturing, Journal of Modelling in Management, Journal of Operations Management, Journal of Organizational Change Management
Journal of organizational excellence, Journal of Pediatrics and Adolescent Medicine, Journal of Science and Technology Policy Management, Journal of Systems and Software, Journal of the Operational Research Society, Management Decision, Manufacturing Engineer, Mechatronic, Operations Management Research Process Management Journal Production & Manufacturing Research Resources, Conservation and Recycling, Robotics and computer-integrated manufacturing SN Applied Sciences, Strategic HR Review, Strategy & Leadership, Supply Chain Forum, Supply Chain Management: An International Journal, Technological Forecasting, and Social Change, The Quality Assurance Journal, The Surgeon, Journal of the Royal Colleges of Surgeons of Edinburgh and Ireland, Transactions on Robotics and Automation, Advances in Materials and Modern Manufacturing

2.5.1.1.2 Distribution of Research Articles Based on Publications

The distribution of articles based on publications is shown in figure 2.3. Most articles were published in Emerald, followed by Inderscience and Taylor & Francis publications.

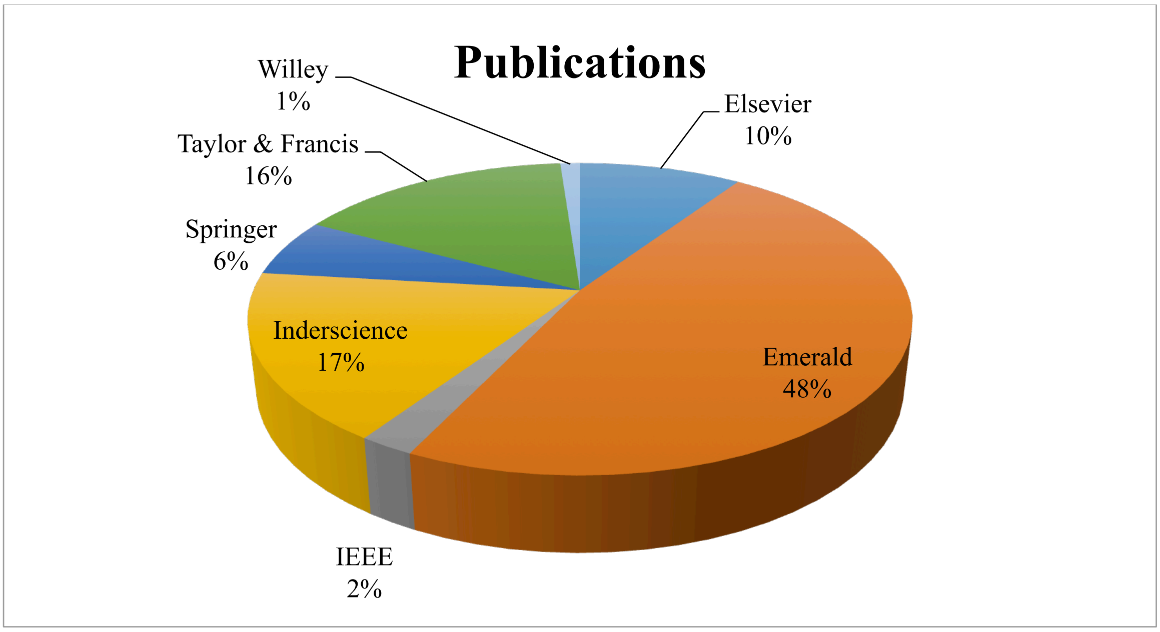

Figure 2.3: Distribution of reviewed research articles based on publication

2.5.1.1.3 Distribution of Research Articles Over Time

The distribution of Research Papers over Time is presented in figure 2.4. The trend line represents that most of the research works in the LSS field was done after 2010 and increased afterwards. AM trend line represents the moderate amount of work that has been done in the year 2000-2010; after that, AM attracted researchers, and a significant amount of work was carried out from 2010 to august 2022. Leagile amalgamation is attracting researchers, as this is a buzzing area of research. Research articles related to Integrated LSS-AM were found very few. The chart represents that LSS, AM, and Leagile individually attract researchers over a while. The amalgamation of LSS-AM is still in the infant stage.

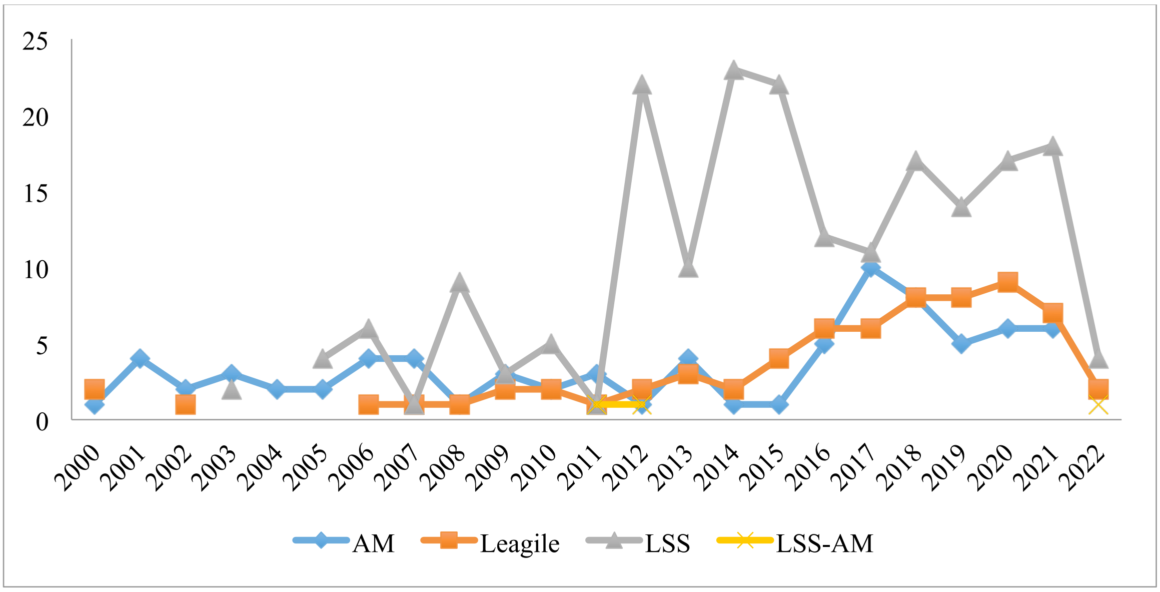

Figure 2.4: Year-wise distribution of reviewed articles

2.5.1.1.4 Distribution of Research Articles Based on Country

The distribution of research articles region-wise is presented in figure 2.5. It represents that Indian authors alone are contributing 145 number of research articles followed by the UK and US. This demography represents that LSS, AM, Leagile and their integration are becoming a buzzing area of research among researchers across the globe.

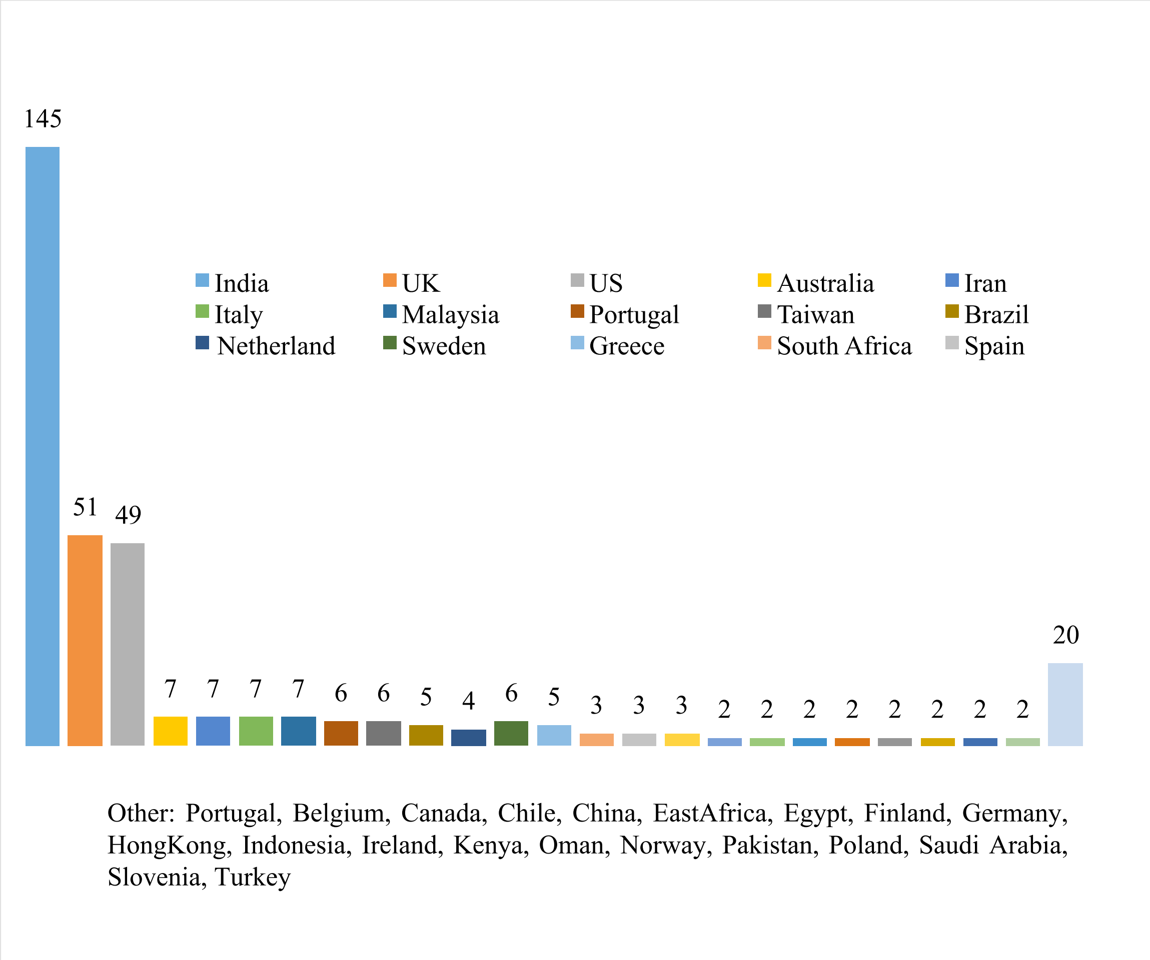

Figure 2.5: Distribution of research articles over country wise

2.5.1.1.5 Distribution of Research Articles based on Author Profile

The figure represents that academicians published 96 percent of articles. Industry experts contributed merely 3 percent of research articles. Only 1 percent of authors are both academicians and Industry experts.

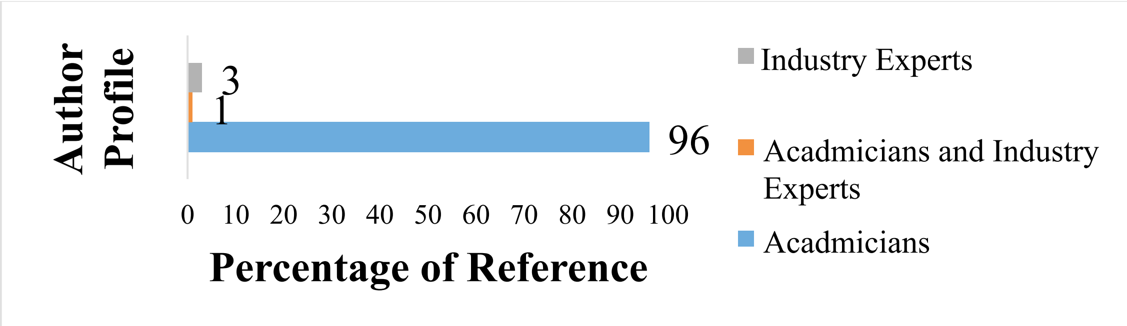

Figure: 2.6 Distribution of research articles based on author profile

2.5.1.6 Distribution of Research Articles based on Research Methodology

Table 2.6 depicts that less than 25 percent of papers are conceptual or descriptive in nature, discuss LSS, AM and their integration's fundamental concepts, or describe the LSS, AM, or Leagile content or process, performance, and measurement issues. The rest of the articles deal with verifying theory based on empirically or exploratory. Articles based on exploratory cross-section methodology are contributing 8 percent of total articles, which is less than the number of articles based upon exploratory-longitudinal and empirical verification. This represents a positive sign in the area of research in LSS, AM and their integration compared to other research areas where most of the research is based on exploratory cross-section methodology. Some articles are based on a combination of different research methodologies

Table 2.6: Distribution of research articles based on research methodology

Type of Methodology	No. of Article	Percentage
Descriptive	51	15%
Descriptive & Comparative	4	1%
Conceptual	14	4%
Conceptual & Comparative	4	1%
Comparative	6	2%
Comparative & Exploratory Cross- Section	3	1%
Comparative &Empirical	12	3%
Conceptual & Empirical	13	4%
Conceptual & Exploratory Cross-section	4	1%
Conceptual & Exploratory Longitudinal	1	0%

Descriptive & Exploratory Cross-Section	7	2%
Descriptive & Empirical	22	6%
Descriptive & Exploratory Longitudinal	8	2%
Empirical	74	21%
Exploratory Cross-Section	29	8%
Exploratory Longitudinal	98	28%
Grand Total	350	100%

2.5.1.1.7 Distribution of Research Articles based on Sector

Figure 2.7 depicts that the maximum number of LSS/AM/their integration is based on the manufacturing sector followed by the service and process sector. The applications of LSS are found almost equal in both the manufacturing and service sectors, whereas AM and Leagile articles are found more in the manufacturing sector than service and process sectors.

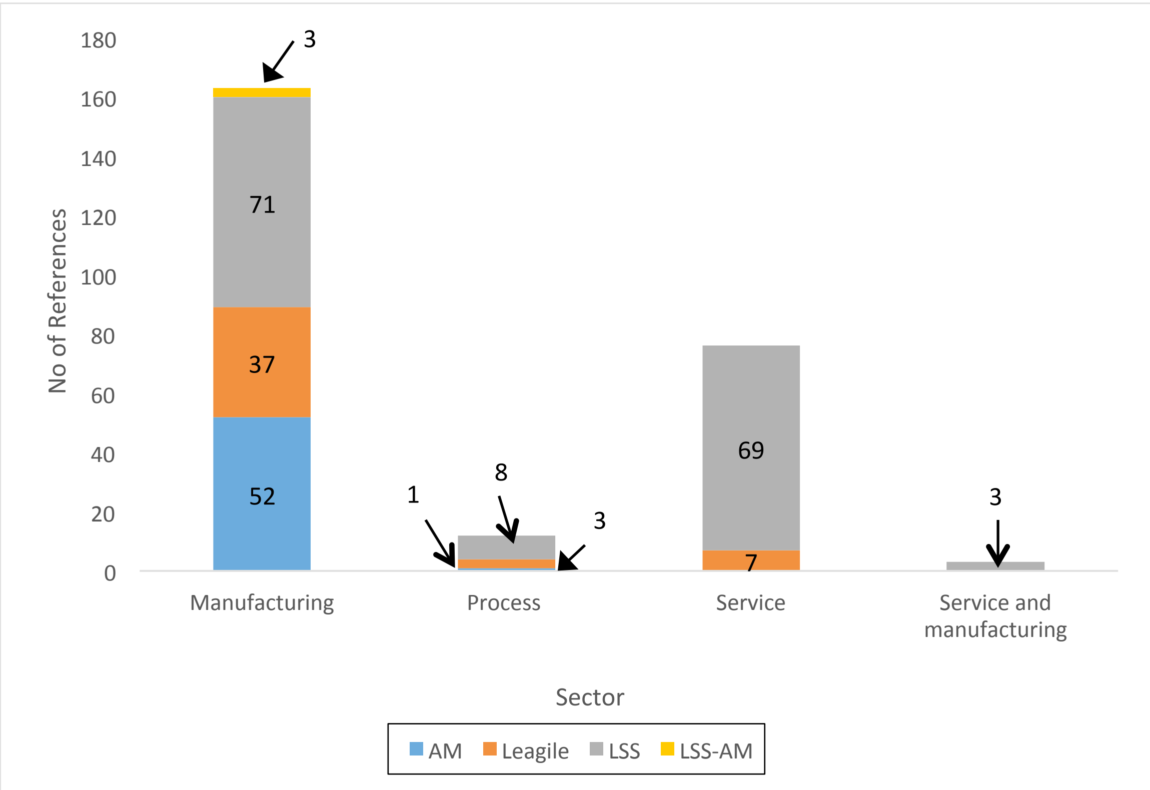

Figure: 2.7 Distribution of research articles based on sectors

2.5.1.1.8 Distribution of Research Articles based on Approach

Figure 2.9 represents that among 350 articles, 57 percent of articles are based on LSS, followed by AM and Leagile approach. On the other hand, only 1 % of articles are found based on the amalgamation of LSS-AM. This represents that most of the researchers are inclined toward the LSS approach.

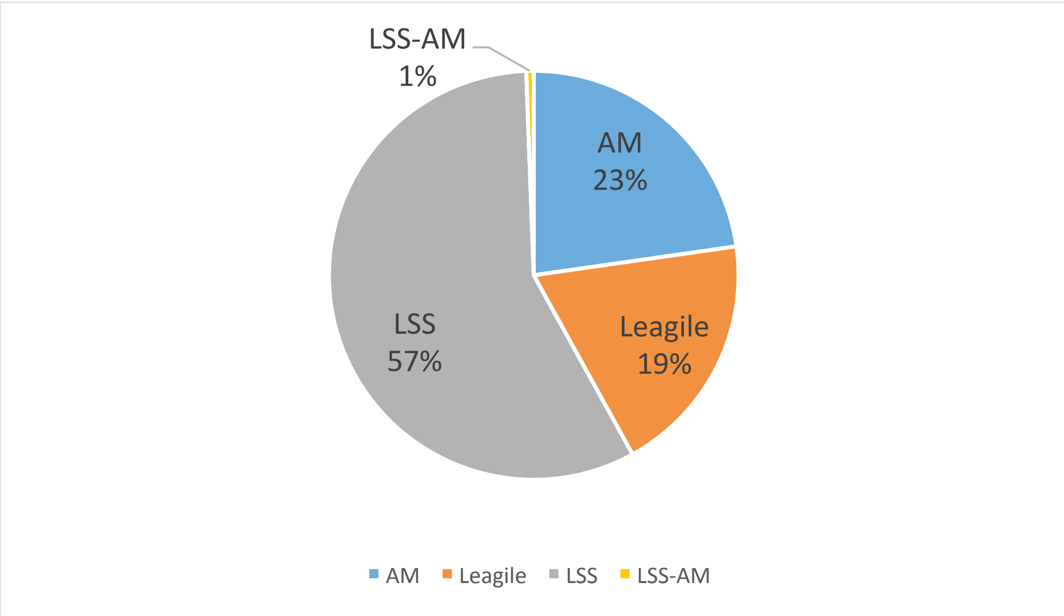

Figure: 2.8 Distribution of research articles based on the approach

2.5.2 Content Analysis

This analysis depicts the critical review of articles based on their content. In this analysis, we analyzed LSS/AM/Leagile/LSS-AM articles based on CSFs; CFFs; tools and techniques; performance outcomes; frameworks; applications in SME's/MSME and current research trends with other approaches.

2.5.2.1 Review Observations, Results and Discussion Based on Content Analysis

In this section, observations, results and discussions based on content analysis of reviewed articles are presented.

2.5.2.1.1 Analysis of Articles Based on CSFs and Methodology used

Critical Success Factors are those factors that enable to implementation of any approach or framework smoothly in any organization. They are essential elements in successfully aligning the organizational resources to achieve the project's objectives (Swarnakar *et al.*, 2021b). Therefore, the identification and selection of CSFs play a vital role in successfully deploying LSS and AM (Laurani and Antony, 2012b; Raval *et al.*, 2018b). This section depicts the work done by various authors for CSFs in the field of LSS/AM/Leagile/LSS-AM and the different methodologies used to analyze them.

Vázquez-Bustelo and Avella (2006) systematically identified AM enablers and analyzed their effect on business performance. Hasan *et al.* (2009) identified ten enablers from literature and established mutual relationships among them through Interpretive Structural Modeling (ISM). Gore *et al.*, (2009) identified AM enablers that gave a competitive edge to the organization and validated them through exploratory factor analysis. Delgado *et al.*, (2010) identified LSS enablers from an extensive literature review and validated them with a case study in financial services. Hilton and Sohal (2012) developed a conceptual framework for LSS implementation and validated the relationship among the LSS enablers, leaders, and organization competency through hypothesis testing. Jayaraman *et al.* (2012) identified enables for LSS implementation in the electronics manufacturing industry in Malaysia and evaluated the effect of these enablers on a company's performance empirically. Dibia and Onuh (2012) developed and deployed the LSS model using soft system methodology in laundry machine manufacturing and identified the critical success factors of LSS in an agile environment. Laureani and Antony (2012b) identified enablers for LSS deployment through an extensive literature review and rated them empirically. Arvind Raj *et al.* (2013) developed a conceptual model of AM enablers, and the importance of each agility enabler was calculated through graph theory. Matawale *et al.*, (2013) identified and developed a mutual relationship among the enablers through ISM. Bakar *et al.* (2015) identified 137 enablers for LSS implementation and grouped them into 13 categories through the Affinity diagram. Tsironis and Psychogios (2016) developed and deployed a multi-factor model of LSS in the service industry and identified the critical enablers of LSS in service industries through a case study approach. Leite and Braz (2016) identified enablers of AM in new product development through exploratory research. Dev and Kumar (2016) identified AM enablers for original equipment manufacturing and prioritized them through AHP (Analytic Hierarchy Process). Lande *et al.* (2016) identified enablers of LSS affecting quality and operational performance in SMEs through a systematic literature review and prioritized the enablers based on the degree of influence in LSS implementation through time-tested statistical tools. Rehman (2017) developed an AHP model to prioritize the agile enablers, and sensitivity analysis was performed to check the robustness of the model. Yadav and Desai (2017) developed an interpretive structural model to identify the contextual relationship among the LSS implementation enablers. Haq and Boddu (2017) identified 20 enablers for leagile deployment in supply chain management and identified their importance through an integrated approach of Fuzzy QFD, AHP, and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Sindhwani *et al.*, (2017b) identified and analyzed the mutual relationship among the enablers of Agile manufacturing systems through Total Interpretive Structural Modelling (TISM).

Potdar and Routroy (2018) identified and classified AM implementation enablers through ISM-Fuzzy MICMAC analysis. Goswami and Kumar (2018) identified and validated the interaction of agility enablers and attributed it to structural equation modeling. (SEM), Raval *et al.*, (2018b) developed a model of LSS implementation enablers through the ISM approach. Virmani *et al.* (2018c) identified and divided the Leagile enablers into cause and effect categories through a fuzzy decision-making trial and evaluation laboratory (DEMATEL) approach. Virmani and Sharma (2019) prioritized the leagile manufacturing enablers through the ISM approach. Kumar and Jain (2020) analyzed the enablers for AM implementation through Pareto analysis to identify the vital few and many trivial enablers. Kumar *et al*. (2020a) used a hybrid approach of AHP and TOPSIS to prioritize the enablers for AM implementation. Kumar *et al.* (2020b) statistically validated the relationship between AM enablers and business performance through the Games–Howell HOC test. Singh and Rathi (2020) identified LSS implementation enablers of LSS in MSME, evaluated them through the relative importance index method, and ranked them by the best-worst method (BWM). Sindhwani *et al.* (2021) identified enablers of the lean-agile approach in the rolling industry through the ISM Approach. Swarnakar *et al.* (2022) identified 33 enablers of LSS and prioritized them best-worst method.

These papers reveal that Multi-Criteria Decision Making (MCDM) is one of the principal methodologies among researchers to analyze CSFs. Different authors give different set of CSFs of LSS/AM/Leagile/LSS-AM individually. Only one article was found that depicted the LSS-AM amalgamation's CSFs.

2.5.2.1.2 Analysis of Articles based on CFFs and Methodology used

Critical failure factors are those factors that are roadblocks to the implementation of any framework or approach. They are impediments to the alignment of resources of any organization to achieve the project objective. So identification and mitigation of these factors are necessary for any project's success. This section depicts the work done by various authors for CFFs in the field of LSS/AM/Leagile/LSS-AM and the different methodologies used to analyze them.

Hasan *et al.* (2007) identified 11 barriers to AM implementation through an extensive literature review and established a contextual relationship among the barriers through the ISM approach. Psychogios *and* Tsironis (2012b) investigated the barriers to LSS implementation through a case study in the airline service industry. Dibia and Onuh (2012) identified LSS implementation barriers in an agile environment during the implementation of LPPO (Lean leadership, people, process, and outcome) in Laundry manufacturing machines. Finally, through a systematic literature review, Antony *et al*. (2012) identified various roadblocks to LSS implementation.

Albliwi *et al.* (2015) identified barriers to the LSS implementation approach in manufacturing through a systematic review of 12 research papers. In addition, Douglas *et al.*, (2015) identified barriers to LSS implementation during a pilot run of the LSS project at the Kenya Institute of Management in Nairobi.

Sindhwani and Malhotra (2017) evaluated the performance of AMs barriers through the Fuzzy Performance Importance Index (FPII) approach. Yadav *et al.* (2018a) Identified 27 LSS adoption barriers and prioritized those barriers with the help of the fuzzy AHP and TOPSIS method, provided 22 solutions to these roadblocks through a case study, and performed a sensitivity analysis to check the robustness of the LSS framework. Sreedharan *et al.*, (2018b) identified 44 critical failures from the literature review and ranked 24 vital CFFs through the TOPSIS SIMO method. Sony *et al.*, (2019) identified 11 reasons for discontinuing the LSS approach through case studies in the manufacturing and service sectors. Gaikwad *et al.*, (2020) identified and ranked the 12 barriers to LSS implementation in SMEs through the Fuzzy TOPSIS method. Kumar *et al.* (2020b) identified 17 barriers to AM implementation and categorized them into five groups. Based on their severity, these groups were ranked through VIekriterijumsko KOmpromisno Rangiranje (VIKOR) analysis. Rathi *et al.* (2021b) identified 31 LSS barriers through a questionnaire survey of automotive parts manufacturing, and the internal consistency of responses was checked using statistical tools like Importance-indexed. Hariyani *et al*. (2022) identified 24 barriers of green LSS-AM from literature review and ranked them though mean median method.

These papers reveal that MCDM is one of the favorite methodologies among the researchers to analyze CFFs, followed by a case study and questionnaire survey. Different authors have given different set of CSFs of LSS/AM/Leagile/LSS-AM individually. Only two articles were found that depicted the LSS-AM amalgamation's CFFs.

2.5.2.1.3 Analysis of Articles based on Tools/Techniques/Methodologies/Practices used

To stay competitive in this marketplace, organizations are adopting LSS/AM/Leagile/LSS-AM. Therefore several tools /techniques/methodologies/practices are identified, proposed by several authors, and practiced by several organizations. LSS /AM /Leagile/LSS-AM have many tools and techniques, and some of them overlap. Different tools /techniques/practices have different purposes such as waste elimination, reduction in process variation, and customization. Many of these tools and techniques are used in combination with each other to attain optimum results. Table 2.7 depicts the review of literary contributions to identify the toolkits of LSS/AM/Leagile used by different industry types.

Table 2.7: Review of LSS/AM/Leagile tools/techniques/practices

	LSS tool kit					AM Tool	Leagile Tool Kit	
Tools/Techniques/Practices	**D**	**M**	**A**	**I**	**C**			**Literare Support**
VSM		*		*			*	De Koning (2008); Chen and lyu (2009); Vinodh *et al*., (2011);Pillai *et al.* (2012);Cabrita *et al.*, (2015); Garza-Reyes *et al.* (2016);Thomas *et al.*,(2016);Guerrero *et al*.,(2017);Ruben, *et al*., (2018);Hill *et al*., (2018); Venugopal and Saleeshya(2019); Sodhi *et al*.,(2020);Chiarini and Kumar (2021); Kaswan et al.(2021); Gupta *et al.* (2022)
Poka-yoke				*	*		*	Kanakana *et al.* (2010); Krishnamurthy and Yauch (2007); Chen and Iyu (2009); Chiarini (2015); Sreedharan and Sunder (2018a); Sunder and Antony (2018);)Chiarini and Kumar (2021)
5S				*			*	Furterer *et al.,* (2005); Krishnamurthy and Yauch (2007); Kumar *et al.*, (2006); De Koning (2008); Chen and lyu (2009); Wang and Chen (2012); Sreeram and Thondiyath (2015); Svensson *et al*., (2015); Sunder and Antony (2018); Chiarini and Kumar (2021); Gupta *et al.* (2022)
SMED				*		*	*	Kanakana *et al*., (2010); Atmaca and Girenes (2013); Elmoselhy (2013); Mehrsai *et al.*, (2014); Chiarini (2015); Sreedharan and Sunder (2018a);Virmani *et al.*,(2018b);Chiarini and Kumar (2021);Elmoselhy(2013);Mehrsai *et al.*,(2014)
5why/Cause and Effect/Root cause analysis			*		*			Chen and lyu (2009); Kumar *et al.*, (2006); Kanakana *et al.*, (2008); Vinodh *et al.*, (2011a); Svensson *et al.,* (2015); Ruben *et al.,* (2017); Sreedharan & Sunder (2018a); Kumar *et al.*, (2019a); Kaswan et al. (2021); Gupta *et al.* (2022)
Failure mode effect analysis					*			Van den Heuvel *et al.*, (2006); Wang and Chen (2012); Cabrita *et al.*,(2015);Sunder and Antony(2018);Trehan *et al.*,(2019)

	LSS tool kit					AM Tool	Leagile Tool Kit	
Tools/Techniques/Practices	**D**	**M**	**A**	**I**	**C**			**Literare Support**
Design of Experiment (DOE)				*				Kumar *et al.* (2006); Kanakana *et al.,* (2010); Vinodh *et al.*, (2011); Vinodh *et al*., (2014); Sunder and Antony (2018); Gupta *et al.* (2022)
Pareto Chart			*					Van den Heuvel *et al.,* (2006); Gibbons (2006); Kanakana *et al*., (2010); Gnanaraj *et al.,* (2010); Vinodh *et al*., (2011); Antony *et al.,* (2012); Wang and Chen (2012); Atmaca and Girenes (2013); Vinodh *et al.,* (2014); Swarnakar and Vinodh (2016); Hill *et al.,* (2018); Gijo *et al.,* (2018); Trehan *et al.*, (2019); Krishnan *et al.* ,(2020);Sharma e*t al.*,(2021); Gupta *et al.* (2022)
Brainstorming			*	*				Cheng *et al.*, (2012); Dora and Gellynck (2015); Chaurasia *et al.*,(2016); Sony (2019);Yadav *et al.*, (2021c)
VisualAnalysis/Management		*		*			*	De Koning *et al.,* (2008); Kanakana *et al.,* (2010); Antony *et al.,*(2012);Elmoselhy(2013); Chaurasia *et al.* ,(2016);Sunder and Antony(2018);Moya *et al.*, (2018); Raval *et al.*,(2018a);Nascimento *et al.,* (2019);Mishra *et al.*,(2021)
PDCA								Sreeram and Thondiyath (2015); Nascimento *et al.*,(2019)
Process Flow chart or AS-IS	*	*						Gnanaraj *et al.*, (2010); Cheng *et al.*, (2012); Svensson *et al.*, (2015); Swarnakar and Vinodh (2016); Deithorn andKovach (2018); Trehan *et al.*, (2019); Sharma *et al.*, (2021)
Control charts					*			Vinodh *et al.*, (2011); Atmaca and Girenes (2013); Vinodh *et al.*, (2014);Garza-Reyes *et al.*, (2016);Thomas *et al.*, (2016);Guerrero *et al.,*(2017); Sreedharan and Sunder(2018a);Sony(2019);Krishnan *et al.*, (2020); Gupta *et al.* (2022)
SIPOC		*						Su *et al.,* (2006); De Koning *et al.,* (2008); Cheng *et al.,* (2012); Antony *et al*.,(2012);Svensson *et al*., (2015);Swarnakar and Vinodh(2016);Sunder and Antony (2018);Chaurasia *et al.*, (2019);Krishnan *et al.*,(2020)

	LSS tool kit					AM Tool	Leagile Tool Kit	
Tools/Techniques/Practices	**D**	**M**	**A**	**I**	**C**			**Literare Support**
Project Charter	*							Gibbons (2006); Kanakana *et al.,* (2010); Gnanaraj *et al.*, (2010); Vinodh *et al.*, (2011); Antony *et al.*, (2012); Vinodh *et al.,*(2014);Dora and r Gellynck (2015); Swarnakar and Vinodh(2016);Sunder and Antony(2018);Sony(2019);Krishnan *et al.,* (2020);Trakulsunti *et al.,*(2020); Yadav *et al.*,(2021c)
TPM				*		*	*	Kumar *et al.,* (2006), Dibia *et al.*,(2012); Virmani *et al.,*(2018, b); Hasan *et al.* (2013); Chaurasia *et al.*, (2016); Sreedharan and Sunder (2018a); Khalfallah and Lakhal (2021); Chiarini and Kumar (2021)
Statistical method: Hypothesis testing (t-test/f-test/ANOVA); Regression analysis			*					Van den Heuvel *et al.*, (2006); Kanakana *et al.,* (2010), Wang and Chen (2012); Guerrero *et al.*, (2017); Sunder and Antony(2018); Sreedharan and Sunder(2018a); Gijo *et al.*,(2018); Sunder and Antony(2018)
Measurement system analysis (MSA)/Gauge R&R		*						Su *et al.*, (2006); Kanakana *et al.,* (2010); Goswami and Kumar (2012); Svensson *et al.,* (2015); Guerrero *et al.*, (2017); Sunder and Antony (2018); Sreedharan and Sunder (2018a); Krishnan *et al.*, (2020)
QFD/Kano Model/HOQ	*					*	*	Gunasekaran et al., (2002); Vinodh and Chintha (2011); Thomas et al., (2016);Haq and Boddu (2017);Shahin and Rezaei(2018)
Pull system/Kanban/JIT				*		*	*	Su et al., (2006); Pillai *et al.* (2012); Elmoselhy (2013);Thomas *et al.,* (2016); Sindhwani *et al.*,(2017b);Sreedharan and Sunder(2018a);Kumar *et al.*(2020a);Chiarini and Kumar (2021)
Check sheet					*			Su *et al.* (2006); Gnanaraj *et al.* (2010); Sreeram and Thondiyath (2015); Yadav *et al.*, (2018a); Sodhi *et al.,*(2020);Sharma *et al.,* (2021)
Standardization/Standardized operating procedure		*			*			Chaurasia *et al.*, (2016); Gijo *et al.,* (2018); Sreedharan and Sunder (2018a); Nascimento *et al.,*(2019); Sharma *et al.*,(2021)

	LSS tool kit					AM Tool	Leagile Tool Kit	
Tools/Techniques/Practices	**D**	**M**	**A**	**I**	**C**			**Literare Support**
Kaizen				*	*		*	Kanakana *et al.* (2010); Atmaca and Girenes (2013); Chaurasia *et al.* (2016); Virmani *et al., (*2018,b); Krishnan *et al*.,(2020)
Gemba		*						Gijo *et al.*, (2018); Nascimento *et al.* (2019); Sharma *et al.,* (2021)
Process Capability (cp,cpk)			*					Kumar *et al.,* (2006); Van den Heuvel *et al.*, (2006); Shahin and Jaberi (2011); Sunder and Antony (2018); Kaswan *et al.* (2021)
Simulation				*		*	*	Gunasekaran and Yusuf (2002); Mostafa *et al.*, (2016); Al-Refaie *et al.*, (2019);Sony (2019);Sharma *et al.*, (2021)
Virtual Enterprise						*	*	Van Hoek *et al.*, (2000); Gunasekaran and Yusuf (2002); Cao and Dowlatshahi (2005); Vinodh and Chintha (2011); Elmoselhy (2013); Chang *et al.,* (2013); Arvind Raj *et al.,* (2013); Mehrsai *et al.,* (2013); Sindhwani (2016a); Sindhwani *et al.*, (2017,b); Virmani *et al*., (2018,b); Soepardi *et al.*, (2018)
CAD/CAE						*		Gunasekaran and Yusuf (2002); Vinodh *et al.,* (2010,b); Vinodh and Kuttalingam (2011);Dibia *et al*.,(2012);Thilak *et al*.,(2017);Sunil *et al*.,(2018)
MRP/ERP				*		*	*	Van Hoek (2000); Hasan *et al.*, (2013); Thomas *et al.*, (2016); Virmani *et al.,* (2018, c); Venugopal and Saleeshya (2019); Virmani and Sharma (2019)
Automation (AGV/Sensors)				*		*	*	Van Hoek (2000); Sharifi and Zhang (2001); Gunasekaran and Yusuf (2002); Ramesh and Devadasan (2007); Gore *et al.*, (2009); Elmoselhy (2013); Mehrsai *et al.,* (2014); Patel and Brahmbhatt (2021)
Information Technology/Electronic Data/Communication						*	*	Sharifi and Zhang (2001); Gunasekaran and Yusuf (2002); Vinodh and Chintha (2011); Elmoselhy (2013); Dubey and Gunasekaran (2015); Haq and Boddu (2015); Virmani *et al.*, (2018,b)

Tools/Techniques/Practices	LSS tool kit D	M	A	I	C	AM Tool	Leagile Tool Kit	Literare Support
Group Technology/Cellular Manufacturing						*	*	Gunasekaran and Yusuf (2002); Elmoselhy (2013); Virmani *et al.,* (2018,b); Lotfi (2019); Balakrishnan *et al.*, (2019); Chiarini and Kumar (2021)
Rapid Prototyping						*	*	Onuh *et al.*, (2006); Vinodh *et al.,* (2010,b); Vinodh *and* Chintha (2011); Thilak *et al.,* (2017); Venugopal and Saleeshya (2019)

These are the tools that have highly appeared in the literature. Low-frequency tools are not included in this analysis. This table has two observations, first is that LSS has tools for waste elimination and process variation but does not have tools for customization and product mix. In contrast, agile has tools/practices for responsiveness and customization to fulfill customers' dynamic demands but does not have tools for waste elimination and reduction in process variation. At the same time, Leagile comprises both waste elimination tools and responsiveness and customization tools but does not have systematic data-driven approach tools to reduce in-process variation and enhance the quality of processes/services. Second observation is, this table represents that lean and some agile/leagile tools/practices are embedded in six sigma's DMAIC approach. Specific tools/practices such as VSM; kaizen, poka-yoke, SMED, TPM; Pull/Kanban; QFD; simulation; virtual enterprises; group technology overlap among LSS, Agile and Leagile. Hence a comprehensive tool kit, which comprises the tools for amalgamation of LSS-AM, is lacking.

2.5.2.1.4 Analysis of Articles based on Frameworks

Frameworks or models are guiding torches for the things to do. It is an overview of a change process /approach/philosophy /strategy to be adopted and became a medium to communicate the organization's new vision. Several researchers, consultants, academicians, and practitioners have developed frameworks about LSS, AM, and their integration. Anand and Kodali (2010) categorized frameworks into two categories, i.e., "design or conceptual" frameworks and "implementation" frameworks. Taking this cue from them, we also categorized identified frameworks similarly. Design/conceptual frameworks are defined as frameworks, which describe what the elements/tools/principals LSS/AM/Leagile comprises, or in other words, they discuss the content of LSS/AM or Leagile. On the contrary, implementation frameworks discuss the roadmap for LSS/AM/Leagile /LSS-AM implementation or, in other words, what is the sequence of activities to be taken up. Gunasekaran *et al.*, (2002) developed a conceptual generic framework for AM strategies. Jin-Hai *et al.,* (2003) developed a conceptual real agile manufacturing framework based on four fundamentals. Ismail *et al*., (2006) developed an agility roadmap for agile implementation in the organization. Vázquez-Bustelo *et al*., (2006) developed a conceptual model of AM based on three manufacturing case studies. Ramesh and Devadasan (2007) developed a conceptual framework for AM. Krishnamurthy and Yauch (2007) proposed a theoretical corporate infrastructure of the Leagile manufacturing concept. Pepper and Spedding (2010) developed a conceptual model of LSS. Gnanaraj *et al.*, (2010) developed a DODMAICS (Deficiency Overcoming Lean Anchorage Define Measure Analyse Improve Control Stabilise (DOLADMAICS) implementation framework for LSS implementation in SMEs.

Shahin and Jaberi (2011) proposed a conceptual framework of leagile production using mass customization, modularization, and postponement and applied this concept in the DMAIC approach of Six Sigma in auto part manufacturing. Vinod *et al.*, (2011a) developed a five-step LSS conceptual framework and lean tools for were LM implementation process.

Psychogios *et al.*, (2012) developed an integrated conceptual framework of LSS. Prasanna and Vinodh (2013) developed a conceptual framework of LSS in which lean five principles (value, value stream, flow, pull, and pursuit of perfection) were integrated with Six Sigma's define, measure, analysis, improve, control, and sustain the cycle. Elmoselhy (2013) proposed an implementation framework for hybrid lean-agile manufacturing systems. Finally, Lemieux *et al.*, (2013) proposed a performance and adoption alignment framework to guide leanness and agility initiatives in product development.

Timans *et al.*, (2014) proposed a 3-phase implementation framework of LSS in SMEs. Nunes *et al.*, (2015) proposed an integrated ergonomic-based LSS framework.

Dubey and Gunasekaran (2015) proposed a conceptual framework of AM having seven elements. Lemieux *et al.*, (2015) proposed a leagile transformation model for product development. Tsironis and Psychogios (2016) proposed a multi-factor conceptual framework for the service industry. Chaurasia *et al.*, (2016) developed an implementation-integrated LSS framework to improve the business improvement performance of oil-exporting countries during the recession. Leite *et al.*, (2016) proposed IPID (identity, prioritize, implement, disseminate) cycle-based framework for implementing lean and agile techniques in product development and proposed an IPID cycle - a road map for implementing lean and agile techniques in product development. Eltawy and Gallear (2017) theoretical represented the lean and agile system. Sunder and Antony (2018) proposed a conceptual framework of LSS for quality excellence in the higher education industry. Sreedharan and Sunder (2018) developed an SDMMAICS (selection, define, measure, map, analyse, improve, control and sustain) LSS implementation framework. Balakrishnan *et al.*, (2019) developed an implemented model for implementing the Leagile manufacturing paradigm in pump manufacturing. Nascimento *et al.,* (2019) proposed an implementation framework based on lean principles, six sigma's DMAIC, and Deming's PDCA for the oil industry. Kumar *et al.,* (2019a) proposed a conceptual framework of AM, which have seven pillars. Patel *et al.,*

(2019) proposed a roadmap for LSS implementation in the manufacturing industry.

Sodhi *et al*., (2020) developed and implemented a Lean Six Sigma project management framework for SMEs. Vallejo *et al*., (2020) proposed a road map of the LSS implementation framework for SMEs. Varl *et al.,* (2020) proposed a generalized implementation framework for the agile manufacturing transformation process for one-of-a-kind product development. This framework is a highly efficient one-of-a-kind product development process transformation according to the principles of agility. Borsci *et al*., (2020) proposed a Lean and Agile Multi-dimensional Process (LAMP) for new product development in healthcare devices and technology. Finally, Piotrowicz *et al*., (2021) developed a conceptual framework to measure the performance of the leagile supply chain.

A review of LSS/AM/Leagile/LSS-AM revealed that although researchers have developed many conceptual and implementation frameworks in LSS/AM/ Leagile individually, only two frameworks integrate LSS-AM under one umbrella were found, which is significantly less in number. So there is a strong need to develop a comprehensive framework that gives a step-by-step guidelines to implement LSS-AM simultaneously.

2.5.2.1.5 Analysis of Articles based on Performance Outcomes

Performance outcomes consist of the expected performance outcomes achieved by implementing LSS/AM/Leagile/LSS-AM. These outcomes are either theoretically stated by several authors or realized by various organizations after implementing these approaches. In addition, a plethora of articles represented these performances in tangible or intangible forms.

Table 2.8 shows the performance outcomes obtained based on the literature review.

Performance outcome LSS/AM/LEAGILE	LSS	AM	Leagile	LSS-AM
Reduction in cost	De Koning *et al.,(*2006); Thomas *et al*.,(2008); Shahin and Alinavaz(2008);Drohomeretski *et al*.,(2014); Albliwi *et al*., (2015); Shamsuzzaman *et al*.,(2018); Muganyi *et al*.,(2019); Latessa *et al*., (2021); Gupta *et al*.(2022)	Newman *et al*., (2000); Gunasekaran andYusuf (2000); Adeleye and Yusuf (2006); Hasan *et al*.,(2008)	Van Hoek (2000); Agarwal *et al*. (2006); Ding et al., (2021); Soni and Kodali (2012); Elmoselhy(2013);Abdollahi *et al*., (2015); Virmani *et al.,* (2017a); Balakrishnan *et al.,* (2018); Udokporo *et al.,* (2020);Ding *et al.,* (2021)	Dibia and Onuh (2012); Hariyani *et al*.(2022)
Increased in profitability/revenue/turnover	Jin *et al.,* (2008); Wang and Chen (2012); Thomas *et al.* (2016); Guerrero *et al.,*(2017); Tetteh (2018);Gijo and Antony(2019); Singh *et al.,* (2019); Bhat *et al*., (2021a); Gupta *et al*.(2022)	Ismail *et al.,* (2006)/Potdar and Routroy (2017); Gunasekaran *et al.,* (2018),	Ghobakhloo andAzar (2018); Eltawy and Gallear	Shahin and Jaberi (2011); Hariyani *et al*.(2022)
Increased in sales/vol./market share	Guerrero *et al*., (2017); Mishra *et al*., (2021); Bhat and Jnanesh (2013); Gupta *et al*.(2022)	Potdar and Routroy (2017); Gunasekaran *et al*., (2018); Kumar *et al*., (2019d)	Virmani *et al*., (2017a);	Shahin and Jaberi (2011)
Reduction in Lead time/cycle time/turnaround time/waiting time/Set up time/machine down time	Vinodh *et al*., (2011); Laureani et al., (2013); Bhat and Jnanesh (2013); Muganyi *et al*., (2019); Sunder (2016,a); Gijo and Antony (2019); Krishnan *et al*.,(2020);Bhat *et al*., (2021a)	Onuh *et al.* (2006); Kumar *et al*. (2019d), Patel and Brahmbhatt (2021)	Eltawy and Gallear (2017); Virmani *et al.,* (2017a); Balakrishnan *et al*., (2018)	Shahin and Jaberi(2011); Hariyani *et al*.(2022)
Reduction or elimination of wastes /NVA (WIP/Rework /Scrap/Transportation/space utilization/defects)	Vinodh *et al*., (2011); Pillai *et al*., (2012); Chiarini (2012); Anderson and Kovach (2014); Laureani *et al.* (2013); Thomas *et al.,* (2016); Garza-Reyes *et al.* (2016); Bhat *et al.,* (2016); Guerrero *et al.*, (2017); Ruben *et al.,* (2017); Trakulsunti *et al.,* (2021);Cabrita *et al.,* (2015),Muganyi *et al.,* (2019);Singh *et al*.(2021); Gupta *et al*.(2022)		Virmani *et al*.; (2017a); Balakrishnan *et al.*, (2018); Sindhwani *et al.*, (2019)	Shahin and Jaberi (2011); Hariyani *et al*.(2022)
Improvement in quality (process capability/DPU/Six Sigma level/FTR/RTY)	Kumar et al., (2006), Vinodh *et al*., (2011), Wang and Chen (2012)(2019); Muganyi *et al*.(2019); Chaurasia *et al.* (2019); Singh et al., (2019); Bhat *et al*.,(2021b); Gupta *et al*.(2022)	Gunasekaran and Yusuf (2002); Ismail *et al*., (2006); Hasan *et al*., (2008); Vinodh *et al*., (2010,a); Potdar *et al.* (2017,c)	Eltawy and Gallear (2017)	Shahin and Jaberi(2011); Hariyani *et al*.(2022)
Improvement in process performance (reduction in	Vinodh *et al*., (2011), Cabrita *et al*.,(2015), Muganyi *et al.,* (2019); Jin *et al.* (2008); Bhat and Jnanesh (2013); Bhat *et al.,* (2016);			Shahin and Jaberi(2011)

process variation/OEE)	Shamsuzzaman *et al.,* (2018); KAM *et al.,(*2021)			
Improvement in stakeholder satisfaction (customer/employees/supplier)	Kumar *et al*., (2006) Tetteh (2018), Haerizadeh *et al*., (2019); Patel and Patel (2021); Gupta *et al*.(2022*)*	Potdar and Routroy (2017); Kumar *et al*., (2019a); Kumar *et al.,* (2019d); Kumar *et al.,* (2021a)	Agarwal *et al*., (2006); Eltawy and Gallear (2017);	Dibia and Onuh (2012); Hariyani *et al*.(2022)
Improvement in responsiveness/Customization/new product development time/product mix/flexibility /service level/Availability		Newman *et al*., (2000); Gunasekaran and Yusuf (2002); Adeleye and Yusuf (2006); Onuh *et al*.(2006); Vinodh *et al*.,(2010,a); Vinodh *et al*., (2010,b); Potdar *et al*. (2017, c); Gunasekaran *et al*.,(2018); Kumar *et al.,* (2019d)	Mason-Jones *et al.,* (2000); Agarwal *et al*., (2006); Chan *et al*., (2009); Politis and Rekkas (2017)	Dibia and Onuh (2012); Shahin and Jaberi (2011); Hariyani *et al.* (2022)

These performance outcomes revealed that LSS improves organization performance in terms of cost reduction, waste elimination, process variation reduction, improving quality in terms of sigma level, and DPMO improve the overall equipment effectiveness; reduce the cycle time; TAT; lead time hence enhance the customer satisfaction. However, in terms of responsiveness, customization, product mix, shorter new product development time, and availability, LSS alone is not capable of achieving. While in AM, these performance outcomes are achieved at optimum cost as, AM does not focus on wastes elimination and process variation reduction, which is the core of LSS. In Leagile, all the performance outcomes include reduction in costs, improvement in bottom-line saving, waste elimination, reduction in cycle time, TAT, lead time, improvement in market share and volume, improvement in responsiveness, product mix, flexibility and service level improve the stakeholder satisfaction are attained except the reduction in process variation. Although only three articles were found based on the amalgamation of LSS-AM, the result revealed that efficiency, effectiveness, and responsiveness might be attendant simultaneously.

2.5.2.1.6 Analysis of Articles based Applications in SME and MSME

Earlier it was an old-school thought that LSS/AM /Leagile are for large-scale industries. Therefore, they will not fit in small-scale or micro-scale enterprises because of their social and financial limitation. However, now the scenario has changed. SMEs and MSMEs face fierce competition and are keen to adopt new approaches to remain competitive. Following are the application of LSS/AM/Leagile found in SMEs and MSMEs.

Kumar *et al.*, (2006) implemented the LSS framework to reduce the defect in a die-casting process. As a result, the organization generates defect per unit (DPU), process capability index, the mean and standard deviation of casting density, yield, overall equipment effectiveness (OEE), and substantial financial savings. Thomas *et al.*, (2008) proposed and implemented an integrated LSS framework cost-effectively at SMEs and found improvement in product quality cost and delivery, OEE. Timans *et al.*, (2012) applied the LSS roadmap in Dutch to eliminate the root causes behind poor flow, waste, and variability. Leite *et al.*, (2016) proposed and implemented a roadmap of lean and agile implementation in the product development stage through IPID (Identity, prioritize, disseminate, Implement). Guerrero *et al.*, (2017), deployed the LSS DMAIC approach to reduce waste and defects and improve quality in furniture manufacturing SMEs. Rauch *et al.*, (2019) proposed and implemented an axiomatic design-based approach to design flexible and agile manufacturing and assembly systems in SMEs. Bhat *et al.*, (2021a) deployed the Lean DMAIC approach in the printing industry (MSME) to improve turnaround time and quality. This study revealed that TAT reduced from an average of 1541.2 min to1303.36 min, consequently improving the sigma level from 0.55 to 2.96, and annual savings of USD 12,000 per year.

This study also revealed that LSS, AM, and Leagile could be successfully implemented in SMEs and MSMEs and open the window for research to implement an integrated LSS-AM approach in SMEs and MSMEs.

2.5.2.1.7 Analysis of Articles based on Research trends of LSS/AM /LEAGILE with other approaches

An amalgamation of approaches is the new trend among the researchers as many organizations have adopted LSS, AM, and Leagile individually, so competitive advantages have been lost. Environmental aspects also compel organizations to include green strategies in their business improvement plan. So researchers are integrating these approaches with other approaches to get a competitive edge. Nicoletti (2013) integrated LSS with digital technology. Banawi and Melissa (2014); Garza-Reyes *et al*., (2014); Garza-Reyes (2015), S.Kumar *et al*., (2015); Vallejo *et al*., (2020); Vinodh *et al*., (2020) with green manufacturing and sustainability approach. Yadav *et al*., (2021); Chiarini and Kumar (2021); Bhat *et al*., (2021b) integrated LSS with Industry 4.0. Gunasekaran *et al*. (2018); Yli-Ojanpera *et al*. (2019) integrated AM practices with big data and industry 4.0. Mittal *et al*., (2017), Udokporo *et al*., (2021) integrated lean, green, and agile practices, and Raji *et al*. (2021) integrated lean and agile strategies with digital technologies. Ghobakhloo and Azar (2018) integrated the lean-agile approach with advanced manufacturing technology. The literature review revealed that integration of LSS/AM/Leagile with other approaches such as Green, Industry 4.0, and big data are booming research areas.

2.6 CONCLUSION AND KEY FINDINGS

This study exhibits and analyzes the various definitions of LSS, AM, and Leagile, reflecting the scope and goals. Existing literature articles based on LSS, AM, and Leagile were also presented. This study presents a review of 350 articles published from 2000 to August 2022. These articles are analyzed descriptively (journals and publishers; author's demography, distribution of articles over time, research methodology, type of sector, type of approach) and content-wise (critical success factors, critical failure factors, performance outcomes, frameworks, tools/techniques/practices; application in SME's and MSME's and research trends of integration).

The followings are the key findings drawn from the current study:

- First, many definitions of LSS, AM, and Leagile have divergent scopes and goals.
- The distribution of articles over some time revealed that the majority of research work in the LSS field was done after 2010 and increased after that.AM trend line represents the moderate amount of work that has been done in the year 2000-2010; after that, AM attracted researchers, and a significant amount of work was carried out from 2010 to 2022. Leagile amalgamation is attracting researchers as a buzzing area of research. Research articles related to Integrated LSS-AM were found very few and published during 2012 to 2014 and 2022.
- Region-wise distribution of articles depicts LSS, AM, and Leagile are becoming a popular area of research among researchers across the globe. Indian authors standalone contributes 145 articles out of 350, followed by UK and US.
- This represents 96 percent of articles published by academicians only. Industry experts contributed merely 3 percent of research articles. Only 1 percent of authors are both academicians and Industry experts.
- Application of LSS/AM/their integration is found in the manufacturing, service, and process sectors. For example, LSS applications are found from automobile manufacturing to healthcare, bolt manufacturing to financial services, FMCG to the construction industry, large manufacturing to SMEs'. On the other hand, applications of AM and Leagile are mostly found manufacturing sector only.

- MCDM is one of the principal methodologies among the researchers to analyze CSFs and CFFs, followed by a case study and questionnaire survey. Different authors give a different set of CSFs and CFFs of LSS/AM/Leagile/LSS-AM individually. Only two articles depicted the LSS-AM amalgamation's CSFs and three articles represented the LSS-AM amalgamation's CFFs collectively.
- A review of LSS/AM/Leagile/LSS-AM revealed that although researchers have developed many conceptual and implementation frameworks in LSS/AM/ Leagile individually, none of the frameworks integrate LSS-AM under one umbrella, is found. Therefore, there is a strong need to develop a comprehensive framework that gives step-by-step guidelines to implement LSS-AM simultaneously.
- Performance outcomes of LSS/AM/Leagile/LSS-AM are either theoretically stated by several authors or realized by various organizations after implementing this approach. As a result, many articles represented this performance in tangible or intangible forms.
- These performance outcomes revealed that LSS improves efficiency and effectiveness of process/service but does not improve responsiveness. In contrast, AM improves responsiveness but does not improve efficiency and effectiveness, whereas Leagile improves efficiency and responsiveness but does not make the process effective. Hence simultaneous implementation of LSS and AM might improve efficiency, effectiveness, and responsiveness in a single effort.
- LSS, AM, and Leagile have been successfully implemented in SMEs and MSMEs. However, the amalgamation of LSS-AM approach implementation is missing.
- Integration of LSS/AM/Leagile with other approaches such as Green; Industry 4.0; Big data is a booming area of research.

2.7 KEY RESEARCH GAPS

Although individual LSS, AM, and Leagile research fields have attracted researchers in the past two decades. However, only two researchers have put effort into their amalgamation. Only two-implementation framework has been developed that integrates the LSS-AM approach under one umbrella

The key research gaps identified from the present study are the following:

- Most researchers developed an integrated framework of LSS/AM/Leagile individually. However, only two researchers have developed an integrated framework for LSS and AM implementation, significantly less in number. Therefore, a strong need arises to develop an integrated LSS-AM implementation framework that gives step-to-step guidelines to implement LSS-AM simultaneously.
- There is hardly any effort made (only 3) to present a comprehensive analysis of integrated LSS and AM concepts, both from a strategic point of view and critical success factors and critical failure factors perspective. Therefore, there is also a need to identify the critical success and failure factors of LSS -AM to make strategies to diminish their adverse impacts.
- Several researchers have used LSS, AM, and Leagile tools/techniques/methodologies/practices individually, but a comprehensive set of tools/techniques/methodologies/practices that integrate LSS and AM is not found. Therefore, there is a need to cohesively set up a toolkit that comprises LSS-AM tools /techniques/methodologies/practices.
- LSS, AM, and Leagile have been successfully implemented in SMEs and MSMEs, and this opens the window for research to implement an integrated LSS-AM approach in SMEs and MSMEs.

2.8 LIMITATIONS

The limitations identified from the present study are the following:

- Only research articles available in the Scopus database published from 2000 to August 2022 and published in Emerald, Taylor francis, IEEE,Wiley, Indesrcience and Elsevier were considered under review.
- Although the utmost care has been taken while selecting the literature articles, there is the possibility that some of the quality research articles might be left out because of their "Title Only" selection, inaccessability and exclusion criteria for citaions for period 2000-2017 (less than 5).

CHAPTER 3

CRITICAL SUCCESS FACTORS AND CRITICAL FAILURE FACTORS FOR LSS-AM IMPLEMENTATION

3.1 INTRODUCTION

To meet ever-changing customer requirements efficiently, effectively and responsively, the implementation of integration of LSS-AM will give leverage to the manufacturing industry. For successful implementation of LSS-AM, it is necessary to understand the factors, which enable the LSS-AM implementation journey to a smooth ride, and the factors, which become roadblocks in the LSS-AM implementation journey. These enabling factors are named critical success factors and roadblocks are named critical failure factors. Various authors identified CSFs/CFFs of LSS/AM/Leagile/LSS-AM and analyzed them by a different methodology that was discussed in chapter 2. Review of these papers revealed that multi-criteria decision-making (MCDM) is one of the prominent methodologies among the researchers to analyze CSF's/CFFs. Different authors have given a different set of CSFs and CFFs of LSS/AM/Leagile/LSS-AM individually. Only one article was found that depicted the LSS-AM amalgamation's CSFs where as two articles depicted CFFs for LSS-AM implementation.

Hence the objectives of this chapter are:

- To identify the LSS-AM CSFs and CFFs from the vast literature review and expert opinion.
- To validate these CSFs and CFFs through Structural Equation Modeling (SEM)
- To build a hierarchical model each for CSFs and CFFs using Fuzzy-Total Interpretative Structural Modeling (Fuzzy-TISM) and to categorise these CSFs and CFFs using MICMAC (Matrice d' Impacts Croisés-Multiplication Appliquée

un Classement)

A proper understanding and analysis of CSFs and CFFs for LSS-AM implementation will help Indian manufacturing industries to find out an effective way to utilize and allocate their resources to achieve the LSS-AM objectives and mitigate any hindrance in the implementation process.

To serve these objectives this chapter is categorized into 6 sections i.e. 3.2 explains the adopted methodology; section 3.3 describes the validation of CSFs to LSS-AM implementation through SEM and development of hierarchical model of validated CSFs through Fuzzy-TISM and MICMAC analysis; 3.4 describes the validation of CFFs through SEM and development of hierarchical model of validated CFFs through Fuzzy-TISM and MICMAC analysis; section 3.5 discusses the results obtained from the study followed by section 3.6 which describes the conclusion limitation and direction for future work.

3.2 RESEARCH METHODOLOGY

In the present study, we have applied a triangulation research strategy, which used both quantitative and qualitative analysis to intensify the validation of the collected data and hypothesis. In this adopted methodology, quantitative analysis was performed as per data obtained through a questionnaire survey within the Indian manufacturing industry while qualitative analysis was performed based on interaction with and feedback from academia and industry experts. Various approaches i.e. questionnaire survey, SEM; Fuzzy –TISM and MICMAC were applied to achieve the research objectives. Figure 3.1 depicts the step-by-step methodology adopted for validation of factors and development of model.

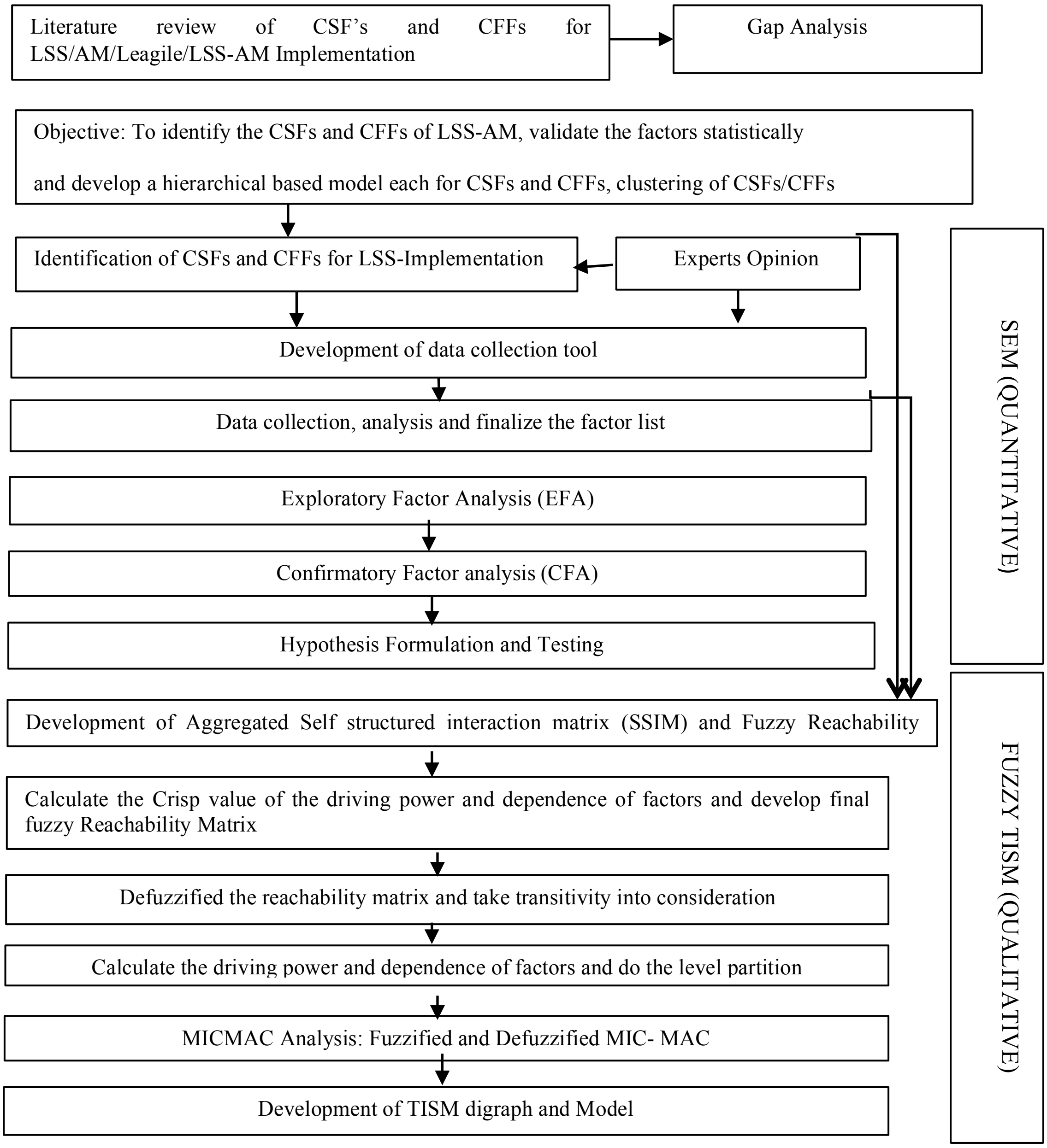

Figure 3.1 Methodology adopted for factors validation and models development

3.2.1 Identification of CSFs and CFFs for LSS-AM Implementation

Several researchers have analyzed the various CSFs and CFFs for LSS and AM individually. A multi-step methodology has been adopted to identify the key CSFs and CFFs for LSS-AM. In the first step list of identified CSFs /CFFs from reviewing the articles based on

CSF's/CFFs for LSS, AM, Leagile and LSS-AM implementation was developed. A comprehensive list of LSS-AM CSFs/CFFs was prepared and discussed with an expert panel which was constituting 11 industrial experts and 15 academicians, in a semi-structured interview form to check whether all CSFs and CFFs were incorporated or not. According to them all CSFs and CFFs for LSS-AM implementation were relevant and included. Table 3.1 and 3.2 describes the list of identified CSFs and CFFs.

Table 3.1: Identified CSFs for LSS-AM implementation from literature review

S. No.	**CSFs of LSS-AM**	**Alias**	**Description**	**Literature Support**
1	Technology advancement	C1	To match the pace with the dynamic demands of customers it is necessary to upgrade the organization's existing technology from time to time and the organization should also welcome new technologies whenever the need arises	Vázquez-Bustelo and Avella (2006); Ramesh and Devadasan (2007); Gore *et al.* (2009); Raj *et al.* (2013); Leite and Braz (2016); Lande *et al*. (2016); Yadav and Desai (2017); Sindhwani *et al.* (2017a); Haq and Boddu (2017); Soepardi *et al*. (2018); Potdar and Routroy (2018); Goswami and Kumar (2018); Sindhwani and Malhotra (2018); Potdar *et al*. (2018); Gunasekaran *et al.* (2019); Virmani and, Sharma (2019);Kumar *et al.* (2020a); Raji *et al.* (2021); Bhat et al. (2021a); Swarnakar *et al.* (2022)

2	Virtual enterprise	C2	Virtual enterprise's concept helps to leverage the competencies of partners, based on the demand, and thus reduces the response time. Often a single organization may not be capable to fulfill fast changing demand of customers quickly. Hence they form temporary alliances with partners to fulfill customers demand responsively and cost effectively.	Hasan *et al.* (2009); Vinodh *and* Chintha (2011); Jayaraman *et al*. (2012); Raj *et al.* (2013); Guru Dev and Kumar (2016); Sindhwani *et al.* (2017a); Sindhwani *et al*. (2017b); Haq and Boddu (2017); Goswami and Kumar (2018); Sindhwani and Malhotra (2018); Virmani and, Sharma (2019)
3	Project Selection and Prioritization	C3	Proper project selection is a crucial CSF for the success of LSS-AM projects. Project selection should be focused on those CTQs characteristics or processes that help the organization financially and maximize the customer satisfaction. Projects must be prioritized according to their criticality in the continuous improvement process.	Snee (2010); Antony *et al.* (2012); Jayaraman *et al.* (2012); Psychogios and Tsironis (2012); Dibia and Onuh (2012); Lertwattanapongchai and Swierczek (2014); Douglas *et al.* (2015); Bakar *et al.* (2015); Yadav and Desai (2017); Moya *et al.* (2018); Vaishnavi and Suresh (2020); Patel and Patel (2021); Yazdi *et al*. (2021); Swarnakar *et al.* (2022)

4	Organization infrastructure	C4	For implementing LSS-AM in any organization, basic organization infrastructure is a prerequisite. For instance, it is strongly recommended to have some degree of communication infrastructure and enough resources to deploy LSS-AM.	Vázquez-Bustelo and Avella (2006); Ramesh and Devadasan (2007); Hasan *et al.* (2009); Snee (2010); Vinodh *and* Chintha (2011); Dibia and Onuh (2012); Lemieux *et al*. (2013); Douglas *et al.* (2015); Bakar *et al.* (2015); Guru Dev and Kumar (2016); Yadav and Desai (2017); Sindhwani *et al*. (2017a); Sindhwani *et al.* (2017b); Soepardi *et al.* (2018); Goswami and Kumar (2018); Sindhwani and Malhotra (2018); Raval *et al.* (2018b); Singh and Rathi (2020); Bhat *et al.* (2021a); Swarnakar *et al.* (2022)
5	Employee empowerment and Link to human resources-based actions (promotions, bonuses, etc.)	C5	Employees are important assets of any organization. To execute the LSS-AM project successfully management must involve employees in making any decision so that they feel empowered. Further to drive LSS-AM through our organization, it is important to incentivize people with linked actions such as bonuses or performance related perks.	Vázquez-Bustelo and Avella (2006); Hilton and Sohal (2012); Laureani and Antony (2012b); Bakar *et al*. (2015); Tsironis, and Psychogios (2016); Yadav and Desai (2017); Haq and Boddu (2017); Moya *et al.* (2018); Potdar and Routroy (2018); Potdar *et al.* (2018); Virmani and, Sharma (2019); Kumar *et al*. (2020b); Vaishnavi and Suresh (2020);Yazdi *et al*. (2021); Swarnakar *et al.* (2022)

6	Top management commitment	C6	To commence any business process improvement initiatives in any organization, top management commitment, and constant involvement is an essential factor. A positive mindset of top management is vital for LSS-AM deployment.	Vázquez-Bustelo and Avella (2006); Ramesh and Devadasan (2007); Hasan *et al.* (2009); Snee(2010);Delgado (2010); Hilton and Sohal (2012);Antony *et al.* (2012); Jayaraman *et al.* (2012); Psychogios and Tsironis (2012); Laureani and Antony (2012b); Dibia and Onuh (2012)Raj *et al.* (2013); Matawale *et al*. (2013);Antony (2014); Lertwattanapongchai and Swierczek (2014); Douglas *et al.* (2015); Bakar *et al.* (2015); Tsironis, and Psychogios (2016); Guru Dev and Kumar (2016); Lande *et al.* (2016); Yadav and Desai (2017); Sindhwani *et al.* (2017a); Sindhwani *et al.* (2017b); Rehman (2017); Soepardi *et al.* (2018);Moya *et al.* (2018); Sindhwani and Malhotra (2018); Potdar *et al.* (2018); Saini *et al.* (2018); Raval *et al.* (2018b); Virmani and, Sharma (2019); Kumar *et al.* (2020b); Vaishnavi and Suresh (2020); Davidson *et al.* (2020); Swarnakar *et al.* (2021a); Patel and Patel (2021); Raji *et al.* (2021); Bhat *et al.* (2021a); Raval *et al*. (2021);

				Yazdi *et al.* (2021); Swarnakar *et al.* (2022)
7	Organization Culture	C7	Organizational culture is a very important CSF, which decides the acceptance or rejection of any process improvement initiative in any organization. It is an organization member's belief system that includes their way of traditional working and attitude toward adaptation of new methods to achieve goals.	Vázquez-Bustelo and Avella (2006); Ramesh and Devadasan (2007); Delgado (2010); Hilton and Sohal (2012); Bailey *et al.* (2012); Psychogios and Tsironis (2012); Laureani and Antony (2012b); Tsironis, and Psychogios (2016) Yadav and Desai (2017); Sindhwani *et al*. (2017b); Moya *et al.* (2018); Goswami and Kumar (2018); Kumar *et al.* (2020b); Davidson *et al.* (2020); Raval *et al.* (2021); Yazdi *et al.* (2021); Swarnakar *et al.* (2022)
8	Multi-skilled workforce	C8	To anticipate the rapidly changing market demand quickly, a multi-skill workforce is needed.	Vázquez-Bustelo and Avella (2006); Ramesh and Devadasan (2007); Leite and Braz (2016); Sindhwani *et al.* (2017a); Sindhwani *et al.* (2017b); Rehman (2017); Soepardi *et al*.

				(2018) Goswami and Kumar (2018); Sindhwani and Malhotra (2018); Virmani and, Sharma (2019)
9	Communication and Collaboration with stakeholders	C9	To make the LSS-AM project a huge success, there should not be any hindrance in communication with internal and external stakeholders. Frequent communication among the LSS team within an organization can identify the scope for improvement and help in developing strategies accordingly. Effective communication with customers helps in collecting a large amount of data and market information through various sources for identifying the target customers and their requirements. Further to enhance the quality and design of products, purchase management system and strategic partnership, an effective collaboration and long-term cooperative relationship with the supplier are needed.	Vázquez-Bustelo and Avella (2006); Hilton and Sohal (2012); Antony *et al.* (2012); Bailey *et al.* (2012); Dibia and Onuh (2012); Matawale *et al*. (2013); Lemieux *et al*. (2013); Antony (2014); Lertwattanapongchai and Swierczek (2014); Douglas *et al*. (2015);Tsironis, and Psychogios (2016);Leite and Braz (2016);Guru Dev and Kumar (2016); Lande *et al.* (2016);Yadav and Desai (2017); Haq and Boddu (2017); ; Soepardi *et al.* (2018);Moya *et al*. (2018); Potdar and Routroy (2018); Potdar *et al.* (2018); Raval *et al*. (2018b); Gunasekaran *et al.* (2019); Virmani and, Sharma (2019); Kumar *et al.* (2020b); Costa *et al.* (2020); Vaishnavi and Suresh (2020; Davidson *et al.* (2020); Swarnakar *et al*. (2021a); Patel and Patel (2021); Bhat *et al.* (2021a); Raval *et al.* (2021); Yazdi *et al.* (2021)

10	Change management	C10	Change management plays a significant role in the transition journey of an organization in the LSS-AM process improvement initiative because these initiatives need a change in organization structure, process, and people behaviour. It is necessary to manage these changes effectively to endure the benefits of the LSS-AM initiative	Ramesh and Devadasan (2007); Delgado (2010); Bailey *et al.* (2012); Douglas *et al.* (2015); Lande *et al.* (2016); Soepardi *et al.* (2018); Goswami and Kumar (2018);
11	Training and knowledge management	C11	For effective implementation of LSS-AM in any organization, comprehensive training in lean six sigma tools sets and technology advancement is a prerequisite. Along with that, it is vital to select and provide Lean Six sigma green belt/black belt /master black belt training to the right people to channel their capability to execute the LSS-AM project successfully.	Vázquez-Bustelo and Avella (2006); Hasan *et al.* (2009); Delgado (2010); Vinodh and Chintha (2011); Antony *et al.* (2012); Jayaraman *et al.* (2012); Bailey *et al.* (2012); Dibia and Onuh (2012); Raj *et al.* (2013); Matawale *et al.* (2013); Antony (2014); Douglas *et al.* (2015); Bakar *et al.* (2015); Leite and Braz (2016); Lande *et al.* (2016);Yadav and Desai (2017); Soepardi *et al.* (2018); Saini *et al.* (2018); Raval *et al.* (2018b);Kumar *et al.* (2020a); Vaishnavi and Suresh (2020);Patel and Patel (2021);Raji *et al.* (2021); Bhat *et al.* (2021a); Raval *et al.* (2021); Yazdi *et al.* (2021);

				Swarnakar *et al.* (2022)
12	Financial capability	C12	Financial resources are required for training of people in LSS techniques; technology advancement and cost of implementation. Financial capability is crucial CSF for successful completion of any LSS-AM of project.	Jayaraman *et al.* (2012); Yadav and Desai (2017); Raval *et al.* (2018b); Virmani and, Sharma (2019); Kumar *et al.* (2020b); Bhat *et al.* (2021a); Raval *et al*. (2021); Swarnakar *et al.* (2022)
13	Information technology	C13	Information technology enables organization to share real time information with their stakeholders quickly and effectively. IT also helps to keep updated the organization by sensing the fast changing market demand and further to fulfill those demands responsively IT provides different set of soft wares i.e. CAD, CAM, MRP ERP etc.	Ramesh and Devadasan (2007); Hasan *et al.* (2009); Bailey *et al.* (2012); Psychogios and Tsironis (2012); Raj *et al.* (2013); Matawale *et al.* (2013); Guru Dev and Kumar (2016); Lande *et al.* (2016); Sindhwani *et al.* (2017a); Sindhwani *et al.* (2017b); Haq and Boddu (2017); Potdar and Routroy (2018); Goswami and Kumar (2018); Sindhwani and Malhotra (2018); Potdar *et al.* (2018); Bhat *et al*. (2021a); Raval *et al*.

				(2021); Yazdi *et al.* (2021)
14	Alignment of strategies	C14	For the long-term sustainability of LSS-AM initiatives, the goal of this business improvement strategy must be aligned with the vision statement of the company.	Matawale *et al.* (2013); Antony (2014); Lertwattanapongchai and Swierczek(2014); Bakar *et al.* (2015); Tsironis, and Psychogios (2016); Lande *et al.* (2016); Yadav and Desai (2017); Haq and Boddu (2017); Soepardi *et al.* (2018); Saini *et al.* (2018); Raval *et al.* (2018b); Vaishnavi and Suresh (2020); Sindhwani *et al.* (2021); Bhat *et al*. (2021a)

Table 3.2: Identified CFFs for LSS-AM implementation from literature review

S.No	**CFF**	**Alias**	**Description**	**Literature support**
1	Lack of training and skill development	B1	Implementation of LSS-AM, training and skill development of employees is very important, it would be a barrier if the organization misses taking it to account.	Hasan *et al*. (2007); Chen *et al*. (2009); Carvalho *et al*. (2011); Antony *et al*.(2012); Albliwi *et al*.(2015);Yadav *et al*.(2018a); Potdar *et al*.(2017b); Sreedharan *et al*.(2018a); Raval *et al*..(2018a); Sony *et al*. (2019); Sindhwani *et al.* (2019); Patel *et al*. (2019); Gaikwad *et al.*

				(2020); Patel and Patel (2021); Mishra *et al.* (2021); Kaswan *et al.* (2021); Hariyani *et al.* (2022); Sharma, and Khan (2022)
2	Insufficient resources	B2	While implementing LSS-AM in an organization, the project team may need resources such as financial resources, human resources, IT resources etc. The lack of such resources will be a barrier for implementation of LSS-AM	Hasan *et al.* (2007); Chen *et al.*(2009); Snee(2010);Huang and Li (2010); Shahin and Jaberi(2011); Carvalho *et al*.(2011);Antony *et al*.(2012); Psychogios and Tsironis (2012); Albliwi *et al*.(2015);Yadav *et al*.(2018a); Potdar *et al*.(2017b); Virmani *et al*.(2018,a); Sreedharan *et al*.(2018a); Raval *et al.* (2018a); Sindhwani *et al.*(2019); Patel *et al.*(2019); Gaikwad *et al.*(2020);Kumar *et al* (2020c);Patel and Patel(2021);Mishra *et al*.(2021); Kaswan *et al*.(2021); Hariyani *et al.*(2022)
3	Poor Project Selection	B3	Poor project selection and prioritization can lead to wrong or delayed results. It does not only draining the organization financially but also time consuming. Hence it's a barrier to	Snee (2010); Shahin and Jaberi(2011); Carvalho *et al*.(2011);Antony *et al*.(2012); Yadav *et al*.(2018a);Antony *et al*.(2017); Sreedharan *et al.*(2018a); Raval *et al*.(2018a); Sony *et al*.(2019);Patel

			the implementation of LSS-AM implementation.	and Patel(2021); Kaswan *et al*.(2021)
4	Lack of top management commitment	B4	To commence any business process improvement initiatives in any organization, top management commitment, and constant involvement is an essential factor. Missing this commitment from top management can be a huge barrier to the implementation of LSS-AM.	Hasan *et al. (*2007); Chen *et al*. (2009); Snee (2010); Huang and Li (2010); Shahin and Jaberi (2011);Carvalho *et al*.(2011); Psychogios and Tsironis (2012) ;Albliwi *et al*.(2015);Yadav *et al*.(2018a); Potdar *et al*.(2017b);Antony *et al*.(2017) ; Sreedharan *et al*.(2018a); Raval *et al*..(2018a); Sony *et al*. (2019); Sindhwani *et al.* (2019); Gaikwad *et al.* (2020); Kumar *et al.* (2020c); Haider and Khan (2020);Patel and Patel(2021);Mishra *et al*.(2021); Kaswan *et al.(*2021); Hariyani *et al*.(2022); Sharma, and Khan (2022)
5	Organization culture support	B5	An organizational culture that does not support change, value learning, and development, can be a barrier to the implementation of LSS - AM.	Hasan *et al*. (2007); Chen *et al*.(2009); Snee (2010);Huang and Li (2010); Shahin and Jaberi (2011); Carvalho *et al*.(2011);Antony *et al*.(2012); Psychogios and Tsironis (2012); Albliwi *et al.(*2015);Douglas *et al.* (2015); Yadav *et al.*(2018a);

				Potdar *et al*.(2017b);Antony *et al*.(2017); Sreedharan *et al*.(2018a); Raval *et al.*.(2018a); Gaikwad *et al.*(2020);Kumar *et al* (2020c);Mishra *et al*.(2021); Kaswan *et al*.(2021); Hariyani *et al.*(2022);
6	Lack of communication and collaboration with stakeholders	B6	Communication is the key for driving change in an organization, and poor communication in an organization may result in poor implementation of LSS-AM. Suppliers are valuable partners of an organization and this change may also impact them, hence if an organization does not have a good collaboration with the supplier it's a barrier to LSS-AM implementation. Most of the change starts from the voice of the customer and the result of change should also result in favor of customers. Poor collaboration with customers is a barrier to LSS-AM implementation	Hasan *et al*. (2007); Chen *et al.* (2009); Snee(2010); Carvalho *et al.*.(2011); Shahin and Jaberi (2011); Antony *et al*. (2012); Albliwi *et al.* (2015); Potdar *et al*. (2017b); Antony *et al*. (2017); Sreedharan *et al*. (2018a); Raval *et al.* (2018a); Sindhwani e*t al*. (2019); Sony *et al*. (2019); Patel and Patel (2021); Mishra *et al*. (2021)

7	Poor infrastructure	B7	Lean-AM implementation will require a basic infrastructure and a poor infrastructure of an organization can be a barrier to its implementation	Hasan *et al*. (2007); Chen *et al*(.2009); Huang and Li (2010); Carvalho *et al.(*2011); Potdar *et al*.(2017b); Sreedharan *et al*.(2018a); Raval *et al*.(2018a); Sindhwani *et al.(*2019);Kumar *et al* (2020c); Kaswan *et al*.(2021); Hariyani *et al*.(2022);
8	Lack of employee involvement	B8	Employees are important assets to the organization. They lead and drive change in organizations; Hence if the organizations do not involve employees in their decision are more prone to failure.	Chen *et al* (2009); Snee (2010); Shahin and Jaberi (2011); Carvalho *et al*. (2011); Antony *et al.* (2012); Psychogios and Tsironis (2012); Albliwi *et al*. (2015); Yadav *et al*. (2018a); Antony *et al.* (2017); Sreedharan *et al*. (2018a); Raval *et al*. (2018a); Sony *et al*. (2019); Patel and Patel (2021); Mishra *et al*. (2021); Sharma, and Khan (2022); Hariyani *et al*.(2022)
9	Lack of good-quality data	B9	Incorrect or missing data can lead to incorrect LSS-AM project results, hence it is a barrier	Chen *et al*. (2009); Carvalho *et al*. (2011); Antony *et al*. (2017); Raval *et al*. (2018a); Sindhwani *et al.* (2019); Mishra *et al*. (2021)

3.2.2 Development of Survey Instrument, Data Collection and Data Analysis

In the next step, to check whether all identified CSFs/CFFs were relevant to manufacturing industries or not, survey instruments have been developed for data collection.

3.2.2.1 Development of Questionnaire and Data Collection

This questionnaire was designed based on literature and experts' panel opinions. A survey instrument was pre-tested by the experts' panel. They were requested to critically review the survey from the viewpoint of each item and clarity of structure and were asked about any kind of difficulty or ambiguity they had faced in responding to the questionnaire item and requested to suggest resolving the same. After the pre-testing and modification, the final questionnaire was prepared (see Appendix A.2) in Google form. From the pre-test, the average completion time was come out around 10 minutes. The questionnaire had three parts. The first part comprises the demographic information of the participant and companies i.e. type of industry, no. of employees, position, year of experience etc. The second and third parts of the questionnaire contained questions related to CSFs and CFFs of LSS-AM respectively.

The participants were asked to rate factors as 1-2 if strongly disagree; 3-4 if disagree; 4-6 if neither agree nor disagree; 6-8 if agree and 8-10 if strongly agree on a 10-point likert scale based on their level of agreement. This kind of scale helps participants to make an exclusive and conclusive choice.

After development of survey instrument a paramount work was selection of sample for which the questionnaire was developed. Since the main objective of the questionnaire was to measure the respondents perceptions about the identified factors for LSS-AM in manufacturing industries. For this Manager and above person having more than 5 years of experience in manufacturing sector was selected as sample for this study. It was thought that

Director, General Manager, Associate General Manager, Unit Head, Senior Manager and Managers are likely leaders for driving LSS and AM initiatives in their respective organizations hence they were suitable sample for this study. Next to estimate the adequate sample size, which represents the characteristics of population, the following formula is used (Ostle and Malone 1988)

$$n = (Z/B)^2 \times [P \times (1 - P)] \qquad \text{..........(3.1)}$$

Where: n= size of sample;

Z= Values for a particular value of Confidence coefficient

B = Variability or bound error

P= Proportion of participants having experience at least 5 years

We assume P value is 50 % as no previous information was available (Uhlik and Lores, 1998) and other values we used were B= 10 % and Z = 1.96 at 95% of confidence level. Hence the total estimated sample was obtained 96. From the literature it was revealed that in survey not all participants return the questionnaire. A total of 268 questionnaires were sent to the pan-India manufacturing industry through various modes such as email, social media (LinkedIn, Whatsapp). Despite of regular reminders, only 109 responses were received. Further investigation of the questionnaire revealed that 9 responses were incomplete. So we were left with 100 sound responses for further analysis, which was above the estimated sample size required for analysis. This represented the 37.73 % response rate, which is above the minimum response rate (30%) required for statistically reliable information (Sekaran, 2005; Khaba *et al*. 2020). The entire duration of survey was 2 months.

3.2.2.2 Data Analysis

It is necessary that the collected data must be reliable and valid so that it can be useful for other research and analysis. The reliability of factors is evaluated through Cronbach's alpha, the most widely common measure to determine the internal consistency of data, collected from likert scale-based surveys. Reliability indicates the internal consistency of data. It is defined as the degree to which the selected CSFs and CFFs will give the same results for the same individual at a different time or in other words yield similar results under consistent circumstances. To check the reliability of each CSF and CFF in terms of Cronbach's alpha, an internal consistency analysis was performed in SPSS 28. The value of Cronbach's alpha could take any value between 0 to1. However, the minimum value of Cronbach's alpha is 0.7 needed for establishing the internal consistency of data (Gliem and Gliem, 2003). To check the reliability of each factor in terms of Cronbach's alpha, an internal consistency analysis was performed in SPSS 28. The validity of factors is evaluated by factor analysis and to check the fitness of data for factor analysis three measures i.e. Correlation matrix, Barlett's test of sphericity and Kaiser-Meyer-Oklin (KMO) measure of sampling adequacy are found in the literature (Sangwan *et al*., 2014; Mundra and Mishra, 2021). Corrected Item Total Correlation (CITC) denotes the correlation of one item with the composite scores of other items except for the particular item in question, creating the set. (Sangwan *et al*., 2014). Although the CITC value should be >.40 (Moghaddam *et al*., 2021, Ware and Gandek, 1998; Mundra and Mishra, 2021) is considered for factor analysis but some researchers (Sangwan *et al.,* 2014) eliminated only those items which have a CITC value less than. 30. KMO measure value should be greater than 0.50 is recommended to check the sample adequacy for factor analysis (Sangwan *et al.* 2014, Mundra and Mishra 2021).

3.2.3 Description of Structural Equation Modeling (SEM)

To empirically validate the CSFs and CFFs, SEM has been applied. SEM is a wide-ranging set of statistical techniques that permit a set of relations between independent (directly observed or latent -not directly observed) and dependent variables (directly observed or latent not directly observed), to be examined and a casual relationship among the observed and latent variables are also tested with the help of pre-stated hypothesis (Ullman and Bentler, 2012; Mueller, 2019). It combines factors analysis and path analysis to develop a measurement model and structural model respectively. Further factor analysis has two phases: the primary phase is exploratory factor analysis (EFA) and the secondary is confirmatory factor analysis (CFA). In an exploratory analysis, variables are grouped into a few constructs. To carry out EFA Maximum likelihood with Varimax rotation has been used to develop constructs of CSFs/CFFs in the current study, and the eigenvalue is 1, KMO Barlett test for sample adequacy was used for factor extraction in SPSS 28. The reason behind applying the EFA as a statistical tool was to examine the overall dimensions of a measurement instrument by multivariable data structures (Swarnkar *et al*., 2022). After that, the confirmatory factor analysis was performed as the uni-dimensionality of constructs, which cannot be measured by EFA itself (Mundra and Mishra, 2021). CFA was performed in AMOS 26 software to confirm the result of EFA. The CFA model develops the measurement model and validates it. After this path analysis was performed to test the pre-stated hypothesis. Following are the six basic steps of SEM suggested by (Bollen and Long, 1993):

Step 1: Specification of model

Specify the model, which represents the relationship among the directly observed (measured) and not directly observed (latent) variables.

Step 2: Identification of Model

It is necessary to identify the model before any parametric estimation. Model identification can fall under three categories i.e. identified (if the degree of freedom (DOF) is zero); over-identified (if DOF is positive) and unidentified (if DOF is negative). The DOF represents the difference between the no. of sample variables and the estimated variable (Singh and Rathi, 2021)

Step 3: Data collection:

The sample size is important to perform SEM analysis. In the current study 100, sound responses were received from participants, who belong to manufacturing industries.

Step 4: Parameter estimation:

For parameter estimation Maximum likelihood estimation (MLE) is adopted in the present study as it gives more accurate and unbiased results when the sample size is less than 300 (Singh and Rathi, 2021).

Step 5: Model fit testing:

Model fit testing is performed to evaluate how well proposed models fit with the data. Model fit is categorized into the goodness and badness of fit of the model with data. The goodness of fit is evaluated by several indexes like the goodness of fit index (GFI), adjusted goodness of fit index (AGFI), normed-fit index (NFI), Tucker–Lewis index (TLI), comparative fit index (CFI), and the ratio of chi-square statistics and degree of freedom (CMIN/ DF). For continuous data, the minimum acceptable value of GFI AGFI is .8 (Khaba *et al.*, 2020) while CFI, NFI TFI is 0.9 (hair *et al.*, 2009; Khaba *et al.*, 2020) represents the acceptable fit of the model and the significance value of CMIN/DF ≤ 0.5 (Hair *et al*., 2009; Sangwan *et al*., 2014). The badness of fit is also measured by the Badness of fit indexes i.e. Root mean square error of approximation (RMSEA), and SRMR (Standardized Root Mean Square Residual) (Khaba *et al*., 2020). For continuous data acceptable values of RMSEA and SRMR <0.08 (Ullman and Bentler, 2003)

Step 6: Re-specification of the model: Re-specification involves adjusting the specified or estimated models either by freeing or fixing the variables.

The CSFs and CFFs were statistically validated but SEM does not give the roadmap of CSFs and CFFs in which order they need to implement. Hence to develop the roadmap of CSFs and CFFs Fuzzy-TISM approach was used.

3.2.4 Description of Fuzzy-TISM Approach

To develop the hierarchical model of CSFs/CFFs of LSS-AM implementation Fuzzy-TISM methodology has been adopted. Fuzzy TISM integrates fuzzy theory with the TISM approach. The TISM approach is an extended version of Interpretive Structural Modeling (ISM). ISM is an MCDM approach in which a group of people come together and work as a team to develop a hierarchy structure, which depicts the direction of contextual relationships among variables in a set (Sage, 1977; Mishra *et al.*, 2015). But the limitation of ISM is, it does not answer how one CSF is contextually related to the other CSFs. To overcome this limitation Sushil (2012) developed TISM, which explains the interrelationship among the CSFs by adding interpretive matrix steps in the ISM approach (Jena *et al.*, 2017). But TISM does not include the fuzziness during the decision-making process. Hence the fuzzy theory is integrated with the TISM approach and named Fuzzy-TISM. Considering the advantages of Fuzzy TISM in decision-making, Mohanty and Shankar (2017); Virmani *et al.* (2017b) and Jain and Soni (2018) applied Fuzzy –TISM to analyze sustainable CSFs, key performance indicators of Leagile and flexible manufacturing system performance variables respectively in the recent past.

The steps used in this approach are as follows:

Step1: Determine CSFs/CFFs of LSS-AM implementation in the manufacturing industry by comprehensive literature review and opinions of experts from industries and academics. Several linguistics terms (VH-very high; H-high; M-medium; L-low; VL: very low) have been used to analyze the influence of one factor over another. The crisp method has been applied in Fuzzy -TISM. The linguistic scale is presented in table 3.3 and triangulation fuzzy number is presented in figure 3.2.

Table 3.3: Linguistic scales for the influence

Linguistic terms	Linguistic values
Very high influence (VH)	(.8,1,1)
High influence (H)	(.6,.8,1)
Medium influence (M)	(.4,.6,.8)

Low influence (L)	(.2,.4,.6)
No influence (No)	(0,0,.2)

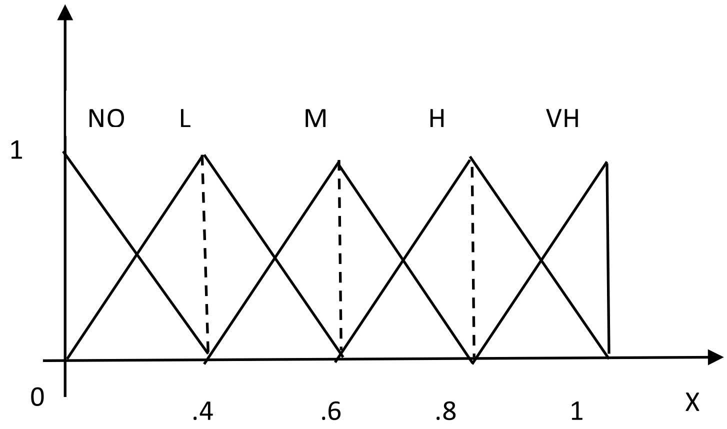

Figure 3.2: Triangular fuzzy numbers for linguistics terms

Step 2: Development of Structural self-interaction matrix (SSIM) and Aggregated Self structured interaction matrix (SSIM)

The level of contextual relationship among the factors has been given in several linguistics terms (VH-very high; H-high; M-medium; L-low; VL: very low) by expert panels to analyze the influence of one factor over another through semi-structural interviews. Based on industry and academia experts' opinions, the relationship among the factors was established and given by the following various symbols to develop the initial self-structural matrix (SSIM).

- V: Indicates factor x influences y but y does not influence x; the complementary link is shown by V followed by {(VH) if very high; (H) if high, (M) if Medium impacts, (L) if Low impact; or (NI) if no impact}
- A: Indicates the factor y influences x but x does not influence y; complementary link is shown by A followed by {(VH) if very high; (H) if high, (M) if Medium impacts, (L) if Low impact; or (NI) if no impact}
- X: Indicates both the factor x and y influence each other; complementary link is shown by X trailed by {(VH) if very high; (H) if high, (M) if Medium impacts, (L) if Low impact; or (NI) if no impact}
- O: Indicates both factors x and y have no relation; complementary link is displayed by O trailed by no influence (NI)

For Aggregated SSIM development, the mode method has been applied. In Aggregated SSIM, the responses, which have maximum frequency, are separated and chosen to analyze subsequently and assigned the linguistic values as per Table 3.3

Step 3: Development of final Fuzzy Reachability Matrix

To transform Aggregated SSIM into a fuzzy reachability matrix following different possible scenario has been considered:

- If (i, j) entry is V (VH): in this scenario, (i,j) entry will be represented as (.8,1.0,1.0) and entry (j,i) will be represented as (0,0,.2)
- If entry (i, j) is V (H): In this scenario (i, j) entry will be represented as (0.6, 0.8 1.0) and entry (j, i) will be expressed by as 0{NI} which is shown as (0, 0, 0.2).

- If entry (i, j) is V (M): In this scenario, entry (i, j) will be represented as (0.4, 0.6, 0.8) and entry (j, i) will be expressed by as 0{NI} which is expressed as (0, 0, 0.2).
- If entry (i, j) is V (L): In this scenario, entry (i, j) will be represented as (0.2, 0.4, 0.6) and entry (j, i) will be represented by as 0{NI} which is shown as (0, 0, 0.2).
- If entry (i, j) is A (VH): In this scenario, entry (i, j) will be represented as O {NI} and will be represented by (0, 0.2, 0.5) and entry (j, i) will be shown as (0.8, 1.0, 1.0).
- If the entry (i, j) is A (H): In this scenario, entry (i, j) will be represented as O {NI} and will be shown by (0, 0,.2) and entry (j, i) will be represented as (0.6, 0.8, 1.0).
- If the entry (i, j) is A (M): In this scenario, entry (i, j) will be represented as O {NI} and will be expressed by (0, 0,.2) and entry (j, i) will be represented as (0.4, 0.6, 0.8).
- If the entry (i, j) is A (L): In this scenario, entry (i, j) will be represented as O {NI} and will be expressed by (0, 0, 0.2) and entry (j, i) will be expressed as (.2,.4,.6).
- If entry (i, j) is X (VH): In this scenario, entry (i, j) will be represented by (0.8, 1.0, 1.0) and entry (j, i) will be expressed as (0.8, 1.0, 1.0).
- If entry (i, j) is X (H): In this scenario, entry (i, j) will be represented by (0.6,.8, 1.0) and entry (j, i) will be expressed as (0.6,.8, 1.0).
- If entry (i, j) is X (M): In this scenario, entry (i, j) will be represented by (0.4,.6, .8) and entry (j, i) will be expressed as (0.4,.6, .8)
- If entry (i, j) is X (L): In this scenario, entry (i, j) will be represented by (.2, .4, .6) and entry (j, i) will be expressed as (0.2, 0.4, .6).
- If entry (i, j) is X (O) in this scenario, entry (i, j) will be represented by (0, 0, .2) and entry (j, i) will be expressed as (0, 0, .2).

Table 3.4 depicts the various symbols and their linguistic terms for the final reachability matrix

Table 3.4: Fuzzy triangular linguistic terms for final fuzzy reachability matrix

(X, Y) entry in aggregated SSIM	(X, Y) entry in the Fuzzy Reachability matrix	(Y, X) entry in fuzzy reachability matrix
V (VH)	(0.8,1,1)	(0,0,.2)
V (H)	(.6, .8,1)	(0,0.2)
V (M)	(.4, .6,.8)	(0,0,.2)
V (L)	(.2, .4,.6)	(0,0,.2)
V (Ni)	(0,0,.2)	(0,0,.2)
A (VH)	(0,0,.2)	(0.8,1,1)
A (H)	(0,0.2)	(.6,.8,1)
A (M)	(0,0,.2)	(.4,.6,.8)
A (L)	(0,0,.2)	(.2,.4,.6)
A (Ni)	(0,0,.2)	(0,0,.2)
X (VH)	(0.8,1,1)	(0.8,1,1)
X (H)	(.6,.8,1)	(.6,.8,1)
X (M)	(.4,.6,.8)	(.4,.6,.8)
X (L)	(.2,.4,.6)	(.2,.4,.6)
X (NO)	(0,0,.2)	(0,0,.2)
O (NO)	(0,0,.2)	(0,0,.2)

Step 4: Crisp value of each CSF was analyzed as per the subsequent procedure given by Khatwani *et al.* (2014)

Let B_k –(l_k,m_k,u_k) a positive triangular fuzzy number where k=1,2,3...n

B_k^{crisp} denotes the crisp value of fuzzy number

STEP 4.1 Calculating:

$DELTA = R - L$..................(3.2)

R= max (u_k), L=min (l_k) ;

STEP 4.2: Calculation for lower, middle, and upper values.

$x_{lk} = (l_k - L)/DELTA, x_{mk} = (m_k - L)/DELTA, x_{uk} = (u_k - L)/DELTA.$ .... (3.3)

Step 4.3: Calculation of normalized left score (ls) and right score (rs) values:

$x_j^{ls} = x_{mj}(1 + x_{mk} - x_{lk})$ And $x_k^{rs} = x_{uk}(1 + x_{uk} - x_{mk})$................(3.4)

Step 4.4: Calculation of total normalized crisp values using the following equation:

$x_k^{crisp} = \left[x_k^{ls} * \left(1 - x_k^{ls}\right) + x_k^{rs} * x_k^{rs}\right]/[1 - x_k^{ls} + x_k^{rs}]$..................(3.5)

Step 4.5: Calculation of crisp value for B_K

$B_K^{Crisp} = L + x_k^{crisp} * DELTA$.................(3.6)

Step 5: Defuzzified the reachability matrix and the transitivity is taken into account i.e. if factor 1 is related to 2, and factor 2 is related to factor 3 then there must be some relation between factor 1 and 3.

Step 6: Driving power and dependence was computed by adding the rows 1's and column 1's of each CSF respectively

Step 7: Partition of levels takes place by the no. of iteration

Step 8: Based on linguistic terms Fuzzy TISM digraph has been drawn

Step 9: Development of Fuzzy TISM model by removing and substituting the transitivity links and factors nodes by statement respectively in digraphs.

3.2.5 Description of MICMAC Analysis

The main purpose of the MICMAC (Matrice d' Impacts Croisés-Multiplication Appliquée un Classement) analysis of this study is to identify and analysis of CSFs to LSS-AM implementation in a fuzzy environment. After calculating the dependence and driving power of each factor, MICMAC analysis for final fuzzified reachability matrics and final de-fuzzified reachability matrics was performed to group the factors into the following four clusters:

(i) Autonomous cluster: In this, factors those are having weak driving power and dependence fall under this cluster. The factors of the autonomous cluster are disconnected from the system

(ii) Dependent cluster: In this, factors those are having strong dependence and weak driving power come under this cluster.

(iii) Linkage cluster: In this, factors those are having high driving power and high dependence fall under this cluster.

(iv) Independent cluster: In this, factors those are having low dependence and high driving power come under this cluster.

3.3 VALIDATION OF LSS-AM CSFS THROUGH SEM AND DEVELOPMENT OF ROADMAP OF CSFS FOR LSS-AM IMPLEMENTATION THROUGH FUZZY-TISM

In this section the identified CSFs are validated through SEM. Further hierarchical structure of CSFs for LSS-AM implementation are developed and analyzed through Fuzzy-TISM and MIC-MAC approaches. A detailed description of this hybrid approach is following:

3.3.1 Validation of CSF's through SEM

3.3.1.1 Collection of Data and Analysis

Data was collected from the pan India manufacturing industry through a questionnaire survey. The CSFs are rated on a scale of 10. A total of 268 questionnaires were sent and 109 responses were received. Further investigation of the questionnaire, 9 responses were found incomplete. So we are left with 100 sound responses for further analysis. To test the internal consistency of collected data, the Cronbach alpha reliability test was performed in SPSS 28 and obtained a value of .883 which is>.7, the recommended value. The CITC value of most of CSFs is>.4 which is recommended. Only 1 CSF has a value less than the recommended value but the elimination of this did not further improve the Cronbach alpha (see table 3.5). The mean value of all CSFs ranges from 7.02 to 9.2 with a maximum standard deviation value of 1.08 exhibiting that all the identified CSFs are important.

Table 3.5: Reliability test for CSFs data

CSFs	Mean	Std. Deviation	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
C1	7.02	.97225	0.499	0.877
C2	9	.98041	0.483	0.879
C3	7.18	.94044	0.513	0.877
C4	7.14	1.07327	0.577	0.874

C5	7.16	.96253	0.386	0.880
C6	9.2	.98473	0.714	0.870
C7	9.04	.99280	0.538	0.876
C8	7.06	1.08566	0.609	0.872
C9	8.24	.95082	0.598	0.873
C10	8.72	.95474	0.615	0.872
C11	7.22	1.02079	0.615	0.873
C12	7.48	1.05951	0.626	0.871
C13	7.24	1.00252	0.556	0.875
C14	7.44	1.05012	0.621	0.871

3.3.1.2 Factor Analysis

For factor analysis, SPSS 28 software is used. The first EFA was performed on sample size (n=100) of 14 CSFs. Kaiser-Meyer-Olkin (KMO) .822 and Bartlett's test": chi-square value 1091.959 and degree of freedom. 91 were found in the current study.

3.3.1.2.1 EFA for CSFs to LSS-AM implementation

EFA was performed on the CSFs for LSS-AM implementation in SPSS 28.Based on that 14 CSFs were grouped into three constructs having an Eigenvalue >1. The constructs were named organization commitment towards change related (OCF); resource capability related (RCF) and technology related (TF). The result of EFA reveals that all factors in their respective constructs have loading values above the minimum recommended value 0.45 (Hair et al. 1995; Sangwan *et al*., 2014; Mundra and Mishra; 2021). Hence all the CSFs contribute well to the respective constructs. The EFA model for CSFs is shown in figure 3.3

Table 3.6: Factor loading for CSFs

CSFs	OCF	RCF	TF	Standardized Estimate	C.R.*	AVE
C6	0.953			.98	0.924	
C7	0.932			0.92		
C10	0.826			0.85		
C14	0.807			0.82		0.676
C3	0.63			0.67		
C9	0.6			0.53		
C12		0.95		.96	0.884	
C4		0.787		0.79		
C5		0.782		0.81		0.61
C11		0.635		0.64		
C8		0.631		0.66		
C13			0.965	.96	0.894	
C1			0.871	0.94		0.744
C2			0.551	0.63		

Notes: P<0.001 for all coefficients , * C.R. –Composite reliability

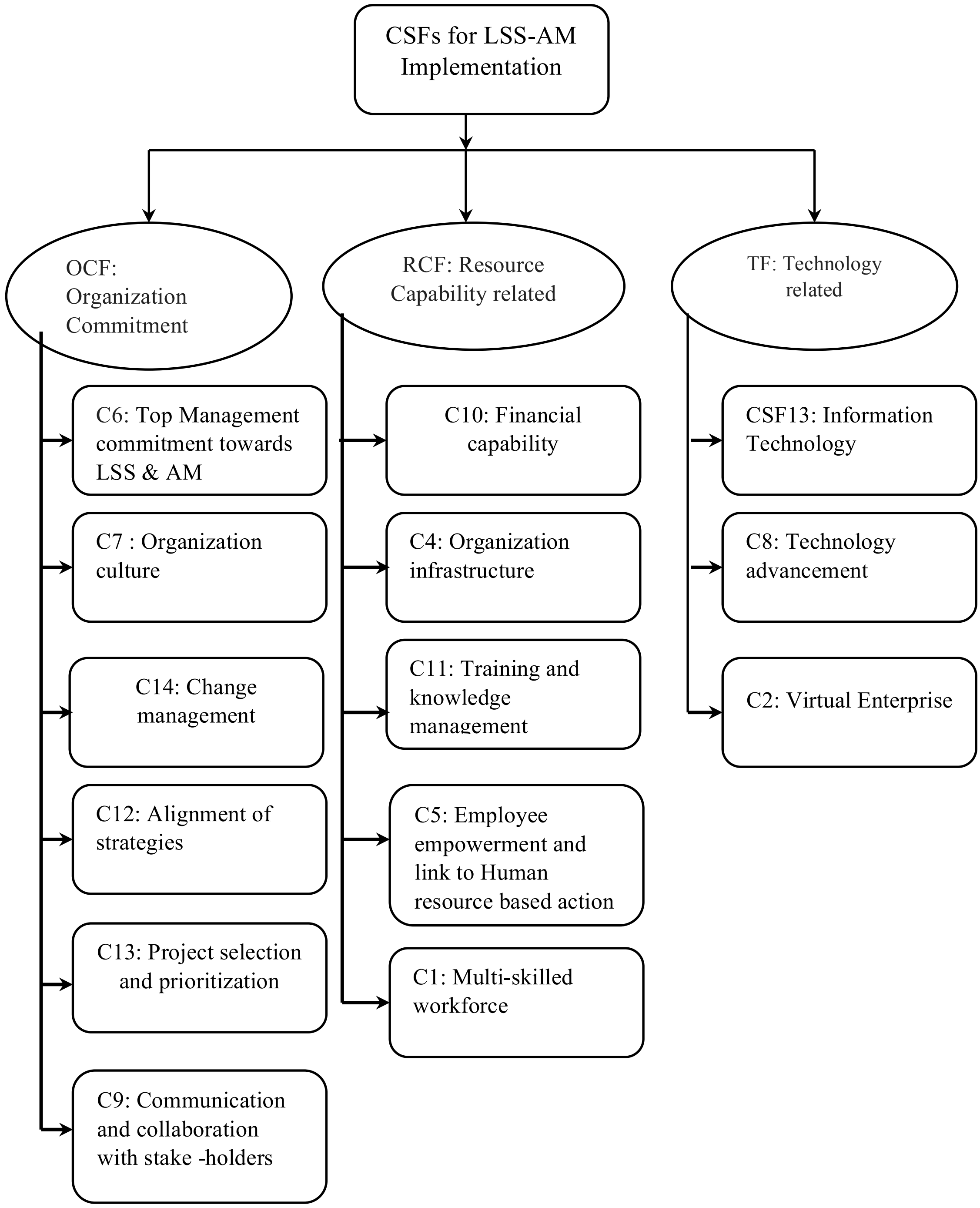

Figure 3.3: EFA model of CSFs for LSS-AM implementation in the manufacturing industry

3.3.1.2.2 Confirmatory Factor Analysis (CFA) for CSFs to LSS-AM Implementation

To examine the outcomes of EFA; CFA was performed. The output of EFA is fed to the AMOS 26 software. CFA confirms the measurement model consistency and tests the hypothesis for the structural model. The measurement model shown in figure 3.4 is containing 14 observed variables. Rectangular and oval shape blocks represent observed variables and latent variables respectively. The error in measuring the value of an observed variable is known as measurement error. Measurement errors (e1, e2, e3.....e14) are presented by small oval shape blocks and connected through a single-headed arrow to their respective observed variables.

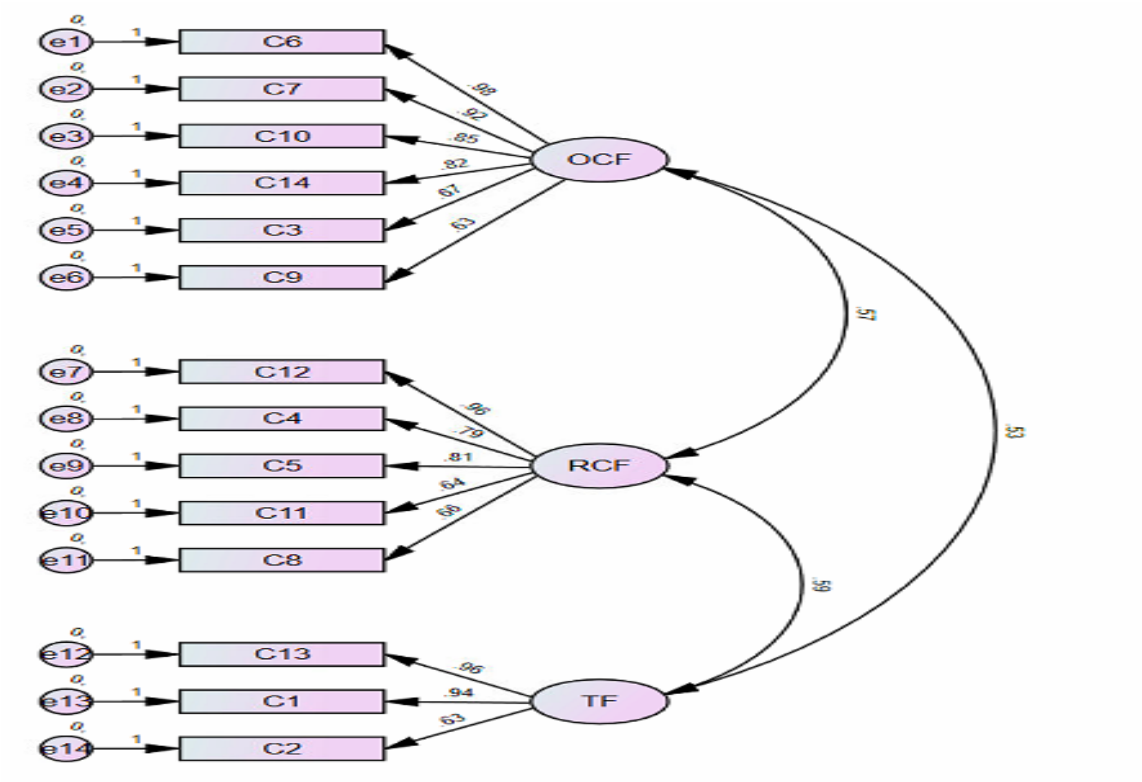

Figure 3.4: Measurement model of LSS-AM CSFs

3.3.1.2.2.1 Model fit of CSFs Measurement Model

For evaluation of the model, the following model fit indices were obtained with recommended values. The measurement model's results have revealed that it is well fitted with the available sample data.

Table 3.7: Analysis of Model Fit of CSFs Measurement Model

Index	**Estimated value**	**Recommended value**	**Reference**
CMIN	117.639	-	
DF	74.000	-	
***p*-value**	0	< 0.005	
CMIN/DF	1.590	< 5.0	Marsch and Hocevar, (1985); Hair *et al*., (1995)
RMSEA	.077	<. 08	Hair *et al*., (1995)
SRMR	0.077	< 0.08	Hair *et al*., (1995)
GFI	0.871	Close to one	Hair *et al*., (1995); Dawes *et al*., (1998)
AGFI	0.817	Close to one	Hair *et al*., (1995)
CFI	0.959	> 0.90	Hair *et al*., (1995); Byrne (2001)

3.3.1.2.2.2 Validity of Scales

The validity of the scale was confirmed through academia and industry expert's opinion

3.3.1.2.2.3 Construct Validity

Convergent validity; discriminant validity and face validity evaluation are needed for construct validity. Among this, face validity is assured as the CSFs adopted in this paper were obtained from available literature of related research areas. The extent to which different methods of measuring a variable provide the same results is known as convergent validity (O'Leary-Kelly and Vokurka, 1998), which can be obtained by testing the composite reliability (CR); Cronbach Alpha Average Variance Explained (AVE). The cut-off values are CR>.6; CR>AVE and AVE>.5 Hundleby and Nunnally (1968). At present Cronbach alpha value of each CSF was >0.7; AVE>0.5 hence construct's convergent validity is established.

Table 3.8: Discriminant validity of CSFs measurement model

Constructs	OCF	RCF	TF
OCF	.822*[a]		
RCF	0.205	.781*[a]	
TF	0.413	0.346	.863*[a]

*** a –Square root of AVE**

Discriminant validity is known as the level to which the measures of distinct unobserved variables are exclusively dissimilar from each another (O'Leary-Kelly and Vokurka, 1998).

To establish discriminant validity, the values of AVE must be more than the squared inter-construct correlations (Fornell and Larcker, 1981). Table 3.8 represents AVE and squared inter-construct correlation values in diagonal and off-diagonal elements respectively. It can be seen that the off-diagonal elements were of all the CSFs less than the corresponding diagonal values; thus the discriminant validity has been achieved. Since all three validities i.e.

face; convergent and discriminant were established in the present study hence the construct validity of the measurement model was found good. The empirical results of CFAs were used to test the appropriate hypotheses to find the relationships among the constructs. CFA also shows the CSFs are loaded under the pattern obtained in the EFA

3.3.1.3 Structural Model of CSFs

Structural model presents the casual relationship among the constructs. The hypothesis is articulated to test the validity of full structural model. Following hypothesis are stated on the basis of conclusions obtained from the Fuzzy-TISM model of CSFs.

3.3.1.3.1 Formulation of Hypothesis

In the present study to interpret the data obtained from the survey, the following hypothesis has been formulated:

H1. The Organization Commitment toward change-related construct supports the resource capability-related construct.

H2: The Organization Commitment towards change-related construct supports technology-related construct.

H3: The resource capability-related construct support to technology-related construct.

3.3.1.3.2 Hypothesis Testing

The constructs hypothesis testing was performed. In this study, maximum-likelihood estimation was used to estimate the fitness indices of the structure model. The results are as follows:

Table 3.9: Results of hypothesis testing for CSFs' to LSS-AM

	Hypothesis	β value	p-value	Result
H1	OCF→RCF	0.303	0.044	Accepted
H2	OCF→TF	0.597	0.032	Accepted
H3	RCF→TF	0.678	0.013	Accepted

The structure model is shown in figure 3.5. It depicts the hypothesized relationships among the 3 constructs. Latent variables (C1; C2; C3) are shown as elliptical-shaped while their respective observed rectangular shapes represent variables and are headed toward their corresponding constructs. Residual errors (r2; r3) are shown in a small elliptical shape and headed towards C2; C3 respectively. To accept or reject the hypothesis the p-value, and standardized regression weights (β-value) are shown in table 3.9. Results revealed that the entire hypotheses were accepted and data of Model fit of the structural model are CMIN/df=1.590; CFI=.959; NFI=.898; RFI=.875; IFI=.960; TLI=. 950; GFI=.971; AGFI=.817; RMSEA=.077 depicts under the recommended value, depicts a good fit of the model.

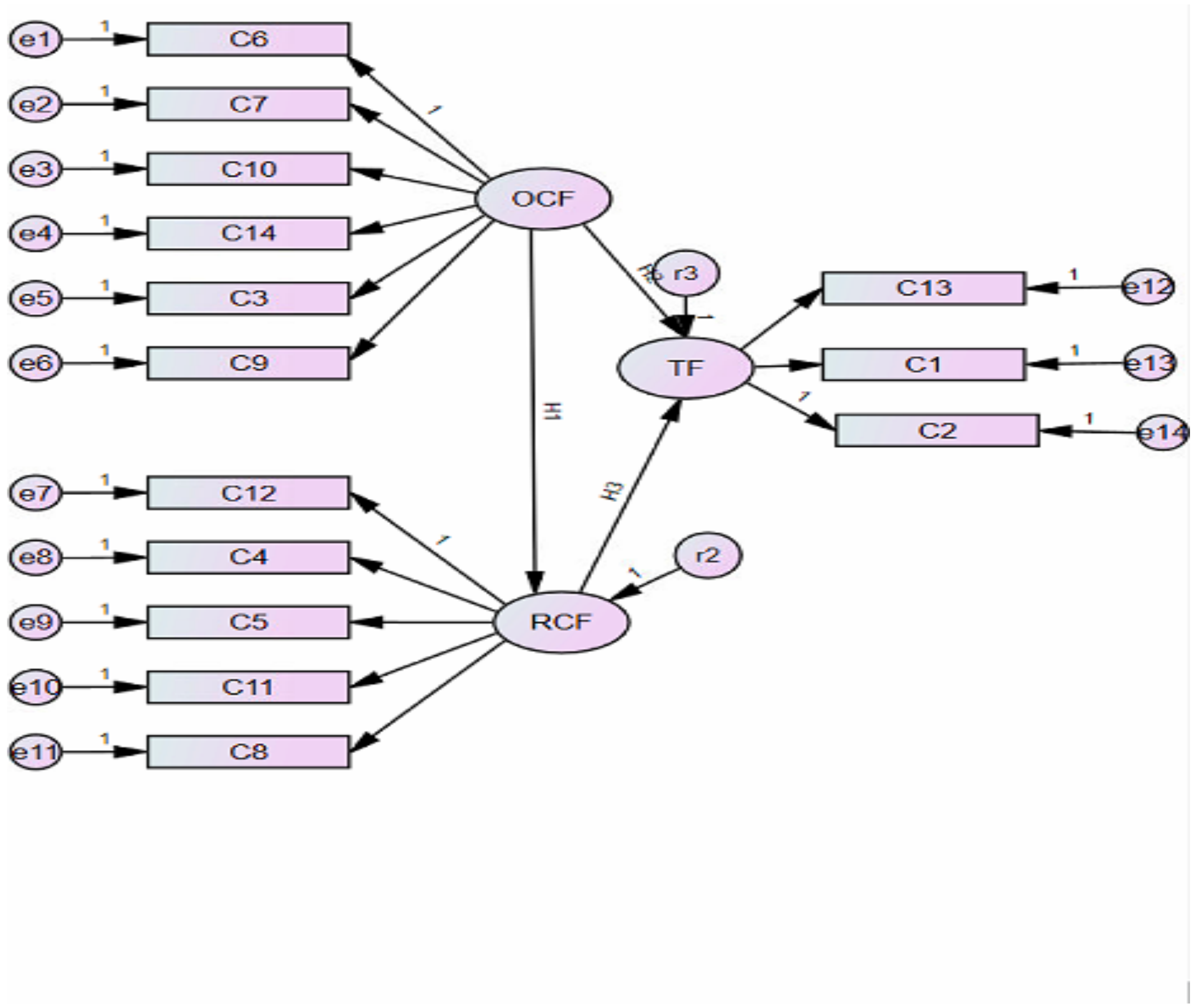

Figure 3.5: Structural model of LSS-AM CSFs

3.3.2 Development of LSS-AM CSFs Model through Fuzzy-TISM

All 14 CSFs that help the implementation of LSS-AM in the manufacturing industry were identified from a vast literature review and validated through SEM.

3.3.2.1 Development of Structural Self-Interaction Matrix (SSIM) and Aggregated Structural Self-Interaction Matrix for CSFs

The level of contextual relationship among the CSFS has been given in several linguistics terms (VH-very high; H-high; M-medium; L-low; VL: very low) by an expert panel to analyze the influence of one CSF over another through a semi-structural interview. The relationship among the CSFs was denoted by V, A, X and O followed by linguistic terms. The crisp method has been applied in Fuzzy-TISM. Due to space limitations, individual experts' responses cannot be displayed here. However, Aggregated SSIM is shown in the table 3.10 developed by taking the mode of responses obtained from the experts. For easy interpretation of these symbols, a small example is exhibited here.

1. C1 has a very high influence on achieving C 2 but if C2 does not influence to achieve C1 then the contextual relationship between them is labeled as V (VH)
2. C4 has a high influence on achieving C1 and but if C1 does not influence to achieve of C4 then the contextual relationship between them is labeled as A (H)
3. C1 and C9 have a medium influence on achieving each other than the contextual relationship among them is labeled as A (H)
4. C7 and C12 do not have any relation other than the contextual relationship among them is labeled as O (NO)

Due to space limitations, individual experts' responses cannot be displayed here. However, taking the mode of responses obtained from the experts develops Aggregated SSIM shown in table 3.10.

Table 3.10: Aggregated Structured Self-Intersection Matrix (SSIM) for LSS-AM's CSFs

CSFs	**C14**	**C13**	**C12**	**C11**	**C10**	**C9**	**C8**	**C7**	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**
C1	A (H)	A (VH)	A (M)	A (VH)	A (H)	X (M)	X (H)	A (M)	A (H)	A (VH)	A (H)	A (H)	V (H)	
C2	A (VH)	A (H)	A (H)	A (H)	A (M)	A (H)	A (VH)	A (VH)	A (VH)	A (H)	A (VH)	A (M)		
C3	A (H)	X (VH)	A (M)	X (M)	A (VH)	V (M)	V (H)	A (H)	A (H)	X (VH)	X (H)			
C4	A (M)	X (VH)	A (VH)	X (VH)	A (H)	V (VH)	V (VH)	A (VH)	A (VH)	X (H)				
C5	A (H)	X (M)	A (H)	X (H)	A (VH)	V (H)	V (VH)	A (H)	A (H)					
C6	V (VH)	V (H)	V (H)	V (H)	V (H)	V (H)	V (H)	X (H)						
C7	V (H)	V (H)	O (NI)	V (M)	V (VH)	V (VH)	V (H)							
C8	A (H)	A (VH)	A (H)	A (H)	A (H)	X (H)								
C9	A (VH)	A (H)	A (H)	A (VH)	A (H)									
C10	X (M)	V (H)	X (VH)	V (H)										
C11	A (H)	X (VH)	A (H)											

C13	A (VH)
C14	

3.3.2.2 Development of Initial Fuzzy Reachability Matrix for CSFs

Aggregated SSIM matrix is first converted into a fuzzy reachability matrix (see table 3.11).

Table 3.11: Fuzzy reachability matrix based on aggregated fuzzy SSIM matrix for CSFs

CSFs	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
C1	_	H	NO	NO	NO	NO	NO	H	M	NO	NO	NO	NO	NO
C2	NO	_	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
C3	H	M	_	H	VH	NO	NO	H	M	NO	M	NO	VH	NO
C4	H	VH	H	_	H	NO	NO	VH	VH	NO	VH	NO	VH	NO
C5	VH	H	VH	H	_	NO	NO	VH	H	NO	H	NO	M	NO
C6	H	VH	H	VH	H	_	H	H	H	H	H	H	H	VH
C7	M	VH	H	VH	H	H	_	H	VH	VH	M	NO	H	H
C8	H	VH	NO	NO	NO	NO	NO	_	H	NO	NO	NO	NO	NO
C9	M	H	NO	NO	NO	NO	NO	H	_	NO	NO	NO	NO	NO

C10	H	M	VH	H	VH	NO	NO	H	H	_	H	VH	H	M
C11	VH	H	M	VH	H	NO	NO	H	VH	NO	_	NO	VH	NO
C12	M	H	M	VH	H	MO	NO	H	H	VH	H	_	H	VH
C13	VH	H	VH	VH	M	NO	NO	VH	H	NO	VH	NO	_	NO
C14	H	VH	H	M	H	NO	NO	H	VH	M	H	VH	M	_

Table 3.12: Final fuzzy reachability matrix for CSFs

CSF	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	******	**##**
C1	_	(.6, .8,1)	(0,0, .2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.4,.6,.8)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(1.6,2.2,4.8)	2.62
C2	(0,0, .2)	_	(0,0, .2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,2.8)	0.36
C3	(.6, .8,1)	(.4,.6,.8)	_	(.6,.8,1)	(.8,1,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.4,.6,.8)	(0,0,.2)	(.4,.6,.8)	(0,0,.2)	(.8,1,1)	(0,0,.2)	(4.6,6.2,8.4)	6.31
C4	(.6, .8,1)	(.8,1,1)	(.6, .8,1)	_	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.8,.1,1)	(.8,1,1)	(0,0,.2)	(.8,1,1)	(0,0,.2)	(.8,1,1)	(0,0,.2)	(5.8,7.4,9)	7.36
C5	(.8,1,1)	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	_	(0,0,.2)	(0,0,.2)	(.8,1,1)	(.6,.8,1)	(0,0,.2)	(.6,.8,1)	(0,0,.2)	(.4,.6,.8)	(0,0,.2)	(5.2,6.8,8.8)	6.86
C6	(.6, .8,1)	(.8,1,1)	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	_	(.6,.8,1)	(.6,.8,1)	(.6,.8,1)	(.6,.8,1)	(.6,.8,1)	(.6,.8,1)	(.6,.8,1)	(.8,1,1)	(8.4,11,13)	10.69
C7	(.4, .6,.8)	(.8,1,1)	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	(.6,.8,1)	_	(.6,.8,1)	(.8,1,1)	(.8,1,1)	(.4,.6,.8)	(0,0,.2)	(.6,.8,.1)	(.6,.8,1)	(7.6,10,11.8)	9.75

C8	(.6, .8,1)	(.8,1,1)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	_	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(2,2.6,5)	2.99
C9	(.4, .6,.8)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	_	(0,0,.2)	(0,0,2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(1.6,2.2,4.8)	2.62
C10	(.6,.8,1)	(.4,.6,.8)	(.8,1,1)	(.6,.8,1)	(.8,1,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.6,.8,1)	_	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	(.4,.6,.8)	(6.8,9,11)	8.84
C11	(.8,1,1)	(.6,.8,1)	(.4,.6,.8)	(.8,1,1)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.8,1,1)	(0,0,.2)	_	(0,0,.2)	(.8,.1,.1)	(0,0,.2)	(5.4,7,8.8)	7.01
C12	(.4,.6,.8)	(.6,.8,1)	(.4,.6,.8)	(.8,1,1)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	_	(.6,8.,1)	(.8,1,1)	(6.8,9,11)	8.84
C13	(.8,1,1)	(.6,.8,1)	(.8,.1,.1)	(.8,.1,1)	(.4,.6,.8)	(0,0,.2)	(0,0,.2)	(.8,1,1)	(.6,.8,1)	(0,0,.2)	(.8,.1,.1)	(0,0,.2)	_	(0,0,.2)	(5.6,7.2,8.8)	7.17
C14	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	(.4,.6,.8)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.8,1,1)	(.4,.6,.8)	(.6,.8,1)	(.8,1,1)	(.8,.1,.1)	_	(7,9.2,11)	9.01
*	(7.2,9.6,11.6)	(8.4,11,12.8)	(5.6,7.4,9.4)	(6.2,8,9.6)	(5.6,7.4,9.6)	(.6,.8,3.4)	(.6,.8,3.4)	(7.8,10.2,12.2)	(7.6,10,11.8)	(2.6,3.4,5.6)	(5.4,7.2,9.4)	(2.2,2.8,5)	(6,7.8,9.6)	(2.6,3.5,5.6)		
#	9.41	10.71	7.42	7.92	7.46	1.14	1.14	9.99	9.77	3.72	7.27	3.14	7.77	3.72		

*** Dependence; ** Driving power; # B_k crisp Dependence; ## B_k crisp Driving**

3.3.2.3 Development of Final Fuzzy Reachability Matrix for CSFs

Based on this fuzzy reachability final Fuzzy reachability matrix was obtained by converting (i, j) and (j, i) entries as per the scenario discussed in the Fuzzy-TISM methodology and is shown in Table 3.12. Further to compute the driving power and dependence for each CSF, it is necessary to calculate the Crisp Value of each CSF. The crisp value is computed by Eqs. 3.2 to 3.6. Driving Power for fuzzy value (1.6, 2.2, 4.8) of CSF 1

STEP 1 Calculating Delta using equation 3.2:

DELTA=R-L; R= 11.8, L=0

DELTA=11.8

STEP 2: Calculation for lower, middle, and upper values using equation 3.3:

$x_{l1} = \frac{1.6-0}{11.8}, x_{m1} = (2.2-0)/11.8 \; x_{u1} = (4.8-0)/11.8$

$(x_{l1}, x_{m1} . x_{u1}) = (.135593; .186441; .40678)$

Step 3: Calculation of normalized left score (ls) and right score (rs) values using equation 3.4:

$x_1^{ls} = .135593 * (1 + .186441 - .1355930)$

x_1^{ls} =0.177419355

and $x_1^{rs} = .40678(1 + .40678 - .186441)$

x_1^{rs} =0.333333333

Step 4: Calculation of total normalized crisp values using equation 3.5:

$x_1^{crisp} = [0.177419355 * (1 - 0.177419355) + 0.333333333 * 0.333333333]/$

[1 −0.177419355+0.333333333]

x_1^{crisp} =0.222380595

Step 5: Computation of crisp value for B_K using equation 3.6:

$$B_{1\ driving}^{Crisp} = 0 + 0.222380595 * 11.8$$

$$B_{1driving}^{Crisp} = 2.6249$$

Similarly the crisp value of dependence of CSF 1:

$B_{1depdence}^{Crisp}$ =9.411498714

Like this, we obtained the crisp values of driving power and dependence of each CSF (see table 3.12). Detailed calculation is provided in table A.3.1 in Appendix A.3.

3.3.2.4 Development of Final Defuzzified Reachability Matrix for CSFs

Defuzzified the fuzzy reachability matrix by replacing all VH, H, and M entries with 1 and L, NI entries as 0. Further transitivity has been checked and marked as * in table 3.8. Further summing up the rows 1's and column 1's of each CSF in the final reachability matrix has given the driving power and dependence respectively (see table 3.13)

Table 3.13: Defuzzified final reachability matrix

CSFs	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	Driving power
C1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	4
C2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
C3	1	1	1	1	1	0	0	1	1	0	1	0	1	0	9
C4	1	1	1	1	1	0	0	1	1	0	1	0	1	0	9
C5	1	1	1	1	1	0	0	1	1	0	1	0	1	0	9
C6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
C7	1	1	1	1	1	1	1	1	1	1	1	1*	1	1	14
C8	1	1	0	0	0	0	0	1	1	0	0	0	0	0	4
C9	1	1	0	0	0	0	0	1	1	0	0	0	0	0	4
C10	1	1	1	1	1	0	0	1	1	1	1	1	1	1	12
C11	1	1	1	1	1	0	0	1	1	0	1	0	1	0	9
C12	1	1	1	1	1	0	0	1	1	1	1	1	1	1	12
C13	1	1	1	1	1	0	0	1	1	0	1	0	1	0	9
C14	1	1	1	1	1	0	0	1	1	1	1	1	1	1	12
Dependence	13	14	10	10	10	2	2	13	13	5	10	5	10	5	**122/122**

3.3.2.5 Level Partition of CSFs

After the calculation of the driving power and dependence of each CSF, level partitioning was performed. To identify the level of each CSF, first reachability; antecedent and intersection set were identified. In reachability set of a factor includes all the factors, to which it assists to achieve including itself. The antecedent set of a factor consists of those factors, which are helping to achieve it including itself. The intersection set consists of factors, which are the result of the intersection of reachability and antecedent set. After that the CSFs, which are having the same set of reachability and intersection CSFs; are segregated from the remaining CSFs for the next iteration and positioned at the topmost of the hierarchy in the model. This represents these CSFs will not help to achieve other CSFs. Similarly, no. of iterations have been done to identify the level of each CSFs. As a result, all CSFs were divided into five levels of hierarchy (see tables 3.14 and 3.15). Remaining iterations are presented in tables A.3.3 to A.3.5 in Appendix A.3.

Table 3.14: Level partition of defuzzified matrix of CSFs (1st Iteration)

CSFs	Reachability set	Antecedent set	Intersection set	Level
C1	1,2,8,9	1,3,4,5,6,7,8,9,10,11,12,13,15	1,8,9	
C2	2	1,2,3,4,5,6,7,8,9,10,11,12,13,14	2	I
C3	1,2,3,4,5,8,9,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	
C4	1,2,3,4,5,8,9,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	
C5	1,2,3,4,5,8,9,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	
C6	1,2,3,4,5,6,7,8,9,10,11,12,13,14	6,7	6,7	
C7	1,2,3,4,5,6,7,8,9,10,11,12,13,14	6,7	6,7	
C8	1,2,8,9	1,3,4,5,6,7,8,9,10,11,12,13,14	1,8,9	
C9	1,2,8,9	1,3,4,5,6,7,8,9,10,11,12,13,14	1,8,9	
C10	1,2,3,4,5,8,9,10,11,12,13,14	6,7,10,12,14	10,12,14	
C11	1,2,3,4,5,8,9,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	
C12	1,2,3,4,5,8,9,10,11,12,13,14	6,7,10,12,14	10,12,14	
C13	1,2,3,4,5,8,9,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	
C14	1,2,3,4,5,8,9,10,11,12,13,14	6,7,10,12,14	10,12,14	

Table 3.15: Level partition of each CSF

S.NO.	CSF	Level No.
1	C2	I
2	C1, C8, C9	II

3	C3, C4, C5, C11, C13	III
4	C10, C12, C14	IV
5	C6, C7	V

3.3.2.6 Development of Fuzzy TISM Digraph of CSFs

Based on the linguistic term; a fuzzy digraph (see figure 3.6) has been developed. In this, both direct and indirect relationships are analyzed. CSFs' are represented in nodes and connected by arrows. Each arrow indicates the different levels of influence of CSFs on each other. The digraph is formed in a tree-like structure where parent node CSFs and child node CSFs are joined through branches. These branches have four types of child nodes containing CSFs. Leftmost child nodes having enablers which have very high linguistic values are linked to the parent node enablers by a bold thick arrow; child nodes containing CSFs with high linguistic values are joined to parent node enablers through a light arrow; while child nodes containing CSFs with medium linguistic values joined to parent node CSFs' by semi-broken line and transitivity links are connected by a dotted line to parent CSF. Each Parent CSF is connected to the other same-level parent nodes and parent CSF, which is one level above as per the hierarchy obtained from the level partition. For example let's take C7 as a parent node, which is at the bottom-most level of the hierarchy. The left-most child nodes contained CSFs C2, C4, C9, C10 and C16 which are having very high linguistics terms given by experts, joined to the parent node CSF 7 by a dark bold line; the second child node containing CSFs C3, C5, C6, C8, C13, and C14 joined to CSF C7 by branch, denotes the linguistic term "high" as per the expert's decision to the CSF C7; while next child node consisting CSF C1, C11 and connected by CSF C7 through a branch which represents the linguistic term "medium" as per experts choice. The fourth child node consists of CSF C12 and is joined by CSF C7 through a dotted arrow to represent the transitivity condition between them. Hence the relation of CSF C7 in the parent node to the other CSFs is shown by the several branches to denote different linguistic terms. Similarly, each CSF is considered as a parent node and connected to the other CSFs by various branches. Further to connect CSF's parent nodes, the parent node of CSF C7 is joined to the same level parent node CSF C6 by a light arrow, which depicts the linguistic term "High" as per the expert's replies while the parent node of CSF C7 is connected through the just above parent node CSF's C10, C14, C12 by bold, light and dotted arrow respectively to determines the linguistic term very high; high and transitivity condition between them. Like this finally, we obtained the Fuzzy-TISM digraph.

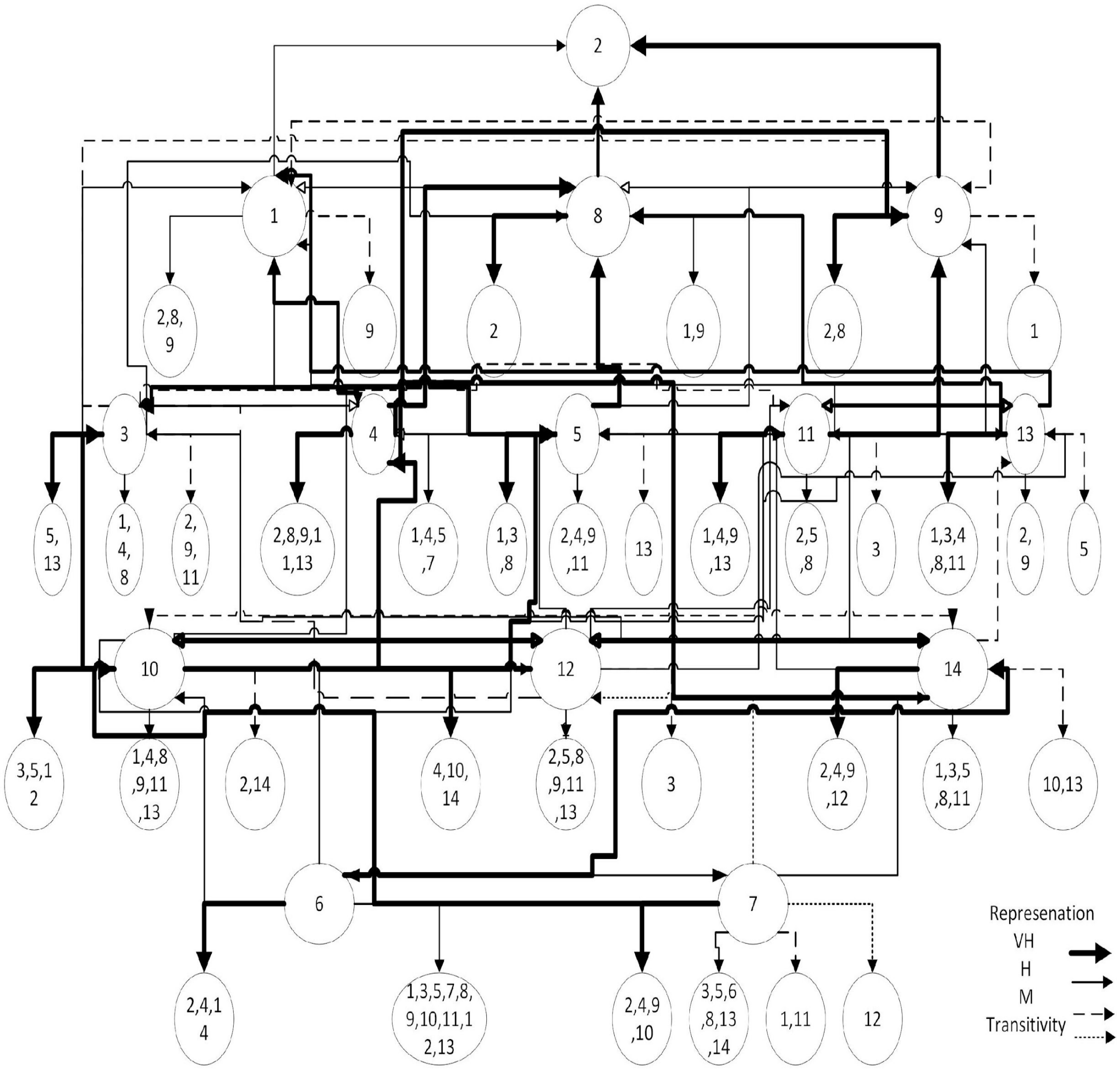

Figure 3.6: Fuzzy-TISM digraph of LSS-AM CSFS

3.3.2.7 Development of Fuzzy –TISM model of CSFs

To obtain the Fuzzy-TISM model from the Fuzzy-TISM digraph, all the transitivity links were removed. Only the direct links among the CSFs, which were having VH, H, and M degrees of influence, were denoted by a dark bold thick line, thick line and dashed line respectively while the L and NI degrees of influence were eliminated. (See figure 3.7)

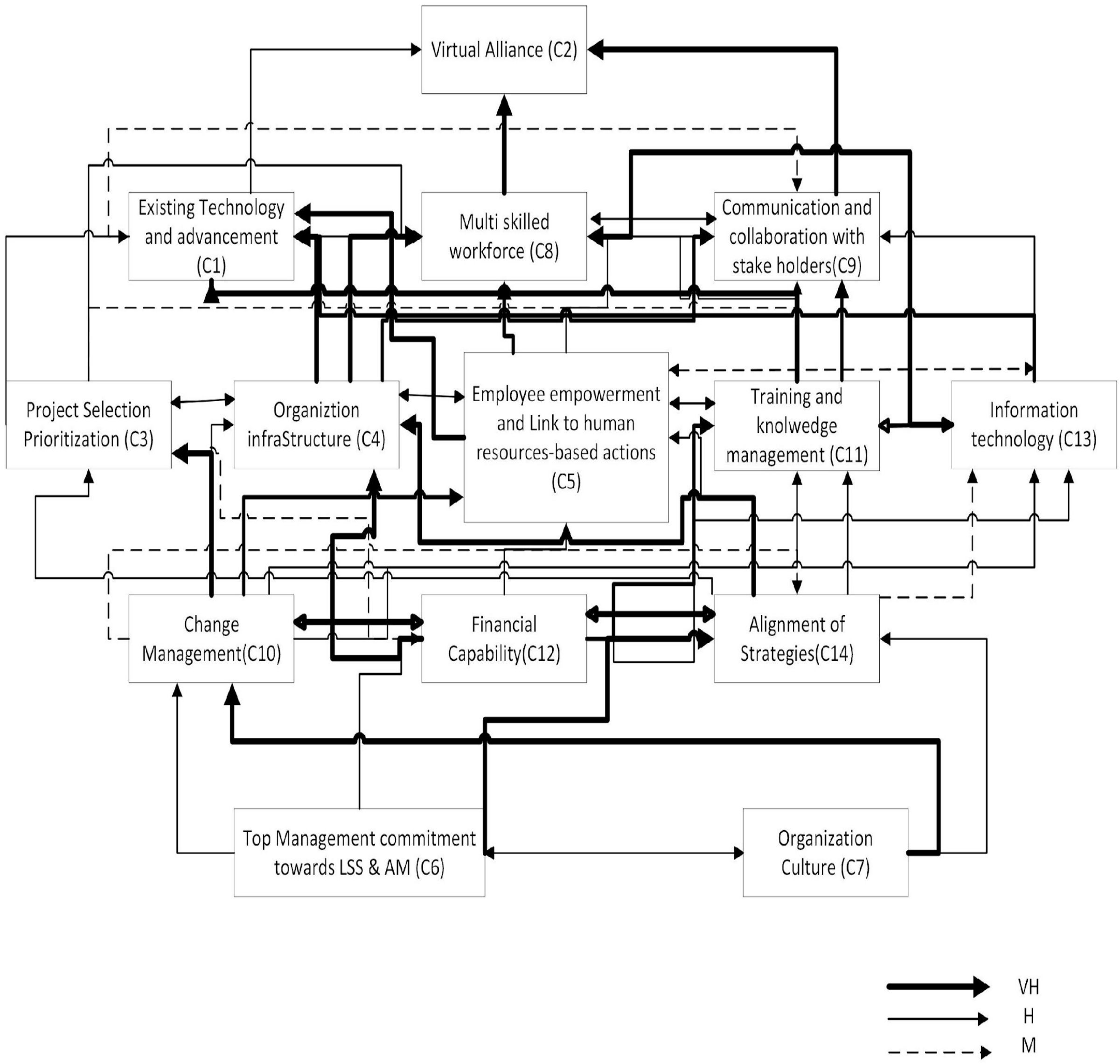

Figure 3.7: Fuzzy-TISM model of LSS-AM CSFs

3.3.4 MICMAC Analysis

After calculating the dependence and driving power of each CSF, MICMAC analysis was performed to group the CSFs into 4 clusters. Autonomous clusters: In both fuzzified and de-fuzzified cases, no CSF comes under this category, which represents all CSFs considered in this study, which is significantly useful. (ii) Dependent clusters: In the fuzzified case, CSFs

C1, C2, C3, C8, and C9 come under this category while in the defuzzified case CSFs C1, C2, C8, and C9 fall under this due to their predominance driving power and low driving power. (iii) Linkage clusters dependence CSFs C4, C5, C8, C9, and C11 come under this category in a fuzzified case while in a defuzzified case CSFs C3, C4, C5, C11, and C13 fall under the linkage category because of their high driving and high dependence. The fourth cluster is an independent cluster, in which CSFs C6, C7, C10, C12, and C14 have low dependence and high driving power in both fuzzified and defuzzified. Together figure 3.8 and 3.9 show the transition of enablers from one cluster to another due to their fuzziness and sensitivity. The strength of Fuzzified-MICMAC analysis is as it separates the autonomous enablers; dependent; independent; linkage during uncertainty.

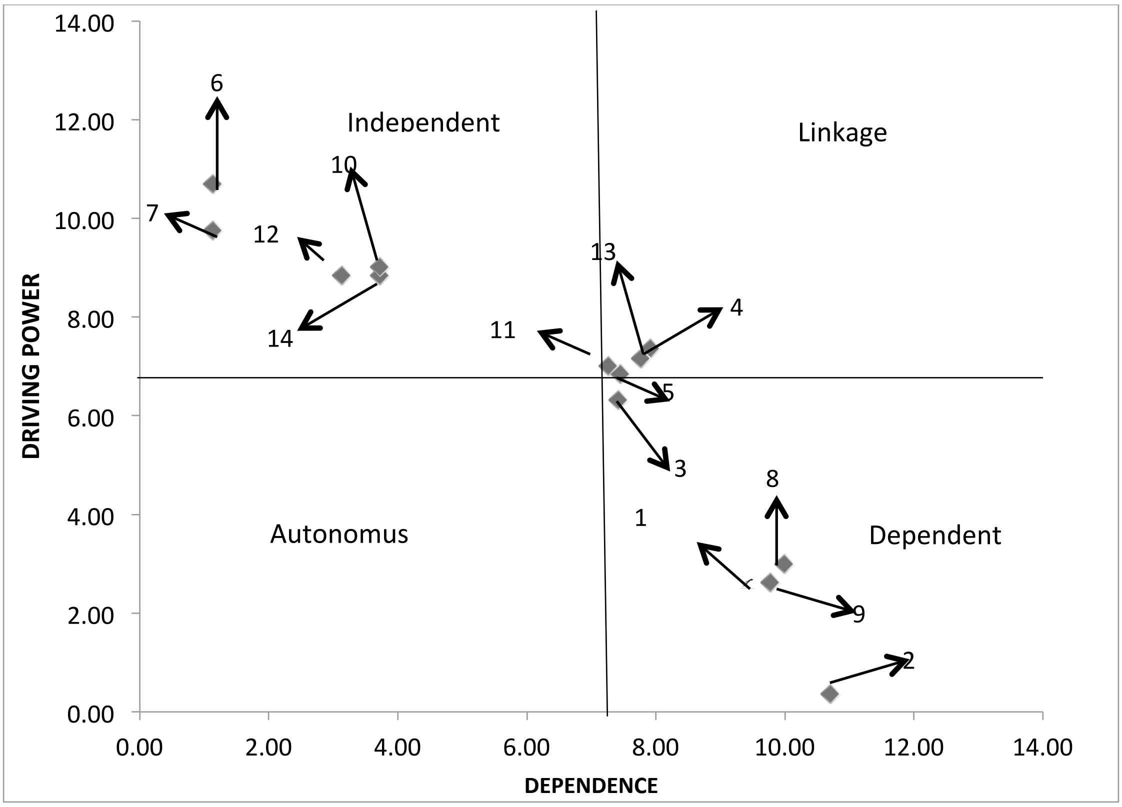

Figure 3.8: Fuzzy MIC-MAC analysis of CSFs

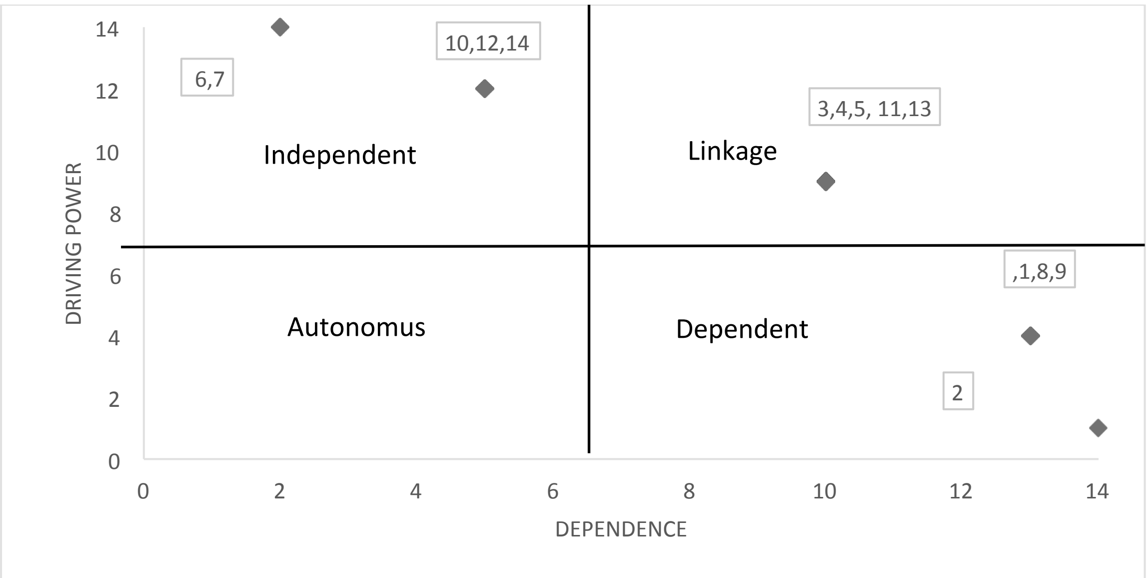

Figure 3.9: Defuzzified MIC-MAC analysis

The developed fuzzy-TISM and outcome of MICMAC analysis help the organization to identify which CSF help to achieve other CSFs with the degree of influence and give guidance in the LSS-AM implementation process.

3.4 VALIDATION OF LSS-AM CFFS THROUGH SEM AND DEVELOPMENT OF ROAD MAP OF CSFS FOR LSS-AM IMPLEMENTATION THROUGH FUZZY-TISM

In this section the identified CFFs were validated through SEM. Further hierarchical structure of CFFs for LSS-AM implementation are developed and analyzed through Fuzzy-TISM and MIC-MAC approaches. A detailed description of this hybrid approach is following:

3.4.1 Validation of CFFs through SEM

3.4.1.1 Collection of Data and Analysis

The same survey instrument collected data for CFFs. The value of Cronbach alpha was found .830, which is>.7, the recommended value. The CITC value of most of CFFs is>.4 which is recommended (see table 3.16). The mean value of all CFFs ranges from 6.16 to 8.28 with a maximum standard deviation value of 1.05 revealing that all the identified CFFs are important.

Table 3.16: Reliability test of CFFs data

CFFs	Mean	Std. Deviation	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
B1	7.0200	.96325	.467	.821
B2	7.1400	.98032	.574	.815
B3	6.1600	.92042	.453	.824
B4	8.2800	.9899	.521	.819
B5	8.2400	.97223	.401	.829
B6	6.7200	.99342	.714	.790
B7	6.4000	1.0534	.608	.806
B8	7.2400	.98566	.568	.810
B9	6.7100	.96023	.720	.788

3.4.1.2 Factor Analysis

For factor analysis, Kaiser-Meyer-Olkin (KMO) 0.689 and Bartlett’s test”: chi-square value 740.501 and degree of freedom 36 were found.

3.4.1.2.1 EFA for CFFs to LSS-AM implementation

In EFA analysis, CFFs were grouped into three constructs having an Eigenvalue >1. The constructs were named as resistance towards change related (RTCB); resource constraints related (RCB) and poor project management related (PPMB). The result of EFA reveals that all factors in their respective constructs have loading values above the minimum recommended value (Sangwan *et al.*, 2014; Mundra and Mishra, 2021). Hence all the CFFs contribute well to the respective constructs. The EFA model for CFFs is shown in figure 3.10

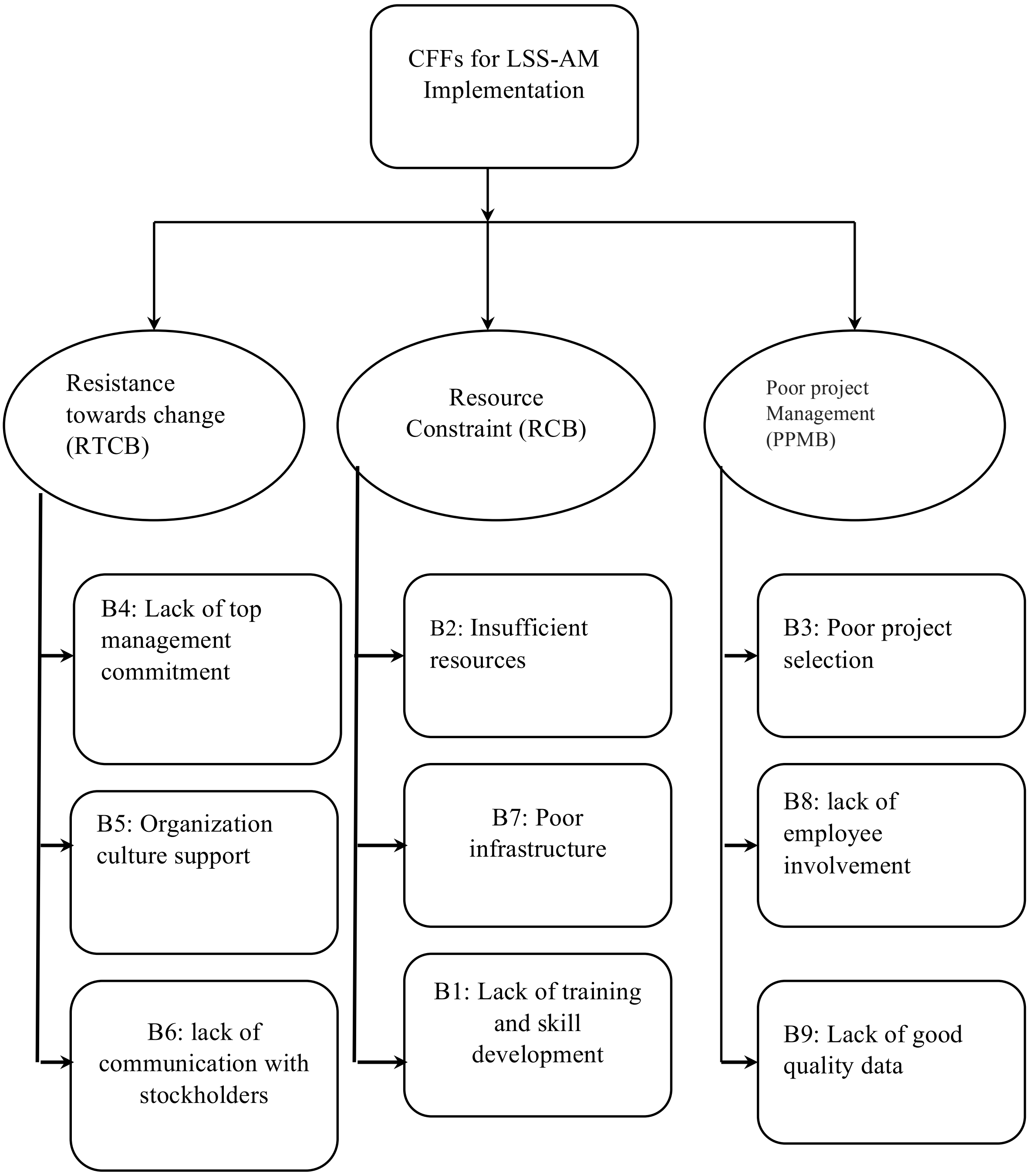

Figure 3.10: EFA model of CFFs to LSS-AM implementation

Table 3.17: Factor loading for CFFs

CFFS	RTCB	RCB	PPMB	Standardized Estimate	C.R.*	AVE
B4	.981			1.000		
B5	.914			.954	.949	.861
B6	.826			.821		
B2		.980		1.000		0.743
B7		.901		.962	.	
B1		.604		.653	.893	
B3			.966	.768		
B8			.762	.664	.853	
B9			.593	1.000		0.67

Notes: P<0.001 for all coefficients, * C.R. –Composite reliability

3.4.1.2.2 Confirmatory Factor Analysis (CFA) for CFFs to LSS-AM Implementation

To confirm the results of the EFA model of CFFs, CFA was performed. The output of the EFA analysis of CFFs was fed to AMOS software. Based on that measurement model of CFFS, containing 14 observed variables is developed. (See figure 3.11)

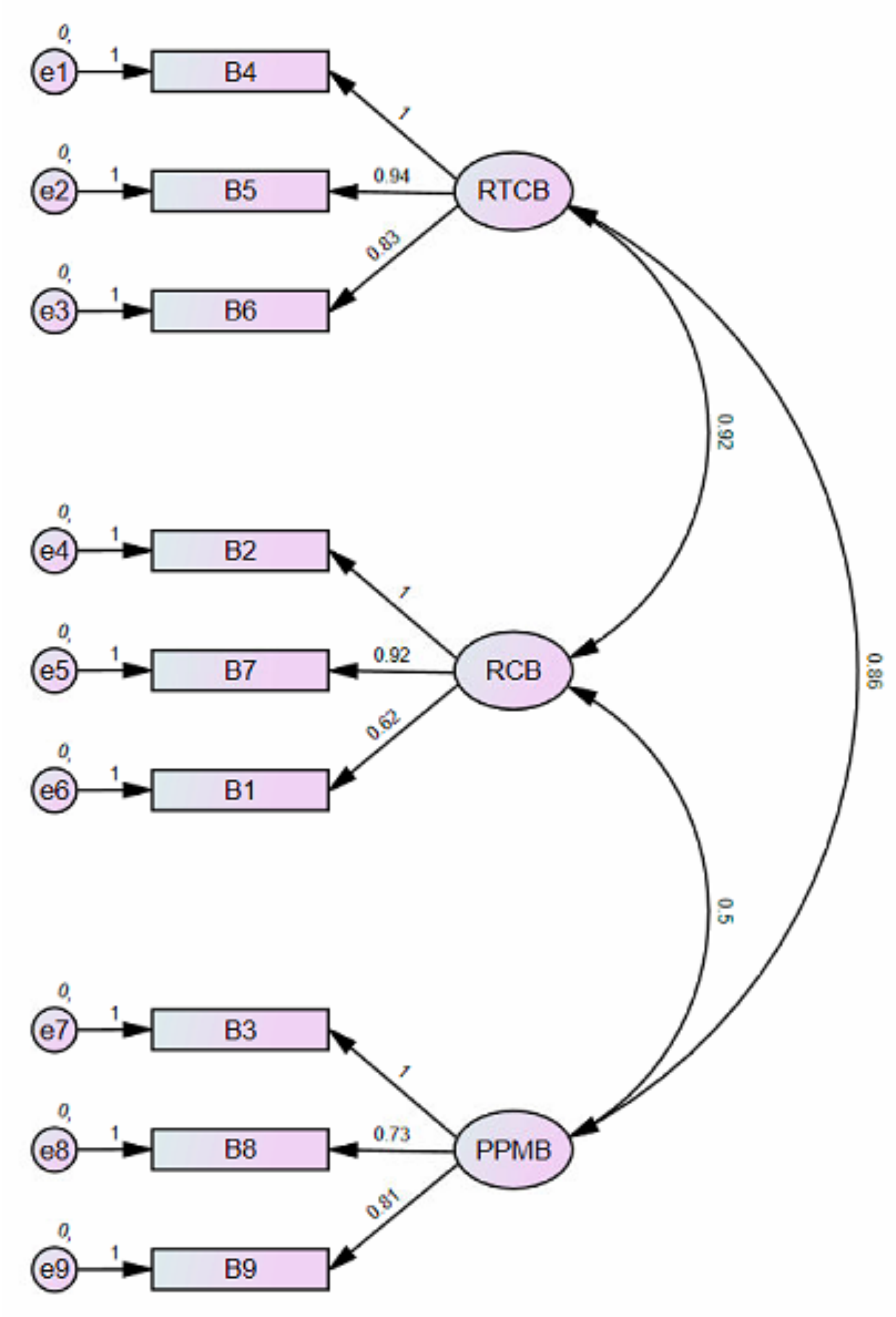

Figure 3.11: Measurement model of CFFS for LSS-AM Implementation

3.4.1.2.2.1 Model fit of CFFs Measurement Model

For evaluation of the models, the following model fit indices were obtained with recommended value. The measurement model's results have revealed that it is well-fitted with the available sample data.

Table 3.18: Model Fit of CFFs measurement model

Index	Estimated value	Recommended value	Reference
CMIN	34.258	-	
DF	24	-	
***p*-value**	0	< 0.005	
CMIN/DF	1.427	< 5.0	Marsch and Hocevar, (1985); Hair *et al*., (1995)
RMSEA	.066	<. 08	Hair *et al*., (1995)
SRMR	0.065	< 0.08	Hair *et al*., (1995)
GFI	0.934	Close to one	Hair *et al*., (1995); Dawes *et al*., (1998)
AGFI	0.879	Close to one	Hair *et al*., (1995)
CFI	0.986	> 0.90	Hair *et al*., (1995); Byrne (2001)

3.4.1.2.2.2 Validity of Scales

The validity of the scale was confirmed through academia and industry expert's opinion

3.4.1.2.2.3 Construct Validity

Convergent validity; discriminant validity and face validity evaluation are needed for construct validity. Among this, face validity is assured as the CFFs adopted in this chapter were obtained from available literature on related research areas. Cronbach alpha value of each CFF was >0.7; AVE>0.5 hence construct's convergent validity is established.

Table 3.19: Discriminant validity of CFFs measurement model

Constructs	RTCB	RCB	PPMB
RTCB	.928*[a]		
RCB	0.265	.862*[a]	
PPMB	0.333	0.293	.819*[a]

*** a –Square root of AVE**

Table 3.19 represents AVE and squared inter-construct correlation values in diagonal and off-diagonal elements respectively. It can be seen that the off-diagonal elements were of all the CFFs less than the corresponding diagonal values; thus the discriminant validity has been achieved. Since all three validities i.e. face; convergent and discriminant were established in the present study hence the construct validity of the measurement model was found good.

3.4.1.3 Structural Model of CFFs

Structural model presents the casual relationship among the constructs. The hypothesis is articulated to test the validity of full structural model. Following hypothesis are stated on the basis of conclusions obtained from the Fuzzy-TISM model of CFFs.

3.4.1.3.1 Formulation of Hypothesis

In the present study to interpret the data obtained from the survey, the following hypotheses has been formulated:

H1. The resistance towards change-related CFFs construct (RTCB) influence the resource constraint-related CFFs to construct (RCB)

H2: The resource constraint related CFFs construct (RCB) influence the poor project management related CFFs to construct (PPMB)

H3: The resistance towards change-related CFFs construct (RTCB) influences the poor project management related CFFs to construct (PPMB)

3.4.1.3.2 Hypothesis Testing

To test the relationship among the three constructs hypothesis testing was performed. In this study, maximum-likelihood estimation was used to estimate the fitness indices of the structure model. The results are as follows:

Table 3.20: Results of Hypothesis for CFFs to LSS-AM

	Hypothesis	β value	p-value	Result
H1	RTCB ➔RCB	0.265	0.006	Accepted
H2	RCB ➔ PPMB	0.220	0.015	Accepted
H3	RTCB ➔ PPMB	0.275	0.002	Accepted

The structure model is shown in figure 3.12. To accept or reject the hypothesis the p-value, and standardized regression weights (β-value) are shown in table 3.21. Results revealed that the entire hypotheses were accepted and data of Model fit of the structural model are CMIN/df=1.427; CFI=.986; NFI=.956; RFI=.933; IFI=.986; TLI=. 979; GFI=.934; AGFI=.879; RMSEA=.066 depicts under the recommended value, depicts a good fit of the model.

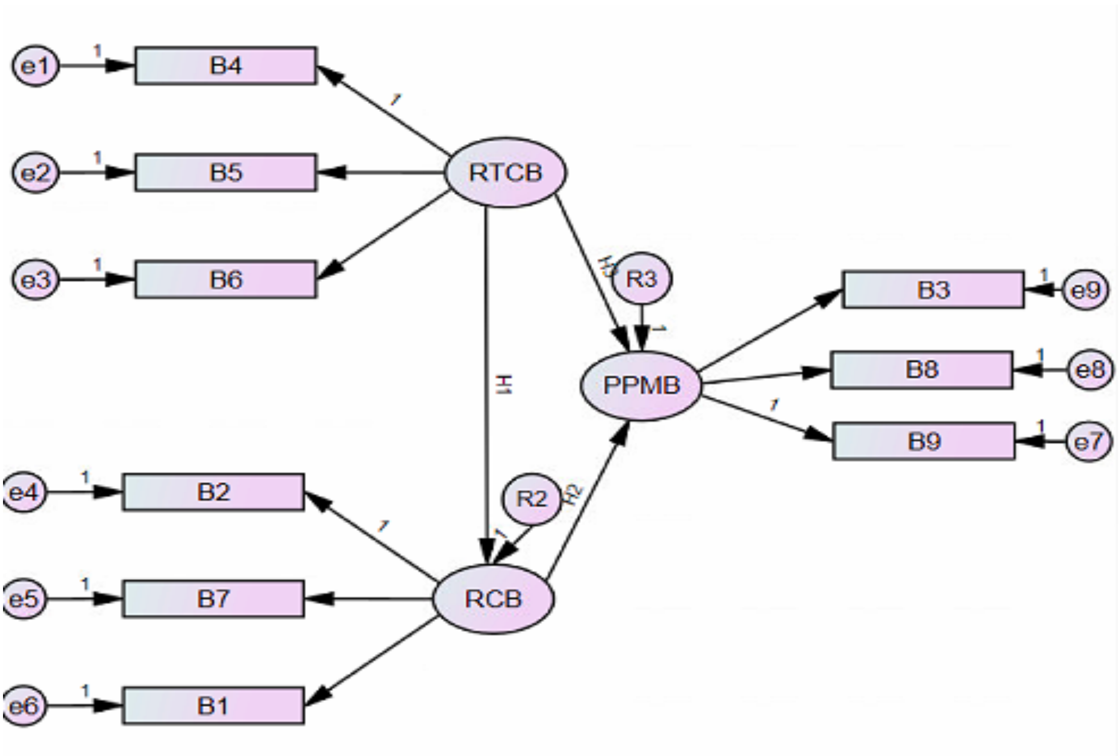

Figure 3.12: Structural model of CFFs for LSS –AM implementation

3.4.2 Development of Fuzzy-TISM Model of CFFs for LSS-AM Implementation

A total 9 CFFs were identified that impediment the implementation of LSS-AM in the manufacturing industry from a vast literature review and expert panel opinion.

3.4.2.1 Development of Structural self-interaction matrix (SSIM) and Aggregated Structural self-interaction

The degree of mutual relationship among the CFFS has been given in several linguistics terms (VH-very high; H-high; M-medium; L-low; VL: very low) by an expert panel to analyze the influence of one CFF over another through a semi-structural interview. The crisp method has been applied in Fuzzy TISM. For easier interpretation of these, a small example is explained here.

1. B1 has a very high influence on achieving B3 but B3 does not influence to achieve then the contextual relationship between them is labeled as V (VH)
2. B5 has a high influence on achieving B2 and but if B2 does not influence to achieve of B5 then the contextual relationship between them is labeled as A (H)
3. B1 and B6 have a high influence on achieving each other than the contextual relationship among them is labeled as X (H)

Table 3.21 depicts aggregated SSIM, which was developed by taking the mode of responses obtained from the expert panel

Table 3.21: Aggregated SSIM matrix for CFFs to LSS-AM

CFFs	**B9**	**B8**	**B7**	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**
B1	V (H)	V (H)	X (H)	X (H)	A (VH)	A (VH)	V (VH)	A (VH)	
B2	V (VH)	V (VH)	V (VH)	V (VH)	A (H)	A (M)	V (VH)		
B3	V (VH)	X (VH)	A (H)	A (M)	A (VH)	A (VH)			
B4	V (VH)	V (VH)	V (H)	V (VH)	X (H)				
B5	V (VH)	V (H)	V (VH)	V (VH)					
B6	V (M)	V (VH)	V (VH)						
B7	V (H)	V (H)							

B8	V (VH)
B9	

3.4.2.2 Development of Initial Fuzzy Reachability Matrix for CFFs

Aggregated SSIM matrix of CFFs is first converted into a initial fuzzy reachability matrix (see table 3.22). Based on this fuzzy reachability final Fuzzy reachability matrix was obtained by converting (i,j) and (j, i) entries as per the scenario discussed in the Fuzzy-TISM methodology and is shown in Table 3.23

Table 3.22: Fuzzy reachability matrix of CFFs to LSS-AM based on aggregated fuzzy SSIM matrix

CFFs	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**
B1	_	NO	VH	NO	NO	H	H	H	H
B2	VH	_	H	NO	NO	VH	VH	VH	VH
B3	NO	NO	_	NO	NO	NO	NO	VH	VH
B4	VH	M	VH	_	H	VH	H	VH	VH
B5	VH	H	VH	H	_	VH	VH	H	VH
B6	H	NO	M	NO	NO	_	VH	VH	M
B7	H	NO	H	NO	NO	NO	_	H	H
B8	NO	NO	VH	NO	NO	NO	NO	_	VH
B9	NO	NO	NO	NO	NO	NO	NO	NO	_

3.4.2.3 Development of Final Fuzzy Reachability Matrix for CFFs

Based on the fuzzy reachability final Fuzzy reachability matrix was obtained by converting (i,j) and (j, i) entries as per the scenario discussed in the Fuzzy-TISM methodology and is shown in Table 3.18. Further to compute the driving power and dependence for each CFF, it is necessary to calculate the Crisp Value of each CFF. The crisp value is computed by Eqs. 3.2 to 3.6. Driving Power for fuzzy value (3.2, 4.2, 5.6) of CFF 1

STEP 1 Calculate Delta using equation 3.2:

DELTA=R-L; R= 7.8, L=0

DELTA=7.8

Step 2: Calculation for lower, middle, and upper values using equation 3.3:

$x_{l1} = \frac{3.2-0}{7.8}, x_{m1} = (4.2 - 0)/7.8 \; x_{u1} = (5.6 - 0)/7.8$

$$(x_{l1}, x_{m1} . x_{u1}) = (0.410256; 0.538462; 0.717949)$$

Step 3: Calculation of normalized left score (ls) and right score (rs) values using equation 3.4:

$x_1^{ls} = 0.410256 * \; (1 + 0.538462 - 0.410256)$

$$x_1^{ls} = 0.477273$$

and $x_1^{rs} = 0.717949(1 + 0.717949 - 0.538462)$

x_1^{rs} =0.608696

Step 4: Calculation of total normalized crisp values using equation 3.5:

$x_1^{crisp} = [0.477273 * (1 - 0.477273) + 0.608696 * 0.608696]/[1 - 0.477273 + 0.608696]$

x_1^{crisp} =0.547977

Step 5: Computation of crisp value for B_K using equation 3.6:

$$B_{1\ driving}^{Crisp} = 0 + 0.547977 * 7.8$$

$$B_{1driving}^{Crisp} = 4.274221$$

Similarly the crisp value of dependence of B 1:

$B_{1depdence}^{Crisp}$ =3.8864206

Through this, we obtained the crisp values of driving power and dependence of each CFF. (see table 3.23). Detailed calculation is provided in table A.3.2 in Appendix A.3.

Table 3.23: Final Fuzzy reachability matrix of CFFs to LSS-AM

CFFs	B1	B2	B3	B4	B5	B6	B7	B8	B9	**	##
B1	_	(0,0,.2)	(.8,1,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.6,.8,1)	(.6,.8,1)	(.6,.8,1)	(3.2,4.2, 5.6)	4.27422 1482
B2	(.8,1,1)	_	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.8,1,1)	(.8,1,1)	(.8,1,1)	(.8,1,1)	(4.6,5.8, 6.4)	5.65134 1991
B3	(0,0,.2)	(0,0,.2)	_	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(.8,1,1)	(.8,1,1)	(1.6,2,3. 2)	2.18098 9325
B4	(.8,1,1)	(.4,.6,.8)	(.8,1,1)	_	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	(.8,1,1)	(.8,1,1)	(5.6,7.2, 7.8)	6.98752 1306
B5	(.8,1,1)	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	_	(.8,1,1)	(.8,1,1)	(.6,.8,1)	(.8,1,1)	(5.6,7.2, 8)	6.99823 784

B6	(.6,.8,1)	(0,0,.2)	(.4,.6,.8)	(0,0,.2)	(0,0,.2)	_	(.8,1,1)	(.8,1,1)	(.4,.6,.8)	(3,4,5.2)	4.039890996
B7	(.6,.8,1)	(0,0,.2)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(0,0,.2)	_	(.6,.8,1)	(.6,.8,1)	(1.8,2.4,4)	2.635720365
B8	(0,0,.2)	(0,0,.2)	(.8,1,1)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	_	(.8,1,1)	(1.6,2,3.2)	2.180989325
B9	(0,0.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	_	(0,0,1.6)	0.19311412
*****	(2.8,3.6,4.8)	(1,1.4,3)	(4.8,6.2,7)	(0.6,0.8,2.4)	(0.6,0.8,2.4)	(3,3.8,4.8)	(3.6,4.6,5.6)	(5,6.4,7.2)	(5.6,7.2,7.8)		
##	3.864206269	2.282608781	5.140480625	1.978632153	2.006132085	3.937720168	4.210926319	5.338674502	5.357142857		

*** Dependence; ** Driving power; # Bk crisp Dependence; ## Bk crisp Driving**

3.4.2.4 Development of Final Defuzzified Reachability Matrix for CFF

Defuzzified the fuzzy reachability matrix by replacing all VH, H, and M entries with 1 and L, and No entry with 0. Further transitivity has been checked and marked as * in table 3.24. Further summing up the rows 1's and column 1's of each CFF in the final reachability matrix has given the driving power and dependence respectively.

Table 3.24: Defuzzified final reachability matrix of CFFs to LSS-AM

CFFs	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**DRIVING**
B1	1	0	1	0	0	1	1	1	1	6
B2	1	1	1	0	0	1	1	1	1	7
B3	0	0	1	0	0	0	0	1	1	3
B4	1	1	1	1	1	1	1	1	1	9
B5	1	1	1	1	1	1	1	1	1	9
B6	1	0	1	0	0	1	1	1	1	6

B7	1	0	1	0	0	1*	1	1	1	6
B8	0	0	1	0	0	0	0	1	1	3
B9	0	0	0	0	0	0	0	0	1	1
Dependence	6	3	8	2	2	6	6	8	9	50/50

3.3.2.5 Level Partitions of CFFs

After the calculation of the driving power and dependence of each CFF, level partitioning was performed. To identify the level of each CFF, a total of five iterations have been done. As a result, all CFFs were divided into five levels of hierarchy (see tables 3.25 and 3.26). Remaining iterations are presented in tables A.3.7 to A.3.10 in Appendix A.3.

Table 3.25: Level partition of reachability matrix of CFFs to LSS-AM (1st Iteration)

CFFs	Reachability	Antecedent	Intersection set	Level
B1	1,3,6,7,8,9	1,4,5,6,7	1,6,7	
B2	1,2,3,6,7,8,9	2,4,5	2	
B3	3,8,9	1,2,3,4,5,6,7,8	3,8	
B4	1,2,3,4,5,6,7,8,9	4,5	4,5	
B5	1,2,3,4,5,6,7,8,9	4,5	4,5	
B6	1,3,6,7,8,9	1,4,5,6,7	1,6,7	
B7	1,3,6,7,8,9	1,4,5,6,7	1,6,7	

B8	3,8,9	1,2,3,4,5,6,7,8	3,8	
B9	9	1,2,3,4,5,6,7,8,9	9	I

Table 3.26: Level partition of each CFF to LSS-AM

S.NO.	CFF	Level No.
1	B9	I
2	B3, B8	II
3	B1, B6, B7	III
4	B2	IV
5	B4, B5	V

3.4.2.6 Development of Fuzzy-TISM Digraph of CFFs

Figure 3.13 depicts the Fuzzy-TISM model for LSS-AM CFFs. This model has also five levels of hierarchy. At the bottom of this digraph, CFF B4 and CFF B5 come. For parent node B 4, the left-most child nodes contained CFFs B1, B3, B6, B8, and B9 which are having very high linguistics terms given by experts, joined to the parent node B 4 by a dark bold line; the second child node containing CFFs B5, B7 joined to CFF B4 by light line, denotes the linguistic term "high" as per the expert's decision to the B4; while next child node consisting B2 and connected by B4 through a dashed line which represents the linguistic term "medium" as per experts choice. Hence the relation of B4 in the parent node to the other CFFs is shown by the several branches to denote different linguistic terms. Similarly, each CFF is considered as a parent node and connected to the other CFFs by various branches. Further to connect CFF's parent nodes, the parent node of B4 is joined to the same level parent node B5 by a light arrow, which depicts the linguistic term "High" as per the expert's replies while the parent node of B4 is connected though the just above parent node B2 by dashed arrow respectively to determines the linguistic term medium condition between them. Similarly, the final Fuzzy-TISM model of CFFs for LSS-AM implementation has been developed.

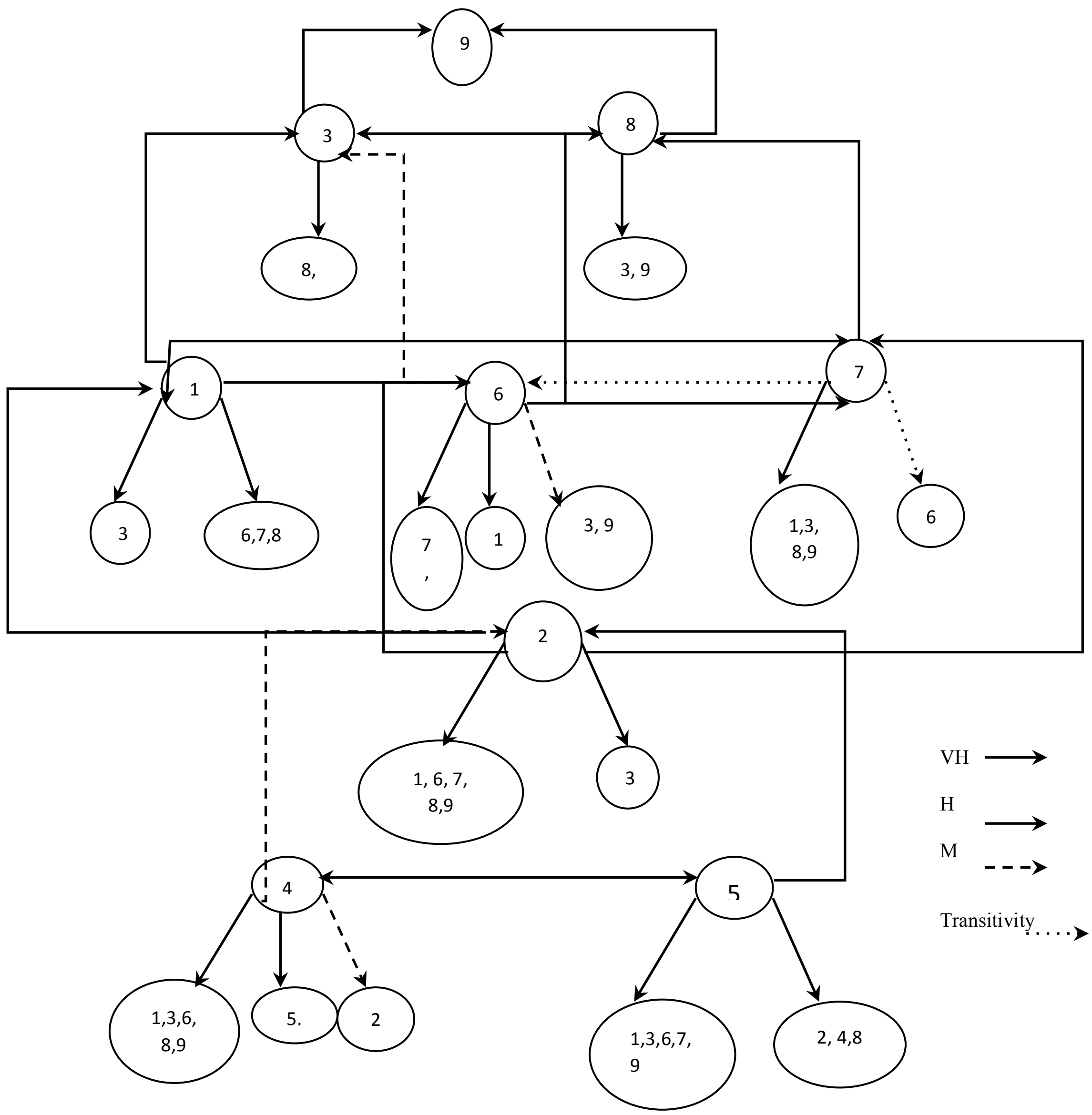

Figure 3.13: Fuzzy-TISM Digraph of CFFs for LSS-AM implementation

3.4.2.7 Fuzzy –TISM model of CFFs

Removing all the transitivity's links, L, and NI degree of influence link from the Fuzzy-TISM digraph has developed the fuzzy-TISM model. Only the direct links among the CFFs, which were having VH, H, and M degree of influence, were denoted by a dark bold thick line, thick line and dashed line respectively (See figure 3.14)

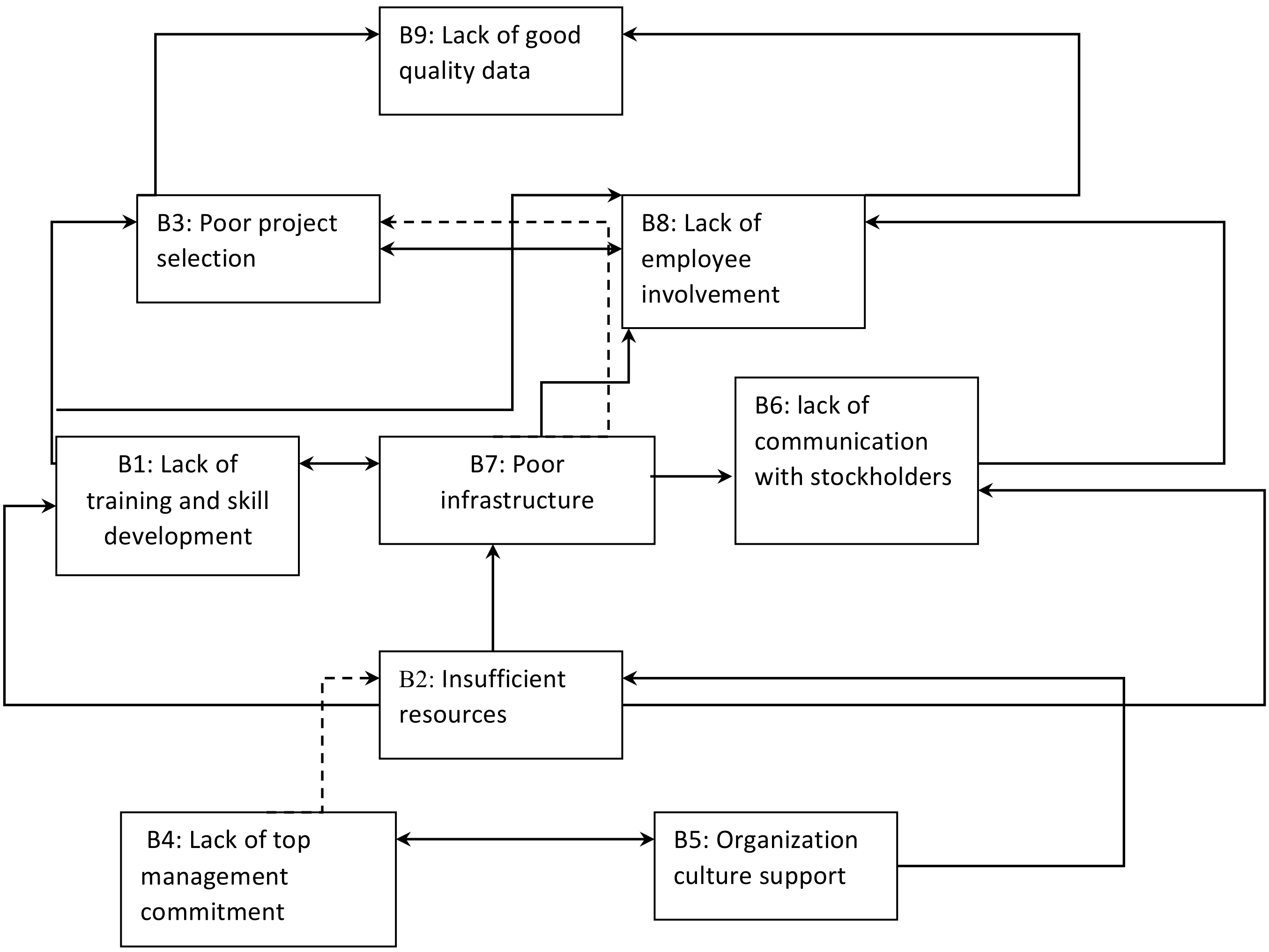

Figure 3.14: Fuzzy-TISM model of CFFs for LSS-AM implementation

3.4.3 MICMAC Analysis of CFFs

After calculating the dependence and driving power of each CFF, MICMAC analysis was performed to classify the CFFs into 4 clusters. Autonomous clusters: In both fuzzified and de-fuzzified cases, no CFF falls under this category, which depicts all CFFs considered in this study, which is significantly useful. (ii) Dependent clusters: In the fuzzified case, CFFs B3, B7, B8, and B9 come under this category while in the defuzzified case CSFs B3, B8, and B9 fall under this due to their dominant driving power and low driving power. (iii) Linkage clusters dependence CFFs B1, and B6 come under this category in a fuzzified case while in a defuzzified case CFFs B1, B6, and B7 fall under the linkage category because of their high driving and high dependence. The fourth cluster is an independent cluster, in which CFFs B2, and B4, B5 have low dependence and high driving power in both Fuzzified and defuzzified. Together figure 3.15 and 3.16 represent the transition of CFF from one cluster to another due to their fuzziness and sensitivity. The strength of Fuzzified-MICMAC analysis is as it separates the autonomous enablers; dependent; independent; linkage during uncertainty. The developed fuzzy-TISM and outcome of MICMAC analysis help the organization to identify which CFFs are pivot roadblocks of LSS-AM implementation and their degree of influence on other CFFs. This will guide practitioners to pay more attention to mitigating the major impediments and helps managers to formulate the strategy for LSS-AM implementation in their organization.

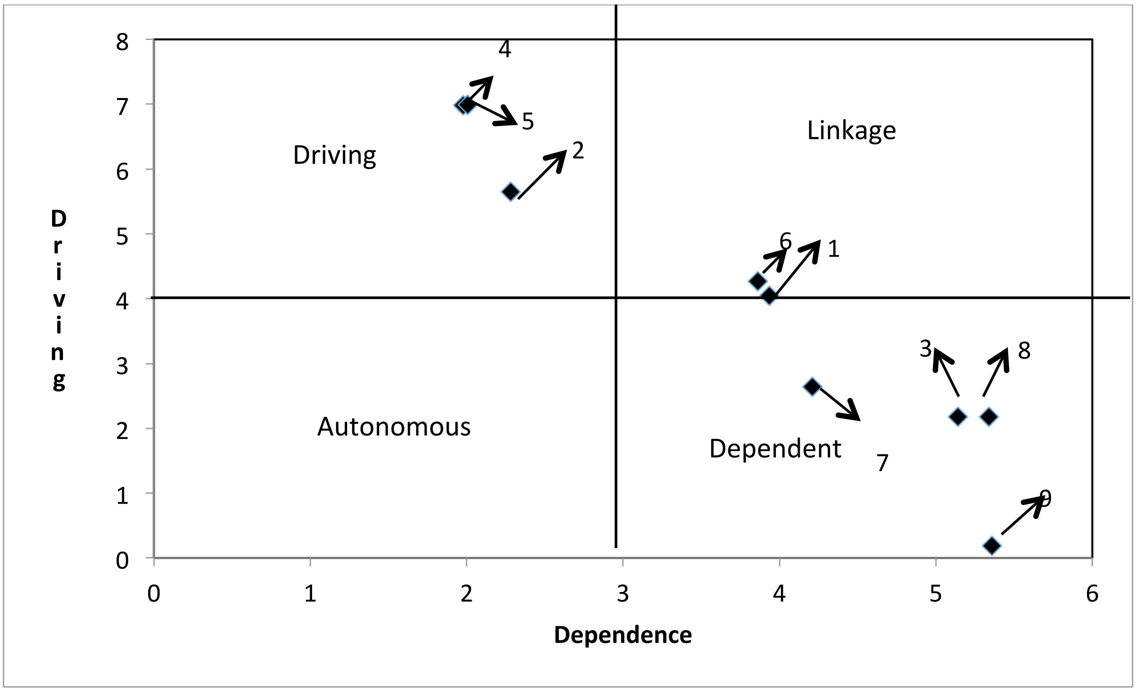

Figure 3.15: Fuzzy MIC-MAC Analysis of CFFs

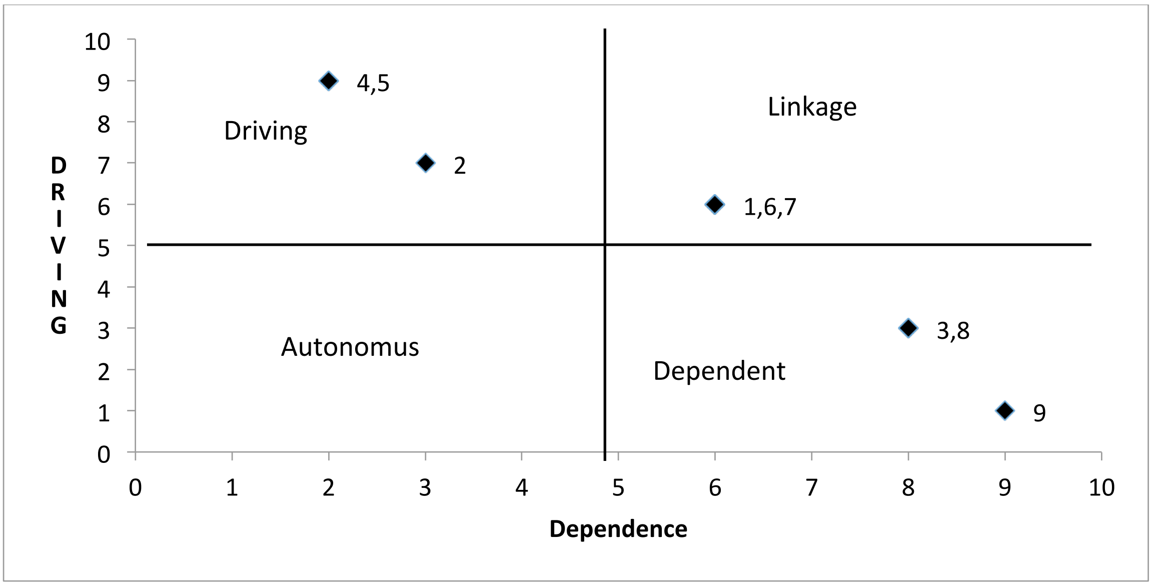

Figure 3.16: MIC-MAC Analysis of CFFs

3.5 RESULTS AND DISCUSSION

The results obtained from FUZZY-TISM, MICMAC and SEM of CSFs to and CFFs for LSS-AM implementation are discussed below:

3.5.1 Results and discussion of SEM and Fuzzy –TISM, MICMAC analysis for LSS-AM CSFs

SEM approach has been applied to statistically validate the CSFs, which were identified from literature. The results revealed that the proposed CSFs are statistically valid and empirically acceptable. From the exploratory factor analysis, the 14 CSFs are grouped into 3 constructs named as OCF: Organization Commitment towards change related construct; RCF: Resource capability related construct and TF: technological related constructs. OCF consists 6 CSFs' i.e. top Management commitment towards LSS & AM (C6); organization culture (C7); change management (C14); alignment of strategies (C12); project selection and prioritization (C13) and communication and collaboration with stakeholders (C9). RCF consists of 6 CSFs i.e. financial capability (C10); organization infrastructure (C4); training and knowledge management (C11); employee empowerment and link to human resources action (C5) and multi-skilled workforce (C1). TF consists of 3 CSFs i.e. information technology (C13); existing Technology Advancement (C8) and virtual alliances (C2). The output of EFA was tested by CFA. A measurement model is developed and the model fit is tested from confirmatory factors analysis. Results of CFA depict that model has a good fit. A further structural model was developed and validated by hypothesis testing. Three hypotheses were tested. Results reveal that the Organization Commitment towards change-related construct (OCF) supports resource capability-related construct (RCF) and technological-related constructs (TF). Resource capability-related construct (RCF) supports technological-related constructs (TF) to implement LSS-AM.

Further to develop the roadmap of CSFs for LSS-AM implementation, hierarchal model was developed by Fuzzy-TISM approach. This model for LSS-AM CSFs has decided the hierarchy level of 14 CSFs to LSS-AM implementation through five iterations.

V level: At the bottom level, CSFs' Top management commitment (C6) and Organization culture (C7) develop a solid foundation for LSS-AM implementation. The success of LSS-AM in any manufacturing industry depends upon top management's attitudes and the organizations' people's keenness towards improvement initiatives. Further, these 2 CSFs will assist its next levels of CSFs.

IV level: 3 CSFs i.e. change management (C10); financial capabilities (C12) and alignment of strategies (C14); are placed. It is necessary to align LSS-AM as a business strategy along with the vision statement of industries. For successful implementation of LSS-AM effective allocation of financial resources is also required. Organizational culture and top management further make the transition journey smooth by properly managing the change.

III Level: 5 CSFs i.e. project selection prioritization; organization infrastructure, employee empowerment and link to human resources–based actions; training and knowledge management and information technology are placed. For the success of LSS-AM implementation, project selection plays a pivotal role. The wrong selection of the project is not only time-consuming but also financially draining for the organization. Real-time information sharing throughout the organization improves communication. For successful implementation of LSS-AM, Organization needs to train their employees rigorously in the fundamentals of LSS and automation. Financial capabilities and change management help organizations to provide the LSS or automation training to the right person and provide the necessary infrastructure for LSS-AM implementation. Employees involved in the LSS-AM project must be rewarded and recognized so that employees feel empowered and motivated hence further improving the team spirit and long-term focus view of employees.

II level: Existing technology advancement and augment of new technology (C1); multi-skilled workforce (C8) and Communication and collaboration with stakeholders (C9) came at the second level of hierarchy. For successful implementation of LSS-AM clear understanding of VOC (voice of customer) and market information effective communication and collaboration with stakeholders are needed and multiskilling of the workforce is required to fulfill dynamic market demand responsively. Market information is a prerequisite for advancement in existing technologies or opens the door for new technology in any organization.

I level: At the top of the hierarchy virtual alliance (C2). Good supplier relationship helps to build virtual enterprises, which helps the organization to meet the dynamic demands of customers responsively. This enables the organization to deploy LSS-AM successfully.

The result of the MICMAC analysis stresses that "Top management commitment; organization culture; change management; financial capabilities (C12) and alignment of strategies" are the independent CSFs. They are the most vital CSFs, as they have higher driving power and assist the other CSFs to do so (Swarnakar *et al.,* 2021a). This implies that other CSFs of LSS-AM were persuaded by these CSFs and earlier attention on these CSFs helps policymakers or decision-makers to prioritize their resources effectively to implement LSS-AM successfully.

3.5.2 Results and Discussion of SEM and Fuzzy –TISM, MICMAC analysis for LSS-AM CFFs

SEM approach has been applied to statistically validate the identified CFFs. All 9 CFFs were found reliable and valid. From the exploratory factor analysis, the 9 CFFs are grouped into 3 constructs named as RTCB: resistance towards change related constructs; RCB: Resources constraints related constructs and PPMB: poor project management related constructs. RTCB consists of 3 CFFs lack of top management commitment towards LSS & AM; lack of organization culture support (B5) and lack of communication and collaboration with stakeholders (B6). RCB comprises 3 CFFs insufficient resources (B2); poor infrastructure (B7) and lack of training and skill development (B1). PPMB construct consists of 3 CFFs i.e. poor project selection (B3); lack of employee involvement (B8) and poor quality data (B9). A measurement model is developed and the model fit is tested from confirmatory factors analysis. Results of CFA depict that model has a good fit. A further structural model was developed and validated by hypothesis testing. Three hypotheses were tested. Results reveal that the resistance towards change-related construct (RTCB) leads to resource constraints-related constructs (RCB) and poor project management-related constructs (PPMB). Resources constraints related construct (RCB) lead to poor project management-related constructs in LSS-AM implementation. Further Fuzzy-TISM model for LSS-AM CSFs has placed 9 CFFS for LSS-AM implementation across the five levels of the hierarchy through five no. of iterations.

V level: Two CFFs lack of top management commitment towards LSS-AM implementation (B4) and lack of supportive organization culture (B5) form the base of the hierarchy structure. This implies that the lack of top management commitment and reluctance to culture change is the major roadblock to the LSS-AM implementation journey in the manufacturing industry which influences the next levels of CFFs.

IV level: CFF insufficient resources (B2), was placed at the fourth level of the hierarchy. Insufficient resources (financial, human etc.) are a hindrance to LSS-AM implementation.

III level:

Lack of training and skill development (B1), poor infrastructure (B6) and Lack of communication and collaboration with stakeholders (B7) came at the III level of the hierarchy. For LSS-AM implementation automation, training and multiskilling are required a good amount of investment in the short term. Insufficient resources become lead to a lack of training and poor infrastructure. Poor infrastructure causes poor communication among the stakeholders. Lack of communication among internal and external stakeholders becomes a hindrance to LSS-AM project success. Lack of collaboration with suppliers causes a longer lead time to fulfill the dynamic demand of customers. In addition to this, if the VOC is not taken into account during LSS-AM implementation, the project outcome will be left the organization with dissatisfied customers, which is a huge failure of the LSS-AM project.

II level: CFFs poor project selection (B3) and lack of employee involvement (B8) was placed at the second level of the hierarchy. Poor project selection results in a waste of time, and wastage of resources and outcomes, which is not desired. Lack of communication between top management and employees causes a lack of involvement of employees in LSS-AM implementation

V: At the top of the hierarchy lack of good quality data (B9) was placed. Poor project selection (B3) and lack of employee involvement (B8) lead to poor quality data, which ultimately causes a failure of LSS-AM's project

The result of MICMAC analysis for CFFs reveals that lack of top management commitment towards LSS-AM implementation (B4) and lack of supportive organization culture (B5) and insufficient resources (B2)" are the independent CFFs. They are major CFFs, as they have higher driving power and help the other CFFs to become the impediments in the LSS-AM implementation process. This implies that other CFFs of LSS-AM were influenced by these CFFs and earlier attention on these CFFs helps policymakers or decision-makers to make strategies to alleviate these CFFs.

3.6. CONCLUSIONS AND LIMITATIONS

Nowadays manufacturing industries are required to become efficient, effective and responsive to fulfill the dynamic and customized demands of customers at low cost with uncompromising quality at a shorter lead time. All these order-winning criteria can be achieved by integrating LSS and AM approaches, which eliminate waste and reduce process variation and bring responsiveness & flexibility simultaneously. In the present study, the CSFs and CFFs for LSS and AM execution in the manufacturing industry were identified, structured, and analyzed. The identified factors were statistically validated through SEM. Further Fuzzy Total Interpretive Structural Modeling (TISM) based models were created not only to depict a proper hierarchy among the identified LSS-AM CSFs and CFFs but also to represent the level of influence of one factor on another in manufacturing industries. These are further grouped into 4 clusters using Fuzzy-MICMAC. These models offer more robust results as it allows decision-makers to evaluate the effects of system variables on each other. These models of LSS-AM CSFs and CFFs would provide step-by-step guidance to decision providers, scholars, and consultants to implement LSS-AM successfully. This study is different from prior studies on the implication of integrated LSS-AM throughout the implementation in Indian manufacturing industries. First, no significant efforts have been made to identify a comprehensive array of CSFs and CFFS for LSS-AM implementation under one umbrella. Second, no previous relevant scientific research work has been found to integrate the SEM, Fuzzy-TISM and MICMAC approaches for categorizing the CSFs/CFFs of LSS-AM implementation in the manufacturing sector. This hybrid approach not only validated the CSFs /CFFs of LSS-AM implementation but also provide a roadmap for the implementation of LSS-AM to managers; decision-makers and practitioners and help them to prioritize the CSFs and mitigate CFFs as per their driving power and dependence. Third, this study used triangulation research methodology to find the intuitive and accurate knowledge of CSFs and CFFs to make the LSS-AM implementation journey straight sailing in the manufacturing industry. This study has limitations too as only 14 CSFs and 9 CFFs were considered and were validated by 100 sound responses from India only. The proposed fuzzy-TISM models are based on experts' opinion hence some degree of biasedness might be present. Further the proposed models are manufacturing sector-centric. More generic LSS-AM models can be seen as the underpinning for the future work.

CHAPTER 4

DEVELOPMENT OF AN INTEGRATED LSS-AM IMPLEMENTATION FRAMEWORK

4.1 INTRODUCTION

Rapid globalization, dynamic demands, and volatility are compelling organizations to adopt new business strategies to foothold in the market. Therefore integration of LSS –AM is a convincing strategy to foster the organizations in fulfilling dynamic demands responsively with uncompromising quality at low cost. To achieve long-term sustainable gain from LSS-AM, a well-developed LSS-AM framework is required. Several researchers, consultants, academicians, and practitioners have developed frameworks about LSS, AM, and Leagile individually over a while. In this chapter, an attempt has been made to review them critically based on several taxonomies such as conceptual and implementation type of frameworks, source of frameworks, mode of verification, and no. of elements (tools/constructs/practices) and performed a comparative analysis of existing frameworks. A review of the existing articles revealed that existing frameworks are flooded with lots of shortcomings. Comprehensive lists which comprise the principles, practices, tools and techniques or constructs (now on call as an element) of LSS-AM under one umbrella are missing and at the same time, a structured framework which depicts the step-by-step process to implement LSS-AM is also not found. Hence in this chapter, an integrated implementation framework of LSS-AM has been proposed to resolve some of these limitations. Further, the proposed framework is validated through descriptive statistics analysis. The chapter serves the following objectives:

(1). To identify the progression of LSS and AM frameworks over 22 years of span.

(2). To identify the percentage of frameworks based upon design/conceptual and implementation basis.

(3). To identify the sources of the framework

(4). To identify the frequency and mode of verification of frameworks.

(5). To identify the different elements/tools/constructs/principals used for developing the frameworks of LSS and AM.

To fulfill the above objectives the chapter is arranged as follows: Section 2 presents a comprehensive literature review of existing frameworks of LSS, AM, Leagile, and LSS-AM. Section 3 discusses the taxonomies of frameworks. Section 4 presents a comparative analysis of the existing frameworks to recognize the inadequacies of each framework. Section 5 presents the identification of a standard set of LSS-AM implementation elements. Section 6 highlights the development of an integrated LSS-AM implementation framework and elaborates on the features of the proposed integrated framework.. Section 7 sums up the conclusion and future direction of the work

4.2 REVIEW OF EXISTING FRAMEWORKS OF LSS, AM, LEAGILE AND LSS-AM

Existing review articles found in chapter 2 were mostly focused on LSS, AM, and Leagile individually. A comprehensive literature review consists of all of the LSS, AM and Leagile frameworks under one umbrella are missing. Raval and Kant (2017) reviewed 58 frameworks based on lean, Six Sigma, and LSS. They classified these frameworks into seven categories i.e. novelty of the framework, source of the framework, mode of verification, elements/tools/constructs, and performed a comparative analysis of the framework based on the type of framework, abstractness, number of elements, and comprehensiveness. Yadav *et al.* (2017) reviewed 26 LSS frameworks and categorized them based on the novelty of the framework, source of the framework, mode of verification, design, etc.

Following are the definitions of frameworks given by different authors:

Anand and Kodali (2010) defined framework as "a guiding torch that helps a manager in providing necessary direction during the change management programs that are implemented in an organization". Bhamu and Sangwan (2016) defined framework as "an organized outcome-based plan, which defines clear standards to be set by the organization". Yadav *et al.* (2017) defined framework as "a key in arranging, organizing and intellectualizing information and actions to ensure the desired outcomes". Hence we define a framework as an organized structure, which arranges a line of action to be followed by an organization to achieve the desired goals of any change management initiatives. It may constitute constructs/elements/tools, which an organization needs to adopt when it tries to deploy a different way of functioning. A plethora of researchers developed LSS, AM, and Leagile frameworks to improve the measures of a competitive matrix. A total of 41 frameworks are critically reviewed and discussed in table 4.1.

Table 4.1: Critical review of existing LSS, AM, Leagile and LSS-AM frameworks

Authors and year	**Contribution**	**Limitations**
Gunasekaran *et al*., (2002)	Developed a Conceptual generic framework of AM strategies and relevant technologies	However, this framework discussed some of the practical aspects of agility in manufacturing but was based on a literature review and some case studies. Further, it did not answer how to implement AM in an organization. In addition to this, the quality aspect was also untouched.
Jin-Hai *et al*., (2003)	Developed a conceptual real agile manufacturing framework based on four fundamentals.	The feasibility of this framework was not tested.
Kumar *et al*. (2006)	Developed an implementation framework based on several organization visits. It is based on the classical DMAIC approach and validated by a case study	However, the prerequisite for this DMAIC framework was not discussed.
Ismail *et al*., (2006)	Developed an agility roadmap for agile implementation in the organization based on three interactive implementation phases.	This framework is an implementation framework and validated through a case study but this framework does not depict the role of any tools of AM in implementation.
Vázquez-Bustelo *et al*.(2006)	Developed a conceptual model of AM based on three manufacturing case studies. The core of the framework consists of 5 elements whereas turbulence and business performance manufacturing strength was the input and output of the frameworks respectively.	This framework is conceptual and does not guide how to implement these practices on a real-time basis to deliver business performance and manufacturing strength
Ramesh and Devadasan (2007)	Developed 20 criteria conceptual framework of AM and gave step-by-step procedure to implement them.	Although the authors provided the procedure of implementation of 20 of these criteria, real-time implementation was missing
Krishnamurthy and Yauch (2007)	Proposed a theoretical corporate infrastructure of the Leagile manufacturing concept.	However, the toolset required to implement Leagile manufacturing was not discussed.
Zhang and Sharif (2007)	Developed a conceptual framework for the implementation of agility as a manufacturing strategy in manufacturing industries. This comprises three main constructs i.e. agile drivers; manufacturing tasks and manufacturing choices	This framework was validated empirically but real-time implementation was not described.

Chen and Lyu (2009)	Developed an implementation DMAIC framework based on a survey and visit to the touch panel organization. In this framework, different lean tools are embedded in each phase of DMAIC	This framework was validated by a case study but it does not describe the role of stakeholders in the implementation process.
Pepper and Spedding (2010)	Developed a conceptual model of LSS in which the lean approach is used for identification of the current state and identify the area of improvement while six sigma is applied to improve those identified areas.	However, this framework neither discusses DMAIC nor the lean tools, which are usually embedded in each phase of DMAIC.
Gnanaraj *et al*. (2010)	Developed a DODMAICS (Deficiency Overcoming Lean Anchorage Define Measure Analyse Improve Control Stabilise (DOLADMAICS) implementation framework for LSS implementation in SMEs.	Although DODMAICS comprises most of the tools' the role of stakeholders and VSM tools are not included in it.
Shahin and Jaberi (2011)	Proposed a conceptual framework of Leagile production using mass customization, modularization, and postponement and applied this concept in the DMAIC approach of Six Sigma in auto part manufacturing	Although authors have integrated Lean agile and the Six Sigma approach under one umbrella, tools such as VSM, kaizen, virtual enterprises, and control charts were missing.
Vinodh *et al.* (2011)	Developed a five-step LSS implementation framework and lean tools imbedded in the DMAIC approach to improve the First time yield (FTY) of the valve assembly line	This framework depicts the step-by-step implementation process of DMAIC and their respective tools usage in each phase but the pre-implementation prerequisite and post-implementation phases were not discussed.
Psychogios *et al*. (2012)	Developed an integrated conceptual framework of LSS based on a multifactor approach	Although this framework comprises the main facilitators of LSS implementation in the service industry real-time implementation and LSS tools needed for implementation were not discussed
Dibia and Onuh (2012)	Developed a Lean leadership, people, process and outcome (LPPO) model for LSS deployment in an agile environment	Although the authors used tools from the LSS tool kit but agile environment tools were not discussed
Prasanna and Vinodh (2013)	Developed a conceptual framework of LSS in which lean five principles (value, value stream, flow, pull, and pursuit of perfection) were integrated with Six Sigma's Define, Measure, Analysis, Improve, Control, and sustain the cycle.	This framework comprises almost all of the toolset of LSS implementation but the role of stakeholders was not discussed.

Elmoselhy (2013)	Proposed an implementation framework for hybrid lean-agile manufacturing systems. This hybrid lean-agile manufacturing system (HLAMS) comprises four technical facets i.e. 1. Flexible-focused factory 2. Globalized fractal E-manufacturing 3. Innovative value chain 4	The framework was automotive sector-oriented and not generic
Lemieux *et al*. (2013)	Proposed a performance and Adoption Alignment framework to guide leanness and agility initiatives in product development.	The feasibility of this framework was tested through a case study but the framework does not describe the predefined activities and does not include the role of change management, which is a vital element of any improvement initiative.
Tenera *et al*. (2014)	Developed a five-stage DMAIC framework for LSS deployment for project management improvement in the service industry	This framework was validated by a case study in the telecommunication industry but the framework was not discussed as the pre-requisite for LSS deployment.
Timans *et al*. (2014)	Proposed a 3-phase implementation framework of LSS in SMEs.	It discussed the vital enablers needed for LSS deployment in SMEs but does not focus on the barriers to LSS deployment. Further, the tools required to deploy LSS were also not explained.
Nunes *et al*. (2015)	Proposed an integrated ergonomic-based LSS framework	The feasibility of proposed framework was not tested.
Dubey and Gunasekaran (2015)	Proposed a conceptual framework of AM having six constructs, these are technologies, empowerment of workforce, customer focus, supplier relationship management, flexible manufacturing systems and organizational culture	This framework does not include the role of top management commitment, HR policies, virtual alliances and motivation, which are the vital elements for AM. Although the framework was validated empirically the impact of this framework on performance outcomes was also not analyzed.
Tsironis and Psychogios (2016)	Proposed a multi-factor conceptual framework for the service industry.	The framework was based on the qualitative data obtained from top management people of three case companies but the front line employee which were directly involved in the LSS application were not approached. Secondly, this framework is service-centric and conceptual.
Chaurasia *et al.* (2016)	Developed an implementation integrated LSS framework to improve the business improvement performance of oil-exporting countries during the recession	This framework was developed based on oil industry experts' opinions but it does not consider the uncertainty of business strategies associated with the oil extracting process.
Leite *et al*.(2016)	Proposed IPID (identity, prioritize, implement, disseminate) cycle-based framework for implementing lean and agile techniques in product development and proposed an IPID cycle - a road map for implementing lean and agile techniques in	This framework is implemented in SMEs for the product development process but the details of lean and agile tools used in the implementation process were not discussed.

	product development.	
Garza-Reyes *et al.* (2016)	Developed an implementation DMAIC-based LSS framework to reduce the ship loading time in the iron ore palletizing. The framework consists of six elements.	Although this framework was implemented in real-time it does not discuss the pre-implementation phase for LSS implementation.
Eltawy and Gallear (2017)	Theoretical represented the lean and agile system based on input, operational process and output	The feasibility of the framework in real time was not tested.
Potdar *et al.* (2017b)	Developed an implementation-benchmarking framework of AM for enhancing agility. It consists of a total of 9 phases and 36 steps in those nine phases	This framework was conceptual; real-time feasibility needs to be checked.
Guerrero *et al.* (2017)	Developed an implementation LSS framework for furniture manufacturing SMEs. It consists of five phases and 12 tools in total	Although the framework is validated by the case study but the pre-implementation phase and post-implementation phase was not discussed.
Sunder and Antony (2018)	Proposed a conceptual framework of LSS for quality excellence in the higher education industry.	This framework is not generic as it is customized for higher education industries and further the feasibility of the framework was also not tested on a real-time basis.
Sreedharan and Sunder (2018a)	Developed an SDMMAICS (Selection, Define, Measure, Map, Analyse, Improve, Control and Sustain LSS implementation framework.	The proposed framework was conceptualized and validated through manufacturing industries only
Hill et al. (2018)	Developed a generic framework of LSS, which comprises lean and six sigma cycles. In each lean cycle phase, the DMAIC approach is implemented	The proposed framework did not use any tool to identify the VOC.
Venugopal and Saleeshya (2019)	Developed a conceptual framework to integrate lean and agile strategies to achieve the five aspects of sustainability	Although this framework was validated by data collection in Ayurveda hospital, the real-time implementation was not presented.
Balakrishnan *et al.* (2019)	Developed an implemented model for implementing the Leagile manufacturing paradigm in pump manufacturing.	Although this framework was validated by a hypothetical case study but the common toolkit for leagile implementation was not discussed.

Nascimento *et al.*(2019)	Proposed an implementation framework based on lean principles, six sigma's DMAIC, and Deming's PDCA for the oil industry.	The framework does not give a list of toolsets, which need to be used for LSS implementation. Further, this framework is oil industry-centric and was validated based on oil industry experts' experience.
Kumar *et al.* (2019a)	Proposed a conceptual framework of AM, which have seven pillars	The main limitation of this framework is it's a conceptual framework and does not provide a comprehensive tool required for AM implementation
Patel *et al*., (2019)	Proposed a roadmap for LSS implementation in the manufacturing industry.	Although this framework comprises almost all the tools for LSS implementation, measurement system analysis (MSA) was not included and real-time application of the framework was missing.
Sodhi *et al*., (2020)	Developed and implemented a Lean Six Sigma project management framework for SMEs.	Although, the framework integrates the DMAIC approach with lean tools the framework does not include project charter, MSA, or VOC in LSS deployment.
Vallejo *et al*., (2020)	Proposed a road map of the LSS implementation framework for SMEs. This framework is a highly efficient one-of-a-kind product development process transformation according to the principles of agility.	Although this framework describes the CSFs for each stage but does not provide the toolset for LSS implementation. Further, this framework was based on the questionnaire survey, hence the applicability of this framework needs to be tested in real-time.
Borsci *et al*., (2020)	Proposed a Lean and Agile Multi-dimensional Process (LAMP) for new product development in healthcare devices and technology	This framework is health sector centric and not generic.
Trakulsunti *et al.* (2020)	Developed a road map for LSS practitioners in healthcare to reduce medical errors. This framework comprises three phases i.e. culture readiness; preparation, initialization and implementation, and sustainability	LSS experts and healthcare validated the developed framework through a survey but the real-time implementation was not described.

4.3 TAXONOMIES FOR THE EXISTING FRAMEWORKS

A total of 41 frameworks were identified in the previous section. From the literature review, it was revealed that some frameworks focus on assisting managers in the implementation process of LSS and AM while some pay attention to helping managers to understand what LSS and AM comprise. Over a period of time, researchers use both model and implementation framework terms. Yusuf and Aspinwall (2000) distinguished these two terms when reviewing TQM frameworks. They described "a model answers the questions of what TQM is and explains the overall concepts or elements it comprises, while the implementation framework answers "how to kind of questions and gives guidelines to the way forward. In this paper taxonomies for the existing frameworks are adopted from Anand and Kodali (2010). Table 4.2 represents the classification of LSS, AM, and Leagile frameworks.

Table 4.2: Classification of LSS/AM/Leagile/LSS-AM frameworks

Taxonomies of frameworks						
S.NO	**Authors and year**	**Approach**	**Type C/I**	**Source**	**Verification**	**Mode**
1	Gunasekaran *et al.* (2002)	AM	C	O	Y	Case study
2	Jin-Hai *et al*. (2003)	AM	C	A	N	N
3	Kumar *et al.* (2006)	LSS	I	O	Y	Case study
4	Ismail *et al*., (2006)	AM	I	A	Y	Case study
5	Vázquez-Bustelo *et al*.(2006)	AM	C	O	N	N

6	Ramesh and Devadasan (2007)	AM	I	A	N	N
7	Krishnamurthy and Yauch (2007)	Leagile	C	A	Y	Case study
8	Zhang and Sharif (2007)	AM	C+I	A	Y	Survey
9	Chen and Lyu (2009)	LSS	I	O	Y	Interview
10	Pepper and Spedding (2010)	LSS	C	A	N	N
11	Gnanaraj *et al*., (2010)	LSS	I	A	Y	Case study
12	Shahin and Jaberi (2011)	LSS-AM	I	A	Y	Case study
13	Vinodh *et al*.(2011)	LSS	I	A	Y	Case study
14	Psychogios *et al.* (2012)	LSS	C	IE	N	N
15	Dibia and Onuh (2012)	LSS-AM	I	A	Y	Case study
16	Prasanna and Vinodh (2013)	LSS	C	A	Y	Case study
17	Elmoselhy (2013)	Leagile	I	A	Y	Case study
18	Lemieux *et al*. (2013)	Leagile	C	A	Y	Case study
19	Tenera *et al*. (2014)	LSS	I	A	Y	Case study
20	Timans *et al.* (2014)	LSS	I	A	N	N
21	Nunes *et al*.(2015)	LSS	C	A	N	N
22	Dubey and Gunasekaran (2015)	AM	C	A	Y	Survey
23	Tsironis and Psychogios (2016)	LSS	C	A	Y	Interview
24	Chaurasia *et al.* (2016)	LSS	I	A	Y	Interview

25	Leite *et al*. (2016)	Leagile	I	A	Y	Case study
26	Garza-Reyes *et al*.(2016)	LSS	I	A	Y	Case study
27	Eltawy and Gallear (2017)	Leagile	C	A	N	N
28	Potdar *et al*. (2017b)	AM	I	A	N	N
29	Guerrero *et al.* (2017)	LSS	I	A	Y	Case study
30	Sunder and Antony (2018)	LSS	C	A	N	N
31	Sreedharan and Sunder (2018a)	LSS	I	A	Y	Case study
32	Hill et al.(2018)	LSS	I	A	Y	Case study
33	Venugopal and Saleeshya (2019)	Leagile	C	A	Y	Interview
34	Balakrishnan *et al*. (2019)	Leagile	I	A	Y	Case study
35	Nascimento *et al*. (2019)	LSS	I	IE	Y	Semi-structured interview
36	Kumar *et al.* (2019a)	AM	C	A	N	N
37	Patel *et al*. (2019)	LSS	I	A	N	N
38	Sodhi *et al.* (2020)	LSS	I	A	N	N
39	Vallejo *et al*. (2020)	LSS	I	O	N	N
40	Borsci *et al*. (2020)	Leagile	C	IE	Y	Case study
41	Trakulsunti *et al.* (2020)	LSS	I	A	Y	Survey

Where: C- Conceptual, I: Implementation, AM-Agile Manufacturing, LSS-Lean Six Sigma, A-Academician, O-

organization, IE-industry expert

4.3.1 Categorization Scheme of Frameworks based on the Type

Anand and Kodali (2010) categorized frameworks into two categories i.e "design or conceptual" frameworks and "implementation" frameworks. Taking this cue from them, we also categorized identified frameworks in the same manner. Design/conceptual frameworks are defined as frameworks, which described the type of elements/tools/principles LSS/AM /Leagile comprises, or in other words, they discuss the content of LSS/AM or Leagile. On the contrary Implementation, frameworks discuss the roadmap for LSS/AM or Leagile implementation or in other words what is the sequence of activities to be taken up. From table 4.2, it is analyzed that 16 authors developed conceptual frameworks while 24 frameworks were implementation type. Only Zhang and Sharif (2007) developed both conceptual and implementation types of framework.

4.3.2 Categorization Scheme of Frameworks based on the Type of Approach

In this categorization scheme, frameworks are categorized based on the type of approach i.e LSS, AM, Leagile and LSS-AM. From table 4.2 it was revealed that the majority of frameworks are based on the LSS approach (22 out of 41) whereas 9 frameworks were based on AM and 8 Leagile each and merely 2 frameworks integrate LSS and AM approaches together.

4.3.3 Categorization Scheme of Frameworks based on the source of the framework

Table 4.4: LSS-AM element analysis

	LSS-AM Element Set																									
Authors	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Gunasekaran *et al*. (2002)																						*	*	*	*	*
Jin-Hai *et al*. (2003)																							*	*	*	
Kumar *et al*. (2006)	*		*	*			*	*					*	*	*		*	*								
Ismail *et al*. (2006)																							*	*		
Vázquez-Bustelo *et al*.(2006)																						*	*		*	
Ramesh and Devadasan (2007)							*																*			
Krishnamurthy and Yauch (2007)		*	*	*	*																		*			
Zhang and Sharif (2007)																						*	*		*	
Chen and Lyu (2009)		*					*	*		*	*		*	*	*	*	*	*								*

Gnanaraj *et al*. (2010)	*					*	*				*							*			*					
Shahin and Jaberi (2011)		*																*					*			
Vinodh *et al*. (2011)		*				*	*			*							*									
Psychogios *et al*. (2012)																*							*			
Dibia and Onuh (2012)			*	*																						*
Prasanna and Vinodh (2013)	*	*				*	*										*									
Elmoselhy (2013)					*																	*		*	*	*
Lemieux *et al*. (2013)		*				*	*										*									
Tenera *et al*. (2014)	*										*					*										
Timans *et al*. (2014)																										
Nunes *et al*. (2015)																								*		
Dubey and Gunasekaran (2015)																*						*	*	*	*	
Tsironis and Psychogios (2016)																*							*			

Chaurasia *et al*. (2016)		*		*		*	*	*									*		*	*	*					
Leite *et al.* (2016)									*																	
Garza-Reyes *et al*.(2016)	*	*					*				*					*		*								
Eltawy and Gallear (2017)																						*	*		*	
Potdar *et al*. (2017b)																										
Guerrero *et al.* (2017)		*								*				*	*		*									
Sunder and Antony (2018)	*	*					*	*			*			*	*		*	*		*	*					
Sreedharan and Sunder (2018a)	*	*	*			*	*				*				*	*	*									
Hill *et al*.(2018)		*				*	*												*							
Venugopal and Saleeshya (2019)																						*	*	*		
Balakrishnan *et al*. (2019)																										
Nascimento *et al*. (2019)			*						*										*	*						
Kumar *et al*. (2019a)																						*	*			

Patel *et al*. (2019)	*			*		*	*	*		*	*	*					*	*			*			*		
Sodhi *et al*. (2020)	*	*	*			*	*						*													
Vallejo *et al*. (2020)																*										
Borsci *et al*. (2020)																						*			*	
Trakulsunti *et al*. (2020)	*											*														

Where A-Project charter; B Value stream mapping (VSM); C-5S; D-Poka-yoke; E-Single Minute Exchange of Die (SMED); F-Pareto chart; G-5 why(W)/Cause & effect (C&E) diagram; H-Failure mode effect analysis(FMEA);I-:Gemba; J: Design of Experiment (DOE);K: Supplier input output customer (SIPOC)/Process flow; L: Brainstorming;M: Total productive maintenance(TPM);N-Statistical method: Hypothesis testing (t-test/f-test/ANOVA); Regression analysis; O-Measurement system analysis (MSA);P: QFD/Big Y drill/Kano; Q- Control charts; R- Process baselining (Process capability/first-time yield (FTY)/DPU(Defects per unit);S-Kaizen; T-Visual Management; U-Check sheet/Histogram/Affinity; V-automation and technology (AGV/Rapid prototyping);W-IT for communication; X-Software's and simulation(CAD/CAM/CAE/ERP/MRP);Y-Virtual Enterprises; Z-JIT/KANBAN/PULL

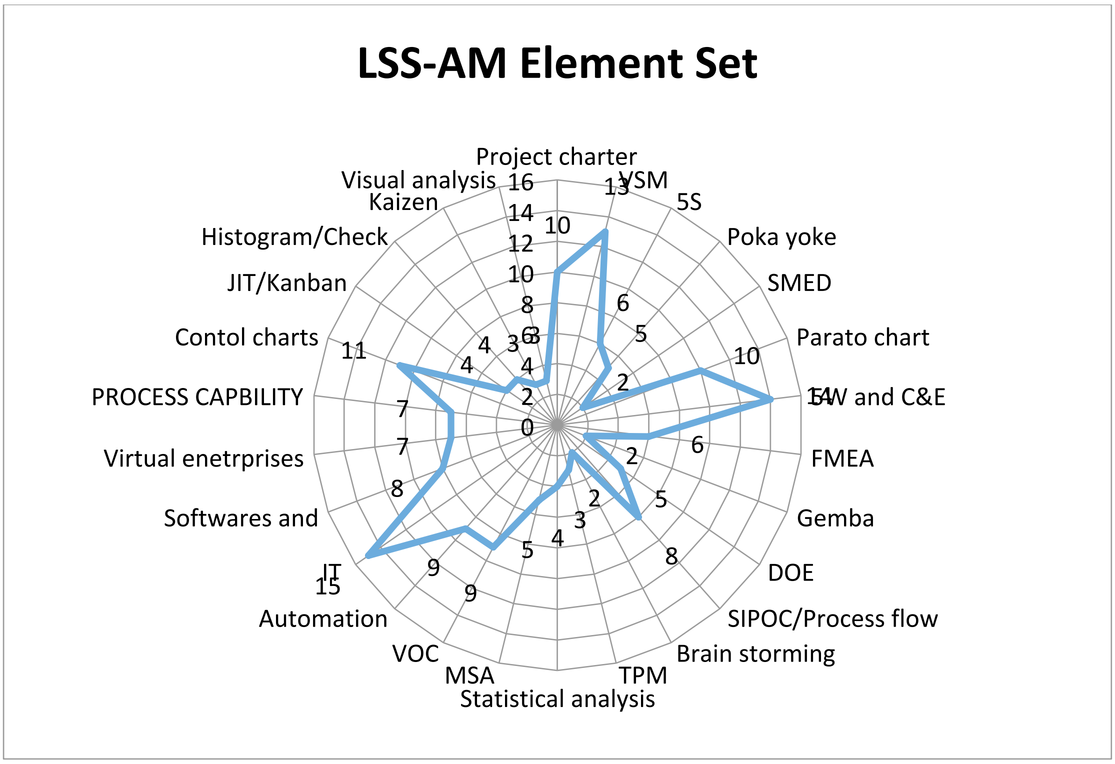

Figure 4.1: LSS-AM Element Set

4.6 DEVELOPMENT OF AN INTEGRATED LSS-AM IMPLEMENTATION FRAMEWORK

The proposed implementation framework encompasses three phases viz., pre-implementation, implementation and post-implementation. These are discussed below:

4.6.1 Pre-Implementation Phase

This phase is the initiation phase of the LSS-AM implementation journey in any organization. This phase creates the basic awareness of lean; six sigma and agile manufacturing concepts among the top management and employees of all levels in

4.6.1 Pre-Implementation Phase

This phase is the initiation phase of the LSS-AM implementation journey in any organization. This phase creates the basic awareness of lean; six sigma and agile manufacturing concepts among the top management and employees of all levels in any organization. This phase is also the commitment creation phase towards the LSS-AM in an organization, which develops the foundation for LSS-AM implementation. Further, this phase eliminates the doubts around LSS-AM implementation and benefits among the employees and management. This phase comprises three levels i.e. understanding the basic concepts of lean, six sigma and AM; the second phase is a pre-requisite for LSS -AM and the third phase is LSS-AM preparation.

4.6.1.1 Knowledge Creation of Lean, Six Sigma and AM basic Concepts

This phase creates a foundation of lean six sigma and agile manufacturing basics i.e. what is lean philosophy; what are the types of wastes and their identification and effect on organization performance; what is six sigma methodology and its benefits; what is agile manufacturing and its benefits and explain the individual's shortcomings and benefits of LSS-AM integration and explain the role of stakeholders in value creation etc. among the top management and employees.

4.6.1.2 Prerequisite

The success of LSS-AM implementation depends on some solid foundation of pre-requisites that include drivers for LSS-AM; certain CSFs top management commitment; supportive organization culture, financial resources; organization infrastructure; communication & collaboration with stakeholders and information technology whereas mitigation of certain failure factors such as resistance to change organization culture and lack of employee involvement are vitals. These CSFs and CFFs were already discussed in chapter 3. Further crucial drivers for LSS-AM implementation are identified from reviewed frameworks and discussed in table 4.5

Table 4.5: Drivers from LSS-AM implementation

S. No.	Drivers	Definition	References
1	Market turbulence	Due to the Covid-19 situation, war conditions and Government policies, industries are facing high turbulence in terms of customer demand, cost, and labor & raw material availability etc. To sustain this turbulence, industries are looking forward to a way to become efficient, effective and responsive concurrently.	Gunasekaran *et al.* (2002); Zhang and Sharifi (2007); Vázquez-Bustelo *et al.* (2006); Shahin and Jaberi (2011); Elmoselhy (2013);Lemieux *et al.* (2013) ; Dubey and Gunasekaran (2015) ; Eltawy and Gallear (2017); Venugopal and Saleeshya (2019); Kumar *et al.* (2019a)
2	Dynamic customers' demands	Customers' expectations are changing rapidly in terms of product design, quality and price hence industries should be responsive enough to full fill such changing customer demands.	Gunasekaran *et al.* (2002) ;Vázquez-Bustelo *et al.*(2006); Ramesh and Devadasan (2007) Pepper and Spedding (2010); Shahin and Jaberi (2011) ; Elmoselhy (2013);Lemieux *et al.* (2013); Dubey and Gunasekaran (2015) ; Leite *et al.* (2016); Balakrishnan *et al.* (2019) ; Kumar *et al.* (2019a); Piotrowicz *et al.* (2021)

3	Shrinking profitability –to-cost ratio	Due to the current market scenario, the cost of raw materials and labor costs has increased significantly. In addition to this, industries are compelling to give competitive prices of the product to sustain in the market which results in a shrinking profitability-to-cost ratio.	Gunasekaran *et al*. (2002); Kumar *et al*. (2006); Zhang and Sharifi (2007); Ramesh and Devadasan (2007); Shahin and Jaberi (2011); Dibia and Onuh (2012); Tenera *et al*. (2014); Chaurasia *et al*. (2016); Guerrero *et al*. (2017); Sreedharan and Sunder (2018a); Nascimento *et al*. (2019); Kumar *et al*. (2019a); Patel *et al*. (2019); Sodhi *et al*. (2020);Vallejo *et al*. (2020) ; Piotrowicz *et al*. (2021)
4	Technology advancement	Industries are required to advance their technologies in line with their competitors to compete in the market and match customers' expectations.	Jin-Hai *et al*., (2003) ;Zhang and Sharifi (2007); Vázquez-Bustelo *et al*.(2006); Elmoselhy (2013);Kumar *et al*. (2019a)
5	High-quality expectations	Customers are demanding superior quality products at low cost.	Zhang and Sharifi (2007); Kumar *et al*. (2006); Vázquez-Bustelo *et al*. (2006); Chen and Lyu (2009); Pepper and Spedding (2010); Shahin and Jaberi (2011); Vinodh *et al*. (2011); Dibia and Onuh (2012); Elmoselhy (2013); Tenera *et al*.(2014); Chaurasia *et al*. (2016); Guerrero *et al*. (2017); Sunder and Antony (2018); Sreedharan and Sunder (2018a); Nascimento *et al*. (2019); Patel *et al*. (2019); Sodhi *et al*. (2020); Vallejo *et al*. (2020); Trakulsunti *et al*. (2020) ; Piotrowicz *et al*.(2021)

6	Shorter lead time	Customers are demanding products at the earliest. Further, a shorter lead time gives a competitive edge in the market.	Zhang and Sharifi (2007); *Kumar et al.*(2006);Chen and Lyu (2009); Shahin and Jaberi (2011);Vinodh *et al*. (2011); Elmoselhy (2013); Leite *et al*. (2016)
7	Product mix and availability of products	Customers are demanding a variety of products to select the desired product with a shorter lead time.	Vázquez-Bustelo *et al*.(2006); Shahin and Jaberi (2011); Elmoselhy (2013); Dubey and Gunasekaran (2015) ; Leite *et al*., (2016); Eltawy and Gallear (2017); Balakrishnan *et al.* (2019) ; Piotrowicz *et al*. (2021)
8	Shorter time to market and new product development time	To compete and capture the market share, industries are under pressure to reduce their time to market and new product development time.	Gunasekaran *et al*. (2002) ;Zhang and Sharifi (2007);Ramesh and Devadasan (2007) ; Dibia and Onuh (2012); Elmoselhy (2013); Lemieux *et al*. (2013) ; Dubey and Gunasekaran (2015) ;Leite *et al*. (2016); Venugopal and Saleeshya (2019);Kumar *et al*., (2019a); Borsci *et al.* (2020)
9	Customization at optimum cost	Customers are also demanding customized products. Industries are required to be more responsive to cater to customization product demand to the customer at optimum cost	Gunasekaran *et al.* (2002) ; Jin-Hai *et al.* (2003); Vázquez-Bustelo *et al.*,(2006); Shahin and Jaberi (2011); Dibia and Onuh (2012); Elmoselhy (2013); Leite *et al*., (2016); Eltawy and Gallear (2017); Venugopal and Saleeshya (2019); Balakrishnan *et al.* (2019) ;Kumar *et al.* (2019a)

4.6.1.3 Preparation

This phase comprises training and education regarding change management; training of LSS and automation. Change management plays a significant role in the transition journey of an organization in the LSS-AM process improvement initiative because these initiatives need a change in organization structure, process, and people behavior. It is necessary to manage these changes effectively to endure the benefits of the LSS-AM initiative. Training in change management helps to mitigate the organization's resistance to change behaviors and makes the transition journey a smooth ride. Training and education of lean tools; agile tools; basics of statistics. Yellow/green/black belt training of LSS develops a strong foundation of these concepts and helps in the selection of the right project, and collection of good quality data, which are very crucial for LSS-AM implementation. Further training and education help to develop a multi-skill workforce that can perform multiple tasks and develop an environment of CI and anticipate the rapidly changing market demand quickly. Further, the training and education help the effective and efficient allocation of resources in the LSS-AM implementation journey

4.6.2 The Implementation Phase

The implementation phase is based on five phases DMAIC approach, which is define; measure; analyze; improve and control. Each phase is embedded with several tools of lean; six sigma and agile. Each phase is discussed below:

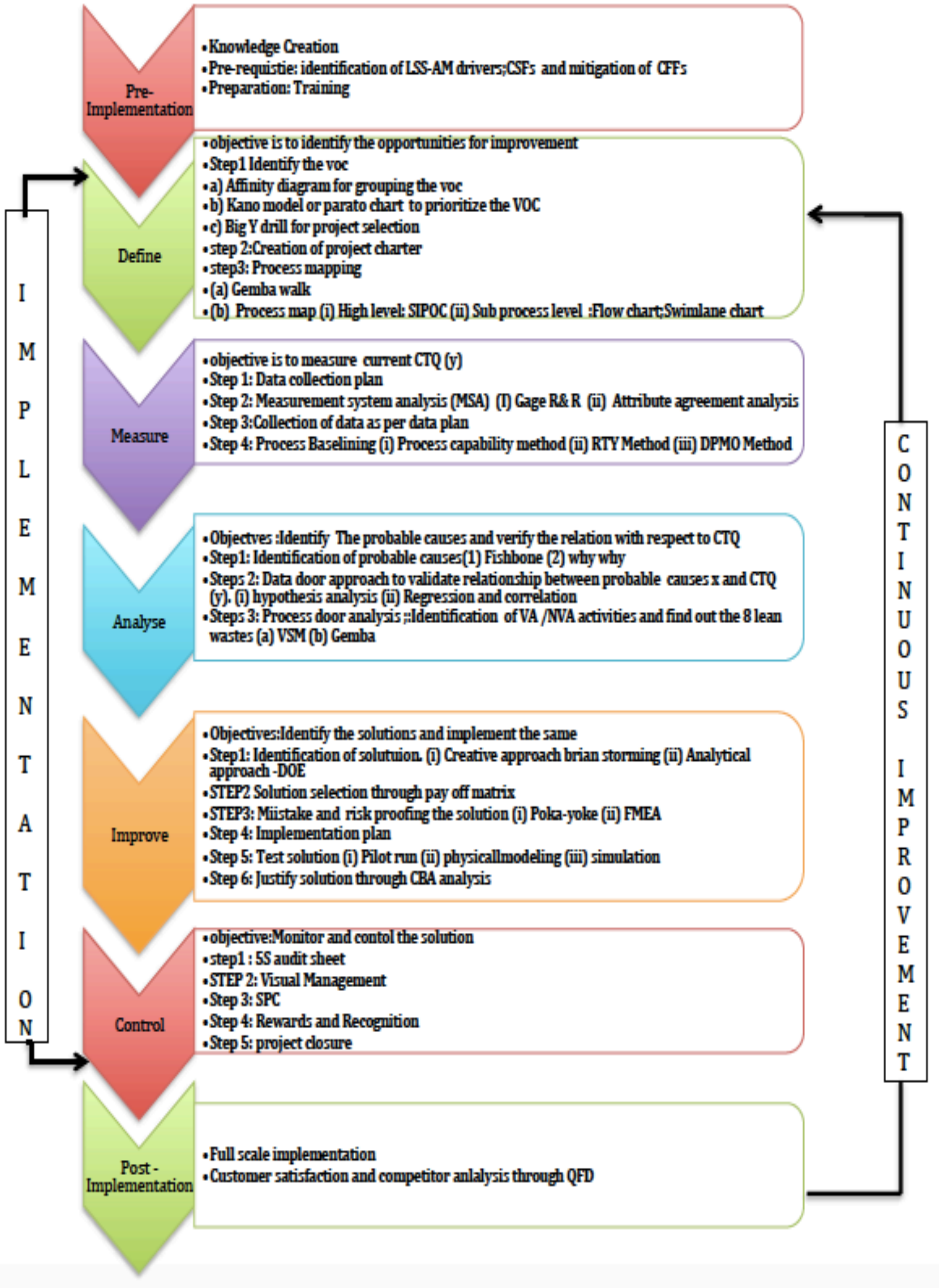

Figure 4.2: Proposed Implementation framework of LSS-AM

4.6.2.1 Define Phase

The objective of the define phase is to identify the opportunities for improvement and to define the problem. The following steps are to be followed:

Step 1: To identify opportunities for improvement

- Voice of Customer (VOC)

To identify opportunities for improvement voice of customers (VOC) need to be identified. VOC describes the stated and unstated needs of customers. For any organization customers are internal (Management /employees) and External (end users of the product). The VOC can be identified by surveys, feedback; complaints and focused group discussion. Further to analyse these several VOCs, first they are categorized and then prioritized. To categorise and prioritized the VOC; the affinity diagram and Pareto chart can be used.

- ➢ Affinity diagram

  The VOC collected from customers is countless and vague. To sort the VOC affinity diagram can be used. For, this each VOC is noted on a post in bold letters. A team of the focused group sort these VOCs into 5 to 10 related grouping simultaneously without talking to each other. Based on the consensus of the focused group each grouping creates header cards. The final affinity diagram is drawn by connecting all finalized header cards with their respective grouping. Hence the vagueness and repetition of VOCs are eliminated and VOCs are reduced into a few groups.

- ➢ Pareto Chart

  It is not possible to pay attention to all the VOCs at the same time.

Hence Pareto chart is used to prioritize the VOCs. This analysis is also known as 80/20 or vital few trivial many analyses. The Pareto chart graphically represents 80 per cent of problem that occurs and 20 percent of causes hence improvement team can prioritize quality problem and focus on those causes where the largest gains can be obtained. This chart supports the identification of VOCs which have the highest contribution to customer dissatisfaction. This prioritization helps to identify critical to quality (CTQ) parameters.

- Selection of the project

The whole DMAIC approach work around the following equation

$$y= f(x)$$

Where y represents the project goal, also known as CTQ or KPOV (key performance output variable), which needs to be improved and where x represents independent parameters which influence y and are also known as causes of problem or key process input variable (KPIV).

Selection of the right project is a very crucial step in any CI approach. If the selected project goal CTQ is not aligned with the business or customer needs (BIG Y) then the management will conclude that this project is waste of time and resources only and it is not contributing to any business process improvement (Ray and Das,2010). Hence for this Big Y drill analysis can be used which aligns the project output CTQ with customer needs (Big Y)

Step 2: Creation of project charter

To start the journey of deployment, the LSS-AM team should have a project charter. This project charter describes the business case; problem statement; goal statement; project scope and milestones. The business case describes the worthiness of the project; the problem statement describes what is wrong; the goal statement describes the objectives of the improvement whereas the project scope defines the boundaries of the process in which we are going to improve and milestones describe the detailed project plan with main steps and their target completion dates.

Step 3: Process Mapping

The objective of process mapping is to have an end-to-end understanding of the process. For process mapping, a two-fold approach is used.

- Two-Fold Approach

➢ Gemba Walk – Gemba is a Japanese term, which means the real place. To understand any process end to end it is necessary to go and see what is going on the shop floor and collect information about the process.

➢ Creation of Process Map

  Based on the information collected about the process, is used to develop a process map. The Process maps are classified into two levels:

  ❖ High-Level Process Mapping – This type of process mapping is done on a macro level. It does not describe the micro details of the process. SIPOC (Supplier Input Process Output Customer) is this type of process mapping

- ❖ Activity (Sub Process) level process Mapping – This describes the process at the micro level. Flowcharts; swim lane charts and value stream mapping (VSM) fall under this category.

4.6.2.2 Measure Phase

The objective of the measure phase is to baseline the current performance of the process. The baselining means to identify the current Six Sigma level and process capability of the process. To baseline the process following steps are carried out.

Step 1: Data collection plan

The data collection plan is the roadmap for data collection. The success of any project depends upon the quality of the data. Hence data plan helps to ensure that useful and accurate data has been collected to answer the process questions.

Step 2: Measurement System Analysis (MSA)

The Measurement system that collects the data for CTQs must be validated as all measurement systems have some percent of the variation. A validated measurement system gives unbiased results and represents the true value of the intended factors to be measured. Based on the nature of the data, there are two methods of MSA.

- Gage R&R: If the data, which needs to be measured, is continuous then the gauge R& R method is used.
- Attribute agreement analysis (AAA):
  If the data, which needs to be measured, is continuous then the gauge AAA method is used.

Step 3: Collection of data as per the data collection plan

After validation of the measurement system, data is collected as per the data collection plan.

Step 4: Process baselining

In this step, the current performance of the process is identified by analysis of the current process capability of the process. The process capability of any process is defined as how well a stable process can meet its customer requirement. To measure the capability of the process Six Sigma level is calculated. Six Sigma is a metric, which indicates how well the process is performing. Based on the type of data, the following methods can be adopted to determine the process capability.

- Process capability index (C_p and C_{pk}) Method: If the data is continuous or variable type this method is adopted. C_p (process capability index) indicates the potential of the process when the process means is perfectly centred otherwise Cpk (actual process capability index) is used when the mean is not at the centre. Based on the C_{pk}, the sigma level is calculated.
- Defects per million opportunity method (DPMO): When the data is discrete or attribute type, process capability is calculated by DPMO. Based on the value of DPMO, the sigma level is calculated
- Rolled throughput yield (RTY)

  It is another metric of Six Sigma for attribute data, which indicates the probability of getting the unit right at the first time. It helps to detect opportunities for improvement.

4.6.2.3 Analyze Phase

The objective of this phase is to identify the probable causes (xs) that influence the CTQ (y) and validate the probable causes. For this following steps are used:

Step 1: Identification of Probable causes

First, identify the probable causes that influence the CTQs by root cause analysis. The following tools can be used to identify the probable causes:

- Cause and Effect diagram: It is also known as the fishbone or Ishikawa diagram. It is a visual tool that helps the improvement team to brainstorm and organize the probable causes (xs) for a specific effect (y) in a logical manner. Further, sort them based on non-controllable and controllable causes.
- 5 Why analysis: 5-why analysis is used to drill down the root causes by asking 5 times why.

Step 2: Data Door Approach

The objective of this step is to validate the relationship between probable causes (x) and the CTQ (y). To identify the identified probable causes, that affect the y statistical method i.e. hypothesis testing; correlation analysis and regression analysis can be used.

Step 3: Process Door Approach

To analyse the process current value stream mapping (CVSM) is drawn. VSM separates the non-value added activity and value-added activities. Further from VSM, the process improvement team can identify the 8 types of lean wastes i.e. defects; overproduction; inventory; over-processing; transportation; motion; waiting and not the utilization of talent that need to be eliminated.

4.6.2.4 Improve Phase

The objective of the improve phase is to identify the solutions and implement the same. Steps involved in this steps are as follows:

Step 1: Identification of solutions

To identify the solutions for the causes (xs) identified in the analyze phase two types of approaches can be applied, are:

- Creative Approach

  In the creative approach solutions' ideas are generated and evaluated through a brainstorming session.

- Analytical approach

  In analytical approach solutions, ideas are generated and evaluated by the design of experiment (DOE). The DOE aims to identify which input variables (xs) have the highest influence on output (y) and further help to set the value of influential xs that y can be optimized. DOE is used for product or process excellence at the lowest costs.

Step 2: Solution Selection

The objective of this phase is to select the solution from the possible solutions identified in the previous step. The Pay-off matrix can be used to select the solution. It is a matrix between benefit and effort. In this, all possible generated solutions are categorized into four quadrants. The solutions which fall under low on benefits are outrageously rejected then the focus shifts to the high effort/high benefits solutions and are rationalized for implementation.

Step 3: Mistake proofing of solutions and Risk- proofing of solutions

Creating a process or a product such that, while using the same you cannot do a mistake intentionally also. For this, the poka-yoke concept is used. Poka-yoke is a Japanese word which means error-proofing and a poka-yoke device is a small low-cost mechanism that either prevents a mistake from happening or makes the mistake visible at a glance.

Failure mode effect analysis (FMEA) is used to risk-proof the solution. It identifies the various modes of failure and causes of defects in a process. It prevents the occurrence of failure or letting go of internal and external customers. It is used when the effect of failure is potentially severe.

Step 4. Implementation plan

Develop a good implementation plan, which incorporates allocating responsibilities and time frames.

Step 5: Test the solutions

The objective of this step is to confirm the potential solutions. It can be done through a pilot study, physical modeling and simulation

- Testing essential

To test the solution create a data plan; collect the data and verify the process has improved by process capability analysis.

Step 6: Justify the solutions

Justify the solutions by identifying the tangible and intangible benefits. Further, perform the cost-benefit analysis (CBA) and justify the benefits of the project in front of the management

4.6.2.5 Control Phase

The objective of the control is to sustain the gains obtained from the DMAIC project by controlling and monitoring the process so that all the efforts made by the project team does not in vain. The steps involved in the control phase are

Step 1: 5S Audit sheet

The 5S audit sheet helps to ensure that the five steps of five S i.e. sort, set in order, shine, standardize and sustain are practiced effectively.

Step 2: Visual Management

Visual management helps to create a self-explaining workplace. It also helps to differentiate the abnormal situation in the workplace. Displaying the standard operating procedure (SOPs); practicing 5S etc. are the practices for visual management.

Step 2: Statistical process control (SPC)

Statistical process control is used to identify the variation due to special and common causes. For SPC control charts are used. Control charts monitor the variation of X's and detect changes caused by special causes. Further helps to analyze the process will go out of control in near future hence corrective measures can take place earlier. There are different control charts which can be drawn based on the type of data that needs to be measured

Step 3: Reward and recognition

To take the leverage of the DMAIC project for long-term effective involvement of employees is required. To empower those, a rewards and recognition system is used. It helps to motivate them and create a continuous improvement environment in the organization. If the efforts of employees do not get rewarded and acknowledged there are very high chances that they will again shift to their old practices.

Step 4: Project closure

The Last step of the control phase is project closure. It consists of documentation of the results of the project in terms of three dimensions of business measures i.e. lean's efficiency; Six Sigma's effectiveness and agile's responsiveness to attain the profitable growth of the organization as shown in the table 4.6. Further, the result is communicated to the management to get a sponsor sign-off on the project charter.

Table: 4.6 List of KPI for LSS-AM business performance

Approach	Business performance related to	Key performance indicators (KPIs)
Lean		Manufacturing Cost
		Rework and scrap
		Transportation and Movement
	Efficiency	Work in process (WIP)
		Process cycle efficiency (PCE)
		Space creation
		Set up time
		Cycle time
		Waiting time
		Lead time
		Takt Time
		OEE
	Moral	No of Kaizen /Quality Circle
	Safety	Near Miss/ No of Safety Incidents
Six Sigma		Process capability
		DPU/DPMO
	Effectiveness	Six Sigma level
		RTY/FTY
		Lead time
AM	Responsiveness	New product development time

		Change over time
		Service level
		Waiting time
	Flexibility	Number of cross-trained people
		Number of product families/ Variety
		Number of operations the machine can do,
		number of tools machine can hold

4.6.3 Post-Implementation Phase

The post-implementation phase completes the LSS-AM implementation process. After implementing the implementation plan on the full scale the organization must be patient to see the positive outcomes from full-scale implementation. This phase encompasses observing the results and analyzing the entire process.

4.6.3.1 Customer Satisfaction and Competitor Analysis

The ultimate aim of any organization is customer satisfaction. A central complaint registration system to record the various complaints from customers is needed. Further, do a competitor analysis to find the organization's relative position in the market and identify the opportunity for improvement. This information collected from the market is vital for the success of the organization. Regular customer feedback surveys can track the customer's opinion about the quality of the product. Further, a customer information data system should be developed to save the database of existing and future customers, which helps in identifying customer preferences, collecting and storing their feedback, complaints and customer satisfaction survey and service reports.

4.6.3.2 Continuous Improvement (CI)

Continuous improvement is a never-ending journey for perfection that involves gradually developing skills and capabilities in an organization to identify new areas of improvement and resolve problems through different tools. In other words, CI is a loop for perfection in which problem identification and solution go cyclically so, there is always an opportunity for improvement; the pursuit of perfection is the spirit of the LSS-AM team. But the proposed framework is theoretical, hence needs to be verified to affirm its applicability.

4.7 CONCLUSIONS AND LIMITATIONS

This chapter provides a comprehensive literature review of 42 frameworks of LSS, AM, Leagile and LSS-AM are based on several taxonomies such as type; approach; source; verification and mode of verification. Further, the reviewed frameworks were compared based on abstractness; utilization of frameworks; comprehensiveness and degree of fit basis. A review of frameworks revealed that several researchers, consultants, academicians and practitioners have developed frameworks about LSS, AM and Leagile individually over a period of time but only 2 frameworks have integrated the LSS-AM approach among the 41 frameworks which is significantly very less in number. A review of the existing articles revealed that existing frameworks are flooded with lots of shortcomings. Further comprehensive lists, which comprise the principles, practices, tools and techniques or constructs of LSS-AM collectively are not found at the same time a well-structured conceptual, as well as implementation framework of LSS-AM, is also not present. Given this, a comprehensive list of LSS-AM practices, tools, principles, practices, tools and techniques or constructs were prepared. Further considering the strengths and mitigating the weaknesses of the existing frameworks an integrated LSS-AM implementation framework has been developed. The main characteristics of these frameworks are discussed below.

The proposed implementation framework encompasses three phases viz., pre-implementation, implementation and post-implementation. The main characteristics of this integrated framework are:

- The framework accentuates the significance of lean; six sigma and agile in their integration approaches.
- How and the extent to which integrated LSS-AM will benefits need to be comprehended by both management and employees.
- The organization should identify the LSS-AM's pre-requisite such as drivers; CSFs and CFFs to leverage the drivers and CSFs and mitigate the CFFs before initiating the implementation.
- To make the transition journey smooth organization should conduct change management training and LSS and automation training for their employees.
- Both internal and external stakeholders should be involved through training and education for LSS-AM implantation. A further multi-skilled workforce should be developed through training and education.
- The core of the Implementation phase of the LSS-AM framework is the DMAIC approach.
- In the define phase of DMAIC, the LSS-AM implementation team must convert the VOC into CTQs and prioritize those CTQs for project selection. Then developed a clear problem statement.
- In the measure phase, to baseline, the process LSS-AM team should go and see the workplace and develop a high-level SIPOC to understand the process from supplier to customer. Then develop a micro-level process flow diagram

and collect the data. Further, calculate the current process capability of the process.

- Analyse phase, the LSS-AM team should identify the probable causes behind the problem with various tools and establish the relationship between the actual causes and CTQs.
- Improve phase, the LSS-AM team should generate improvement suggestions to eliminate the causes identified in analyse phase using different methods and tools and implement the same in a pilot run and the process has improved by process capability analysis. The further team should justify the improvement through cost-benefit analyses and performance measure matrix.
- Control phase, the LSS-AM team should sustain the gains obtained from the DMAIC project by controlling and monitoring the process so that all the efforts made by the project team do not go in vain.
- In the end, project closure should be done and documented the result, which consists of documentation of the results of the project and communicating the same to the management.
- To encourage and empower the employees' a rewards and recognition system should be introduced.
- Customer satisfaction should be reviewed

It is believed that developing this implementation framework help to understand the core concept of LSS-AM and will serve as a guiding torch for the practitioner to implement LSS-AM in any organization in real-time. But the limitations of the present study are, first, the proposed framework was based on only 41 frameworks and merely total 26 elements /tools/ techniques were identified out of 41 frameworks.

CHAPTER 5

INTEGRATION OF LEAN SIX SIGMA AND AGILE MANUFACTURING IMPLEMENTATION: AN ACTION RESEARCH CASE STUDY IN MSME

5.1 INTRODUCTION

The literature review in chapter 2 represents that the applications of LSS/AM/their integration are widely found in the manufacturing, service, and process sectors. For example, LSS applications are found in automobile manufacturing to healthcare, bolt manufacturing to financial services, FMCG to the construction industry, and large manufacturing to SMEs'. On the other hand, applications of AM and Leagile are confined to the manufacturing sector only. It is also observed that LSS, AM, and Leagile approaches have been successfully implemented in micro, small and medium enterprises irrespective of their sizes.

As per the gazette notification (1st June 2020) of the Ministry of MSME (micro small and medium enterprise) India, the government has categorized the enterprises into three segments as shown in Table 5.1

Table 5.1: Enterprises categorization as per Ministry of MSME India (2020)

Type of Enterprises	Investment in plant and machinery (INR)	Annual turnover(INR)
Micro	Less than 1 Crore	Less than 5 Crore
Small	More than 1 Crore and less than 5 Crore	More than 5 Crore and less than 50 Crore
Medium	More than 5 Crore and less than 50 Crore	More than 50 Crore and less than 250 Crore

Efficiency, effectiveness, and competitiveness are the critical levers for the growth of MSMEs (micro, small and medium enterprises) and ultimately contribute to the Indian economy in the long run (Dhwani and Seema, 2015; Bhat *et al*. 2021a). To encourage MSMEs, the government of India initiated several schemes such as the ZED certification scheme; lean manufacturing competitiveness for MSMEs; technology and quality upgradation support; enabling the manufacturing sector to be competitive through quality management standards (QMS) and quality technology tools (QTT); credit linked capital subsidy for technology upgradation (CLCSS) (MSME 2021).

Despite continuous efforts made by the government of India, MSMEs are still facing issues such as high operating costs, low productivity, high production lead time; low service level; backwardness in technology; lack of understanding of quality management and tools (Maiti, 2018; Bhat *et al*., 2021a). To overcome these issues and support the schemes of the government of India, the implementation of LSS-AM in MSME can be seen as a promising business strategy to get a competitive edge in this new era. Hence the objective of this chapter is to implement LSS-AM in an MSME. To fulfill its objective action research case study is carried out in a micro eco-friendly paper products manufacturing industry.

5.2 ACTION RESEARCH CASE STUDY

To implement the integrated LSS-AM proposed framework in an eco-friendly paper products manufacturing industry, an action research (AR) methodology has been adopted. AR is a version of a traditional case study in which a researcher is a participant in the process instead of an independent observer. Further researchers pay more attention to create organizational change and simultaneously understand the process, in which empirical data-based case study is lacking (Bhat *et al*., 2021a). Thus the active participation of all the employees from the organization under study is ensured in AR.

This exploratory nature helps to create case studies and gives a more detailed insight into the CSFs; CFFs and drivers of LSS-AM implementation (Coughlan and Coghlan, 2002; Bhat *et al*., 2019). Moreover, it is one of the better research methodologies of operation management to utilize the potential of practitioners and academicians (Coughlan and Coghlan, 2002).

In the present study the researcher, being a Black belt (BB) in LSS, assisted the eco paper product manufacturing industry to identify the potential causes and implement the solution to improve the efficiency, effectiveness, and responsiveness of the industry. For the deployment of LSS-AM in a selected industry, the implementation framework proposed in the previous chapter was used. The length of the project was seven months. The team of the LSS-AM project comprised a project sponsor (senior manager), the project owner (supervisor), and project facilitators: 1(BB-LSS); 2 industry experts; one academic expert, and 2 team members (1 machine operator; 1 quality check person). In the present study to analyze the data, both data door and process door approaches were used. In-data door approach data were analyzed through Minitab 21.1.0 and in-process door approach data were analyzed through Gemba walk and VSM. VSM was drawn in Edraw Max software

5.3 ABOUT THE CASE COMPANY

Climate change is raising one of the major concerns for the world. Plastic is foremost contributor to climate change. As per the science daily report (2020) world is producing 11 MMT of plastic waste and half of it is produced by single-use of plastic. Single-use plastics such as straws, bags, and cutlery are difficult to recycle and therefore are often not accepted by recycling centres. To take up this concern the central pollution control board, ministry of environment, forest, and climate change India has issued a notification (CPCB, 2022) of a single-use plastic ban effective from 1ST July 2022.

Further people's inclination towards environment-friendly and sustainable lifestyles is driving the growth of the paper straws market. As per the market research report by data bridge (2021) the global market size of paper straws is estimated to reach USD 3723.02 Million by 2029.

Adyah Eco Products (AEP) is an eco-friendly paper products manufacturing MSME, located in Bhilwara, Rajasthan, established in the year 2019. One of the major products of case organization is paper straw. AEP Manufactures paper straws in different lengths and diameters as well as designs and colors as per customer requirements. The standard sizes are 6mm, 8mm, 10mm in diameter, and 200 mm in length while the standard color for straw is white. These paper straws have 3 plies of paper. AEP served Industries, hotels, and restaurants on a pan-India basis. AEP also exports paper straws to the US, Europe, and other major world markets. AEP complied with US FDA and Europe FDA regulations. Management of AEP had an immense focus on customer satisfaction and product quality.

The manpower of AEP was 15 in February 2022, which was a mix of the skilled and semiskilled workforce. Apart from the manufacturing division, the company has other divisions such as production planning; quality and inspection; packaging & shipping, and sales & marketing divisions. The sales and marketing division performs a market survey, provides the customers' requirement, and also handle customer complaints and feedback. The factory was running for 8.5 hours shift (8 hours working; two 15 minutes breaks) with 30 min of overtime if needed for six days a week. AEP had an automatic paper-slitting machine and an automatic straw-manufacturing machine.

5.4 PRE-IMPLEMENTATION PHASE

The researcher is one of the key management members of AEP who had discussed the LSS-AM deployment strategy with other top management members to create basic awareness about lean, six sigma, and agile approaches, their prerequisites, and the benefits of deployment. After an initial discussion, other members of top management agreed to assure full support in the implementation journey. Further basic lean six-sigma and AM awareness training were conducted for all the employees of AEP from top to bottom. In training sessions, employees became aware of the types of waste, lean tools, cost of poor quality, quality tools, and basic statistics; about automation and safety in the workplace. Researcher and other top management members ensured the active participation of all employees.

5.5 IMPLEMENTATION PHASE

In the implementation phase, five phases of DMAIC i.e. define, measure, analysis, and improve and control phase were used. Each phase is discussed below

5.5.1 Define

The objective of the define phase is to identify the opportunities for improvement and to define the problem.

5.5.1.1.Identify the Opportunity for Improvement

To identify the opportunity for improvement following steps were taken:

5.5.1.1.1.Voice of Customer (VOC)

To identify the problem in the process and opportunities for improvement, a detailed study was carried out with the help of the sales and marketing team. A questionnaire-type feedback survey was conducted for the existing customers and VOC was recorded as per the survey. The VOC was prioritized through the Pareto chart (see figure 5.1). On analyzing the Pareto chart, it was observed that the primary reason for customer dissatisfaction was the late delivery of the order. Further from the MIS report, it was found that in the past one-year 168 paper straw orders (160 standard +8 customized) were fulfilled by AEP. The Minimum order quantity (MOQ) was 50,000 pcs of straws. Due to high production lead -time, AEP was unable to fulfill the demand and missed 120 orders in the last year. The average monthly demand was 12, 00,000 pcs of straws (24 orders) while the company was able to fulfill 7, 00,000 pcs of straws (14 orders). Due to this, AEP was suffering from massive customer loss and revenue loss of 24, 00,000 INR per annum. Further, delay in order delivery was affecting the company's reputation in a competitive market.

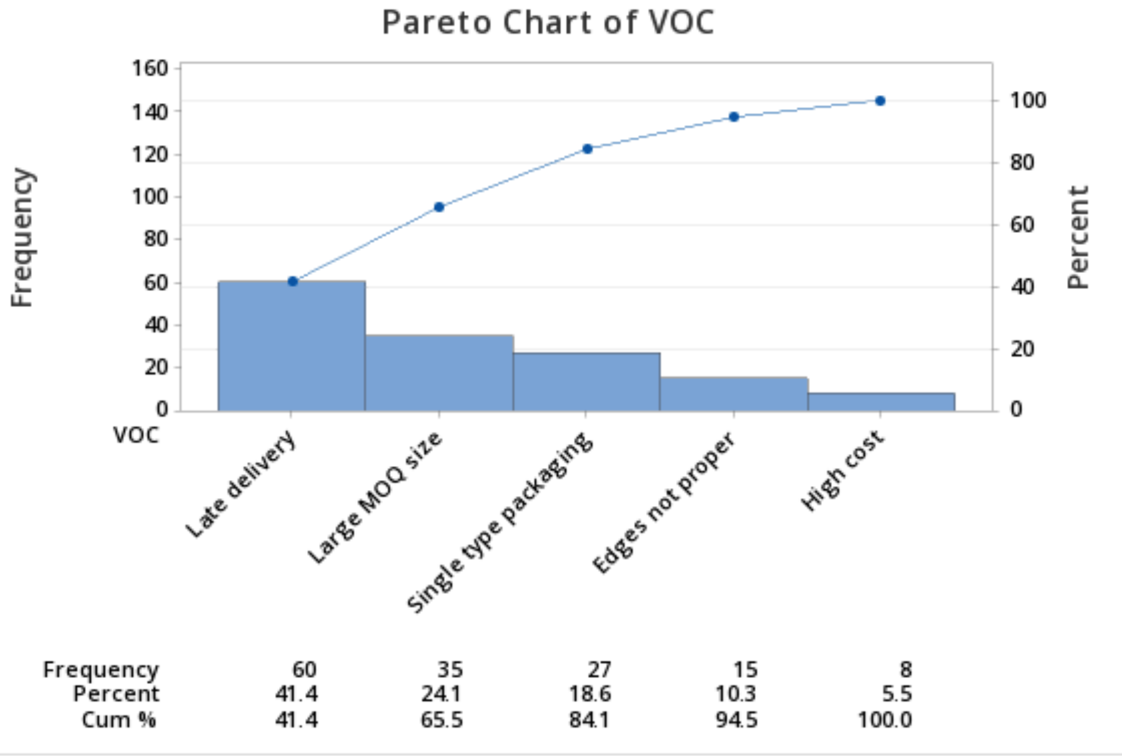

Figure 5.1 Pareto Chart of VOC

5.5.1.2.1 Selection of the Project (Big Y drill)

Selection of the right project is a very crucial step in any CI approach. As the selected project goal (y) is not aligned with the business or customer need (BIG Y) then management will conclude that this project is a waste of time and resources only; it is not contributing to any business process improvement (Ray and Das, 2010). Here from the VOC, late delivery was found as a business Y, and further drilling it down, it was found that the production lead time was one of the major contributors to delay in delivery. Hence reduction in production lead time was selected as a project and production lead time was our CTQ (y), which is measurable.

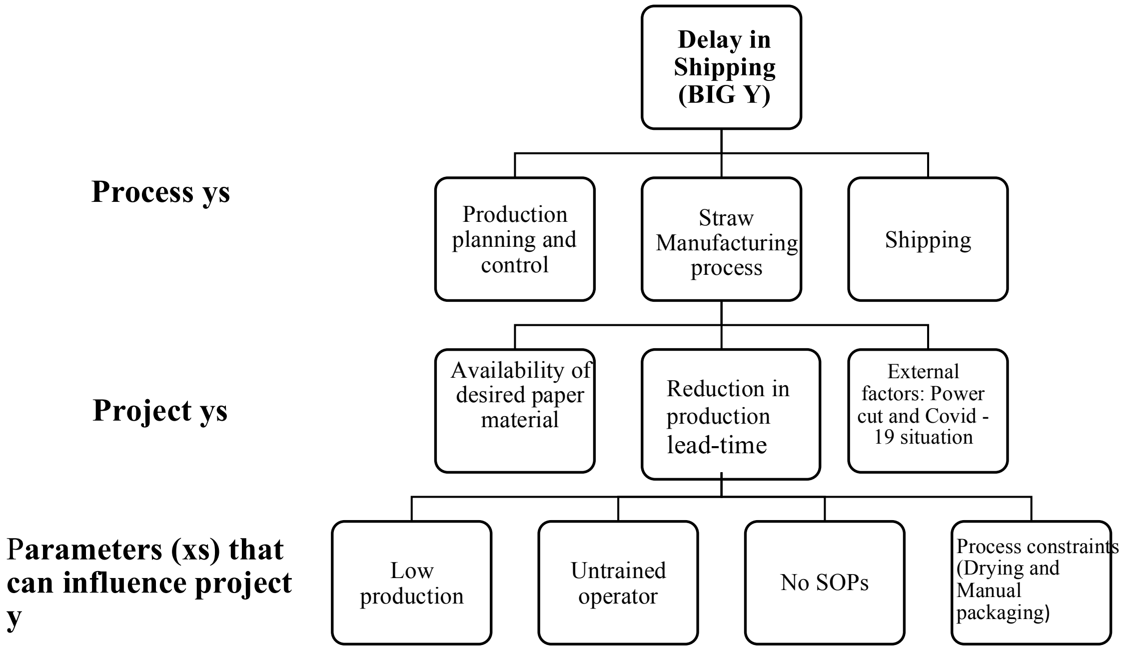

Figure 5.2 Big Y drill for project selection

5.5.1.2 Project Charter

After project selection, the project charter has been developed by the LSS-AM team and is shown in Table 5.1

Table 5.2 Project Charter

<table>
<tr><td colspan="5">Project Title: Reduction in production lead time</td></tr>
<tr><td colspan="4">Problem Statement / Opportunity Statement</td><td>Business Case / Benefits</td></tr>
<tr><td colspan="4">Over the past year, it has been observed through MIS reports of AEP that AEP was missing customer orders regularly due to high shipment time, which was not as per customer expectations. AEP was getting orders for 12 Lakh pc per month while AEP was able to fulfill the demand of 7-lakh pc only. Further, delay in order delivery was affecting the company's reputation in a competitive market and causing huge revenue loss.</td><td>Past one-year 168 paper straw orders (160 standard +8 customized) were fulfilled by AEP. The Minimum order quantity (MOQ) was 50,000 pcs of straws. Due to high production lead -time, AEP was unable to fulfill the demand and missed 120 orders in the last year. The average monthly demand was 12, 00,000 pcs of straws (24 orders) while the company was able to fulfill 7, 00,000 pcs of straws (14 orders). Due to this, AEP was suffering from massive customer loss and revenue loss of 24, 00,000 INR per annum.</td></tr>
<tr><td colspan="4">Goal statement</td><td>Project scope</td></tr>
<tr><td>Metric</td><td>Current level</td><td>Goal / Target</td><td>Target date</td><td>Process Start: Slitting machine setup</td></tr>
<tr><td>Production lead time</td><td>2.4 days (1166min)</td><td>1 day (480 min+ 30 min overtime=510 min)</td><td>01/08/22</td><td>Process Stop: Shipment of Material</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Out of Scope: Warehouse Raw Material Inventory Management customized straws order and other products manufacturing units</td></tr>
<tr><td colspan="4">Timeline</td><td>Team Selection</td></tr>
<tr><td>Phase</td><td>Start</td><td>End</td><td>Status</td><td>Champion: Senior Manager</td></tr>
<tr><td>Define</td><td>1/02/22</td><td>15/02/22</td><td>Completed</td><td>Project owner: Supervisor</td></tr>
<tr><td>Measure</td><td>16/02/22</td><td>1/04/22</td><td>Completed</td><td>Project facilitators: Nidhi Mundra (BB-LSS); 2 industry experts; 1 academic expert</td></tr>
<tr><td>Analyze</td><td>3/04/22</td><td>15/05/22</td><td>Completed</td><td>Member: One machine operator</td></tr>
<tr><td>Improve</td><td>16/05/22</td><td>11/08/22</td><td>Completed</td><td>Member: One quality check person</td></tr>
</table>

Control	13/08/22	31/08/22	Completed			
Roles and Responsibilities						
Name	Approver	Resource	Member	Interested party	Time commitment	
Senior Manager	X				1 hour a week	
Supervisor		X			1 hour daily	
Machine Operator			X		4 hours a week	
Quality check person			X		4 hours a week	
Customer				X	1 hour a month	
Estimated benefits						
Hard gain	Amount	Assumptions	Soft gain	Amount	Assumptions	
Increase in profit	INR 13,08,891	Increase in sales and reduction in manufacturing cost	End customer satisfaction by the reduction in complaints	90% reduction	Shipment time will reduce and quality will improve	
			Sigma increase	By 2.73 Sigma		
			Employee satisfaction	Improvement by 50%	Training will improve confidence and rewards and recognition will add to employee satisfaction	

5.5.1.3 Process Mapping

To understand the straw manufacturing process end-to-end, project facilitators did GEMBA walk on the shop floor. Further for a high-level process mapping, a SIPOC diagram was drawn (see figure 5.3) using Minitab Engage software.

SIPOC

Project Name:
Reduction in Production Lead-Time

Prepared By: NIDHI MUNDRA

Prepared Date: 2/6/2022

SIPOC

	Inputs			Outputs		
Suppliers	Description	Requirements	Process	Description	Requirements	Customers
Paper Vendor	Paper roll	100kg	Slitting	Finished paper straws pack of 100 pcs and 10000 pcs in a box	5 corrugated boxes contain 50,000 pcs of straws which Edges are properly cut and intact	Distributor,Exporters,Hotel and Restaurants;Industries
Glue vendor	Glue	1 drum (50kg)	Straw manufacturing			
Packaging material vendor	BOPP,BOX,TAPE	BOPP 1KG;5 Corrugated boxes,1 large tape	Quality check			
			Drying			
			Packaging			
			Shipping			

Figure 5.3: SIPOC for straw manufacturing

A Further activity process flow diagram was developed as shown in figure 5.4. The flow diagram depicts the straw manufacturing process starts from the slitting process and ends with the shipping of straw orders. In between, there is straw manufacturing, quality check, and drying process. Each process is explained below

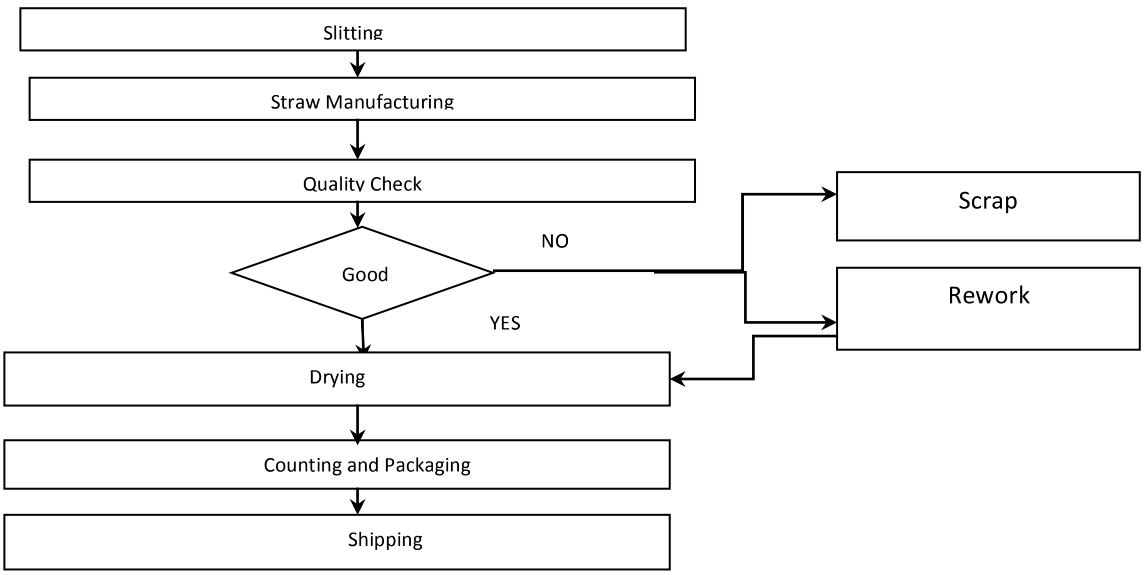

Figure 5.4: Process flow diagram

- Slitting process:

  In the slitting process, the large size of a single roll gets slit into 28 reels of paper by an automatic slitter machine.

- Straw manufacturing process:

  An automatic straw-manufacturing machine manufactures paper straws using paper reels and food-grade adhesive. Three paper reels are rolled over each other and glued using adhesive to make three-ply straw. The rated capacity of the straw manufacturing machine was 35 meters/min.

- Quality check:

  One worker was assigned to check the quality of straws. It segregates the good straws and bad straws (longer or shorter in the desired length, open edges, not visually good). The worker stands near the conveyor where manufactured straws come from the machine and segregate them based on good and bad criteria. The good straws send to the drying unit and whereas open edges straws send to the rework unit. Longer or smaller, aesthetic defectives are dumped.

- Drying process:

  Good straws are sent to the drying unit. In the dying unit, AEP uses an overnight natural drying process in which all straws, which are manufactured in a day, are spread on the sheet and left for overnight drying in the air.

- Counting and Packaging:

Straws are manually counted in 100 pcs of set and packed into BOPP. The packed BOPPs were further packed into a corrugated box. Each corrugated box comprises 100 nos. of BOPPs (10000pcs) of straws.

- Shipping Process

Five corrugated boxes for 50,000pcs are prepared and shipped by local transporters.

5.5.2 Measure

The objective of the measure phase is to baseline the current performance of the process. The baselining means to identify the current Six Sigma level and process capability of the process. To baseline the process following steps are carried out.

5.5.2.1 Data Collection Plan

To measure the current performance of the process, data needs to be collected. For this, a data collection plan was developed as seen in table 5.2. In our case, the production lead time was the CTQ, so data for production lead time needed to be collected.

Table 5.3 Data collection plan

Parameters	Operational Definition	Target	Method/Equipment	Type of Data	Sample size estimation	Reporting Frequency	Responsible for data collection	Data Collection Period
Production lead time (Y)	The time needed to complete 1 order of 50000 pcs	Within 1 day (480 Min)	Digital stopwatch	Continuous	24 orders of 50,000pcs	Daily	Supervisor	7 week

5.5.2.2 MSA and Data Collection

Further before collecting the data measurement system or instrument, which was in our case, a digital stopwatch with a least count of .01 sec was calibrated first. The data for production lead time was collected as per the data collection plan. Data for seven weeks was collected. A total of 24 orders were fulfilled by AEP in that period.

5.5.2.3 Process Base-lining

To check the normality of data, a normality test was performed in Minitab as shown in figure 5.5. The p-value was 0.052, which is greater than .05, which means the collected data was normally distributed. After that, the same data was used to check whether the current process was under statistical control through an individual moving range (I-MR) control chart (see figure 5.6). From the I-MR chart, it was revealed that all the data points were within the control limit. After that, process capability was determined through Minitab by taking the upper specification limit at 510 min. The process capability analysis of data revealed that the Z_{bench} value was 3.70 (negative). This analysis represents that the current process was highly incapable to meet the 510 min window of production lead-time.

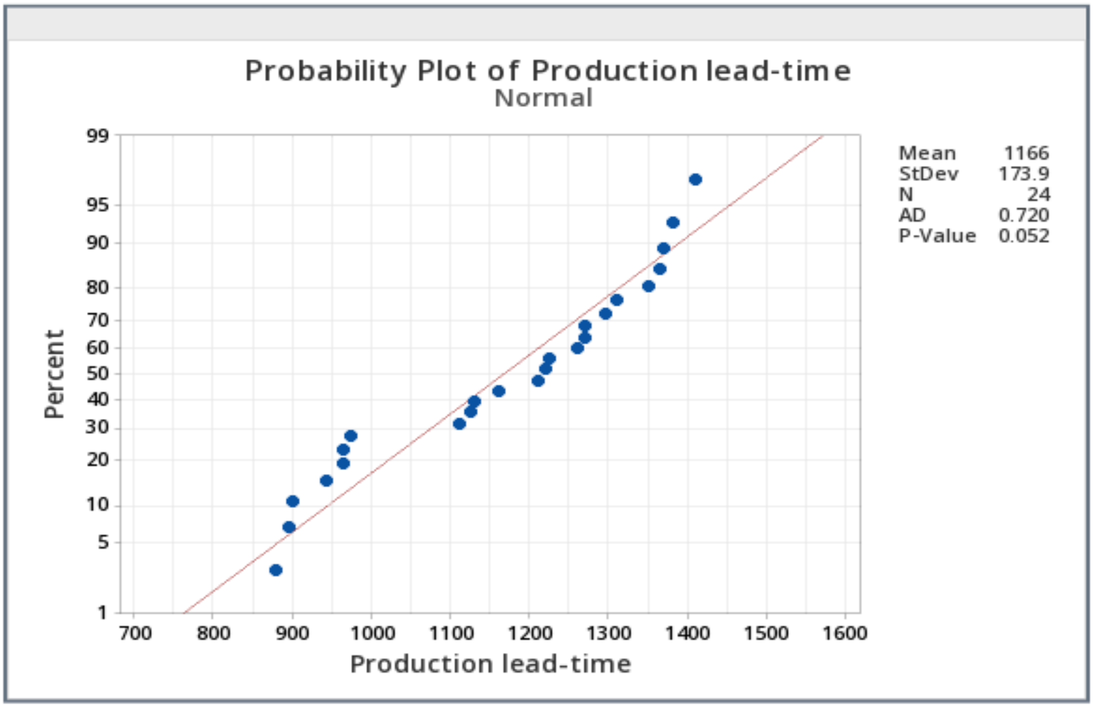

Figure 5.5 Normality test of production lead time data before improvement

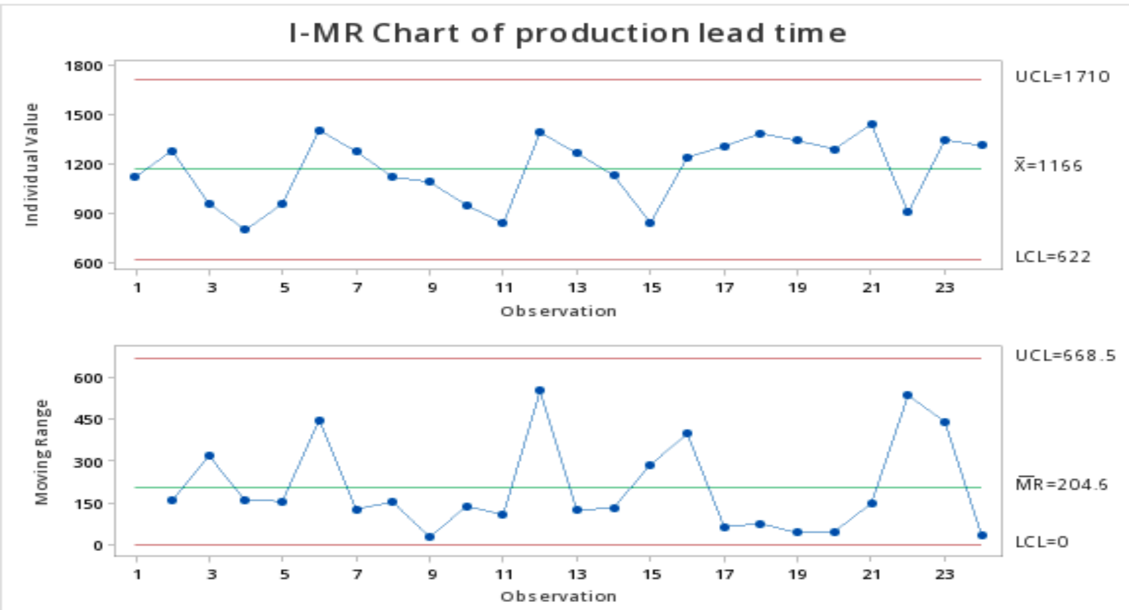

Figure 5.6: I-MR control chart of production lead time before improvement

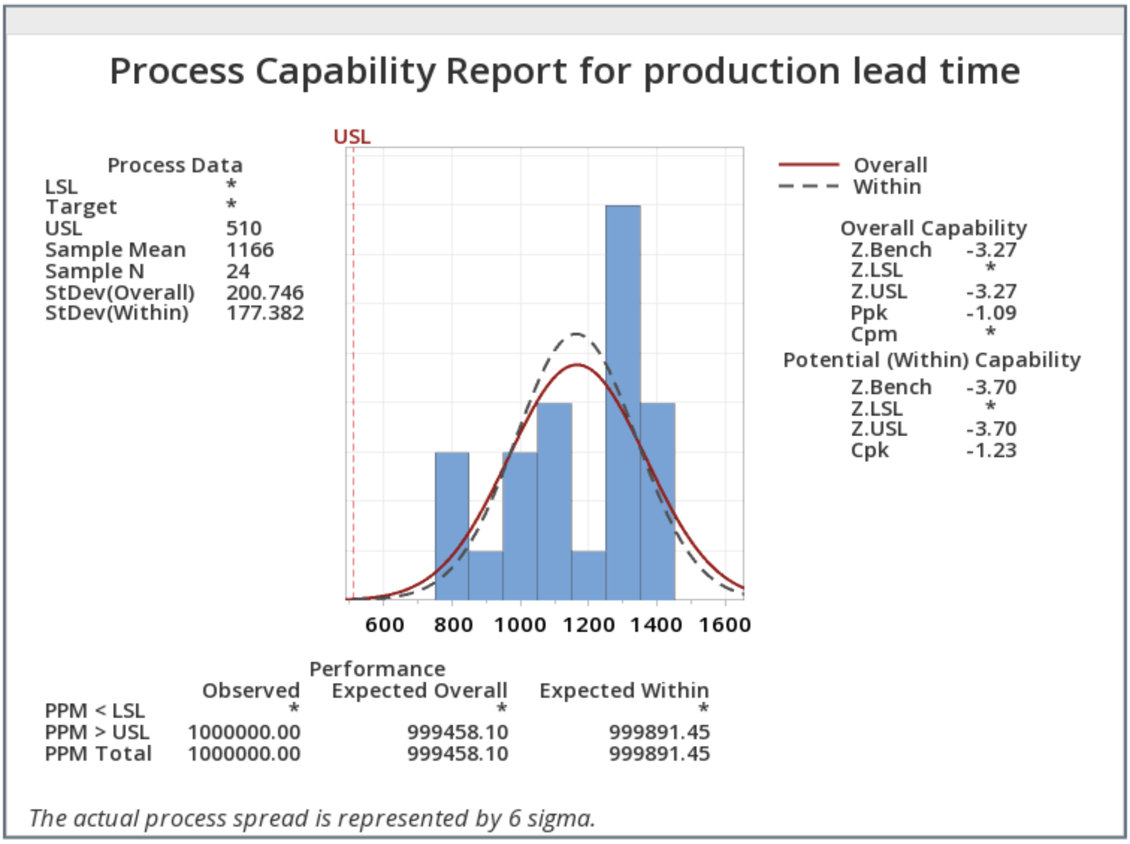

Figure 5.7 Capability analysis before improvement

5.5.3 Analyse

The objective of this phase is to identify the probable causes (X's) that influence the CTQ (Y) and validate the probable causes.

5.5.3.1 Identifying the Probable Causes

To start this phase first, for identifying the probable causes, a brainstorming session with the team and top management was performed and a cause and effect (C&E) was developed. The causes behind the long production lead time were categorized into (5M) man, machine, material, method, and mother nature. As shown in figure 5.8.

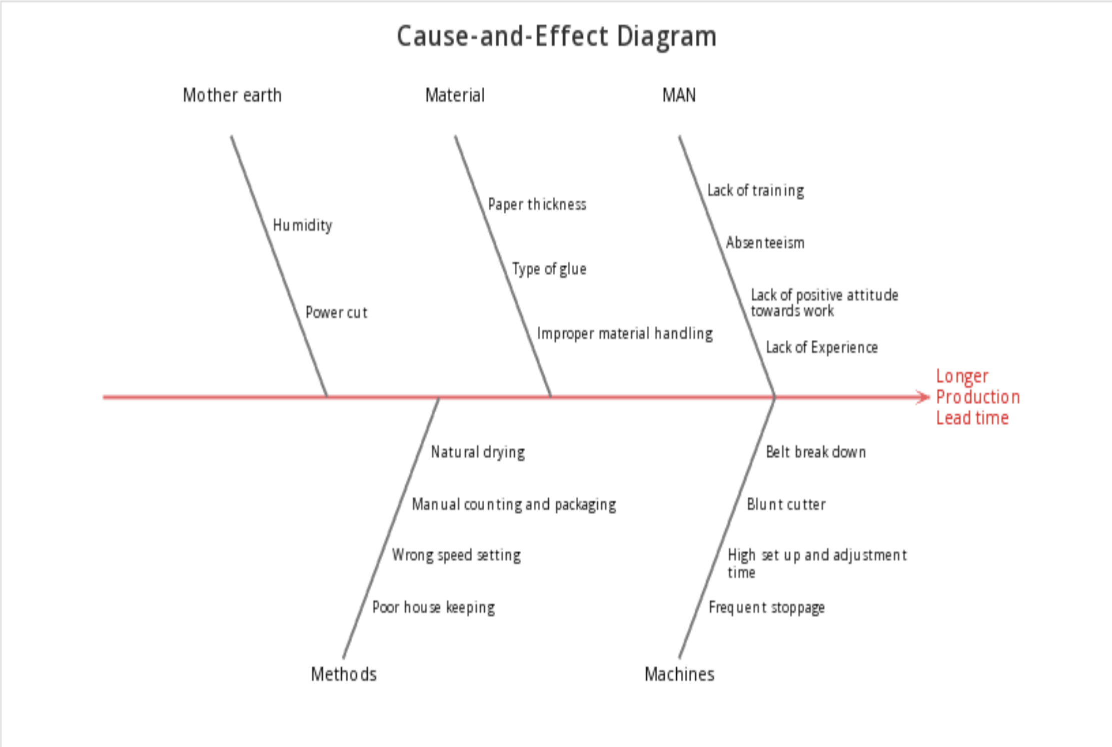

Figure 5.8: Cause and Effect diagram

5.5.3.2 Validation of Probable Causes

These possible causes were validated by the process door and data door approach as shown in table 5.3. Certain potential causes such as wrong speed selection; improper paper thickness and glue quality were validated by the data door approach whereas the validity of potential causes such as "Lack of training", "Absenteeism", "Lack of positive attitude towards work", "Lack of experience", "High setup and adjustment time", “Blunt cutter” “Belt break down”, “Frequent stoppage”, “Improper material handling”, “Natural drying”, “Manual counting”, “Poor housekeeping”, “Humidity”, “Power cut” was checked by process door approach. Each cause was correlated to lean eight wastes i.e. defect, overproduction, waiting, not the utilization of human talent, transportation, motion, inventory, and over-processing (Bhat *et al*. 2021a).

Table 5.4: Validation approaches for probable causes

S.no.	Causes		Desired results	Waste category	Approach for validation	Validation Method
1	Man	Lack of training	Operators should have undergone on-the-job training, especially regarding the handling of machines.	Underutilization of talent	Process door	Gemba
		Absenteeism	Workers should be disciplined and should not take leave without prior notice.	Waiting	Process door	Gemba
		Lack of positive attitude toward work	Workers should take their job seriously and should not sit idle in between the process	Extra processing	Process door	Gemba
		Lack of experience	Should have basic skills to manage production	Not utilization of talent	Process door	Gemba
2	Machine	High setup and Adjustment time	Setup and adjustment time should be minimum.	Waiting	Process door	VSM
		Belt tearing	There should not be any time loss due to belt breakdown	Defect	Process door	Gemba
		Blunt cutter	All straws should have properly cut edges.	Defect	Process door	VSM
		Bending in Alignment rod	No scrap generation and time loss due to bending in the	Defect	Process door	Gemba

			alignment rod.			
3	Material	Improper Paper thickness	The proper paper thickness should be used to avoid scrap generation and frequent stoppage	Defect	Data door	Full factorial DOE
		Improper glue	Proper quality glue should be used to avoid scrap generation and frequent stoppage	Defect	Data door	Full factorial DOE
		Improper material handling	Proper material handling should be done to avoid extra transportation	Transportation	Process door	Gemba
4	Method	Wrong speed setting	Proper selection of speed is required to avoid scrap generation and make enough production to meet customer demand	Defect	Data door	Full factorial DOE
		Natural drying	Drying should be faster and even over the surface	Waiting	Process door	Gemba
		Manual counting and Packaging	Counting and packaging of straws should be quick and accurate	Waiting	Process door	VSM
		Poor Housekeeping	The workplace should be clean and well organized. So that when any tools or material is required,	Waiting	Process door	Gemba

			can be extracted easily without wasting time			
5	Mother Nature	Humidity	To dry the edges of straws properly and speed up the drying process, a less humid environment is needed	Defect	Process door	Gemba
		Power cut	To avoid production loss no power cut should be needed during operating hours.	Waiting	Process door	Gemba

5.5.3.2.1 Data Door Approach

To validate the causes for longer production lead-time, such as wrong speed selection, quality of glue, and paper thickness, the data door approach was used. During the brainstorming session, it was felt that the interaction among the aforementioned parameters might affect the scrap-to-production ratio, hence ultimately enhancing the production lead -time. Thus interaction among these parameters should be considered. So to verify this cause and identify the optimum value of these parameters where scrap to the production ratio was minimum, a general full factorial design of experiment (DOE) had been performed. Although the full factorial design was time-consuming (Bhat *et al*. 2021a) but the advantage of full factorial DOE over the Taguchi method is the that mean square error value is less in full factorial DOE than in the Taguchi method hence provides a more efficient and systematic results (Rafidah *et al.* 2014). AEP was using two qualities of glue (type1 and type 2) from two different vendors, two different types of paper of thickness paper 60 GSM and 90 GSM, and operating the machine at four levels of speed 15 m/min, 25 m/min, 30 m/min, 35 m/min. Table 5.4 represents the factors and their level.

Table 5.5 Factors and their level of experiment

S.no	Factors	Level 1	Level 2	Level 3	Level4
1	Glue	Type 1	Type2*		
2	Paper thickness	60 GSM	90 GSM*		
3	Speed	15 m/min*	25 m/min	30m/min	35m/min
*** Represent the current level**					

A general full factorial design was carried out in Minitab software. A total of 16 runs were carried out based on 3 factors which were having mixed levels (2 factors were having 2 levels while one factor was having 4 factors). The experiment layout developed by Minitab to experiment is shown in Table 5.5

Table 5.6 Experiment layout for DOE

Std. Order	Run Order	PtType	Blocks	Glue type	Paper thickness (GSM)	Speed (m/min)	OUTPUT=SCRAP/PRODUCTION
10	1	1	1	2	60	25	8.7
8	2	1	1	1	90	35	28.2
7	3	1	1	1	90	30	14.9
9	4	1	1	2	60	15	7.5
4	5	1	1	1	60	35	38.9
13	6	1	1	2	90	15	6.4
16	7	1	1	2	90	35	31.6
5	8	1	1	1	90	15	5.3
14	9	1	1	2	90	25	5.3
2	10	1	1	1	60	25	7.5

15	11	1	1	2	90	30	17.6
6	12	1	1	1	90	25	2
12	13	1	1	2	60	35	42.9
11	14	1	1	2	60	30	25
1	15	1	1	1	60	15	6.4
3	16	1	1	1	60	30	22

The experiment was carried out in this order and recorded the scrap/production ratio for each input parameter in MINITAB software and the result of the factorial analysis was analyzed. Table 5.6 depicts the design summary.

From the result of analysis of variance analysis (ANOVA) shown in table 5.7, it was concluded that "Glue", "Speed", and "Paper thickness", "Glue x Speed", and "Speed x Paper Thickness" parameters were significant and had an impact on scrap /production while interaction among "Glue x Paper thickness" and "Glue*Paper thickness*Speed" were found insignificant. Figure 5.9 represents the interaction plots among the parameters. The Pareto chart shown in figure 5.10 represents parameters that had only a significant impact on output. From the Pareto chart, it was observed that speed has the highest effect on scrap-to-production ratio, type of Glue, and paper thickness.

Table 5.7 Design Summary for DOE

Factors:	**3**	**Replicates:**	**1**
Base runs:	**16**	**Total runs:**	**16**
Base blocks:	**1**	**Total blocks:**	**1**

Table 5.8 Analysis of Variance (ANOVA)

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value
Glue	1	23.10	23.102	1026.75	0.001
Paper thickness	1	153.37	153.368	6816.33	0.000
Speed	3	2147.00	715.666	31807.39	0.000
Glue*paper thickness	1	0.07	0.067	3.00	0.225
Glue*speed	3	3.82	1.273	56.57	0.017
Paper thickness*speed	3	52.90	17.635	783.78	0.001
Glue*Paper thickness*speed	3	1.12	.375	15.67	0.189
Error	3	.04	0.022		
Total	18	2637.53			

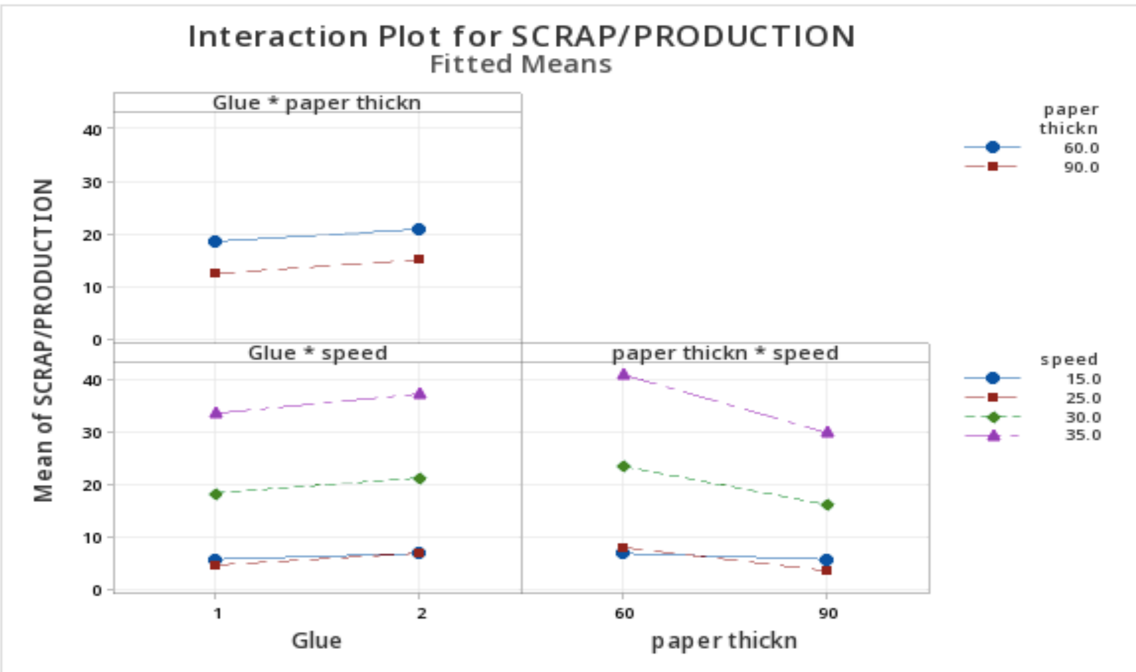

Figure 5.9 Interaction plot for scrap/production

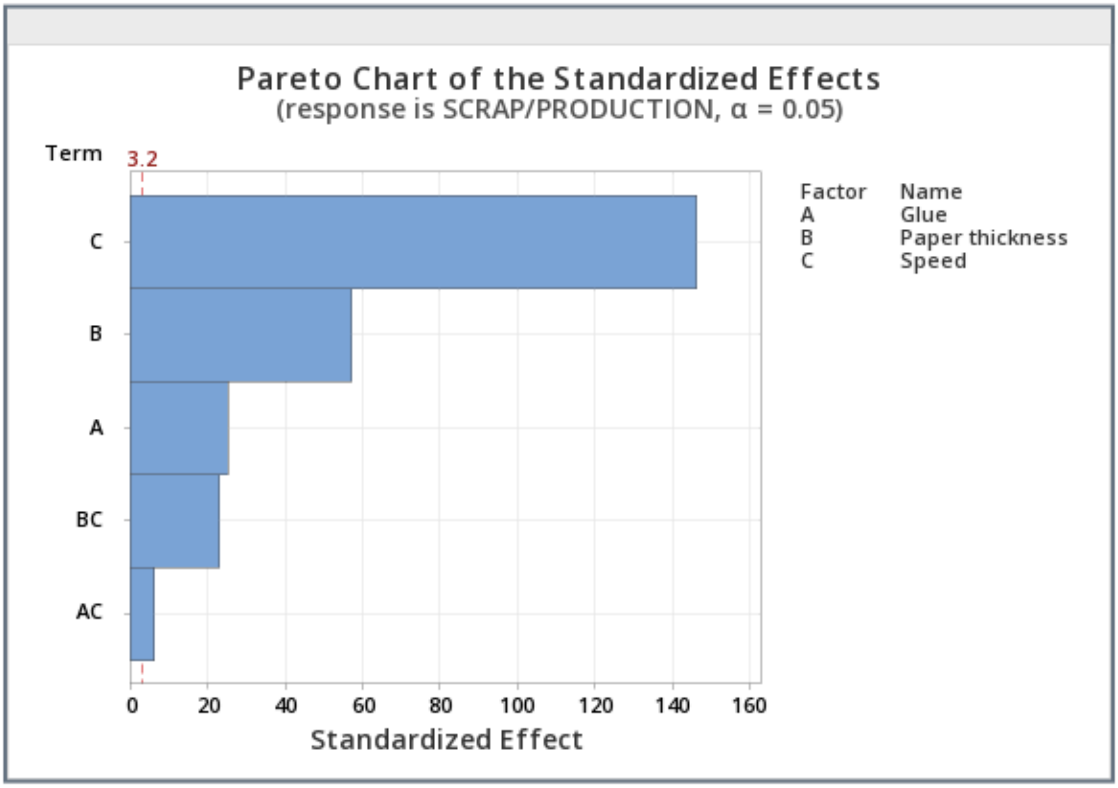

Figure 5.10: Pareto chart of the standardized effects

5.5.3.2.2 Process Door

In the process door approach, the first Gemba walk on the shop floor was performed and developed a current state value stream mapping (CVSM). Table 5.9 represents the observation of Gemba and CVSM.

5.5.3.2.2.1 Gemba

During the Gemba walk, the team discussed comprehensively with the supervisor to determine the actual root causes of longer production lead time. From the Gemba observation, causes such as "Lack of training", "Absenteeism"," "Natural drying", "Poor housekeeping", "Belt tear off", and "Bending in alignment rod" were found as root causes whereas "Lack of positive attitude towards work", "Lack of experience", "Improper material handling", Humidity", and "Power cut" did not affect the production lead- time.

5.5.3.2.2.2. Current Value Stream Mapping

Further causes such as "High set up time"; "Blunt cutter", and "Manual counting" were found as root causes through CVSM. CVSM segregates value-added activities from non-value-added activities. In CVSM the major processes were drawn i.e. slitting, straw manufacturing, quality check, and shipping. The overnight drying process was not shown in CVSM (see figure 5.11). Each process has a data box below it. Which consists of information such as cycle time (C/T); set up and adjustment time Uptime; % scrap; % defect; % RTY (Rolled throughput yield); available time; batch size etc. The triangle shape in between the process represents work-in-process (WIP). AEP was working for 24 days in an 8.5hour shift in which working available time was 480 min (8hr) with a margin of 30 minutes overtime if needed. Monthly customer demand was 12, 00,000 pcs of straws (24 orders) in a month. Hence the per day demand was 50000 pcs of straws (1 order). AEP was practicing batch production. The average total production lead -time was found 1166 minutes. Process cycle efficiency (PCE) was found to be 15%. This represents only 15 percent of the total lead time, our process was adding value to the product. The cycle time for batch size 5000pcs of the straw manufacturing process and counting and packaging process was higher than Takt time.

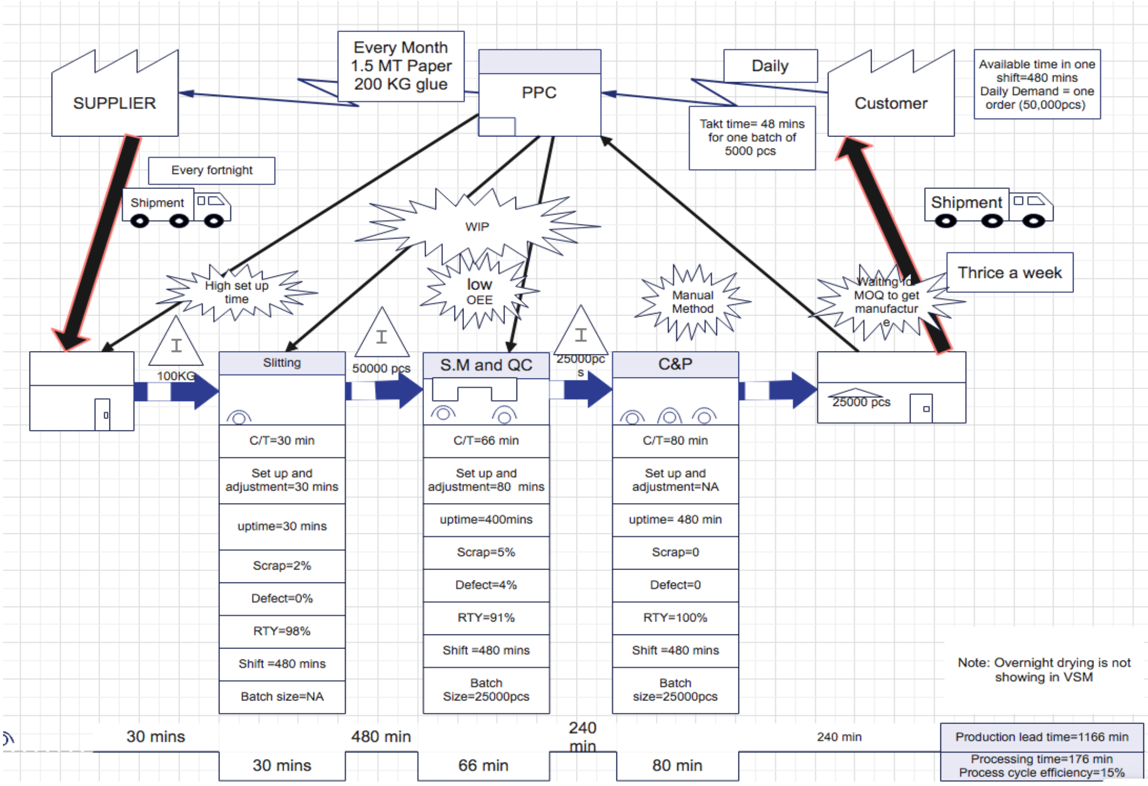

Figure 5.11: Current value stream map of straw manufacturing process

Further Overall equipment effectiveness (OEE) of straw manufacturing (SM) machine and Rolled throughput yield (RTY) of straw manufacturing process are calculated as below:

- Overall equipment effectiveness (OEE) is a key measure of productivity in the manufacturing environment. OEE of the SM machine is calculated below:

$$OEE = Availability * Performance * quality$$

$$Availability = total\ scheduled\ time \ \div Total\ available\ time$$

$$= (480 - 80) \div 480$$

$$= \quad .833$$

$$Performance = Actual\ speed \div Rated\ speed$$

$$= 15 \div 35$$

$$= .428$$

$$Quality = good\ count \div total\ count$$
$$= 50000/52000$$
$$= .96$$
$$OEE = .83 * .428 * .96$$
$$= .34103$$
$$=34.103\%$$

OEE value was found less than 40% , which was considered very poor.

- Rolled throughput yield (RTY)

RTY is defined as the percentage of units from the entire process that is manufactured right at the first time. It is a measure of the quality performance of the process. RTY of the entire process is calculated based on figure 5.12.

RTY = .98*.96*.95

= .894%

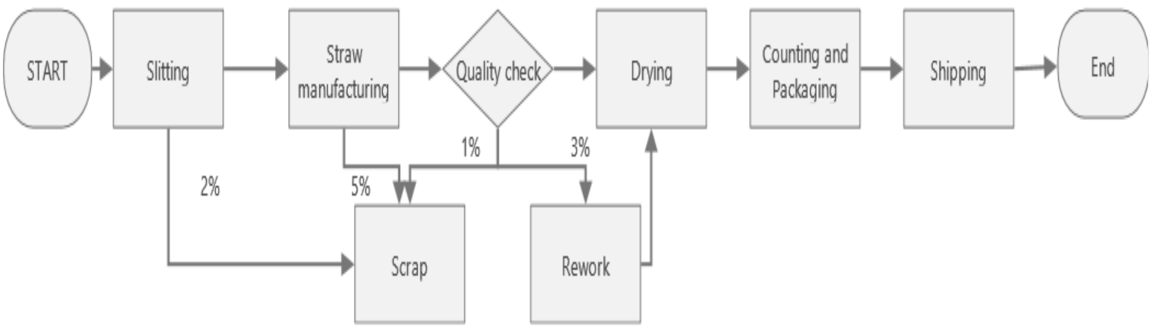

Figure 5.12: RTY of the straw manufacturing process

Hence in the analysis phase, we have identified the root causes (x's) for longer production lead time (y)

Table 5.9: Validation of identified causes (x’s)

S. No.	Causes	Observation	Conclusion
1	Lack of training	No formal refresher training has been given to operators. It was also observed that set-up and adjustment times and scrap generation were very high.	Root cause
2	Absenteeism	Unplanned half-day leaves taken by workers caused delays in the order shipment.	Root cause
3	Lack of positive attitude toward work	Every worker was doing his or her job very sincerely. No one was sitting idle in between the process	Not a Root cause
4	Lack of experience	Each worker has less than 2 years of work experience but that has not affected the production	Not a Root cause
5	Set up and Adjustment time	The setup and adjustment time was very high. This caused a loss of production and hence ultimately contributed to longer production	Root cause

6	Belt Tearing	Due to belt tearing, scrap was getting generated, resulting in low production and low RTY	Root cause
6	Blunt Cutters	Blunt cutters were causing an increase in the generation of defective straws.	Root cause
7	Bending in Alignment rod	Bending in the alignment rod was causing frequent stoppage of the machine.	Root cause
8	Improper Paper thickness	Improper paper thickness was also generating high scrap and low production. Hence contributing to high production lead time	Root cause
9	Improper glue	Improper glue was also generating high scrap and low production. Ultimately it was enhancing production lead time	Root cause
10	Improper material handling	As workstations were near to each other in AEP, material	Not a Root cause

		handling was not enhancing the production lead time	
11	Wrong speed setting	The wrong speed was causing high scrap generation and low production.	Root cause
12	Natural drying	Overnight drying was a constraint in the straw manufacturing process. Instead of overnight drying, there should be an alternative to natural drying to avoid this time-consuming necessary process.	Root cause
13	Manual counting	Manual counting of straws was again a time-consuming process. One should look for an alternative method of counting which is not only economical but also not time-consuming	Root cause
14.	Poor Housekeeping	It was observed that the scrap was spread over the floor near the SM machine; tools were not arranged in the tool crib. Clutter causes untidy floor space. Further corrugated boxes and packing material, consumables, were also not arranged in the store area. Poor access to tools, packing material, and	Root Cause

		consumables causes longer production lead-time	
15	Humidity	Humidity was not impacting the drying process. Hence was not contributing to production lead time	Not a Root cause
16	Power cut	There was no power cut during the operating hours, hence was not affecting the production lead time	Not a Root cause

5.5.4 Improve

The objective of the improve phase is to identify the solutions and implement the same. The Steps involved in this phase are as follows:

5.5.4.1 Identification of Solutions

To identify the solutions for the validated causes (xs), identified in the analysis phase both creative and analytical approaches were used. The solutions for causes such as "Lack of training", "Absenteeism", "Natural drying", "Low uptime", "Manual counting", " Poor housekeeping", "Blunt cutters", "Belt tearing", "Bending of alignment rod", "Set up and adjustment time" were generated through a creative approach using rigorous brainstorming session among team members whereas solutions for "Wrong speed setting", "Improper glue" and "Improper paper thickness" were identified through an analytical approach using DOE.

5.4.5.1.1 Solutions from Creative Approach

Following were the solutions proposed by the brainstorming session:

- Refresher training must be conducted every six months for workers.
- Sense of ownership to be developed among the workers through regular meetings and team building activity.
- Preventive maintenance schedule to be developed and SOP to be developed for setup and adjustment.
- 5S to be implemented in the Straw Manufacturing unit.
- The natural drying process was a major constraint in the SM process. The alternative method of drying was automation hence heater based drier to be installed to reduce the drying time.
- Manual counting and packaging was also a bottleneck process so to speed up this process again automation was needed. Hence, automatic counting and packaging machines are to be installed.

5.5.4.1.2 Solutions from the Analytical Approach

The optimum value of speed, type of glue, and paper thickness was identified through DOE, which was carried out in the measure phase. Figure 5.13 represents the main effects plot for scrap/production. Table 5.9 represents the optimum value of each parameter revealed by the main effect plot.

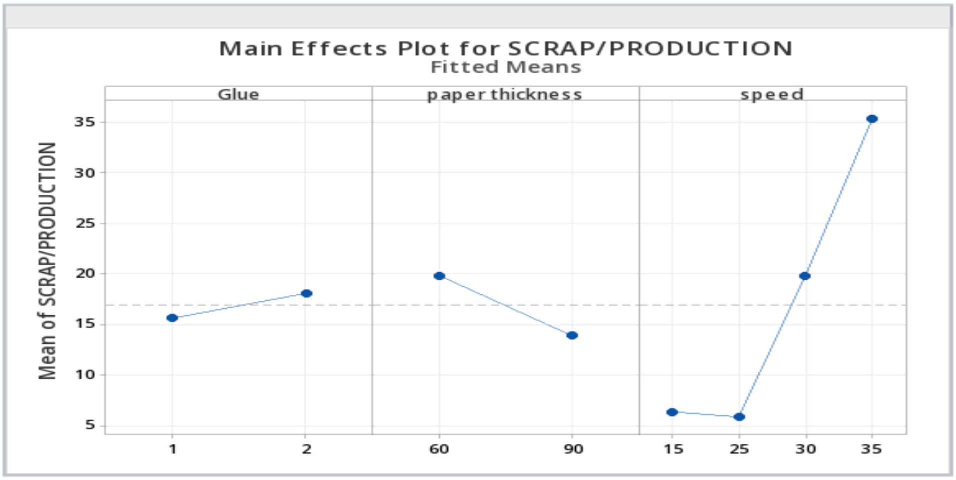

Figure 5.13: Main effects plot for scrap/production

Table 5.10: Optimum level of factors identified by DOE

S.NO	Factor	Optimum level
1	Glue	Type 1
2	Paper thickness	90 GSM
3	Speed	25 m/min

- Based on DOE results SM machines should run at 25 m/min to produce 125 straws in a min.
- To improve the RTY proper training of operators should use the optimum value of parameters obtained from DOE.

5.4.4.2. Solution Selection by Pay-off Matrix

To select and prioritize the proposed solutions, a payoff matrix was developed. Based on the team member's opinions all the identified solutions were categorized into four quadrants. Figure 5.14 represents the payoff matrix. From the payoff matrix, it was revealed that none of the proposed solutions falls under the third and fourth quadrants.

That means none of the solutions gets rejected. Further "Refresher training", "Sense of ownership", "Preventive Maintenance", and "SOP "Selection of the optimum parameter (90 GSM, TYPE 1 Glue, 25m/min)" fell under the low effort and high benefit quadrant. Although automation (heater-based drier, counting, and packaging machine) fall under the high effort and high benefit quadrant but they were a very important solution to reduce production lead- time drastically at relatively low expenses. Hence all the proposed solutions were used for further analysis.

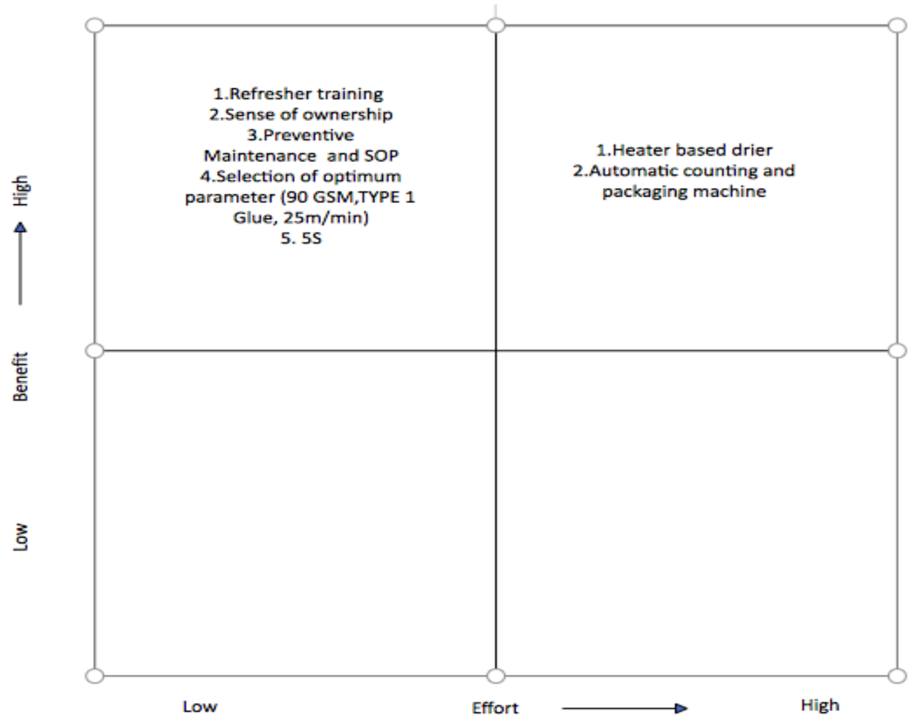

Figure 5.14: Payoff Matrix

5.5.4.3: Risk proofing of the Solution by PFMEA

For risk proofing of the process, process failure mode and effect analysis (PFMEA) was performed. The table represents the PFMEA worksheet. A rigorous brainstorming session among the team was carried out to identify the various modes of failure of each process, their effect, and the causes behind those failures and assigned the value of severity, occurrence, and detection as per Appendix A.4. The current risk priority number (RPN) was calculated by following the formula occurrence

$$RPN = Severity(S) X\ Occurrence\ (OCC) X\ Detection\ (D)$$

Based on the brainstorming session PFMEA sheet was developed through MINITAB Engage software (see table. RPN number below 100 was acceptable (Ozilgen, 2012; Rachieru *et al*., 2013), whereas RPN number 100 and above need preventive actions. In our case, all the process failure modes were having RPN values greater than 100 hence preventive actions were needed to prevent the failure. The team recommended preventive actions and assigned the responsibility to the particular to perform the recommended action. Further, the RPN number was calculated by assuming the expected value of severity, occurrence and detection when the recommended actions were taken. From this analysis, it was found that all the process failure modes' RPN values come down below 100. This revealed that we reduced the chances of process failure from occurring hence the risk-proofing of redesigned process.

Table 5.11: PFMEA sheet

PFMEA (FMEA for Process)

Project Name:

Reduction in production lead time

Prepared By:

LSS-AM Team

Prepared Date:

5/17/2022

Process Details

Process:

Straw Manufacturing Process

Process Owner:

Supervisor

PFMEA

												Revised Metrics			
Process Map – Activity	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Responsibility	Actions Taken	SEV	OCC	DET	RPN
Slitting Process	Cutter does not slit properly	Poor reel Quality	7	No preventive maintenance	6	Visual verification	8	336	Proper alignment and periodic replacement	Operator	Y	2	4	5	40
	The shaft bearing is worn out	The machine makes too much noise	6	No preventive maintenance	6	Noise and Vibration	5	180	Preventive maintenance	Operator	Y	3	4	5	60
	The electric panel does not work	Machine stop working	8	Voltage fluctuation	3	No Electricity supply	5	120	Stabilizer	Management	Y	3	2	2	12
Straw Manufacturing	Belt wore out	Higher defects	8	No preventive maintenance	8	Visual Identification	5	320	Periodic replacement	Operator	Y	3	4	5	60
	Blunt Cutter	Edges do not sharp	7	No preventive maintenance	7	Visual verification	8	392	Preventive maintenance	Operator	Y	2	4	5	40
	Bending in Cutter rod	Production stop	8	Untrained worker	9	Visual Identification	5	360	Training of alignment	Management	Y	3	5	5	75
	The electric panel does not work	Machine stop working	8	Voltage fluctuation	3	No Electricity supply	5	120	Stabilizer	Management	Y	3	2	2	12
Drier and Packaging	Conveyor system	Machine makes too much noise	6	No preventive maintenance	6	Noise and Vibration	5	180	Preventive Maintenance	Operator	Y	3	4	5	60
	The electric panel does not work	Machine stop working	8	Voltage fluctuation	3	No Electricity supply	5	120	Stabilizer	Management	Y	3	2	2	12

Set default display colors

(Optional) Enter values for each condition to display a color for SEV and RPN.

Severity (SEV)		
If SEV >=	8	
Otherwise		
If SEV <=		

Risk Priority Number (RPN)		
If RPN>=	100	
Otherwise		
If RPN<=		

5.5.4.4 Implementation Plan

An implementation plan was developed to implement all these solutions as shown in table 5.12.

Table 5.12: Implementation Plan

Plan	**Activity**	**Responsibility**	**Target date**	**Actual completion date**
Resources plan	Identify resources require (machines/manpower) and allocate the job to concerned	Management	23/05/22	22/05/22
Budget plan	Develop CBA and arrange for necessary funds	Management	8/06/22	6/06/22
Training plan	Identify training needs and develop and implement a training plan	Management	10/07/22	10/07/22
Process implementation plan	Installation of machine	Supervisor	3/07/22	30/06/22
	Do pilot run and identify and resolves the potential problems that can occur in full-scale implementation	Supervisor	11/08/22	11/08/22
Control plan	Develop and implement a control plan	Supervisor	27/08/22	31/08/22

5.5.4.5 Test Solution

The objective of this step was to confirm the potential solutions. A pilot study for 1 month was done. In this pilot run, all the solutions were incorporated. Based on all the potential solutions a future state map was drawn (see figure 5.15). From the future state map, it was revealed that WIP was reduced in between the process and the production lead time had been also reduced from 1166 min to 480 min. Further, the process cycle efficiency was improved from 15 percent to16.6 percent.

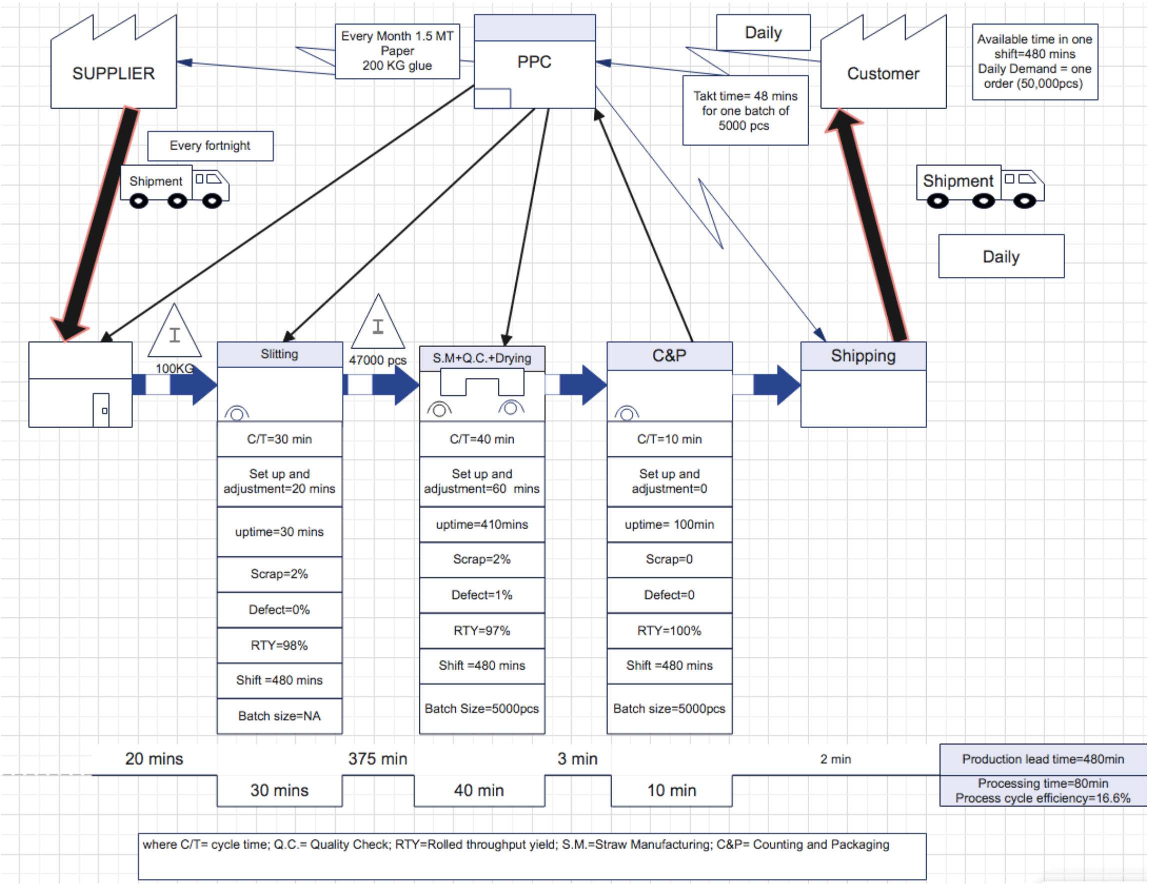

Figure 5.15: Future state map for straw manufacturing process

Again a similar data collection plan was developed and data were collected as per the plan. In one-month duration, a total of 24 orders were fulfilled by the AEP. To analyze the new capabilities indexes of the process, first, the normality of collected data was checked. The value of p was found 0.146, which was greater than .05; hence the data was normally distributed (see figure 5.16). Then the I-MR control chart (see figure 5.17) was drawn to check whether the process was under control or not. The results of the I-MR chart revealed that the process was under control. Then the process capability analysis was performed in Minitab (see figure 5.18) and the results of the process capability analysis revealed that Z bench (overall) = 2.73 (sigma level). This represents that AEP was able to fulfill all 24 orders in a month within the specification limit.

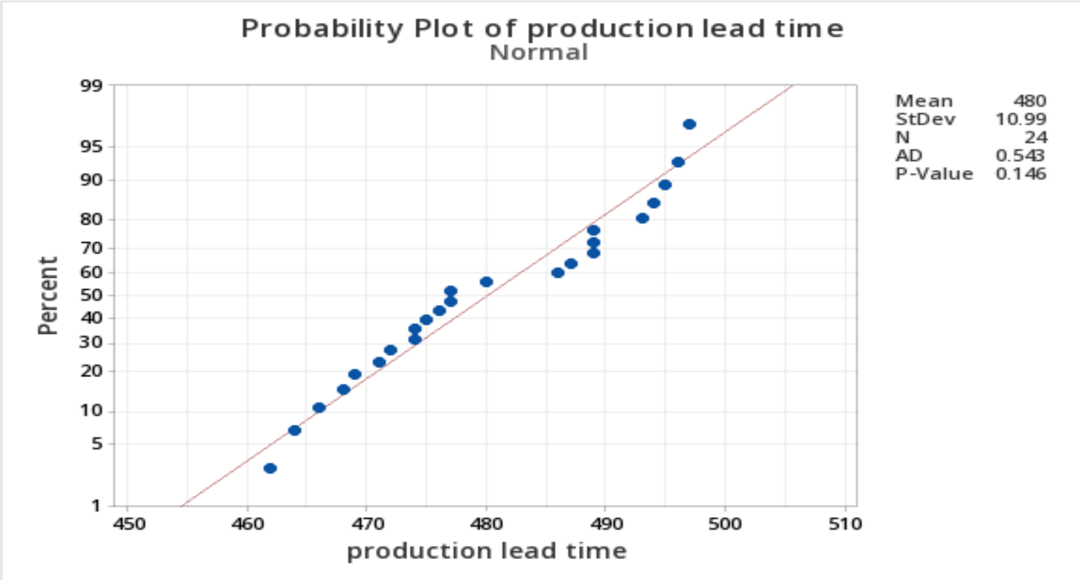

Figure 5.16: Normality test of production lead time data after improvement

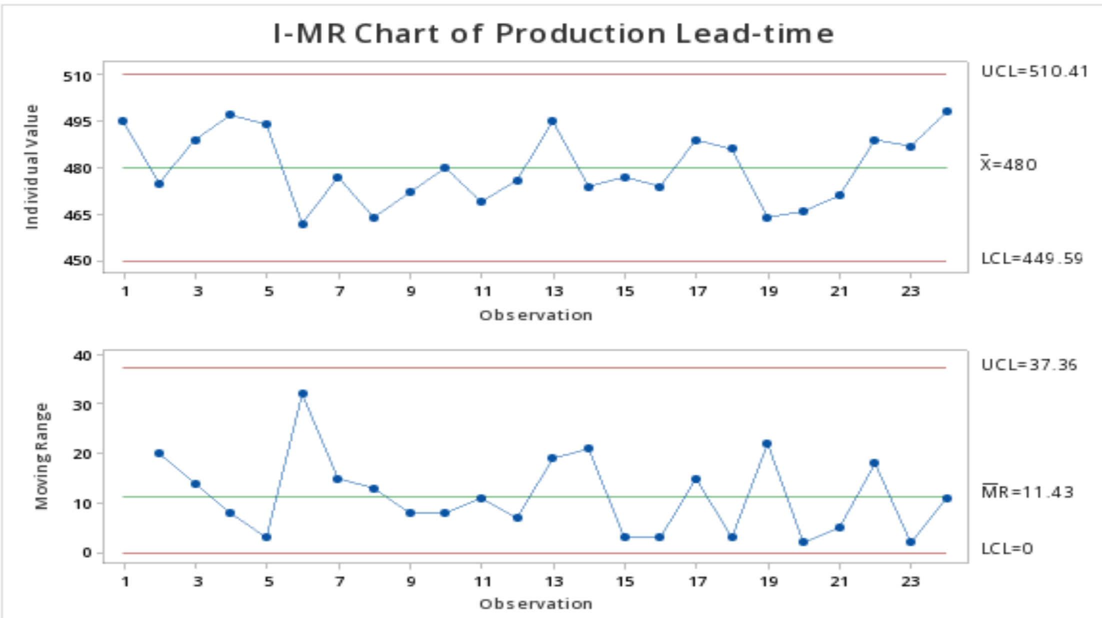

Figure 5.17: I-MR Chart of production lead time after improvement

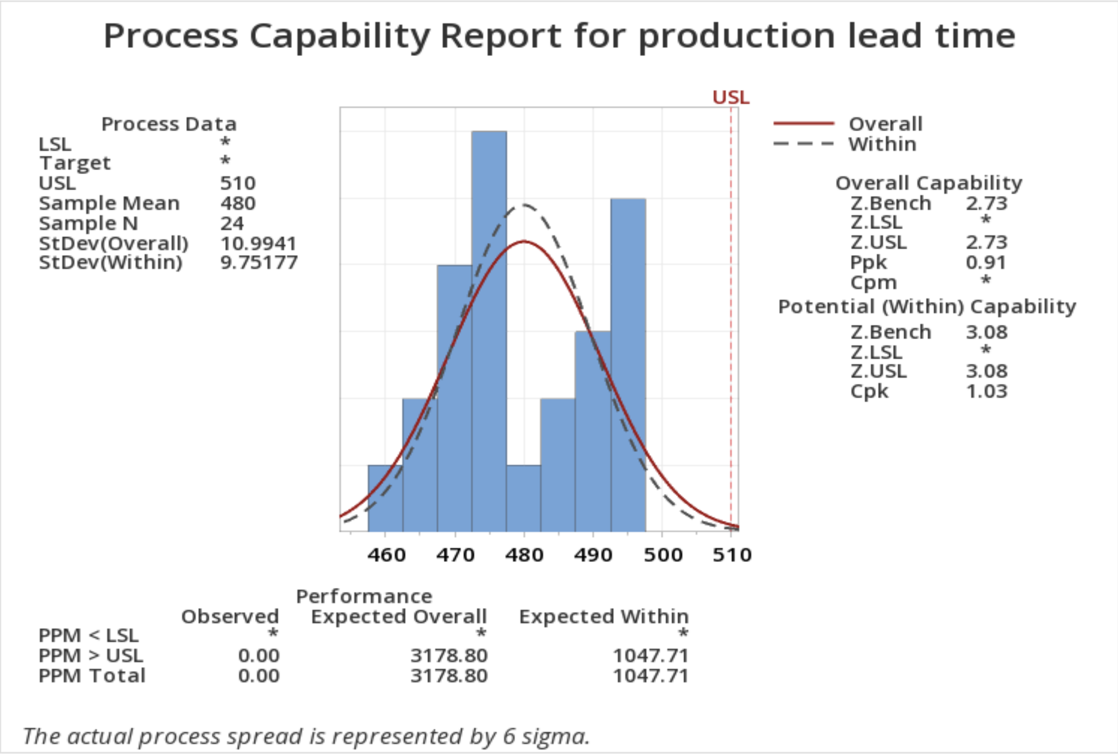

Figure 5.18: Process capability report for production lead-time after improvement

5.5.4.6: Justification of the Solution by CBA

To justify the solutions cost-benefit analysis (CBA) was performed (see table 5.12). From CBA analysis it was observed that there was a tremendous gain in monthly profit and an annual gain was expected at 13, 08,891 INR. Further Return on investment (ROI) will be covered in 3.5 years.

Table 5.13: Cost Benefit Analysis (CBA)

Cost-Benefit analysis (CBA)	
Before Improvement	INR
No of straws per month	700000
Rent	7500
Electricity	2500
Salary and wages	80000

Raw Material	
Paper cost	100800
Glue	20000
Packaging Material	8000
Total cost	218800
Unit cost	0.31
Profit Monthly	61200
After improvement	
No. of straws per month	1200000
Rent	7500
Electricity	4500
Salary and wages	74000
Raw Material	
Paper cost	181440
Glue	34286
Packaging Material	8000
Total cost	309726
Unit cost	0.26
Profit Monthly	170274
The annual increase in profit	1308891
Investment	
Heater drier	5,00,000
Packaging	6,00,000
Installation	50,000
Preventive maintenance (Cost of consumables)	1,00,000
Training cost	20,000
Stabilizer	40,000
Cost of credit	30,00,000

Bonus	50,000
Total Investment	43,60,000
ROI	3.3 Year

5.5.5 Control Phase

The objective of the control is to sustain the gains obtained from the DMAIC project by controlling and monitoring the process so that all the efforts made by the project team are not in vain. The steps involved in the control phase are

5.5.5.1: 5 S Audit Sheet

5S audit sheets were developed by MINITAB workspace (see Appendix A.5) and displayed on quality boards.

5.5.5.2: Visual Management

For visual management, revised process flow charts and SOPs were displayed at various prominent positions on the shop floor. Further before and after pictures were also displayed on the activity board (see figures 5.19 to 5.20)

Figure 5.19: Before improvement pictures

Figure 5.20: After improvement pictures

5.5.5.3: Statistical process control (SPC)

For SPC, a datasheet was developed to monitor the process through control charts (see Appendix A.6). The following figures (see figure 5.21 to figure 5.24) represent the illustration of monitoring the different process parameters based on six days of data.

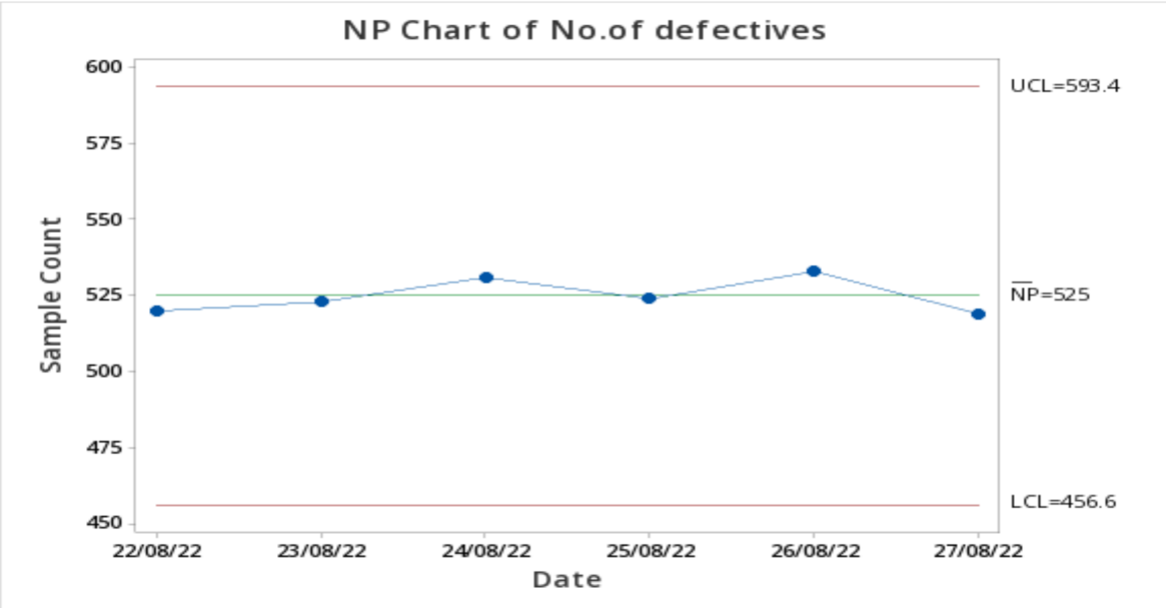

Figure 5.21: np-chart of no. of defectives produced per day

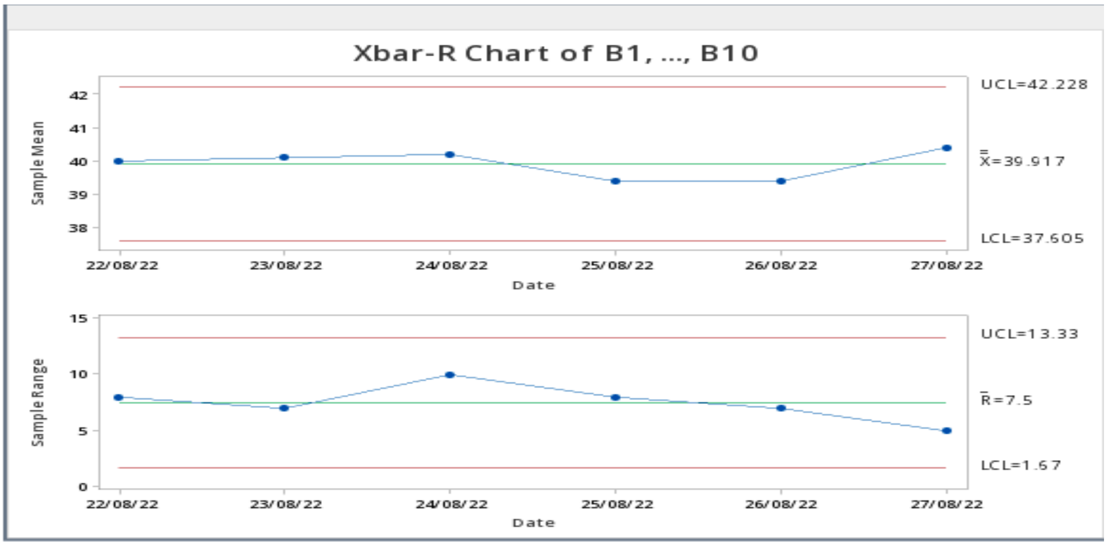

Figure 5.22: Xbar-R chart for monitoring cycle time per batch

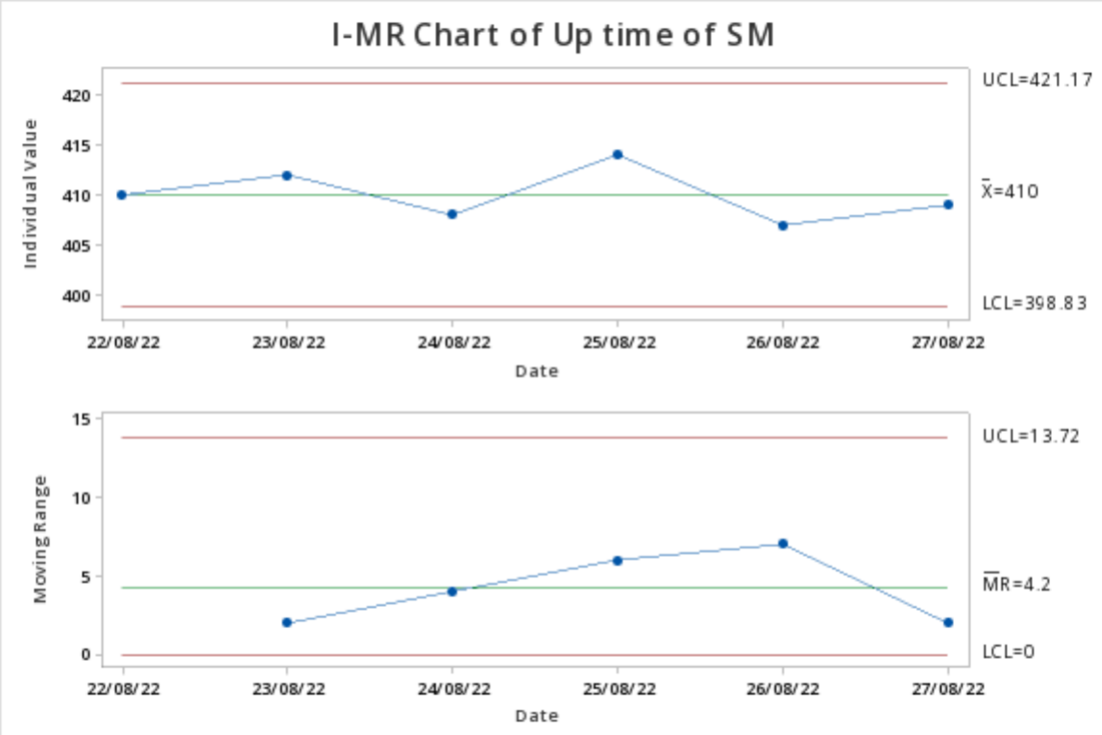

Figure 5.23: I-MR Chart of uptime of SM machine

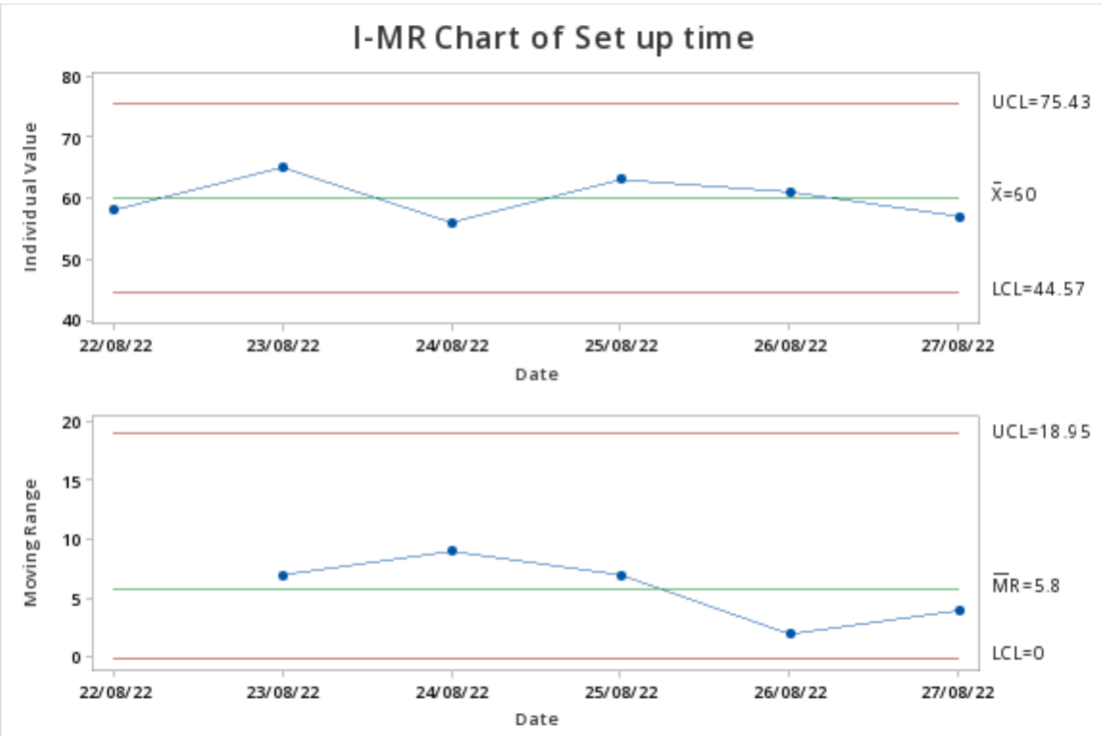

Figure 5.24: I-MR Chart of set-up time of SM machine

Similarly, AEP was advised to monitor the process. These control charts would help to take timely action for out-of-control performance parameters.

5.5.5.4 Reward and Recognition

To take the leverage of the DMAIC project for long-term effective involvement of employees was required. Hence employees were acknowledged and rewarded for their active participation in DMAIC.

5.5.5.5 Documentation of Result and Project Closure

The last step of the control phase was project closure. Figure 5.25 represents the Gantt chart to track the various activities recommended in the implementation plan. The plan was executed well within the target timeline. Table 5.13 represents the results of the project in terms of three dimensions of business measures i.e. efficiency; effectiveness and responsiveness to attain the profitable growth of the organization.

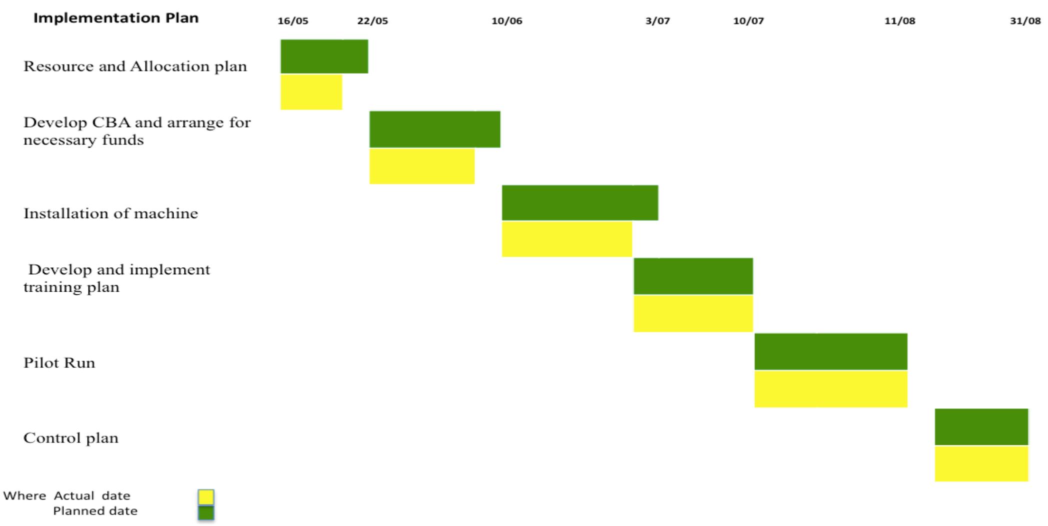

Figure 5.25: Gantt- chart against the implementation Plan

Table 5.14: Results of the project in terms of business performance measure

Business performance	Key performance indicators (KPIs)	Before	After
Lean's efficiency	Manufacturing Cost per unit	.31 INR	0.26 INR
	Process Cycle efficiency	15%	16.60%
	Rework and scrap	11%	5%
	Work in process (WIP) between SM and C&P	25000 PCS	Zero
	Work in the process (WIP) in between slitter and SM	50000 PCS	47000 PCS
	Waiting in a warehouse for MOQ quantity completion	240 min	Zero
	Space creation	NA	115sq ft.
	Set up time slitter	30 min	20 min
	Cycle time (straw manufacturing) for 25000 pcs	66 min	40 min
	Cycle time (Counting and Packaging) for 25000 pcs	80 min	10 min
	OEE	34.10%	60.40%
	Man power reduction in packaging and counting	3	1
	Set up and adjustment time (straw manufacturing)	80min	60min
	Lead time	1166min	60 min
Six Sigma's effectiveness	PPM	999458.1	3178
	Six Sigma level	NA	2.73
	RTY/FTY	89.70%	95%
Agile's Responsiveness	Lead-Time	1166 min	480 min
	Set up and adjustment time (straw manufacturing)	80min	60min
	Service level	Monthly 10 orders were missed on an average	No order was missed in a month
	Variety in packing	100 pcs fix	50,100,200 pcs / packets available
	Flexibility in MOQ	50000pcs	10,000 pcs

5.6 POST-IMPLEMENTATION PHASE

Full-scale implementation of project LSS-AM will be carried out. After implementing the implementation plan on the full scale the organization must be patient to see the positive outcomes of full-scale implementation. It was expected from the CBA analysis that the profit margin of AEP would be increased by INR 13, 08,891

5.6.1 Development of Virtual Enterprises

AEP also did mass customization. For customized straws, AEP gave 15 day lead time to the customers. Although the customization orders were very low, AEP wanted to become more responsive to capture the market share hence was advised to develop a virtual alliance with the suppliers who have in-house printing and die-making capacity to make the overall process more agile.

5.6.2 Customer Feedback Survey and Competitive Analysis

The ultimate aim of any organization is to increase customer satisfaction. AEP was advised to use technology such as CRM to monitor customer complaints and feedback. This system would track the customer's opinion about the product and further help to do a competitive analysis to find the AEP’s relative position in the market and this would help to identify the opportunity for further improvement. This information collected from the market is vital for the success of the organization.

5.7 CONCLUSIONS and LIMITATIONS

The present chapter presents the validation of the framework developed in chapter 4 through an action research-based case study. The case study has been carried out in three phases as per the proposed framework. As one of the project facilitators was the key management member of the organization, this ensured the commitments of other top management members and mitigated the change resistance made by employees. The study has shown the implementation of DMAIC phases in case organization reduces the production lead-time. To carry out this project various tools from lean such as 5S, VSM, Gemba tools from Six Sigma such as Pareto chart, cause, and effect (CE); DOE;

PFMEA; control charts and tools from agile such as automation; virtual enterprises were used prominently in different phases of implementation. The results of the case study revealed that efficiency; effectiveness and responsiveness have significantly improved by eliminating different types of waste; selecting optimum parameters and implementing automation. Further for mass customization virtual enterprises have been developed to fulfill customers varying demands efficiently, effectively, and quickly. By implementing the proposed framework case organization gained tangible benefits in terms of:

- Space creation for 115 Sq. feet for new machine installment.
- Reduction in lead –time from 1166 min (2.4 days) to 480 min (1 day)
- Improvement in production cycle efficiency from 15% to 16.6%
- Improvement in OEE of SM machines from 34.103% to 60.40%
- Improvement in RTY from 89.4% to 95%
- Reduction in order misses PPM from 999458.1 to 3178.
- In Packaging, manpower reduction from 3 to 1
- Reduction in MOQ from 50,000 pcs to of 10,000pcs
- Flexibility in packing from 100 pcs/ packet to 50,100,200 pcs /packet
- Achieve Z_{bench} overall (sigma level) value of 2.73.
- Reduction in unit manufacturing price of straws from .31 INR to .26 INR
- Monthly sales increased from 700000 pcs (14 orders) to 12, 00,000 pcs (24 orders) of straws in a month.
- Annual profit is expected to be increased by 13, 08,891 INR.

Along with these tangible benefits, intangible benefits have been observed in terms of skill upgradation, multiskilling, and improvement in the morale of employees.

Further reduction in lead-time and improvement in service level has improved customer satisfaction and market reputation of the case organization. The limitation of the present study is, the developed framework is validated by a single action research case study in MSME only. Further to check the wider applicability of the framework; this can be implemented in different types and sizes of industries.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

In this chapter, a summary of the research and major conclusions are presented. The objectives of this thesis are (i) To develop LSS and AM CSFs and CFFs (ii) To validate LSS and AM CSFs and CFFs (iii) To develop an integrated implemented framework of LSS & AM based upon the analysis of existing frameworks of LSS and AM (iv) To validate the developed integrated implemented framework through a descriptive statistics analysis and a case study

Chapter 2 presents a systematic literature review of 350 papers on LSS, AM, and their integration published from 2000 to August 2022 to uncover their evolution, definition, and research trends. It exhibits and analyzes the various definitions of LSS, AM, and Leagile, reflecting the scope and goals. Existing literature articles based on LSS, AM, and Leagile were also presented. These articles are analyzed descriptively (Journal and Publishers; Author's Demography, Distribution of papers over time, Research methodology, type of sector, type of approach) and content-wise (critical success factors, critical failure factors, performance outcomes, frameworks, tools/techniques/practices; application in SMEs and SMEs and research trends of integration).

The followings are the key findings drawn from the chapter:

- First, many definitions of LSS, AM, and Leagile have divergent scopes and goals.
- The distribution of articles over some time revealed that the majority of research work in the LSS field was done after 2010 and increased after that. AM trend line represents the moderate amount of work that has been done in the year 2000-2010; after that, AM attracted researchers, and a significant amount of work was

carried out from 2010 to 2022. Leagile amalgamation is attracting researchers as a buzzing area of research. Research articles related to Integrated LSS-AM were found very few and published from 2012 to 2014.

- Region-wise distribution of articles depicts LSS, AM, and Leagile are becoming popular areas of research among researchers across the globe. Indian authors stand-alone are contributing 145 articles out of 350, followed by the UK and US.
- This represents 96 percent of articles published by Academicians only. Industry experts contributed merely 3 percent of research articles. Only 1 percent of authors are both academicians and Industry experts.
- Application of LSS/AM/their integration is found in the manufacturing, service, and process sectors. For example, LSS applications are found in automobile manufacturing to healthcare, Bolt manufacturing to financial services, FMCG to the construction industry, and Large manufacturing to SMEs'. On the other hand, applications of AM and Leagile are mostly found in the manufacturing sector only.
- Multi-criteria decision-making (MCDM) is one of the principal methodologies among the researchers to analyze CSFs and CFFs, followed by a Case study and questionnaire survey. Different authors give a different set of CSFs and CFFs of LSS/AM/Leagile/LSS-AM individually. Only one article depicted the LSS-AM amalgamation's CSFs and two articles represent the LSS-AM amalgamation's CFFs collectively.
- A review of LSS/AM/Leagile/LSS-AM revealed that although researchers have developed many conceptual and implementation frameworks in LSS/AM/ Leagile individually, none of the frameworks that integrate LSS-AM under one

umbrella is found. Therefore, there is a strong need to develop a comprehensive framework that gives step-by-step guidelines to implement LSS-AM simultaneously.

- Performance outcomes of LSS/AM/Leagile/LSS-AM are either theoretically stated by several authors or realized by various organizations after implementing this approach. As a result, many articles represented this performance in tangible or intangible forms.
- These performance outcomes revealed that LSS improves the efficiency and effectiveness of process/service but does not improve responsiveness. In contrast, AM improves responsiveness but does not improve efficiency and effectiveness, whereas Leagile improves efficiency and responsiveness but does not make the process effective. Hence simultaneous implementation of LSS and AM might improve efficiency, effectiveness, and responsiveness in a single effort.
- LSS, AM, and Leagile have been successfully implemented in SMEs and MSMEs. However, the amalgamation of LSS-AM approach implementation is missing.
- Integration of LSS/AM/Leagile with other approaches such as Green; Industry 4.0; Big data is a booming area of research.

Some of the research issues identified from the literature review are:

- Most researchers developed an integrated framework of LSS/AM/Leagile individually. However, only two researchers have developed an integrated framework for LSS and AM implementation, significantly fewer in number. Therefore, a strong need arises to develop an integrated LSS-AM implementation framework that gives step-to-step guidelines to implement LSS-AM simultaneously.

- There is hardly any effort made (only 2) to present a comprehensive analysis of integrated LSS and AM concepts, both from a strategic point of view and Critical success factors and Critical failure factors perspective. Therefore, there is also a need to identify the critical success and failure factors of LSS -AM to make strategies to diminish their adverse impacts.
- Several researchers have used LSS, AM, and Leagile tools/techniques/methodologies/practices individually, but a comprehensive set of tools/techniques/methodologies/practices that integrate LSS and AM is not found. Therefore, there is a need to cohesively set up a toolkit that comprises LSS-AM tools /techniques/methodologies/practices.
- LSS, AM, and Leagile have been successfully implemented in SMEs and MSMEs, and this opens the window for research to implement an integrated LSS-AM approach in SMEs and MSMEs.

Chapter 3 In chapter 3, the CSFs and CFF for LSS and AM execution in the manufacturing industry were identified, structured, and analyzed. The identified factors were statistically validated through SEM. Further Fuzzy Total Interpretive Structural Modeling (TISM) based models were created not only to depict a proper hierarchy among the identified LSS-AM CSFs and CFFs but also to represent the level of influence of one factor on another in manufacturing industries. These are further grouped into 4 clusters using Fuzzy-MICMAC These models offer more robust results as it allows decision-makers to evaluate the effects of system variables on each other. These models of LSS-AM CSFs and CFFs would provide step-by-step guidance to decision providers, scholars, and consultants to implement LSS-AM successfully. This study is different from prior studies on the implication of integrated LSS-AM throughout the implementation in Indian manufacturing industries. First, no significant efforts have been made to identify a comprehensive array of CSFs and CFFS for LSS-AM implementation under one umbrella. Second, no previous relevant scientific research work has been found to integrate the SEM, Fuzzy-TISM and MICMAC approaches for categorizing the CSFs/CFFs of LSS-AM implementation in the manufacturing sector. This hybrid approach not only validated the CSFs /CFFs of LSS-AM implementation but also provide a roadmap for the implementation of LSS-AM to managers; decision-makers and practitioners and help them to prioritize the CSFs and mitigate CFFs as per their driving power and dependence. Third, this study used triangulation research methodology to find the intuitive and accurate knowledge of CSFs and CFFs to make the LSS-AM implementation journey straight sailing in the manufacturing industry.

Chapter 4 provides a comprehensive literature review of 41 frameworks of LSS, AM, Leagile and LSS-AM based on several taxonomies such as type; approach; source; verification and mode of verification. Further, the reviewed frameworks were compared based on abstractness; utilization of frameworks; comprehensiveness and degree of fit basis. A review of frameworks revealed that several researchers, consultants, academicians and practitioners have developed frameworks about LSS, AM and Leagile individually over a period of time but only 2 frameworks have integrated the LSS-AM approach among the 41 frameworks which is significantly very less in number. A review of the existing articles revealed that existing frameworks are flooded with lots of shortcomings. Further comprehensive lists, which comprise the principles, practices, tools and techniques or constructs of LSS-AM collectively are not found at the same time a well-structured implementation framework of LSS-AM, is also not present. In view of this, a comprehensive list of LSS-AM practices, tools, principles, practices, tools and techniques or constructs were prepared. Further considering the strengths and mitigating the weaknesses of the existing frameworks an integrated LSS-AM implementation framework has been developed. The proposed implementation framework encompasses three phases viz., pre-implementation, implementation and post-implementation. The main characteristics of this framework are discussed below:

- The framework accentuates the significance of lean; six sigma and agile in their integration approaches.
- How and the extent to which integrated LSS-AM will benefit needs to be comprehended by both management and employees.
- The organization should identify the LSS-AM's pre-requisite such as drivers; CSFs and CFFs to leverage the drivers and CSFs and mitigate the CFFs before initiating the implementation.
- To make the transition journey smooth, organizations should conduct change management training and LSS and automation training for their employees.
- Both internal and external stakeholders should be involved through training and education for LSS-AM implantation. A further multi-skilled workforce should be developed through training and education.
- The core of the Implementation phase of the LSS-AM framework is the DMAIC approach.
- In the define phase of DMAIC, the LSS-AM implementation team must convert the VOC into CTQs and prioritize those CTQs for project selection. Then developed a clear problem statement.

- In the measure phase, to baseline, the process LSS-AM team should go and see the workplace and develop a high-level SIPOC to understand the process from supplier to customer. Then develop a micro-level process flow diagram and collect the data. Further, calculate the current process capability process.
- In the analyze phase, the LSS-AM team should identify the probable causes behind the problem with various tools and establish the relationship between the actual causes and CTQs.
- Improve phase, the LSS-AM team should generate improvement suggestions to eliminate the causes identified in the analysis phase using different methods and tools and implement the same in the pilot run and the process has improved by process capability analysis. The further team should justify the improvement by cost-benefit analyses and performance measure matrix.
- Control phase, the LSS-AM team should sustain the gains obtained from the DMAIC project by controlling and monitoring the process so that all the efforts made by the project team do not go in vain.
- In the end, project closure should be done and document the result, which consist of documentation of the results of the project and communicating the same to the management.
- To encourage and empower the employees, a rewards and recognition system should be introduced.
- Customer satisfaction should be reviewed

It is believed that developed this implementation framework help to understand the core concept of LSS-AM and will serve as a guiding torch for the practitioner to implement LSS-AM in any organization in real-time.

Chapter 5 presents the validation of the framework developed in chapter 4 through an action research-based case study. The case study has been carried out in three phases as per the proposed framework. As one of the project facilitators was the key management member of the organization, this ensured the commitments of other top management members and mitigated the change resistance made by employees. The study has shown the implementation of DMAIC phases in case organization, to reduce the production lead -time. To carry out this project various elements from lean such as 5S, VSM, Gemba , elements from Six Sigma such as the Pareto chart, cause and effect (CE),DOE, PFMEA, control charts and elements from agile such as automation; virtual enterprises (VE) were used prominently in different phases of implementation. The results of the case study revealed that efficiency; effectiveness and responsiveness have significantly improved by eliminating different types of waste; selecting optimum parameters and implementing automation. Further for mass customization virtual enterprises have been developed to fulfill customers varying demands efficiently, effectively and quickly. By implementing the proposed framework case organization gained tangible benefits in terms of:

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- Improvement in RTY from 89.4% to 95%
- In Packaging, manpower reduction from 3 to 1
- Achieve Z_{bench} overall (sigma level) value of 2.73.
- Reduction in unit manufacturing price of straws from .31 INR to .26 INR
- Reduction in MOQ from 50,000 pcs to of 10,000pcs

- Flexibility in packing from 100 pcs/ packet to 50,100,200 pcs /packet
- Monthly sales increased from 700000 pcs (14 orders) to 12,00,000 pcs (24 orders) of straws in a month.
- Annual profit is expected to be increased by 13,08,891 INR.

Along with these tangible benefits, intangible benefits have been observed in terms of skill upgradation, multiskilling and improvement in the morale of employees. Further reduction in lead-time and improvement in service level has improved customer satisfaction and market reputation of the case organization

Specific Research Contributions of the Thesis

Some specific research contributions of the study:

- This research is a prior attempt to integrate LSS and AM under one umbrella from CSFs; CFFs and framework point of view.
- The comprehensive review of the literature reveals that LSS-AM may be implemented, irrespective of the size of the organization
- CSFs and CFFs of LSS-AM implementation are developed based on an extensive literature review and discussions with the experts' panel.
- A questionnaire survey instrument is developed to collect the data for CSFs and CFFs of LSS-AM implementation.
- The reliability and validity of the LSS-AM CSFs and CFFs models were tested through SPSS 28 and AMOS 26.
- Hierarchy models are developed by the Fuzzy-TISM approach.An implementation framework of integrated LSS-AM is developed based on a critical review of the existing frameworks and discussion with industry experts

- The developed framework is applied in the paper product industry to improve their efficiency, effectiveness and responsiveness.
- The key idea of this research is to help the paper product industries to adopt new integrated business strategies such as LSS-AM in order to take a competitive advantage in the VUCA world.
- This research can be readily extended to other similar industries like ceramic, apparel industries etc., which play a significant role in the nation's economy.

Limitations and Future Scope of the Research

The limitations and future research issues identified from the present study are the following.

- Only research articles available in the Scopus database published during 2000 to August 2022 were considered under review.
- Although the utmost care has been taken while selecting the literature articles, there is the possibility that some of the quality research articles might be left out because of their "Title Only" selection ,low citation criteria and inaccessibility.
- The developed Fuzzy-TISM models of CSFs and CFFs are highly dependent on the perceptions and experience of the experts' panel. In the survey instrument, respondents based on their experience rated CSFs and CFFs and the relevance of those factors to their company hence this lack of objective measures might have created a certain level of biasedness in collected data.
- Only 26 tools /practices/elements were identified for LSS-AM implementation
- The developed framework is validated by a single action research case study, to check the wider applicability of the framework; this can be implemented in different types and sizes of industries.

- The proposed implementation framework does not consider the environmental aspects, which are vital for any organization. Integration of LSS-AM with green practices can be seen as future work.

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A.1 RESEARCH CONTRIBUTIONS MADE BY VARIOUS AUTHORS IN THE FIELD OF LSS, AM, LEAGILE AND LSS-AM

Table A.1: Research contributions

S.No.	Author Name	Author Profile	Country	Year	Industry	Methodology	Work done	Approach
1	Newman *et al.*	A	US	2000	Light Mechanical Assembly	Empirical	Reused the software and hardware design choices to develop an agile manufacturing system	AM
2	Van Hoek	A	UK	2000	Manufacturing	Descriptive & Empirical	Analyzed that, leagility might work well in operational terms because the waste elimination of Lean can contribute to achieving efficiency and responsiveness	Leagile
3	Mason-Jones *et al.*	A	UK	2000	Electronics products	Conceptual & Comparative	Compared lean and agile strategies and developed a road map to becoming a leagile supply chain	Leagile
4	Sanchez and Nagi	A	India	2001		Descriptive	Reviewed 75 agile manufacturing articles based on nine categories, i.e., (i) product and manufacturing systems design; (ii) process planning; (iii) production planning, scheduling, and control; (iv) facilities	AM

							design and location; (v) material handling and storage systems; (vi) information systems; (vii) supply chain; (viii) human factors; (ix) business practices and processes from 1995	
5	Maskell	IE	US	2001		Descriptive	Examined the emergence of agile manufacturing and identified the critical success factors for AM	AM
6	Sharifi and Zhang	A	UK	2001	Manufacturing	Empirical	Proposed a methodology to achieve agility in a manufacturing organization	AM
7	He *et al.*	A	US	2001	Manufacturing	Empirical	Developed a scheduling model for assembly-driven product differentiation strategy in the agile market	AM
8	Gunasekaran and Yusuf	A	US	2002	Generalized	Conceptual	Developed a conceptual framework to present the AM strategies and relevant technology.	AM
9	Gunasekaran *et al.*	A	US	2002	Aerospace Manufacturing	Conceptual & Exploratory Cross-section	Developed a generic conceptual framework and investigated the current level of agility in GEC- Marconi Aerospace	AM

10	Yusuf and Adeleye	A	UK	2002	Manufacturing	Comparative and Exploratory Cross-Section	Proved by exploratory analysis that increasing market instability is a threat to lean production and adoption of agile manufacturing is the solution	AM
11	Antony *et al.*	A	UK	2003		Comparative	Compared to Six Sigma, lean approaches found that maximum benefits can be obtained by blending the best of each.	LSS
12	Moore *et al.*	A	UK	2003	Manufacturing	Descriptive & Empirical	Proposed a virtual engineering approach for designing and controlling agile, modular machinery design	AM
13	Brown and Bessant	A	UK	2003	Automotive	Exploratory Longitudinal	Established a link in manufacturing strategy and two paradigms, i.e.agile and mass customization manufacturing strategy	AM
14	Jin-Hai *et al.*	A	UK	2003	Generalized	Conceptual	Develop a conceptual Real agile manufacturing framework based on four fundamentals	AM
15	Sharma	A	India	2003	Battery Manufacturing	Exploratory Longitudinal	Implemented Six Sigma's DMAIC approach with lean tools in a battery	LSS

							manufacturing company to reduce the cost of capital and streamline the manufacturing process	
16	Elkins *et al.*	IE	US	2004	Automotive	Comparative & Empirical	Developed two decision models, i.e., spreadsheet and decision model for selection of AM and FM	AM
17	Guisinger and Ghorashi	IE	US	2004	Chemical industry	Descriptive & Empirical	Analyzed the trends of Agile practices and virtual organizations in the chemical industry	AM
18	Arnheiterand Maleyeff	A	US	2005		Comparative	Performed a comparative analysis of lean and six sigma and found that integration of Lean and Six Sigma will overcome the limitation of each when applied in isolation in any organization	LSS
19	Furterer and Elshennawy	A	US	2005	Local government service industry	Exploratory Longitudinal	Implemented LSS to improve the quality and timeliness of providing local government services	LSS
20	Marti	IE	Switzerland	2005	Healthcare	Descriptive	Reviewed the challenges of implementing LSS in clinical trial phase 1.	LSS

21	Pickrell *et al.*	A	US	2005	Precision slip ring and integrated motion systems manufacturing	Exploratory Longitudinal	Implemented hybrid Lean and Six Sigma approach in the manufacturer of precision slip rings and integrated motion to reduce cost, cycle time, customer returns, and inventory and increase production capacity.	LSS
22	Cao and Dowlatshahi	A	US	2005	Manufacturing	Empirical	Empirically validated the relationship between enablers of agile manufacturing, i.e., virtual enterprises and information technology to business performance.	AM
23	Devadasan *et al.*	A	India	2005	Pump Manufacturing	Exploratory Longitudinal	Developed and implemented orthogonal array-based experimentation Taguchi model to enhance the quality of the agile manufacturing environment	AM
24	De Koning *et al.*	A	US	2006	Healthcare	Descriptive & Exploratory Cross-Section	Outlined the synergy of lean and six sigma to control the cost; improve the quality, and give better health care in the hospital	LSS
25	Van den Heuvel *et al.*	A	Netherland	2006	Healthcare	Exploratory Longitudinal	Outlined the synergy of lean and six sigma in a hospital	LSS

							environment	
26	Su *et al.*	A	Taiwan	2006	IT-help desk	Empirical	Evaluated the effectiveness of integrated LSS in an information technology help desk	LSS
27	Bendell	A	UK	2006		Conceptual & Comparative	Compared and proposed an integrated heart shape approach for Lean and six sigma	LSS
28	Adeleye and Yusuf	A	UK	2006	Manufacturing	Comparative & Exploratory Cross- Section	Compared Lean, flexibility, and Agile manufacturing competitive models and established their relationship with business performance	AM
29	Onuch *et al.*	A	UK	2006	Manufacturing	Empirical	Established that rapid prototyping and reverses engineering are the enablers of AM	AM
30	Ismail *et al.*	A	UK	2006	Shower and bathtub manufacturing	Descriptive & Empirical	Developed an agility roadmap for SMEs	AM
31	Gibbons	A	UK	2006	Manufacturing	Descriptive & Exploratory Longitudinal	Applied triangulation approach using LSS to improve the OEE of plant	LSS
32	Kumar *et al.*	A	UK and India	2006	SME: Automobile die casting	Exploratory Longitudinal	Implemented LSS framework to reduce the defect in a die-casting process	LSS

33	Vázquez-Bustelo and Avella	A	Spain	2006	Automotive	Conceptual & Empirical	Developed a conceptual framework and empirically analyzed it through four case study	AM
34	Agarwal *et al.*	A	India	2006	FMCG	Exploratory Cross-Section	Investigated the relationship between the lead time, cost, quality, and service level and the leanness and agility through ANP	Leagile
35	Byrne *et al.*	IE	US	2007		Conceptual	Discussed the role of LSS in innovation	LSS
36	Ramesh and Devadasan	A	India	2007		Descriptive	Developed a conceptual model of agile manufacturing based on the 20 criteria. An extensive literature review identified these 20 criteria.	AM
37	Hasan *et al.*	A	India and US	2007	Manufacturing	Conceptual & Empirical	Studied and Identified AM barriers and established contextual relationships among them	AM
38	Yauch	A	US	2007	Manufacturing	Descriptive	The analyzed team attributes needed to deploy AM using the balance theory framework	AM
39	Zhang and Sharifi	A	UK	2007	Manufacturing	Exploratory Cross-Section	Proposed and analyzed an implementation framework of agility as a manufacturing	AM

							strategy	
40	Krishnamurthy and Yauch	A	US	2007	Manufacturing	Descriptive & Exploratory Cross-Section	Developed a theoretical-based leagile framework and demonstrated how the legality concept could be applied in multi-unit corporate enterprise.	Leagile
41	Näslund	A	US	2008		Comparative	Performed a comparative literature analysis of Six sigma to Total quality management and Lean-to -Just in time	LSS
42	Shah *et al.*	A	India	2008	Manufacturing	Comparative & Empirical	Compared the synergic performance of lean and Six Sigma with the isolated performance of lean	LSS
43	Proudlove *et al.*	A	UK	2008	Healthcare	Comparative	Examined the experience implementation of Six Sigma in healthcare and used the same to implement lean practices	LSS
44	Hu *et al.*	A	US	2008	Semiconductor manufacturing	Empirical	Developed a multi-objective decision-making model for project selection in LSS.	LSS
45	Thomas *et al.*	A	UK	2008	Small engineering	Exploratory Longitudinal	Proposed and cost-effectively implemented integrated LSS	LSS

							framework at SMEs	
46	Pranckevicius *et al.*	A	US	2008	Cup manufacturing	Exploratory Longitudinal	Deployed LSS DMAIC model in plastic cup manufacturing to improve the process	LSS
47	Jin *et al.*	A	US	2008	Healthcare	Empirical	Implemented lean thinking principles and six sigma procedure in health care logistics center	LSS
48	Shahin and Alinavaz	A	IRAN	2008		Conceptual & Comparative	Compared Lean and Six Sigma and studied the integration of LSS and their frameworks	LSS
49	Ilyas *et al.*	A	India	2008	Petrochemical industry	Empirical	Explained the role of outsourcing to achieve the triple objective: flexibility, agility, and leanness	Leagile
50	Hasan *et al.*	A	India and US	2008	Manufacturing	Empirical	Design and implement a procedure to select a supplier for an organization in an agile manufacturing environment	AM
51	De Koning *et al.*	A	Netherlands	2008	Financial	Empirical	Developed an integrated framework of LSS and implemented it in the financial service sector in dutch and found LSS can bring significant results and improvement	LSS

52	Chen and Lyu	A	Taiwan	2009	Touch panel	Empirical	Developed an integrated LSS framework to improve the quality of touch panel manufacturing	LSS
53	Langabeer *et al.*	A	US	2009	Healthcare	Empirical	Developed a goal theoretic model to test the fitness of LSS in healthcare	LSS
54	Fraser and Fraser	IE	US	2009	Financial organization	Empirical	Implemented an integrated LSS approach in the service industry.	LSS
55	Nambiar	A	US	2009		Descriptive	Developed a taxonomic framework of AM from a state of the art review	AM
56	Hasan *et al.*	A	India	2009	Manufacturing	Descriptive & Empirical	Established mutual relationship among AM enablers through Interpretive Structural modeling	AM
57	Chan *et al.*	A	Hong Kong	2009	Manufacturing	Empirical	Developed a process planning and scheduling model based on leagile and outsourcing principles	Leagile
58	Gore *et al.*	A	India	2009	Finnish steel products network	Exploratory Cross-Section	Identified five enablers of AM and their role in competitive advantage were tested through exploratory factor analysis	AM
59	Hallgren, and Olhager	A	Sweden	2009	Manufacturing	Empirical	Empirically investigated the external and internal	Leagile

							drivers of lean and agile selection and their impact on quality, delivery, cost, and flexibility performance.	
60	Snee	IE	US	2010		Descriptive	Identified the critical advancement of LSS over the last 10-15 years and discussed the new rising trends that suggested the need for methodology evolution	LSS
61	Pepper and Spedding	A	Australia	2010		Descriptive	Reviewed the existing LSS literature and developed a conceptual model of LSS for continuous improvement	LSS
62	Delgado *et al.*	A	Portugal	2010	Financial organization	Exploratory Longitudinal	Implemented LSS in financial services and observed reduction in the operational costs; improvement in process and quality; enhancement of inefficiency, which further improves the agility.	LSS
63	Kanakana *et al.*	A	South Africa	2010	Education Industry	Exploratory Longitudinal	Implemented LSS framework in engineering education university to improve the throughput rate and increase the faculty revenue.	LSS

64	Gnanaraj *et al.*	A	India	2010	SME Foundry	Exploratory Longitudinal	Developed a DODMAICS implementation framework for LSS implementation in SMEs. It consists five-level	LSS
65	Shukla and Wan	A	US	2010	Manufacturing	Empirical	Developed a leagile inventory location model to optimize the cost of inventory	Leagile
66	Huang and Li	A and IE	Taiwan	2010	Personal Computer Original Equipment Manufacture	Descriptive & Empirical	Presented the journey PC OEM process leagility by converting built to configuration-to-order (CTO)	Leagile
67	Vinodh *et al.*	A	India	2010(a)	Electronics Switch Manufacturing	Exploratory Longitudinal	Developed an integrated model of Mass customization and Agile manufacturing and implemented it in Electronics Switch Manufacturing	AM
68	Vinodh *et al.*	A	India	2010(b)	Pump Manufacturing	Exploratory Longitudinal	Developed and implemented an integrated model of AM using CAD and rapid prototyping technologies in product development to satisfy the varying customer demands in a shorter time	AM

69	Shahin and Jaberi	A	IRAN	2011	Ghods manufacturing truck body parts	Descriptive & Exploratory Longitudinal	Proposed a leagile production model consisting of 3 strategies and found out the effect of this model on the quality of the process by DMAIC approach.	LSS-AM
70	Sreenivasa and Devadasan	A	India	2011		Descriptive	Reviewed the existing literature on AM to explore the manufacturing areas where AM application was found.	AM
71	Carvalho *et al.*	A	Portugal	2011		Descriptive & Comparative	Explored the divergences and commitments between the lean, agile, resilient, and green paradigms and investigated the effect of paradigms and practices within supply chain attributes.	LSS
72	Vinodh and Kuttalingam	A	India	2011	Automotive sprocket manufacturing	Exploratory Cross-Section	Investigated computer-aided design (CAD) and computer-aided engineering (CAE) are the enablers of AM through cross-section analysis.	AM
73	Vinodh *et al.*	A and IE	India and US	2011	Automobile valve manufacturing	Exploratory Longitudinal	Developed and deployed the LSS framework in automotive valve manufacturing	LSS

74	Vinodh *and* Chintha	A	India	2011	Rotary switch manufacturing	Exploratory Cross-Section	Validated the fuzzy Quality function deployment role in enhancing the agility of the organization through a case study in rotary switch manufacturing	AM
75	Hilton and Sohal	A	Australia	2012	Manufacturing and service	Conceptual & Empirical	Developed a conceptual framework of LSS CSFs and validated it by hypothesis testing	LSS
76	Chakravorty *et al.*	A	USA	2012	Home furnishing	Exploratory Longitudinal	Implemented LSS into home furnishing industries using 5 phases.	LSS
77	Maleyeff *et al.*	A	USA	2012		Descriptive	Identified the challenges related to implementations of LSS and Value definition Risk factors, Workforce considerations, and the Regulatory environment were the primary modification to standard LSS.	LSS
78	Cheng *et al.*	A	Taiwan	2012	Non -profit	Exploratory Longitudinal	Implement LSS in nonprofit organization. Results revealed that there is a reduction of 70 percent in non-value-added activities.	LSS

79	Pamfilie *et al.*	A	Romania	2012	Service Industry	Empirical	Depicts the role of leadership in the successful deployment of LSS in any organization and linked it with LSS vision and found it helps to achieve employee satisfaction and motivation	LSS
80	Timans *et al.*	A	Netherland	2012	Dutch SME (Manufacturing)	Exploratory Longitudinal	Applied LSS roadmap in SME	LSS
81	Jayaraman *et al.*	A	Malaysia	2012	EMS	Empirical	Identified CSFs and analyzed their impact on LSS implementation in electronic manufacturing services are validated empirically	LSS
82	Gupta *et al.*	A	India	2012	Tyre Manufacturing	Exploratory Longitudinal	Implemented the LSS in the Indian tyre manufacturing industry to reduce excessive defects of a radial tyre and find out the presence of foreign particles in the manufacturing environment and inefficient bead winding process were the leading root causes behind the defects.	LSS

83	Bailey *et al.*	A	USA	2012	Aircraft Manufacturing	Conceptual & Empirical	Implemented LSS in the aircraft manufacturing industry of West Michigan successfully. Results revealed that the implementation raised sales from 30 million dollars per year to 205 million.	LSS
84	Psychogios *et al.*	A	Greece	2012	Telecommunication service industry	Empirical	Developed a multifactor approach for LSS implementation in a telecommunication service industry	LSS
85	Chiarini	IE	Italy	2012	Health care sector	Exploratory Longitudinal	Implemented LSS DMAIC approach in the pharmacy department to reduce health and safety risks of nurses and physicians who manage cancer drug	LSS
86	Gnanaraj *et al.*	A	India	2012	SMEs	Exploratory Longitudinal	Developed a deficiency overcoming Lean Anchorage Define Measure Analyze Improve Control Stabilize (DOLADMAICS) model, which has five-level. Implemented its first level in an SME.	LSS
87	Arumugam *et al.*	A	UK	2012	Airlines	Descriptive & Empirical	Used LSS methodology at airport	LSS

							services to improve process speed and reduce variability	
88	Pillai *et al.*	A	India	2012	Software Industry	Exploratory Longitudinal	Deployed LSS framework in software development to achieve operational excellence and innovation	LSS
89	Wang and Chen	A	Taiwan	2012	PANEL Equipment manufacturer	Exploratory Longitudinal	Demonstrated the application of the LSS approach in forecasting the manufacturing cost for flat panel display manufacturers.	LSS
90	Psychogios and Tsironis	A	Greece	2012	Airlines	Conceptual & Exploratory Cross-section	Identified enablers and barriers by a case study in the airline industry. Proposed an integrated LSS framework based on what, how, and who.	LSS
91	Dibia *et al*.	A	Nigeria	2012	Manufacturing	Comparative & Empirical	Compared and validated the relation of Lean practices with quality management practices in an agile system environment based on leadership, people, process, and outcome point of view	Leagile

92	Dibia and Onuh	A	Nigeria	2012	Laundry machine manufacturing energy systems manufacturing	Descriptive & Empirical	Developed and deployed LPPO (Lean leadership, people, process and outcome) model in two manufacturing industries and identified key enablers of LSS in an agile environment	LSS-AM
93	Gremyr and Fouquet	A and IE	Sweden and France	2012	Manufacturing	Empirical	Analyzed the potential benefits and risks of merging design for six sigma and lean in new product development	LSS
94	Al-Aomar	A	UAE	2012	Construction industry	Exploratory Longitudinal	Demonstrated the construction industry's lean and six sigma practices to reduce waste and cost, increase effectiveness, and improve quality.	LSS
95	Soni and Kodali	A	India	2012	Indian manufacturing	Empirical	Evaluated the reliability and validity of lean, agile, and leagile supply chain constructs in the Indian manufacturing industry through principal component analysis	Leagile
96	Mishra *et al.*	A	India	2012	Manufacturing	Exploratory Cross-Section	Identified and developed a hierarchy model of agile manufacturing drivers through ISM	AM

97	Laureani and Antony	A	UK	2012(a)		Descriptive	Given an overview of various existing certifications of LSS.	LSS
98	Antony *et al.*	A	UK	2012	Education sector	Descriptive	Identified critical success factors and barriers to LSS implementation in higher education institutions.	LSS
99	Laureani and Antony	A	UK	2012(b)	General	Descriptive & Empirical	Identified CSF of LSS from a vast literature review and rated the CSFs empirically	LSS
100	Assarlind *et al.*	A	Sweden	2013	Manufacturing	Empirical	Discussed the multifaceted view on LSS by individual organizations and discussed that there is no standardized way to implement LSS in the organization.	LSS
101	Atmaca and Girenes	A	Turkey	2013	White goods company	Exploratory Longitudinal	Implemented LSS"DMAIC" approach in a 45 cm manufacturing line in a white goods manufacturing industry	LSS
102	Laureani *et al.*	A	Ireland	2013	Hospital	Exploratory Longitudinal	Implemented the LSS by students in the hospital environment through different projects and found	LSS

							various benefits	
103	Chiarini and Bracci	A	ITALY	2013	Hospital	Empirical	Examined the way of LSS implementation in 2 public sector hospitals in Italy.	LSS
104	Gitlow and Gitlow	A	US	2013	Hospital	Conceptual	Suggested that to reduce the increasing hospital cost by switching the traditional management approach to Deming LSS management	LSS
105	Campos	A	Brazil	2013	Manufacturing	Conceptual & Empirical	Developed an instrument based upon the PNQ model to evaluate the lean six sigma elements in one brazil manufacturing industry.	LSS
106	Lee *et al.*	A	UK and Korea	2013	Manufacturing	Comparative &Empirical	Compared lean six sigma practices in South Korea and the UK and found that UK adopts the practices more than Korea	LSS
107	Prasanna and Vinodh	A	India	2013	SME	Descriptive & Empirical	Proposed a model of LSS for SME and validated empirically	LSS
108	Hasan *et al.*	A	India	2013	Manufacturing	Empirical	Developed a model of 14 agile practices through ISM	AM

109	Aravind Raj *et al.*	A	India	2013	Automotive components manufacturing company	Exploratory Longitudinal	Used graph theoretic approach to calculate agility index automotive components manufacturing	AM
110	Chang *et al.*	A	Taiwan	2013	OEM	Exploratory Longitudinal	Applied ISM-ANP approach to prioritize the critical agile factors in new product development at OEM.	AM
111	Matawale *et al.*	A	India	2013	Manufacturing	Exploratory Cross-Section	Developed an ISM framework for lean; agile; leagile enablers	Leagile
112	Elmoselhy	A	Netherland	2013	Automotive sector	Descriptive & Exploratory Longitudinal	Presented a hybrid lean-agile manufacturing system in the automotive industry using four technical facets, i.e., Flexible, focused factory, globalized fractal E-manufacturing, innovative value chain strategies, and designing dynamic manufacturing strategies	Leagile
113	Lemieux *et al.*	A	UK and US	2013	Luxury product industry	Descriptive & Exploratory Cross-Section	Proposed an operational approach to identify adequate leagile improvement initiatives based on performance targets and an adoption	Leagile

							alignment framework in the product development process.	
114	Mutingi	A	South Africa	2013	Manufacturing	Empirical	Investigated the impact of the application of lean and just-in-time policies on a traditional inventory-focused manufacturing system and provided valuable managerial insights for effective implementation of lean and agile manufacturing paradigms	AM
115	Nicoletti	A	Italy	2013	Manufacturing	Exploratory Longitudinal	Demonstrated how the lean Six Sigma method and information can be integrated with the procurement process to reduce the wastes	LSS
116	Bhat and Ganesh	A	India	2013	Hospital	Exploratory Longitudinal	Used lean and DMAIC approach in a hospital to reduce the turnaround time of health records preparation	LSS
117	Sarkar *et al.*	A	India	2013	Insurance company	Exploratory Longitudinal	Applied Lean with six sigma in the service industry to reduce the cycle time of claim settlement in an insurance company	LSS

118	Drohomeretski *et al.*	A	Brazil	2014	Manufacturing	Comparative & Exploratory Cross- Section	Done a comparative and exploratory analysis of lean six sigma and found that LSS gives a more competitive edge than applying lean six sigma in isolation	LSS
119	Antony	A	UK	2014	Education industry	Descriptive	Identified readiness factors for LSS implementation in higher education	LSS
120	Albliwi *et al.*	A	UK	2014		Descriptive	Done a systematic literature review to identify critical failure factors of LSS in service, manufacturing, and other industries	LSS
121	Tenera and Pinto	A	Portugal	2014	Telecommunication service industry	Exploratory Longitudinal	Proposed and validated project management Based lean six sigma model in the telecommunication industry.	LSS
122	Bhat *et al.*	A	India	2014	Health care sector	Exploratory Longitudinal	Develop an integrated LSS model for the healthcare sector. Implementation model in hospitals reduces the cycle time from 3 to 1.5 min; 94% reduction in patient waiting time	LSS
123	Youssouf *et al.*	A	Romania	2014	manufacturing	Conceptual	Developed an integrated framework of LSS based on the DMAIC approach to	LSS

							optimize the maintenance process in the industry	
124	Gijon and Antony	A	India	2014	Hospital	Exploratory Longitudinal	Implemented the Lean Six Sigma approach in a hospital to reduce the average waiting of the patient. Results revealed a significant drop (9.27 from 31.15 min.) in average waiting time of the customer.	LSS
125	Lertwattanapongchai and Swierczek	A	Thailand	2014	MNC company	Comparative &Empirical	Identified CSFs of LSS through extensive literature review and developed a conceptual LSS framework compared the fewer practices in 3 Thailand-based MNCs.	LSS
126	Andersson *et al.*	A	Sweden	2014	Telecom manufacturing	Exploratory Longitudinal	Conducted LSS project in the telecommunication manufacturing line and proved that integrated LSS would improve cost, robustness, flexibility, and agility at the same point in time	LSS
127	Assarlind and Aaboen	A	Sweden	2014	SMEs	Empirical	Identified converters and exhibitors for gradual adoption of LSS in small-medium size Swedish	LSS

							manufacturing industry	
128	Lighter	A	US	2014	Health care	Empirical	Described the LSS benefits in a pediatric hospital to reduce waiting time, cost reduction, and medication error.	LSS
129	Van den Bos *et al.*	A	Netherland	2014	Construction industry	Exploratory Cross-Section	Identified the reason behind the long throughput time in 62 projects of LSS in the construction industry and recommendation for an efficient LSS execution in the construction industry	LSS
130	Anderson and Kovach	A	US	2014	Construction industry	Exploratory Longitudinal	Implemented LSS in the construction industry to reduce welding defects in turnaround projects.	LSS
131	Arthur	A	US	2014	Construction industry	Descriptive	Described the success of the LSS approach in the E-470 Public Highway Authority as they implemented a result-focused approach of LSS rather than floor to approach.	LSS
132	Besseris	A	US	2014	Food industry	Empirical	Empirically validated a multifactorial method to implement LSS in the food industry.	LSS

133	Bhat and Jnanesh	A	India	2014	Health care sector	Exploratory Longitudinal	Implemented LSS in an Indian hospital. Results revealed a significant drop in average waiting time (97%) and queue length (91%).	LSS
134	Panat *et al.*	A	US	2014	Research and development	Exploratory Longitudinal	Implemented LSS in R&D to reduce waste and improve system performance.	LSS
135	Vinodh *et al.*	A	India	2014	Indian rotary switches manufacturing	Exploratory Longitudinal	Deployed LSS methodology in rotary switches manufacturing industry to reduce product defects FTY and enhance the customer satisfaction	LSS
136	Timans *et al.*	A	UK	2014	SME	Descriptive & Empirical	Proposed a three-phase framework for LSS deployment in SMEs	LSS
137	Arvind Raj *et al.*	A	India	2014	Switch Manufacturing	Exploratory Longitudinal	Used the ANP-Fuzzy TOPSIS approach to prioritize the gape of agility gaps in AM project	AM
138	Mehrsai *et al.*	A	Germany	2014	Manufacturing	Comparative &Empirical	Clarified the role of autonomy in lean and agile logistics through simulation	Leagile
139	Purvis *et al.*	A	UK	2014		Descriptive	Explored the meaning of flexibility in lean, agile, and leagile supply networks and articulated a supply	Leagile

							network flexibility framework.	
140	Ismail *et al.*	A	Malaysia	2014	Manufacturing	Exploratory Longitudinal	The LSS tools of DMAIC were applied to determine wastage to reduce the cycle time production in a biopharmaceutical operation.	LSS
141	Banawi and Melissa	A	US	2014	Construction industry	Exploratory Longitudinal	Developed and implemented an integrated framework of lean six sigma and green approaches in the construction industry. This framework provides a bunch of multistage approaches for improving the quality of the process and minimizing the construction industry's environmental impacts.	LSS
142	Garza-Reyes *et al.*	A	UK	2014		Descriptive & Comparative	Discussed green and lean approaches, limitations, and benefits of integrating six sigma with lean green	Combined
143	Albiwi *et al.*	A	UK	2015		Descriptive	Reviewed 37 LSS papers published in the years 2003-2013. Discussed the benefits, critical success factors,	LSS

							barriers, and limitations of LSS in the manufacturing field.	
144	Knapp	A	US	2015	Health care sector	Empirical	Analyzed the relationship between organizational culture and three components of LSS implementation in the healthcare sector	LSS
145	Isa *et al.*	A	US	2015	Education sector	Exploratory Longitudinal	Implemented LSS in construction services to improve the quality of facilities in a university	LSS
146	Hess and Benjamin	A	US	2015	Education sector	Descriptive	Reviewed the application of LSS in the education sector in the past three decades and identified the significant roadblocks in implementing the LSS process.	LSS
147	Douglas *et al.*	A	East Africa	2015	Manufacturing and service	Empirical	Identified CSFs and barriers of LSS in East African service and manufacturing sectors. Also found that the seven QC tools are critical in LSS implementation.	LSS
148	Bakar *et al.*	A	Malaysia	2015		Descriptive	A total of five significant CSFs were identified using an affinity diagram using 97 CSFs from 13 papers.	LSS

149	Dora and Gellynck	A	Belgium	2015	Food industry	Exploratory Longitudinal	Developed, Implemented LSS framework in the medium-sized confectionary industry to reduce the overfilling in gingerbread and reduce the rework to increase the bottom line result.	LSS
150	Nunes	A	Portugal	2015	SME	Conceptual	Developed an integrated framework of LSS and Ergonomics to improve productivity and working conditions.	LSS
151	Mason *et al.*	A	UK	2015	Health care	Descriptive	Done a systematic review to explore the uses of lean six sigma as a quality improvement approach in surgery at a hospital and found that an integrated approach has clinically significant potential for improvement in surgical patients	LSS
152	Indrawati and Ridwansyah	A	Indonesia	2015	Iron ore manufacturing	Exploratory Longitudinal	Developed an integrated LSS program to overcome the long waiting and processing time and type of waste that frequently occurred in operating procedures.	LSS

153	Sanders	A	US	2015	Health care sector	Exploratory Longitudinal	Implemented integrated LSS to reduce the turnaround time (TAT) for emergency department (ED) specimens in a hospital	LSS
154	Randall and Maleyeff	A	US	2015	Investment sector	Empirical	Used LSS to improve investors' behavior to make rational decisions during investments.	LSS
155	Ndaita *et al.*	A	Kenya	2015	Banking sector	Empirical	Assessed the stage of LSS implementation among the five stages in a national bank operational division in Kenya.	LSS
156	Sahay	IE	India	2015	Service Industry (Higher education)	Empirical	Used LSS approach in the talent acquisition process	LSS
157	Sunder	A	India	2015	Corporate	Comparative &Empirical	Highlighted the commonalities and differences between lean and six sigma from a corporate perspective	LSS
158	Vinodh and Swarnakar	A	India	2015	Automotive industry	Empirical	Used hybrid MCDM techniques to select the optimal project for LSS in an automotive manufacturing industry.	LSS
159	Chiarini	A	Italy	2015	Plastic mould manufacturer	Exploratory Longitudinal	Implemented LSS in plastic mould manufacturer to	LSS

							improve the OEE	
160	Svensson *et al.*	A	Saudi Arabia and the UK	2015	Higher education	Empirical	Observed the benefits of LSS deployment in vast-scale projects rolling out in the university to enhance the business performance and efficiency	LSS
161	Cabrita *et al.*	A	Portugal	2015	Bolts manufacturing	Exploratory Longitudinal	Deployed LSS approach in the bolt manufacturing industry to reduce downtime of stamping	LSS
162	Sreeram and Thondiyath	A	India	2015	Valve and tank manufacturing	Empirical	Proposed an integrated lean and six sigma system design engineering framework based on Deming's PDCA cycle and verified applicability by three system design case study	LSS
163	Dubey and Gunasekaran	A	India	2015	Manufacturing industry	Descriptive & Empirical	Developed a theoretical framework of AM and validated empirically by confirmatory factor analysis	AM
164	Soltan and Mostafa	A	Australia	2015	Manufacturing	Empirical	Developed a hierarchy-based lean-agile framework with the help of the AHP-ANP approach and also proposed a healthy	Leagile

							enterprise model.	
165	Lemieux *et al.*	A	France	2015	Luxury product industry	Descriptive	Proposed a leagile transformation model for product development that guides manufacturers in the construction of a road map and the management of its deployment in line with both lean and agile improvement objectives	Leagile
166	Suomalainen *et al.*	A	Finland	2015	Software Industry	Descriptive & Empirical	Proved empirically that continuous planning is an essential aspect of Agile and lean product development	Leagile
167	Abdollahi *et al.*	A	IRAN	2015	Manufacturing	Empirical	Developed a model for supplier selection in the lean and agile organization by Hybrid ANP, data envelopment, and FUZZY DEMATEL	Leagile
168	Garza-Reyes	A	UK	2015		Descriptive & Comparative	Reviewed green lean integrated approaches and discussed the green lean limitation, and investigated its compatibility with six sigma	Combined

169	Kumar *et al.*	A	India	2015	Manufacturing	Empirical	Developed an integrated framework of LSS, green and sustainable approach. Barriers and critical success factors were also identified.	LSS
170	Sreedharan and Raju	A	India	2016		Descriptive	Performed literature review of 235 LSS articles from 2003 to 2015. Analyzed the articles on-time distribution, author, profile, research methodologies, and sector basis.	LSS
171	Yadav and Desai	A	India	2016		Descriptive	Done 189 LSS papers review from 58 journals published from 2001 to 2014.	LSS
172	Swarnakar and Vinodh	A	India	2016	Automotive component manufacturing	Exploratory Longitudinal	Deployed Lean Six Sigma (LSS) framework to facilitate defect reduction and enhance bottom-line results of an automotive component manufacturing organization.	LSS
173	Antony *et al.*	A	UK	2016	Manufacturing	Exploratory Longitudinal	Investigated the link between LSS and innovation through regression analysis. Results revealed that LSS fosters incremental process	LSS

							innovation. However, it also can influence radical/breakthrough innovation.	
174	Garza-Reyes *et al.*	A	Oman	2016	Iron Ore Pelletising	Exploratory Longitudinal	Deployed LSS approach in the iron ore palletizing manufacturing industry to reduce defects and improve process capability	LSS
175	Thomas *et al.*	A	UK	2016	Aerospace manufacturing company	Exploratory Longitudinal	Proposed a new Strategic Lean Six Sigma Framework (SLSSF) that attempts to create a more balanced and integrated approach between the Lean and Six Sigma elements.	LSS
176	Tsironis, and Psychogios	A	Greece and UK	2016	Service Industry	Conceptual & Exploratory Longitudinal	Identified CSFs and developed a multi-factored model for the Service industry	LSS
177	Chaurasia *et al.*	A	India	2016	Oil sector	Conceptual	Proposed a LSS implementation framework to improve the performance of oil-exporting countries during the economic pitfall and recession	LSS
178	Leite and Braz	A	Portugal	2016	Manufacturing	Exploratory Cross-Section	Described an exploratory methodology approach to identify the appropriate AM	AM

							practices and their effects on operational performance.	
179	Dev and Kumar	A	India	2016	OEM	Empirical	Analyzed and prioritized the critical success factors through AHP approach	AM
180	Sindhwani and Malhotra	A	India	2016a	Manufacturing	Exploratory Cross-Section	Identified and analyzed the attributes which influence the implementation process AM and each other as well fuzzy agility evaluation (FAE) approach and questionnaire survey	AM
181	Shahin *et al.*	A	US and Iran	2016	Manufacturing	Descriptive & Empirical	Developed a method to determine the decoupling point in the leagile chain.	Leagile
182	Sindhwani, and Malhotra	A	India	2016b	Manufacturing	Exploratory Cross-Section	Presented an intangible framework of various barriers associated with AMS and presented in the form of a single numerical index value along with their performance through the fuzzy performance importance index (FPII) approach	AM
183	Nurdiani *et al.*	A	Switzerland	2016	Software	Exploratory Longitudinal	Conducted a Tertiary study to find empirical evidence regarding the impact of Lean practices and agile	Leagile

							practices and their impacts on project constraints risk.	
184	Kumar *et al.*	A	India	2016	Foundry	Empirical	Empirically investigated the awareness of Agile manufacturing in Indian SMEs	AM
185	Sharma and Kulkarni	A	India	2016	Army vehicle	Exploratory Longitudinal	Discussed the concepts of lean and agile to manage the spares parts of the army and to make use of them at the opportune time	Leagile
186	Mostafa *et al.*	A	US	2016	Construction	Descriptive	Developed a thematic framework of lean and agile principles for the offsite construction industry	Leagile
187	Leite *et al.*	A	Portugal	2016	SME	Descriptive	Proposed a road lean and agile implementation in the product development stage through IPID (Identity, prioritize, disseminate, implement)	Leagile
188	Lande *et al.*	A	Qatar and India	2016	SME	Exploratory Cross-Section	Identified and prioritized the critical success factors by exploratory analysis in SMEs	LSS
189	Shokri *et al.*	A	UK	2016	SME	Empirical	Validated the role of people in the LSS implementation	LSS

							process empirically	
190	Bhat *et al.*	A	India	2016	Hospital	Exploratory Longitudinal	Applied LSS framework in a medical record department to reduce TAT of the medical record preparation process	LSS
191	Galankashi and Helmi	A	Malaysia	2016	Manufacturing	Conceptual & Empirical	Proposed new assessment tools operational activities leagility through AHP approach	Leagile
192	Sunder	A	India	2016(a)	Higher education industries	Exploratory Cross-Section	Implement LSS in HEI to reduce the book search time in the library.	LSS
193	Sunder	A	UK	2016(b)	Banking and service	Exploratory Cross-Section	Applied multi-phase methodology to understand the role of LSS in the banking and financial services industry	LSS
194	Guerrero *et al.*	A	US	2017	Furniture Manufacturing SME	Exploratory Longitudinal	Deployed LSS DMAIC approach to reducing waste and defects and improving quality in furniture manufacturing SME	LSS
195	Kumar *et al.*	A	India	2017	Automobile manufacturing	Exploratory Cross-Section	Established a relationship among the AM practices to achieve agility in automobile manufacturing	AM

196	Eltawy and Gallear	A	UK	2017		Conceptual & Comparative	Reviewed and compared leanness and agility. Developed a conceptual framework for lean and agile system	Leagile
197	Thilak *et al.*	A	India	2017		Descriptive	Reviewed an application of computer-aided design (CAD) to achieve agility in the case of producing the components of pumps.	AM
198	Rehman	A	India	2017	Manufacturing	Exploratory Cross-Section	The analytical hierarchy process (AHP) tool identified and ranked the agility enablers. In addition, sensitivity analysis is done to check the robustness of the ranking.	AM
199	Politis and Rekkas	A	Greece	2017	Flexible pellet	Exploratory Longitudinal	Implementing lean and agile manufacturing settings for the production of flexible pellet dosage.	Leagile
200	Shokri	A	UK	2017	SME manufacturing	Descriptive & Exploratory Longitudinal	Analysis of the three business improvement practices of Lean, Six Sigma, and Lean Six Sigma (LSS) identified the research gaps and classification framework.	LSS

201	Antony *et al.*	A	US	2017		Descriptive	Performed a vast literature review of 150 research papers over the 15 years of span and categorized them into three categories	LSS
202	Alhuraish *et al.*	A	France	2017		Comparative	Compared the lean and six sigma based on their respective critical factors	LSS
203	Yadav and Desai	A	India	2017	Manufacturing and service	Exploratory Cross-Section	Identified and developed a hierarchy model of 20 LSS enablers using a hybrid ISM-FUZZY approach	LSS
204	Lu *et al.* (2017)	A	UK	2017	Education	Conceptual	Developed a conceptual framework that depicts the role of leadership in the LSS implementation approach in HEI.	LSS
205	Yadav *et al.*	A	Qatar and India	2017		Descriptive	Reviewed 26 frameworks of LSS, published articles during the 2000-2017 time frame	LSS
206	Salah	A	UAE	2017		Comparative	Compared lean six sigma and innovation and developed an integrated framework of them.	LSS
207	Safaie	A	IRAN	2017	Manufacturing	Comparative &Empirical	Investigated the connection between agile and CMMI and six sigma	AM

208	Haq and Boddu	A	India	2017	Food and food product	Empirical	Analyzed the 20 Leagile enablers through QFD and Fuzzy logic · TOPSIS AHP	Leagile
209	Mittal *et al.*	A	India	2017	Manufacturing	Conceptual & Empirical	Proposed lean green agile model for sustainability and. The entropy approach; VIKOR analysis; MOORA approach was used to rank the identified enablers	Leagile
210	Ruben *et al.*	A	India	2017	Automotive Manufacturing Component	Exploratory Longitudinal	Developed and implemented an integrated DMAIC framework embedded with lean and green practices to achieve operational and environmental performances	LSS
211	Douglas *et al.*	A	UK and Kenya	2017	Education	Empirical	Empirically evaluated the readiness factor of organization culture towards LSS adoption in Kenya Institute of Management (KIM)	LSS
212	Potdar *et al.*	A	India	2017(a)	Generalized	Descriptive	Reviewed 300 papers of AM published from 1993 to 2016	AM
213	Sindhwani *et al.*	A	India	2017(a)	Manufacturing	Empirical	Developed a model of AM enablers through ISM	AM
214	Virmani *et al.*	A	India	2017(b)	Manufacturing	Empirical	Developed a fuzzy TISM model of KPI of	Leagile

							leagile manufacturing .12 KPIs	
215	Potdar and Routroy	A	India	2017	Automobile manufacturing	Exploratory Longitudinal	Developed a set of key performance indicators (KPIs) for agile manufacturing (AM) by fuzzy analytic hierarchy, and Agile performance was evaluated by performance value analysis	AM
216	Potdar *et al.*	A	India	2017(b)	Manufacturing	Conceptual & Exploratory Cross-section	Developed a conceptual benchmarking framework of AM for enhancing agility	AM
217	Sindhwani *et al.*	A	India	2017(b)	Manufacturing	Empirical	Identified and analyzed the mutual relationship among 11 enablers of agile manufacturing system (AMS) through total interpretive structural modeling (TISM) and MICMAC analysis-based framework model	AM
218	Virmani *et al.*	A	India	2017(a)	Manufacturing	Exploratory Cross-Section	Developed a leagile barriers model by interpretive structural modeling	Leagile
219	Potdar *et al.*	A	India	2017(c)	Automobile manufacturing	Descriptive & Exploratory Longitudinal	Identified and analyzed the agile manufacturing barriers (AMBs) for establishing a cause	AM

							and effect relationship among fuzzy DEMATEL	
220	Nabass and Abdallah,	A	Jordan	2018	Manufacturing	Empirical	Examined the effect of AM on business performance and operation performance through SEM	AM
221	Sunder and Antony	A	India and UK	2018	Service Industry (Higher education)	Conceptual	Developed a Conceptual framework for LSS implementation in Higher Education	LSS
222	Hill *et al.*	A	Egypt	2018	Aerospace engine Maintenance Repair and Overhaul (MRO) facility.	Exploratory Longitudinal	Implemented the LSS framework in the MRO facility to reduce late material calls and reduce and stabilize Order To Receipt (OTR) times.	LSS
223	Sreedharan and Sunder	A	India	2018a	Automotive OEM	Conceptual & Empirical	Developed a novel LSS framework SDMMAIC (Select, Define, Measure, Map, Analyse, Improve, Control, Sustain), and validated empirically	LSS
224	Gijo *et al.*	A	India	2018	Auto ancillary conglomerate manufacturing	Exploratory Longitudinal	Deployed LSS in HEI to improve advice waiting time, enhance student satisfaction and enrolment	LSS
225	Tetteh	A	India	2018	Education Industry	Comparative & Empirical	Compared LSS and performance management	LSS

							frameworks in the education industry.	
226	Moya *et al.*	A	Chile	2018	SME	Conceptual & Empirical	Developed an assessment model to identify the capability of SMEs for the deployment of LSS.	LSS
227	Yadav *et al.*	A	India	2018(a)	Manufacturing industry	Empirical	Identified LSS adoption 27 barriers and prioritized those barriers with the help of fuzzy AHP and TOPSIS method, and provided 22 solutions to these roadblocks through a case study. In addition, performed a sensitivity analysis to check the robustness of the LSS framework.	LSS
228	Singh and Rathi	A	India	2018		Descriptive	Reviewed a total of 216 papers based on LSS in various sectors, published from 2000 to 2018	LSS
229	Yadav *et al.*	A	India	2018b	Manufacturing industry	Conceptual & Empirical	Developed a three-stage hybrid framework of LSS implementation and tested it through a case study	LSS
230	Potdar and Routroy	A	India	2018	Electrical Hardware Manufacturing	Empirical	Analyzed enablers of AM through a case study	AM

231	Goswami and Kumar	A	India	2018	SME Auto ancillary	Descriptive & Empirical	Analyzed the agile manufacturing practices in small and medium enterprises (SMEs) within the auto-ancillary sector Using SEM	AM
232	Sindhwani and Malhotra	A	India	2018	Manufacturing industry	Exploratory Cross-Section	Ranked the AMS facilitators through the Entropy approach, MOORA method, VIKOR, and a cross-sectional survey	AM
233	Potdar *et al.*	A	India	2018	Automobile manufacturing	Exploratory Longitudinal	Quantified, evaluated, and compared the implementation performance of agile manufacturing program through a graph-theoretic approach in an automobile manufacturing	AM
234	Balakrishnan *et al.*	A	India	2018	Pump manufacturing	Exploratory Longitudinal	Design and Implemented leagile manufacturing in pump manufacturing and discussed the challenges and benefits of implementation	Leagile
235	Ghobakhloo and Azar	A	IRAN	2018	Automobile part manufacturing	Descriptive & Exploratory Cross-Section	Literature review followed by a cross-section survey about the relationships between advanced manufacturing	Leagile

							technologies (AMT), lean manufacturing (LM), agile manufacturing (AM), and business performance.	
236	Gunasekaran *et al.*	A	US and UK	2018	Manufacturing	Exploratory Longitudinal	Examined the role of big data and business analytics (BDBA) in agile manufacturing practices.	AM
237	Sunil *et al.*	A	India	2018	Manufacturing	Descriptive & Comparative	The literature was reviewed to identify the next research stage whose outcome will enable today's manufacturing companies to become agile.	AM
238	Muraliraj, J. *et al.*	A	Malaysia	2018		Descriptive	Reviewed literature in Lean Six Sigma through multiple criteria to identify trends, existing research gaps, and future opportunities in the LSS field.	LSS
239	McArthur and Bortoluzzi	A	Canada	2018	Construction	Descriptive & Exploratory Longitudinal	Studied the Lean-Agile approach to address the research gap of low-effort, flexible approaches to FM-BIM model creation and maintenance, and its effectiveness is analyzed through five	Leagile

							case studies	
240	Raval *et al.*	A	India	2018,b	Manufacturing	Exploratory Cross-Section	Identified and developed a hypothetical model of LSS enablers through Interpretive structural modelling (ISM) and MICMAC analysis	LSS
241	Saini *et al.*	A	US and UK	2018		Empirical	Identified and validated the critical success factors related to the effectiveness of transferring tacit knowledge in the lean and agile construction process.	Leagile
242	Shahin and Rezaei	A	IRAN	2018	Home appliance producer	Empirical	Prioritize lean production (LP) and agile production (AP) factors based on costs of quality (COQ) by literature review and developing two separated houses of quality (HOQ)	Leagile
243	Sunder *et al.*	A	India	2018		Descriptive	Reviewed 175 papers of LSS published in the field of LSS in the service industry	LSS

244	Shamsuzzaman *et al.*	A	Malaysia	2018	Telecom company	Exploratory Longitudinal	Applied systematic LSS framework in the telecom industry to reduce lead time and improve the customer satisfaction	LSS
245	Raval *et al*.	A	India	2018,a		Descriptive	Reviewed and categorized 190 papers published from 2000 to 2016	LSS
246	Sunder and Mahalingam	A	India	2018	Health Care	Exploratory Longitudinal	Applied five-phase LSS approach in 5 higher education systems	LSS
247	Soepardi et al.	A	India	2018		Conceptual and Descriptive	Reviewed and Classified AM literature articles and developed a Conceptual Framework of AM enablers	AM
248	Ahmed *et al*.	A	Malaysia	2018	Healthcare	Exploratory Cross-Section	Evaluated and compared the level of LSS practices in private vs. public hospitals in Malaysia	LSS
249	Deithorn and Kovach	A	US	2018	Oil and Gas Service provider	Exploratory Longitudinal	Deployed LSS approach based on DMAIC approach to reduce the billing process time	LSS
250	Virmani *et al.*	A	India	2018a		Descriptive	Reviewed the existing literature on leagile manufacturing systems and explained the role of decoupling points in leagile scenario	Leagile

251	Virmani *et al.*	A	India	2018b	Manufacturing	Empirical	Developed a TISM model of 16 social implication models of leagile manufacturing.	Leagile
252	Sreedharan and Sunder	A	India	2018(b)		Descriptive	Reviewed the critical success factors of four continuous improvement strategies, i.e., TQM, Six Sigma, Lean, and LSS, from 47 papers	LSS
253	Virmani *et al.*	A	India	2018c	Manufacturing	Empirical	Assessed the leagile CSFs' empirically through the DEMATEL approach	Leagile
254	Sreedharan *et al.*	A	India and UK	2018	Manufacturing	Descriptive & Empirical	44 critical failures were identified from the literature review and ranked 24 vital CFFs through the TOPSIS SIMO's method	LSS
255	Mishra *et al.*	A	India	201	Health Care	Descriptive & Exploratory Cross-Section	Developed an implementation leagile approach for healthcare services.	Leagile
256	Trehan *et al.*	A	India	2019	Bulb manufacturing company	Exploratory Longitudinal	Deployed LSS methodology in bulb manufacturing to reduce the defect	LSS
257	Nascimento *et al.*	A	BRAZIL	2019	Oil industry	Conceptual & Empirical	Proposed an integrated conceptual framework based on lean principles, six sigma's DMAIC, and Deming's	LSS

							PDCA for the oil industry and validated empirically.	
258	Haerizadeh *et al.*	A	IRAN and INDIA	2019	Higher education	Exploratory Longitudinal	Deployed LSS in the higher education industry to baseline student satisfaction levels and improve the overall rating by 10 percent; decreased student advising wait times by 15 percent, and increased enrollment by 5 percent.	LSS
259	Balakrishnan *et al.*	A	India	2019	Pump manufacturing	Exploratory Longitudinal	Developed a leagile implementation framework for pump manufacturing industries	Leagile
260	Sánchez *et al.*	A	Spain	2019	Manufacturing	Exploratory Longitudinal	Analyzed the relationship between agile manufacturing and the firm management capacities related to innovation and production flexibility	AM
261	Yli-Ojanpera *et al.*	A	Sweden	2019	Manufacturing	Exploratory Longitudinal	Developed two primary Industry 4.0 reference architectures by industry-driven initiatives, namely the German Industry 4.0 and the US-led Industrial Internet	AM

							Consortium.	
262	Rauch *et al.*	A	Italy	2019	SME	Exploratory Longitudinal	Proposed and implemented an Axiomatic Design-based approach for the design of flexible and agile manufacturing and assembly systems in SME	AM
263	Gunasekaran *et al.*	A	US and UK	2019		Descriptive	Reviewed the literature on the evolution of manufacturing agility and identified attributes of agile manufacturing, the drivers of agile manufacturing, and enablers	AM
264	Al-Refaie *et al.*	A	US	2019	Pharmaceutical	Exploratory Longitudinal	Identified the appropriate lean or agile practice(s) to enhance the performance of the filling process in the pharmaceutical industry by data envelopment analysis and simulation	Leagile
265	Virmani and Sharma	A	India	2019	Manufacturing	Exploratory Cross-Section	Identified and developed a leagile enabler's model by interpretive structural modeling.	Leagile

266	Lotfi	A	UK	2019	Manufacturing	Comparative &Empirical	Empirically studied and clarified the boundaries of the three concepts of lean, agile, and resilience using Survey data.	Leagile
267	Alexander *et al.*	A	UK	2019	SME	Descriptive	Reviewed articles regarding LSS application in SMEs	LSS
268	Gijo and Antony	A	India	2019	IT solutions	Exploratory Longitudinal	Implemented Lean DMAIC approach in its solution industry to improve the process	LSS
269	Li *et al.*	A	UK	2019	Higher education	Exploratory Longitudinal	Implemented LSS using DMAIC to improve the service processes in higher education institutes.	LSS
270	Sony *et al.*	A	India	2019		Exploratory Cross-Section	Identified 11 reasons behind the factors causing LSS discontinuance in various industries	LSS
271	Kumar *et al.*	A	India	2019(a)		Conceptual	Proposed a conceptual AM framework by doing a comparative analysis of 17 frameworks	AM
272	Chaurasia *et al.*	A	India	2019	Automotive industry	Exploratory Longitudinal	Implemented LSS strategy based on DMAIC framework to improve the First time right and reduced scrap generation in the automotive industry	LSS
273	Sony	A	India	2019	Power sector	Exploratory Longitudinal	Demonstrated the LSS methodology in a power sector to reduce inefficiency and improve customer	LSS

							satisfaction, profits	
274	Sindhwani *et al.*	A	India	2019	Manufacturing	Exploratory Cross-Section	Developed an integrated Lean, green, agile manufacturing systems barrier through the TISM approach	Leagile
275	Alkunsol *et al.*	A	Jordan	2019	Pharmaceutical manufacturing	Empirical	Empirically tested the effect of LSS on business performance in Pharmaceutical manufacturing organizations.	LSS
276	Venugopal and Saleeshya	A	India	2019	Ayurveda Pharmaceutical industry	Exploratory Longitudinal	Developed and validated an integrated model of lean and agile manufacturing with a focus on sustainability	Leagile
277	Muganyi *et al.*	A	South Africa	2019	Chemical manufacturing industry	Exploratory Longitudinal	Implemented integrated LSS approach in the chemical manufacturing industry to improve the process and increase the bottom line result	LSS
278	Raval *et al.*	A	India	2019	Manufacturing	Exploratory Cross-Section	Developed a performance measurement system of LSS through a balanced scorecard method and validated through a cross-section survey	LSS
279	Patel *et al.*	A	India	2019		Descriptive	Reviewed 127 literature articles based	LSS

							on LSS and developed a conceptual model of LSS	
280	Singh *et al.*,	A	India	2019	Manufacturing	Exploratory Longitudinal	Demonstrated the use of value stream and six-sigma methodology to improve the production lead time and work-in -progress (WIP) inventory.	LSS
281	Iqbal *et al.*	A	Pakistan	2020	Apparel industries	Comparative &Empirical	Developed an integrated framework of lean-agile, TQM, common internal infrastructure (CII), common external infrastructure (CEE), TOP management commitment, and their impact on operational, financial, and marketing performance is tested by SEM, and results reveal that agile and lean synergy gives a competitive edge to the organization by enhancing the process performance.	Leagile
282	Khalfallah *et al.*	A	Tunisia	2020	Manufacturing	Empirical	They empirically validated a framework representing the relationship between lean and agile practices.	Leagile

283	Qamar *et al.*	A	UK	2020	Automotive sector	Comparative &Empirical	They performed a tradeoff between quality and flexibility for agile and lean organizations.	Leagile
284	Narkhede *et al.*	A	India	2020	Original Equipment Manufacturing	Conceptual & Empirical	Identified 12 Lean-Agile barriers from an extensive literature review and established a mutual relationship with the help of an expert's opinion.	Leagile
285	Kumar *et al.*	A	India	2019(b)		Descriptive	Critically reviewed 33 critical success factors of AM implementation and by Pareto analysis found 8 CSFs are vital few which account for 82.66 percent of occurrence and 24 CSFs are useful many accounts 17.34 percent of occurrence.	AM
286	Kumar *et al.*	A	India	2019(c)	Manufacturing	Empirical	Several statistics techniques investigated the relationship between agile critical factors on business performance. Games–Howell HOC test was applied to test the significance.	AM
287	Kumar *et al.*	A	India	2019(d)	Manufacturing	Exploratory Cross-Section	Evaluated the Agile practices in Indian manufacturing industries through a	AM

							cross-section survey.	
288	Sodhi *et al.*	A	India	2020	Indian SMEs	Conceptual	Developed a conceptual framework for LSS implementation in SME	LSS
289	Vallejo *et al.*	A	UK	2020	Packaging company	Descriptive	Developed a sustainable Lean Six Sigma implementation framework for a Scottish packaging company.	LSS
290	Krishnan *et al.*	A	India	2020	Reamer Manufacturing Industry	Exploratory Longitudinal	Used select, define, measure, improve, control, and sustain (SDMAICS) approach to improve process capability and reduce cycle time.	LSS
291	Rao *et al.*	A	India	2020	Higher education	Descriptive	Proposed LSS framework for Higher education institutions to improve the efficiency and effectiveness of an organization. Also discussed are the fundamental issues, CSFs, and barriers of LSS in the education scenario	LSS

292	Li Y *et al.*	A	China	2020	Textile	Descriptive & Exploratory Longitudinal	Identified the most influential criteria for supplier selection in a leagile environment	Leagile
293	Kumar *et al.*	A	India	2020(a)	Manufacturing industry	Exploratory Cross-Section	Identified and prioritized AM implementation enablers through the AHP-TOPSIS method	AM
294	Varl *et al.*	A	Slovenia	2020	Manufacturing	Descriptive & Exploratory Cross-Section	Presented a case study of product development and design process renovations in one-of-a-kind industrial environments to demonstrate how companies can improve smartness and profitability by utilizing agility concepts.	AM
295	Mostafa *et al.*	A	Australia	2020	Construction	Exploratory Longitudinal	Studied and prioritized the four leagile strategies using MCDM techniques in a house building project	Leagile
296	Borsci *et al.*	A	UK	2020	Health Care Device Manufacturing	Descriptive&Exploratoy Longitudinal	Developed and implemented Lean and Agile Multi-Dimensional Process Map framework as a Health technology assessment (HTA) for the medical device and diagnostic industry in	Leagile

							the UK	
297	Balakrishnan *et al.*	A	India	2020	Pump manufacturing	Exploratory Longitudinal	Developed and implemented the 'pumping for leagility' (PFL) model in an Indian pump manufacturing company.	Leagile
298	Vaishnavi and Suresh	A	India	2020	Health Care	Descriptive & Exploratory Cross-Section	Identified 16 readiness factors of LSS in health care and developed and clustered through ISM-MICMAC analysis.	LSS
299	Gaikwad *et al.*	A	Australia	2020	SME	Empirical	Investigated and ranked the 12 barriers of LSS through the Fuzzy -TOPSIS Method.	LSS
300	Singh and Rathi	A	India	2020	MSME	Empirical	16 CSFs were identified from the literature and finalized through the relative importance index method and ranked by the best-worst method (BWM).	LSS
301	Trakulsunti *et al.*	A	UK	2020	Hospital	Exploratory Longitudinal	Applied LSS approach to reduce the medical errors in hospital	LSS

302	Vinodh *et al.*	A	India	2020	Indian automotive component manufacturing	Empirical	Developed and validated the relationship between the lean six sigma and sustainable manufacturing strategies through SEM	LSS
303	Haider and Khan	A	India	2020	Manufacturing	Exploratory Cross-Section	Evaluated the percentage of effectiveness of Agile barriers through the AHP approach	AM
304	Srinivasan *et al.*	A	India	2020	Manufacturing	Empirical	Developed and validated the relationship between firm performance and collaboration of suppliers using lean and agile strategies in a dynamic environment	LSS
305	Davidson *et al.*	A	Australia	2020	Education	Descriptive	Reviewed quality frameworks of LSS in higher education and identified the enablers, drivers, and barriers of LSS s in HEI	LSS
306	Juliani and De Oliveira	A	Brazil	2020		Descriptive	Systematized the LSS principles and tools	LSS
307	Alblooshi and Shamsuzzaman	A	UAE	2020	Manufacturing	Conceptual & Exploratory Cross-section	A developed conceptual model depicts the relationship between LSS and organizational innovation climate factors.	LSS

308	Udokporo *et al.*	A	UK	2020	FMCG	Empirical	Empirically tested the integration of lean, agile, and green practices on business performance.	Leagile
309	Kumar *et al.*	A	India	2020(b)	Manufacturing	Descriptive & Empirical	Identified 17 barriers to agile manufacturing from extensive literature review and factor analysis.	AM
310	Bhamra *et al.*	A	The UK and Australia	2021		Descriptive	Done a literature review of 53 articles based on a leagile theme	Leagile
311	Costa *et al.*	A	Brazil	2021	Food industry	Empirical	Developed and validated a measurement scale to measure the lean six sigma practices in the food industry.	LSS
312	Hemalatha *et al.*	A	India	2021	Boiler component Manufacturing	Exploratory Longitudinal	Implemented Lean and AM in a boiler manufacturing company to identify the factors and their effects on Work in Process inventory	Leagile
313	Patel and Patel	A	India	2021		Descriptive	Done literature review of 223 articles on Lean, Six Sigma, and Lean Six Sigma	AM
314	Singh *et al.*	A	India	2021	Medical Equipment manufacturing	Empirical	Developed and implemented a framework for project selection in healthcare and medical equipment	LSS

							manufacturing	
315	Alnadi and McLaughlin	A	UK	2021	Generalized	Descriptive	Performed a thematic analysis of Leadership behavior on LSS implementation.	LSS
316	Rathi *et al.*	A	India	2021(a)	Healthcare	Descriptive	Done an exhaustive literature review of LSS in the healthcare sector	LSS
317	Yadav *et al.*	A	India	2021(a)	Manufacturing	Descriptive & Empirical	Investigated the cognitive aspects of LSS through 5W and1 H analysis.	LSS
318	Kam *et al.*	A	Australia	2021	Healthcare	Exploratory Longitudinal	Implemented LSS in publicly funded outpatient ophthalmology services to reduce the patient duration and variability of patient in-clinic time.	LSS
319	Rathi *et al.*	A	India	2021b	Automobile part manufacturing industry	Descriptive & Empirical	Identified 31 barriers of LSS in automotive sectors, and out of the 17 were validated statistically.	LSS
320	Mishra *et al.*	A	India	2021	MSME	Descriptive & Empirical	Described the condition of MSME in post covid era. Discussed the barriers and CSFs for LSS in MSME	LSS

321	Swarnakar *et al.*	A	India	2021a	Automotive sector	Empirical	Investigated the effect of LSS constructs on performance	LSS
322	Swarnakar *et al.*	A	India	2021b	Health Care	Exploratory Longitudinal	Implemented structured Lean Six Sigmas' DMAIC approach to reduce the waiting time and enhance the service quality in a multinational hospital	LSS
323	Yazdi *et al.*	A	India	2021	Oil industry	Descriptive & Empirical	Proposed 22 customized CSF and developed a framework for LSS implementation in the oil industry.	LSS
324	Sharma *et al.*	A	India	2021	Automobile light manufacturing	Exploratory Longitudinal	Applied LSS's DMAIC framework to reduce defect rate and improve productivity in automobile light manufacturing	LSS
325	Patel and Brahmbhatt	A	India	2021	SME	Conceptual & Empirical	Developed a conceptual model of AM performance measures in SME	AM
326	Khalfallah and Lakhal	A	Tunisia	2021	Manufacturing	Empirical	Empirically validated the relationship between TPM and TQM, JIT. In addition, the relationship between JIT and Agile manufacturing is also found validated.	AM

327	Sindhwani *et al.*	A	India	2021	Rolling industry	Exploratory Cross-Section	Developed a weighted ISM model of Lean and Agile deployment key factors for the rolling industry	Leagile
328	Raji *et al.*	A	Italy	2021	Manufacturing	Exploratory Cross-Section	Developed a hierarchy model of industry 4.0 technology, Lean and Agile strategies through ISM	Leagile
329	Chiarini and Kumar	A	UK	2021	Manufacturing	Exploratory Longitudinal	Investigated an integration of possible integration between Lean Six Sigma (LSS) tools and principles and Industry 4.0 technologies through a case study.	LSS
330	Latessa *et al.*	A	Italy	2021	Hospital	Exploratory Longitudinal	Deployed LSS in a hospital to improve the knee and hips surgery process by reducing the average length of stay (LOA) and hospital costs	LSS
331	Bhat *et al.*	A	India	2021(a)	MSME (Printing industry)	Exploratory Longitudinal	Deployed Lean DMAIC approach in the printing industry to improve turnaround time and improve the quality of the process	LSS
332	Yadav *et al.*	A	India	2021(b)		Empirical	Identified and validated the CSFs of LSS and industry 4.0 empirically	LSS

333	Bhat *et al.*	A	India	2021(b)	Process industry	Exploratory Longitudinal	Investigated the root cause behind the impurity in water by integrating LSS, simulation, and Industry 4.0	LSS
334	Raval *et al.*	A	India	2021	Manufacturing	Exploratory Longitudinal	Identified critical success factors from the literature review, and cause and effect analysis were evaluated by DEMATEL analysis. These CSFs' are validated through a case study.	LSS
335	Singh and Rathi	A	India	2021	SME	Empirical	Identified and developed an ISM model of 16 LSS barriers, and SEM is applied to validate the barriers.	LSS
336	Piotrowicz *et al.*	A	Poland	2021		Conceptual	Proposed a framework to identify Lean, Agile, and standard performance metrics for Lean and Agile strategies in a supply chain	Leagile
337	Kaswan *et al.*	A	India	2021	Manufacturing	Descriptive & Empirical	Identified 18 barriers to green Lean Six Sigma from an extensive literature review and categorized them through the principal component	LSS

							method. To prioritize and handle the casual relationship among the barriers, Fuzzy DEMATL (the decision-making trial and evaluation laboratory) validated results using the BEST-Worst method.	
338	Yadav *et al.*	A	India	2021(c)	Manufacturing	Conceptual	Developed an integrated framework of Lean Six Sigma and green practices in a manufacturing environment	LSS
339	Udokporo *et al.*	A	UK	2021	Fast-moving consumer goods (FMCG) industry	Exploratory Longitudinal	Developed and validated a framework for selecting appropriate LAG practices to manage processes and meet customer requirements through Delphi and case studies.	Leagile
340	Mathiyazhagan *et al.*	A	India	2021	Automobile	Empirical	Evaluated and prioritized the Lean and Agile practices to achieve sustainability in the automobile sector in India.	Leagile
341	Kumar *et al.*	A	India	2021(a)	Medium and Large Manufacturing	Empirical	Empirically validated the relationship between Agile manufacturing practices and business	AM

							performance.	
342	Ding *et al.*	A	Spain	2021		Conceptual	Developed an integrated conceptual framework of Lean, Agile, and Industry 4.0	Agile
343	Kumar *et al.*	A	India	2021(b)	Forging	Exploratory Longitudinal	Implemented AM practices in the forging industry to increase productivity and responsiveness.	AM
344	Hariyani *et al.*	A	India	2022	Manufacturing	Descriptive and Empirical	Identified 24 barriers of sustainable green, lean-six sigma-agile manufacturing through vast literature review and ranked them though median and standard deviation method	LSS-AM
345	Citybabu and Yamini	A	India	2022		Descriptive	Reviewed 141 articles based on LSS in Indian context, published during 2010 to 2021	LSS
346	Swarnakar *et al.*	A	India	2022		Empirical	Identified 33 CSFs for LSS implementation and prioritized them by best worst method	LSS
347	Vanichchinchai	A	Thailand	2022	Automotive parts manufacturing	Empirical	Analyzed the impact of three pillars of Toyota way on three pillars of AM through confirmatory factor	

							analysis.
348	Gupta *et al.*	A	India	2022	Die Casting SME	Exploratory Longitudinal	Developed an integrated framework of lean, six sigma and design of constraint and validated through a field study in a die casting company
349	Sharma and Khan	A	Norway and India	2022		Descriptive	Developed a TISM model of five barriers of Lean and Agile Manufacturing implementation
350	Psomas *et al.*	A	Greece	2022		Descriptive	Performed a systematic literature review of 56 research articles based on LSS applications in public administration sector published during 2010 to 2021 and catgorised them into 14 themes

A.2 Cover letter with Questionnaire for CSFs and CFFs to LSS-AM Implementation

Dear Sir / Madam

I am a research scholar in Department of Mechanical Engineering Birla Institute of Technology and Science Pilani, Rajasthan. My research area is in the field of integration of Lean Six Sigma and Agile Manufacturing approaches.

Integration of Lean Six Sigma (LSS) and AM can be seen as a favorable strategy to fulfill the dynamic demand responsively at low cost without compromising on quality. The goal of Lean Six Sigma is to eliminate wastes and reduce the process variation where as Agile Manufacturing (AM) is the strategy by which company can quickly reacts according to demands and expectations of the customers. Many organizations wish to implement LSS and AM to get aforementioned benefits. However, all organizations were not equally successful in implementing LSS and AM. I am doing a research to find factors, which enable or hinder LSS and AM implementation

For this purpose, I designed the attached Google form, containing questionnaire related to my research work. You are requested to spare your valuable time and fill the attached questionnaire. Your thoughtful response will help me to carry out the research work successfully. The collected information will be used for research purpose only. Further if you wish not to disclose you or your company identity, it will be taken care appropriately. I also request you to further forward it to the concerned person in your professional group who can help me by completing this survey.

Please feel free to connect if any additional information related to this questionnaire is required.

Thanking you,

Yours truly,

Nidhi Mundra

Research Scholar

Department of Mechanical Engineering, BITS Pilani (Rajasthan)

Questionnaire

PART I: GENERAL INFORMATION OF PARTICIPATING ORGANIZATION AND

RESPONDING PERSON

Name and address of the organization:__________________________________

Type of the organization: Micro ☐ SSI ☐ Medium Scale ☐ Large -scale ☐

Products of the organization: ____

Management Type: Independently Managed ☐ Limited ☐ Owner Managed ☐

No. of employees: Less than 50 ☐ 50-200 ☐ 200-500 ☐ above 500

Sales turnover: Up to 1 crore ☐ 1 to 5 crore ☐ 5 to 25 crores ☐ above 25 crores

Year of establishment: ____

Name of responding person (OPTIONAL): _____________________________

Designation: ____

Department: ____

Experience (years): ____

Email: ____

Ph.No. / Mobile No. (OPTIONAL)______________________________________

Would you like to be contacted for any further information or a personnel interview? Yes/No

Can I acknowledge you in my research work/thesis?
Yes/No

Can I acknowledge your organization in my research work/thesis? Yes/No

(1) Average age (in years) of shop floor employees:

Under 30 ☐ 30-40☐ 40-50☐ Over 50 ☐

(2) Average stay (in years) of workers in the plant

0-1 ☐ 1-3 ☐ 3-10 ☐ Over 10 ☐

Which one philosophy are you currently practicing?

A. Lean Manufacturing

B. Agile Manufacturing

C. Lean Six-Sigma

D. Integrated Lean Six-Sigma and Agile Manufacturing

E. None

Part II: Critical Success Factors (CSFs) to Lean Six Sigma and Agile Manufacturing Implementation

CSFs: Factors, which are enabling to implement Lean -six sigma and Agile Manufacturing in any organization

Rate the CSFs on a scale of 1 to 10, where:

1-2 if strongly disagree; 3-4 if disagree; 4-6 if neither agree nor disagree; 6-8 if agree and 8-10 if strongly agree. ✔ the correct response

S.No.	CSFs enable to implement of LSS-AM	Strongly disagree (1-2)		Disagree (3-4)		Neither agree nor disagree (4-6)		Agree (6-8)		Strongly agree (8-10)	
1	**Existing Technology and advancement**	1	2	3	4	5	6	7	8	9	10
2	**Virtual enterprise**	1	2	3	4	5	6	7	8	9	10
3	**Project Selection Prioritization**	1	2	3	4	5	6	7	8	9	10
4	**Organization infrastructure**	1	2	3	4	5	6	7	8	9	10
5	**Employee empowerment and Link to human resources-based actions (promotions, bonuses, etc.)**	1	2	3	4	5	6	7	8	9	10
6	**Top management commitment**	1	2	3	4	5	6	7	8	9	10
7	**Organization Culture**	1	2	3	4	5	6	7	8	9	10
8	**Multi skilled workforce**	1	2	3	4	5	6	7	8	9	10
9	**Communication and collaboration with stake holders**	1	2	3	4	5	6	7	8	9	10
10	**Change management**	1	2	3	4	5	6	7	8	9	10
11	**Training and knowledge management**	1	2	3	4	5	6	7	8	9	10
12	**Financial capability**	1	2	3	4	5	6	7	8	9	10
13	**Information technology**	1	2	3	4	5	6	7	8	9	10
14	**Alignment of strategies**	1	2	3	4	5	6	7	8	9	10

Part III: Critical Failure Factors (CFFs) for Lean Six Sigma and Agile Manufacturing Implementation

Rate the CFFs on a scale of 1 to 10, where:

1-2 if strongly disagree; 3-4 if disagree; 4-6 if neither agree nor disagree; 6-8 if agree and 8-10 if strongly agree. ✔ the correct response

S.No.	CFFs which are roadblocks for LSS-AM implementation	Strongly disagree (1-2)		Disagree (3-4)		Neither agree nor disagree (4-6)		Agree (6-8)		Strongly agree (8-10)	
1	Lack of training and skill development	1	2	3	4	5	6	7	8	9	10
2	Insufficient resources	1	2	3	4	5	6	7	8	9	10
3	Poor project selection	1	2	3	4	5	6	7	8	9	10
4	Lack of top management commitment	1	2	3	4	5	6	7	8	9	10
5	Organization culture support	1	2	3	4	5	6	7	8	9	10
6	Lack of communication and collaboration with stockholders	1	2	3	4	5	6	7	8	9	10
7	Poor infrastructure	1	2	3	4	5	6	7	8	9	10
8	Lack of employee involvement	1	2	3	4	5	6	7	8	9	10
9	Lack of good quality data	1	2	3	4	5	6	7	8	9	10

A.3 CALCULATIONS OF CRISP VALUE OF DRIVING, DEPENDENCE AND LEVEL PORTIONING ITERATIONS OF CSFS AND CFFS FOR LSS-AM IMPLEMENTATION

A.3.1 Calculation of Driving Power and Dependence of Each CSF for Fuzzy Final Reachability Matrix

Table A.2.1: Calculation of Driving Power and Dependence of Each CSF for Fuzzy Final Reachability Matrix

CSFs															Calculation for Crisp Value of Driving Power of each CSF											Calculation for Crisp Value of Dependence of each CSF										
CSF	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	******	**L(MIN)**	**R(MAXU)**	**D**	**Xlk**	**Xmk**	**Xuk**	**Xkls**	**Xkrs**	**Xkcrisp**	**##**	*****	**L(MIN)**	**R(MAXU)**	**D**	**Xlk**	**Xmk**	**Xuk**	**Xkls**	**Xkrs**	**Xkcrisp**	**#**
C1	–	(.6, .8,1)	(0,0, .2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.4,.6,.8)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(1.6,2.2,4.8)	0	11.8	11.8	0.13559322	0.186440678	0.406779661	0.177419355	0.333333333	0.222380595	**2.62**	(7.2,9.6,11.6)	0.6	12.8	12.2	-0.021857923	-0.03095241	0.16557377	-0.03123649	0.138378728	-0.011169089	**0.463737118**
C2	(0,0, .2)	–	(0,0, .2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,2.8)	0	11.8	11.8	0	0	0.237288136	0	0.191780822	0.030861282	**0.36**	(8.4,11,12.8)	0.6	12.8	12.2	-0.033460588	-0.046650715	-0.019672131	-0.047274268	-0.019155347	-0.047798164	**0.016862393**
C3	(.6, .8,1)	(.4,.6,.8)	–	(.6,.8,1)	(.8,1,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.4,.6,.8)	(0,0,.2)	(.4,.6,.8)	(0,0,.2)	(.8,1,1)	(0,0,.2)	(4.6,6.2,8.4)	0	11.8	11.8	0.389830508	0.525423729	0.711864407	0.462686567	0.6	0.535127512	**6.31**	(5.6,7.4,9.4)	0.6	12.8	12.2	0	-0.005317417	0.468032787	-0.005345843	0.317665675	0.072211813	**1.480984114**

1.765082618	**1.630252245**	**2.601361394**	**2.375599664**	**0.560563684**	**0.463737118**	**2.149782751**
0.095498575	0.084446905	0.164046016	0.145540956	-0.003232485	-0.011169089	0.127031373
0.356989722	0.338761698	0.458977006	0.433158663	0.160011545	0.138378728	0.406098888
0.001965119	-0.001570146	0.025182538	0.018596168	-0.028626474	-0.03123649	0.01229199
0.554098361	0.513114754	0.82704918	0.75	0.195901639	0.16557377	0.675409836
0.001957426	-0.001562843	0.025108846	0.01853284	-0.028395268	-0.03095241	0.012243904
0.005872278	0.00308862	0.028035163	0.021938284	-0.020318633	-0.021857923	0.016155856
12.2	12.2	12.2	12.2	12.2	12.2	12.2
12.8	12.8	12.8	12.8	12.8	12.8	12.8
0.6	0.6	0.6	0.6	0.6	0.6	0.6
(6.2,8,9.6)	(5.6,7.4,9.6)	(.6,.8,3.4)	(.6,.8,3.4)	(7.8,10.2,12.2)	(7.6,10,11.8)	(2.6,3.4,5.6)
7.36	**6.86**	**10.69**	**9.75**	**2.99**	**2.62**	**8.84**
0.623880597	0.58093332	0.906327921	0.826100647	0.253577727	0.222380595	0.749375632
0.671641791	0.637681159	0.942028986	0.867647059	0.352112676	0.333333333	0.797101449
0.552238806	0.507462687	0.763888889	0.704225352	0.209677419	0.177419355	0.642857143
0.762711864	0.745762712	1.101694915	1	0.423728814	0.406779661	0.93220339
0.627118644	0.576271186	0.93220339	0.847457627	0.220338983	0.186440678	0.762711864
0.491525424	0.440677966	0.711864407	0.644067797	0.169491525	0.13559322	0.576271186
11.8	11.8	11.8	11.8	11.8	11.8	11.8
11.8	11.8	11.8	11.8	11.8	11.8	11.8
0	0	0	0	0	0	0
(5.8,7.4,9)	(5.2,6.8,8.8)	(8.4,11,13)	(7.6,10,11.8)	(2,2.6,5)	(1.6,2.2,4.8)	(6.8,9,11)
(0,0,.2)	(0,0,.2)	(.8,1,1)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.4,.6,.8)
(.8,1,1)	(.4,.6,.8)	(.6,.8,1)	(.6,.8,.1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)
(0,0,.2)	(0,0,.2)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(.8,1,1)
(.8,1,1)	(.6,.8,1)	(.6,.8,1)	(.4,.6,.8)	(0,0,.2)	(0,0,2)	(.6,.8,1)
(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.8,1,1)	(0,0,.2)	(0,0,.2)	_
(.8,1,1)	(.6,.8,1)	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	_	(.6,.8,1)
(.8,.1,1)	(.8,1,1)	(.6,.8,1)	(.6,.8,1)	_	(.6,.8,1)	(.6,.8,1)
(0,0,.2)	(0,0,.2)	(.6,.8,1)	_	(0,0,.2)	(0,0,.2)	(0,0,.2)
(0,0,.2)	(0,0,.2)	_	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(0,0,.2)
(.6,.8,1)	_	(.6,.8,1)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.8,1,1)
_	(.6,.8,1)	(.8,1,1)	(.8,1,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)
(.6, .8,1)	(.8,1,1)	(.6,.8,1)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.8,1,1)
(.8,1,1)	(.6,.8,1)	(.8,1,1)	(.8,1,1)	(.8,1,1)	(.6,.8,1)	(.4,.6,.8)
(.6, .8,1)	(.8,1,1)	(.6, .8,1)	(.4, .6,.8)	(.6, .8,1)	(.4, .6,.8)	(.6,.8,1)
C4	C5	C6	C7	C8	C9	C10

C11	(.8,1,1)	(.6,.8,1)	(.4,.6,.8)	(.8,1,1)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.8,1,1)	(0,0,.2)	–	(0,0,.2)	(.8,.1,.1)	(0,0,.2)	(5.4,7.8,8)	0	11.8	11.8	0.457627119	0.593220339	0.745762712	0.52238806	0.647058824	0.594115111	**7.01**	(5.4,7.2,9.4)	0.6	12.8	12.2	0.003857281	-0.000482368	0.525409836	-0.00048447	0.344329589	0.087802593	**1.67119163**
C12	(.4,.6,.8)	(.6,.8,1)	(.4,.6,.8)	(.8,1,1)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	–	(.6,8,.1)	(.8,1,1)	(6.8,9,11)	0	11.8	11.8	0.576271186	0.762711864	0.93220339	0.642857143	0.797101449	0.749375632	**8.84**	(2.2,2,8.5)	0.6	12.8	12.2	0.016155856	0.012243904	0.675409836	0.01229199	0.406098888	0.127031373	**2.149782751**
C13	(.8,1,1)	(.6,.8,1)	(.8,.1,.1)	(.8,.1,1)	(.4,.6,.8)	(0,0,.2)	(0,0,.2)	(.8,1,1)	(.6,.8,1)	(0,0,.2)	(.8,.1,.1)	(0,0,.2)	–	(0,0,.2)	(5.6,7.2,8.8)	0	11.8	11.8	0.474576271	0.610169492	0.745762712	0.537313433	0.656716418	0.607363184	**7.17**	(6,7.8,9.6)	0.6	12.8	12.2	0.004648887	0.000060354	0.53852459	0.000605991	0.350164002	0.091304302	**1.713912486**
C14	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	(.4,.6,.8)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.8,1,1)	(.4,.6,.8)	(.6,.8,1)	(.8,1,1)	(.8,.1,.1)	–	(7,9.2,11)	0	11.8	11.8	0.593220339	0.779661017	0.93220339	0.657142857	0.808823529	0.763667955	**9.01**	(2.6,3.5,5.6)	0.6	12.8	12.2	0.017116683	0.013415406	0.689344262	0.013465245	0.411320719	0.130534715	**2.192523523**

* Dependence; ** Driving power; # B_k crisp Dependence; ## B_k crisp Driving

A.3.2 Calculation of Driving Power and Dependence of Each CFF for Fuzzy Final Reachability Matrix

Table A.3.2: Calculation of Driving Power and Dependence of Each CFF for Fuzzy Final Reachability Matrix

CFF										Calculation for Crisp Value of Driving Power of each CSF											Calculation for Crisp Value of Driving Power of each CFF										
CFFs	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**	L(MIN)	R(MAXU)	D	Xlk	Xmk	Xuk	Xkls	Xkrs	Xkcrisp	##	*	L(MIN)	R(MAXU)	D	Xlk	Xmk	Xuk	Xkls	Xkrs	Xkcrisp	#
B1	–	(0,0,.2)	(.8,1,1)	(0,0,.2)	(0,0,.2)	(.6,.8,1)	(.6,.8,1)	(.6,.8,1)	(.6,.8,1)	(3.2,4.2,5.6)	0	7.8	7.8	0.41025641	0.538461538	0.717948718	0.477272727	0.608695652	0.547977113	**4.274221482**	(2.8,3.6,4.8)	0.6	7.8	7.2	0.305555556	0.416666667	0.694444444	0.375	0.543478261	0.453361982	**3.864206269**
B2	(.8,1,1)	–	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(.8,1,1)	(.8,1,1)	(.8,1,1)	(.8,1,1)	(4.6,5.8,6.4)	0	7.8	7.8	0.58974359	0.743589744	0.820512821	0.644444444	0.761904762	0.724531025	**5.651341191**	(1,1.4,3)	0.6	7.8	7.2	0.055555556	0.111111111	0.805555556	0.105263158	0.475409836	0.233695664	**2.282608781**
B3	(0,0,.2)	(0,0,.2)	–	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(.8,1,1)	(.8,1,1)	(1.6,2,3.2)	0	7.8	7.8	0.205128205	0.256410256	0.41025641	0.243902439	0.355555556	0.279614016	**2.180989325**	(4.8,6.2,7)	0.6	7.8	7.2	0.583333333	0.777777778	0.361111111	0.651162791	0.619047619	0.630622309	**5.140480625**

1.978632153	**2.006132085**	**3.937720168**	**4.210926319**	**5.338674502**	**5.357142857**
0.191476688	0.195296123	0.463572246	0.501517544	0.658149236	0.660714286
0.507042254	0.513888889	0.534883721	0.515151515	0.65	0.625
0.027027027	0.027027027	0.4	0.487804878	0.674418605	0.75
1	1.027777778	0.638888889	0.472222222	0.361111111	0.138888889
0.027777778	0.027777778	0.444444444	0.555555556	0.805555556	0.916666667
0	0	0.333333333	0.416666667	0.611111111	0.694444444
7.2	7.2	7.2	7.2	7.2	7.2
7.8	7.8	7.8	7.8	7.8	7.8
0.6	0.6	0.6	0.6	0.6	0.6
(0.6,0.8,2.4)	(0.6,0.8,2.4)	(3,3.8,4.8)	(3.6,4.6,5.6)	(5,6.4,7.2)	(5.6,7.2,7.8)
6.987521306	**6.99823784**	**4.039890996**	**2.635720365**	**2.180989325**	**0.19311412**
0.895836065	0.897209979	0.517934743	0.337912867	0.279614016	0.024758221
0.928571429	0.930232558	0.577777778	0.425531915	0.355555556	0.170212766
0.765957447	0.765957447	0.454545455	0.285714286	0.243902439	0
1	1.025641026	0.666666667	0.512820513	0.41025641	0.205128205
0.923076923	0.923076923	0.512820513	0.307692308	0.256410256	0
0.717948718	0.717948718	0.384615385	0.230769231	0.205128205	0
7.8	7.8	7.8	7.8	7.8	7.8
7.8	7.8	7.8	7.8	7.8	7.8
0	0	0	0	0	0
(5.6,7.2,7.8)	(5.6,7.2,8)	(3,4,5.2)	(1.8,2.4,4)	(1.6,2,3.2)	(0,0,1.6)
(.8,1,1)	(.8,1,1)	(.4,.6,.8)	(.6,.8,1)	(.8,1,1)	_
(.8,1,1)	(.6,.8,1)	(.8,1,1)	(.6,.8,1)	_	(0,0,.2)
(.6,.8,1)	(.8,1,1)	(.8,1,1)	_	(0,0,.2)	(0,0,.2)
(.8,1,1)	(.8,1,1)	_	(0,0,.2)	(0,0,.2)	(0,0,.2)
(.6,.8,1)	_	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)
_	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)
(.8,1,1)	(.8,1,1)	(.4,.6,.8)	(.6,.8,1)	(.8,1,1)	(0,0,.2)
(.4,.6,.8)	(.6,.8,1)	(0,0,.2)	(0,0,.2)	(0,0,.2)	(0,0,.2)
(.8,1,1)	(.8,1,1)	(.6,.8,1)	(.6,.8,1)	(0,0,.2)	(0,0.2)
B4	B5	B6	B7	B8	B9

* Dependence; ** Driving power; # Bk crisp Dependence; ## Bk crisp Driving

A.3.3 Iteration of Level partition of Defuzzified matrix of CSFs

TableA.3.3: Level partition of Defuzzified matrix of CSFs (2nd Iteration)

CSF	Reachability set	Antecedent set	Intersection set	Level
C1	1,8,9	1,3,4,5,6,7,8,9,10,11,12,13,15	1,8,9	II
C3	1,3,4,5,8,9,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	
C4	1,3,4,5,8,9,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	
C5	1,3,4,5,8,9,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	
C6	1,3,4,5,6,7,8,9,10,11,12,13,14	6,7	6,7	
C7	1,3,4,5,6,7,8,9,10,11,12,13,14	6,7	6,7	
C8	1,8,9	1,3,4,5,6,7,8,9,10,11,12,13,14	1,8,9	II
C9	1,8,9	1,3,4,5,6,7,8,9,10,11,12,13,14	1,8,9	II
C10	1,3,4,5,8,9,10,11,12,13,14	6,7,10,12,14	10,12,14	
C11	1,2,3,4,5,8,9,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	
C12	1,3,4,5,8,9,10,11,12,13,14	6,7,10,12,14	10,12,14	
C13	1,2,3,4,5,8,9,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	
C14	1,3,4,5,8,9,10,11,12,13,14	6,7,10,12,14	10,12,14	

Table A.3.4: Level partition of defuzzified matrix of CSFs (3rd Iteration)

S.NO.	Reachability set	Antecedent set	Intersection set	Level
C3	3,4,5,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	III
C4	3,4,5,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	III
C5	3,4,5,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	III
C6	3,4,5,6,7,10,11,12,13,14	6,7	6,7	
C7	3,4,5,6,7,10,11,12,13,14	6,7	6,7	
C10	3,4,5,10,11,12,13,14	6,7,10,12,14	10,12,14	
C11	3,4,5,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	III
C12	1,3,4,5,10,11,12,13,14	6,7,10,12,14	10,12,14	
C13	3,4,5,11,13	3,4,5,6,7,10,11,12,13,14	3,4,5,11,13	III
C14	1,3,4,5,10,11,12,13,14	6,7,10,12,14	10,12,14	

Table A.3.5: Level partition of defuzzified matrix of CSFs (4^{th} Iteration)

S.NO.	Reachability set	Antecedent set	Intersection set	level
C6	6,7,10,12,14	6,7	6,7	
C7	6,7,10,12,14	6,7	6,7	
C10	10,12,14	6,7,10,12,14	10,12,14	IV
C12	10,12,14	6,7,10,12,14	10,12,14	IV
C14	10,12,14	6,7,10,12,14	10,12,14	IV

Table A.3.6: Level partition of defuzzified matrix of CSFs (5^{th} Iteration)

S.NO.	Reachability set	Antecedent set	Intersection set	level
C6	6,7	6,7	6,7	V
C7	6,7	6,7	6,7	V

A.3.4 Iteration of Level partition of Defuzzified Matrix of CFFs

Table A.3.7 Level partition of Defuzzified matrix of CFFs (2^{nd} Iteration)

CFFs	Reachability	Antecedent	Intersection set	level
B1	1,3,6,7,8	1,4,5,6,7	1,6,7	
B2	1,2,3,6,7,8	2,4,5	2	
B3	3,8	1,2,3,4,5,6,7,8	3,8	II
B4	1,2,3,4,5,6,7,8	4,5	4,5	
B5	1,2,3,4,5,6,7,8	4,5	4,5	
B6	1,3,6,7,8	1,4,5,6,7	1,6,7	
B7	1,3,6,7,8	1,4,5,6,7	1,6,7	
B8	3,8	1,2,3,4,5,6,7,8	3,8	II

Table A.3.8 Level partition of Defuzzified matrix of CFFs (3^{rd} Iteration)

CFFs	Reachability	Antecedent	Intersection set	level
B1	1,6,7	1,4,5,6,7	1,6,7	III
B2	1,2,6,7	2,4,5	2	
B4	1,2,4,5,6,7	4,5	4,5	
B5	1,2,4,5,6,7	4,5	4,5	
B6	1,6,7	1,4,5,6,7	1,6,7	III
B7	1,6,7	1,4,5,6,7	1,6,7	III

Table A.3.9 Level partition of Defuzzified matrix of CFFs (4th Iteration)

CFFs	Reachability	Antecedent	Intersection set	level
B2	2	2,4,5	2	IV
B4	2,4,5	4,5	4,5	
B5	2,4,5	4,5	4,5	

Table A.3.10 Level partition of Defuzzified matrix of CFFs (5th Iteration)

CFFs	Reachability	Antecedent	Intersection set	Level
B4	4,5	4,5	4,5	
B5	4,5	4,5	4,5	V

A.4: Values for Severity, Occurrence and Detection for PFMEA Calculation

Table A.5.1: Severity, Occurrence and detection scale adopted from KPMG (2019)

	Severity	**Occurrence**	**Detection**
Rating	Criteria-A failure could	Criteria-A failure could	Definition
10	Injure a customer or employee	More than once per day	The defect caused by failure is not detectable
9	Be illegal	Once every 3-4days	Occasional units are checked for defect
8	Render product or service unfit for use	Once per week	Units are systematically sampled and inspected
7	Cause extreme customer dissatisfaction	Once per month	All units are manually inspected
6	Result in a partial malfunction	Once every 3 months	Units are manually inspected with mistake-proofing modification
5	Cause a loss of performance which is likely to result in a complaint	Once every six months	Process is monitored and manually inspected
4	Cause minor performance loss	Once per year	SPC is used with an immediate reaction to out-of-control conditions
3	Cause a minor nuisance but overcome with no performance loss	Once every 1-3 year	SPC as above with 100% inspection surrounding out-of-control conditions
2	Be unnoticed and have only a minor effect on performance	Once every 2-6 year	All units are automatically inspected
1	Be unnoticed and not affect the performance	Once every 6 to 100 year	Defects are obvious and can be kept from affecting the customer

A.5: 5S Audit Sheet

5S Audit

Project Name:

Lead Time Reduction

Prepared By:

Nidhi Mundra

Prepared Date:

8/22/2022

Area:

Straw Manufacturing unit

0	1	2	3	4
Very Unacceptable	Unacceptable	Average	Good	Perfect

1S Sort

No.	Checking Item	Evaluation Criteria	Score
1	Parts and Materials	Are all stock items and work in progress necessary?	
2	Machines and Equipment	Are all machines and pieces of equipment used regularly?	
3	Jigs, Tools and Molds	Are all jigs, tools, molds, cutting tools, and fittings used regularly?	
4	Visual Control	Can all unnecessary items be distinguished at a glance?	
5	Documentation	Are all obsolete documents purged routinely?	

Summary

Subtotal	
Maximum Possible	20
Percent	0.0%

2S Set in Order

No.	Checking Item	Evaluation Criteria	Score
6	Location Indicators	Are shelves and storage areas marked with location indicators?	
7	Item Indicators	Are shelves marked to show which items go where?	
8	Quantity Indicators	Are maximum and minimum allowable quantities indicated?	
9	Marking of Walkways	Are lines or other markers used to clearly indicate walkways and storage areas?	
10	Jigs and Tools	Are jigs and tools arranged to facilitate removing and replacing them?	

Summary

Subtotal	0
Maximum Possible	20
Percent	0.0%

3S Shine

No.	Checking Item	Evaluation Criteria	Score
11	Floors	Are floors kept clean and shiny?	
12	Machines	Are machines wiped clean and free of waste, water, and oil?	

13	Cleaning and Checking	Is equipment inspection combined with equipment maintenance?	
14	Cleaning Responsibilities	Is a person responsible for overseeing cleaning operations?	
15	Maintaining Cleanliness	Do operators sweep floors and wipe equipment regularly?	

Summary

Subtotal	
Maximum Possible	20
Percent	0.0%

4S Standardize

No.	Checking Item	Evaluation Criteria	Score
16	Improvement Memos	Are improvement memos generated regularly?	
17	Improvement Ideas	Are improvement ideas being implemented?	
18	Key Procedures	Are standard procedures clear, documented, and actively used?	
19	Improvement Plans	Are future standards considered?	
20	Operators	Are operators adequately prepared and appropriately dressed?	

Summary

Subtotal	
Maximum Possible	
Percent	

5S Sustain

No.	Checking Item	Evaluation Criteria	Score
21	Training	Is everyone trained in the standard procedures?	
22	Tools and Parts	Are tools and parts stored correctly?	
23	Stock Controls	Are stock controls adhered to?	
24	Procedures	Are procedures up-to-date and reviewed regularly?	
25	Activity Boards	Are activity boards up-to-date and reviewed regularly?	

Summary

Subtotal	0
Maximum Possible	20
Percent	0.0%

Grand Total

Grand Total	0
Maximum Possible	100
Overall Percent	0.0%

A.6 SPC Data Collection Format

Table A.6.1 Control chart data sheet –I

Date	Holiday	Setup time of SM machine (min)	No. of defectives per day	Uptime of SM machine (min)	Responsibility	Remark
29/08/22					Supervisor	
30/08/22					Supervisor	
31/08/22					Supervisor	
01/09/22					Supervisor	
02/09/22					Supervisor	
03/09/22					Supervisor	
04/09/22					Supervisor	
05/09/22					Supervisor	
06/09/22					Supervisor	
07/09/22					Supervisor	
08/09/22					Supervisor	
09/09/22					Supervisor	
10/09/22					Supervisor	
11/09/22					Supervisor	
12/09/22					Supervisor	
13/09/22					Supervisor	
14/09/22					Supervisor	
15/09/22					Supervisor	
16/09/22					Supervisor	
17/09/22					Supervisor	
18/09/22					Supervisor	
19/09/22					Supervisor	
20/09/22					Supervisor	
21/09/22					Supervisor	
22/09/22					Supervisor	
23/09/22					Supervisor	
24/09/22					Supervisor	
25/09/22					Supervisor	
26/09/22					Supervisor	
27/09/22					Supervisor	
28/09/22					Supervisor	
29/09/22					Supervisor	
30/09/22					Supervisor	

Table A.6.2: Control Chart Data Sheet II:

Date	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	Responsibility	Remark
29/08/22											Supervisor	
30/08/22											Supervisor	
31/08/22											Supervisor	
01/09/22											Supervisor	
02/09/22											Supervisor	
03/09/22											Supervisor	
04/09/22											Supervisor	
05/09/22											Supervisor	
06/09/22											Supervisor	
07/09/22											Supervisor	
08/09/22											Supervisor	
09/09/22											Supervisor	
10/09/22											Supervisor	
11/09/22											Supervisor	
12/09/22											Supervisor	
13/09/22											Supervisor	
14/09/22											Supervisor	
15/09/22											Supervisor	
16/09/22											Supervisor	
17/09/22											Supervisor	
18/09/22											Supervisor	
19/09/22											Supervisor	
20/09/22											Supervisor	
21/09/22											Supervisor	
22/09/22											Supervisor	
23/09/22											Supervisor	
24/09/22											Supervisor	
25/09/22											Supervisor	
26/09/22											Supervisor	
27/09/22											Supervisor	
28/09/22											Supervisor	
29/09/22											Supervisor	
30/09/22											Supervisor	

LIST OF PUBLICATIONS

Journals

1. **Mundra, N.** and Mishra, R.P., and Upreti, G.,(2021), " Development of framework for lean implementation: an interpretive structural modeling and interpretive ranking process approach, *SAE International Journal of Materials & Manufacturing*, Vol.14 No. 2, pp.223-242

   Published by ***SAE International,*** ISSN: 2212-8271 [*Scopus Indexed]*

2. Mishra, R.P., Mundra, N. (2022), "Development of a Model of Critical Failure Factors for integrated LSS-AM practices in Indian manufacturing industries: A Fuzzy TISM Approach, *International Journal of System Assurance Engineering and Management,* ***(Accepted)***
   Published by ***Springer,*** ISSN: 0975-6809 *[Scopus Indexed]*

3. **Mundra, N.** and Mishra, R.P., (2021), " Business Sustainability in Post COVID-19 Era by Integrated LSS-AM Model in Manufacturing: A Structural Equation Modeling", *Procedia CIRP*, Vol.98, pp.535-540.

   Published by ***Elsevier,*** ISSN***:*** 2212-8271 [*Scopus Indexed*]

Conference Papers

1. **Mundra, N.** and Mishra, R.P., (2020), "Impediments to lean six sigma and agile implementation: an interpretive structural modeling. *Materials Today: Proceedings*, 28, pp.2156-2160. **(ICAMEN 2020, Manipal University, Jaipur, India)**

   Published by ***Elsevier*** ISSN: 2214-7853 [*Scopus Indexed*]

2. **Mundra, N**., Mishra, R.P. and Mishra, A., (2021), " Enablers for Lean Six Sigma and Agile Implementation: An Interpretive Structural Modeling Approach", *In*

Recent Advances in Mechanical Engineering (pp. 377-384). Springer, Singapore **(ITME 2019,KIET Ghaziabad, India)**

Published by ***Springer*****,** ISBN**:** 978-981-15-8703-0 [*Scopus Indexed*]

Communicated Papers

1. Development and Validation of Critical Success Factors for integrated LSS-AM practices in Indian manufacturing Industries: A Fuzzy TISM-ISM and SEM approach
2. Lean Six Sigma, Agile Manufacturing and their integration: A Systematic Literature review and Future Research Issues
3. Analysis of Lean Six Sigma and Agile Manufacturing frameworks: A Critical Literature Review and Development of an integrated LSS-AM framework

Other Publications

1. Gupta, G., Mishra, R.P. and **Mundra, N.**, (2018), " Development of a framework for Reliability centered Maintenance", *In International conference on Industrial Engineering and Operations Management*, Bandung, Indonesia.
2. Mishra, R.P., **Mundra, N.,** Upreti, G. and Villa-Marulanda, M.,(2020) "Clinical Decision-Making: Developing a 4 C Model Using Graph Theoretic Approach", *Studies in Engineering and Technology*, Vol.7 No.1, pp.30-47.

Brief Biography of Candidate and Supervisor

About the Candidate:

Nidhi Mundra received her B.E in Mechanical from M.B.M Engineering College, Jodhpur (Rajasthan) and M.E. in Manufacturing Systems Engineering from BITS Pilani ,Pilani (Rajasthan) India. She is currently working with HZL Ltd. Udaipur Rajasthan. She is pursuing her PhD in the field of lean six sigma and agile manufacturing from BITS Pilani .She is having 5 years of work experience in the field of teaching and 3 years of experience in manufacturing industry. Her research interests are primarily in the field of lean manufacturing, six sigma, agile manufacturing, lean six sigma, and maintenance. She is certified LSS black belt and associate member of IEI.

About the Supervisor:

Prof. Rajesh Prasad Mishra is working as a Professor in the Department of Mechanical Engineering at BITS, Pilani, Pilani campus, Rajasthan. He completed his B.E. from MGCGV Chitrakoot Satna MP, M.E., and Ph.D. from BITS Pilani. His research interests are in the field of maintenance engineering, lean manufacturing, optimization techniques, manufacturing systems, and simulation and analysis of RAMS. Currently, He is guiding 3 Ph.D students in addition to a considerable number of research practices, dissertations, and thesis supervised. He is also actively involved in research activities in collaboration with universities such as LTU Sweden, UTK Knoxville, etc. He has more than 50 publications in international journals and conferences.