Development of an Integrated Performance Measurement Framework for Leanness Assessment of Manufacturing Organizations

THESIS

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DOCTOR OF PHILOSOPHY

by

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Under the Supervision of

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…Dedicated

to

my beloved parents…

Birla Institute of Technology & Science, Pilani
Pilani Campus

CERTIFICATE

This is to certify that the thesis entitled **"Development of an Integrated Performance Measurement Framework for Leanness Assessment of Manufacturing Organizations"** submitted by **Narpat Ram Sangwa,** ID. No. **2013PHXF0414P** for award of Ph.D. degree of the institute embodies original work done by him under my supervision.

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ABSTRACT

Lean manufacturing has been implemented across a broad spectrum of industries to eliminate or reduce waste and stay competitive in fierce global competition. During last decade, there are many reported failures of lean manufacturing implementation because of many factors like lack of clear understanding of main attributes of leanness and its assessment, and lack of methods for leanness assessment. Existing leanness assessment methodologies do not offer a comprehensive assessment by integrating the assessment of various functional areas of an organization. This study aims to develop an integrated performance measurement framework for leanness assessment and validate it by assessing the leanness of an automotive component manufacturing organization.

Leanness assessment is not enough; leanness improvement is desired. The study explored the leanness assessment through a systematic literature review to trace the evolution of leanness assessment approaches and scope of leanness assessment. The study also identifies the hard and soft lean practices and prioritizes them using interpretive structural modelling (ISM) and interpretive ranking process (IRP) approaches. A case study is conducted to demonstrate the utility of the fuzzy methodology developed for the assessment of employee ownership (a soft lean practice) and its improvement by simple managerial interventions. An integrated value stream map (VSM) is also developed for a complex assembly line to assess the its leanness using the concept of multi-machine activity with a single operator as a unit or work cell. Continuous *kaizen* concept is introduced to improve the leanness of a complex assembly line at an automotive component manufacturing organization.

The developed IPM framework assesses the organization under seven categories – manufacturing process, new product development, human resource management, finance, suppliers, customers, and administration. The study proposes 119 key performance indicators (KPIs) under 26 performance dimensions. The proposed KPIs are categorized as qualitative or quantitative, strategic or operational, social or technical, financial or non-financial, leading or lagging, static or dynamic; and linked to either the eight lean wastes or/and the five lean principles. The integrated framework enables to assess the leanness of an organization at KPI, performance dimension, functional area, and organization levels. The fuzzy methodology used for the assessment of leanness assessment is well established to take care of vague and imprecise information.

The managers at the different levels of hierarchy can use the leanness assessment score to leverage the better performing areas/dimensions and improve poor performing areas/dimensions. It is expected that the hierarchical models developed by using ISM and IRP approaches will find their applications for prioritization and ranking of lean practices for sequential implementation as unstructured implementation of lean practices led to anarchy and failures. The structural models also assist management to assign proper roles to employees/departments for the effective lean implementation.

The proposed integrated VSM for complex assembly environments can be used as a diagnostic tool to find the lean wastes. The study also shows how multi-hierarchical cross-functional teams can diagnose the root causes of the problems by using Ishikawa diagrams, and micro analysis methods of 3M and ECRS to unravel the problematic activities. The study also proposes a new delineation of *kaizen* philosophy – continuous *kaizen* – which means continuous improvements at the global or whole value chain level instead of just ‘change for better’ at local or single workstation level. The proposed integrated VSM for a complex assembly line environment can be replicated by the practitioners to leverage the numerous advantages of VSM under complex environments.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
ATLs	Assistant Team Leaders
BOP	Brought-Out Parts
CLR	Conceptual Literature Review
CONWIP	Constant Work in Process
CPM	Continuous Performance Measurement
DMP	Dynamic Multi-dimensional Performance
ECRS	Eliminate or Combine or Reduce or Shift
ERP	Enterprise Resource Planning
FPY	First Pass Yield
HMLV	High-Mix Low-Volume
HRM	Human Resource Management
IPM	Integrated Performance Measurement
IRP	Interpretive Ranking Process
ISM	Interpretive Structural Modelling
JIT	Just in Time
KPIs	Key Performance Indicators
LAT	Leanness Assessment Tool
LM	Lean Manufacturing
MCDM	Multi-Criteria Decision Making
ME	Manufacturing Engineering
MICMAC	*Matrice d'Impacts Croises-Multipication Applique´ An Classment*
MMAs	Multi-Machine Activities
NPD	New Product Development
OEE	Overall Equipment Effectiveness
PDI	Pre Dispatch Inspection
PGP	Preemptive Goal Programming
PMS	Performance Measurement System
PPC	Production Planning And Control
PSS	Product-Service System

Abbreviation	**Description**
QFD	Quality Function Deployment
QRM	Quick Response Manufacturing
R & D	Research and Development
ROA	Return on Assets
ROI	Return on Investment
RQs	Research Questions
ROS	Return on Sales
SEM	Structural Equation Modelling
SLR	Systematic Literature Review
SMART	Strategic Measurement Analysis And Reporting Technique
SMED	Single Minute Exchange of Dies
SMEs	Small and Medium Enterprises
SPC	Statistical Process Control
SSIM	Structural Self-Interaction Matrix
TLs	Team Leaders
TPM	Total Productive Maintenance
TQM	Total Quality Management
TPR	Throughput Rate
TPS	Toyota Production System
UJ	Universal Joint
VSM	Value Stream Mapping
WIP	Work in Process

CHAPTER 1

INTRODUCTION

1.1 LEAN MANUFACTURING AND LEANNESS ASSESSMENT

After World War II, the Toyota motor company led by Eiji Toyoda, Shigeo Shingo and Taiichi Ohno developed a new manufacturing system, initially known as Toyota Production System (TPS) and later lean production in 1990 (Black, 2007). The term 'lean' was coined by Krafcik in 1988; and Womack, Jones, and Roos (1990) used the term 'lean production' in their book *The Machine That Changed the World* which has received universal acceptance. The lean thinking has created immense awareness among researchers and practitioners to eliminate wastes from manufacturing as well as service industries (Kennedy, 2003; Morgan and Liker, 2006). Lean production also known as lean manufacturing refers to a manufacturing paradigm based on the fundamental goal of continuously minimizing waste and maximizing flow to become highly responsive to the customer demand while producing quality products in an efficient and economical manner (Seth and Gupta, 2005). Various authors have documented quantitative and qualitative benefits of lean implementation.

The advent of recession at the beginning of 21st century forced many organizations worldwide to reduce cost and to be more responsive to customer demands (Bhamu and Sangwan, 2014). It was felt that lean manufacturing (LM) is one of the potential systems to compete globally. Rahman, Laosirihongthong, and Sohal (2010) argued that lean manufacturing is applicable not only for large enterprises but also for small and medium enterprises (SMEs). Lean manufacturing implementation started in automotive industry and later on was adopted by other industries like machinery & equipment, food production, textile, electrical & electronics, furniture, construction, pharmaceuticals, services, *etc*. Lean manufacturing has been adopted by all types of manufacturing systems – batch production to mass productions; discrete production to continuous production; manufacturing sector to service sector; labour-intensive industries to technology intensive industries; and construction industry to assembly industry (Bhamu and Sangwan, 2014).

Leanness has been interpreted diversely in the literature (Wan and Chen, 2008). Leanness is described as a context dependent process (Rees, Scarbrough, and Terry, 1996); a process to realize lean principles (Naylor, Naim, and Berry, 1999); a relative measure whether a company is lean or not (Comm and Mathaisel, 2000; Bayou and de Korvin, 2008); a measure of the adoption of lean manufacturing practices (Susilawati *et al.*, 2013); a degree of performance of lean manufacturing practices (Azevedo, Carvalho, and Cruz-Machado, 2016); a measure of the performance of lean manufacturing practices (Oleghe and Salonitis, 2018); *etc.* Although, leanness has been used in a diverse manner, more and more organizations are implementing lean manufacturing to enhance the leanness of their systems. Leanness assessment is a relative and dynamic process for long term continuous improvement (Bayou and de Korvin, 2008).

Leanness assessment methodologies vary from simple qualitative checklist to complex quantitative mathematical models (Narayanamurthy and Gurumurthy, 2016a). Leanness assessment has been addressed through survey based statistical analysis and case study based analysis of individual organizations (Saurin, Marodin, and Ribeiro, 2011). There are three basic approaches to the leanness assessment in the literature (Afonso and Cabrita, 2015; Behrouzi and Wong, 2013). The first one is based on measuring the degree of implementation of lean tools and techniques. The second is the outcome based assessment resulting from lean implementation. The third one is waste elimination based assessment.

1.2 RESEARCH MOTIVATION

During last few decades, industry has realized the importance of waste reduction and continuous improvement to be globally competitive. An assessment of organizational performance is a pre-requisite for continuous improvement. Lean manufacturing has been implemented to reduce waste and stay competitive. The existing literature shows that there is less research on leanness assessment as compared to lean implementation. The benefits of lean manufacturing cannot be proved unless there is a proper assessment. Moreover, the assessment is necessary for the improvement as Peter Drucker, a well-known management thinker, states 'if you can't measure it, you can't improve it'. There are reported failures of lean manufacturing in organizations (Bortolotti, Boscari, and Danese, 2015; Susilawati *et al.*, 2015; Behrouzi and Wong, 2011; Bhasin and Burcher, 2006; Tiwari, Turner, and Sackett, 2007; Karim and Arif-Uz-Zaman, 2013; Gupta and Kundra, 2012). Lack of a clear understanding of the main attributes to leanness, lean performance and its measurement contributes to lean failures (Anvari, Zulkifli, and Yusuff, 2013). Walter and Tubino (2013) emphasized the need of leanness assessment by stating that the research dearth of methods that evaluate lean implementation might justify the misunderstanding and failure in implementing lean practices. Moreover, many western companies unsuccessfully tried to import Japanese manufacturing techniques to their production systems devoid of existent sociocultural practices, which led to limited benefits (Sezen, Karakadilar, and Buyukozkan, 2012). Bortolotti, Boscari, and Danese (2015) have found that susuccessful plants use soft lean practices more extensively than unsuccessful plants. Hence, more research needs to be done to know whether the lean manufacturing fails in practice due to the inappropriate performance measures or improper assessment or improper implementation or a combination of all.

1.3 CASE ORGANIZATION

Globalization and environmentalism are opening up newer avenues for the transportation industry, especially while it makes a shift towards electric and hybrid cars, which are deemed more environment friendly modes of transportation. This will open up new opportunities and challenges for the automobile industry. Over the next decade, this will lead to newer verticals and opportunities for auto component manufacturers, who would need to adapt to the change. The e-mobility and its growth could impact auto component manufacturers in India in a big way (https://www.mckinsey.com, 2019). It is imperative for auto component manufacturers to start preparing for the ensuing disruption.

The Indian automotive organizations have experienced a remarkable growth during the last decade (Gopal and Thakkar, 2016). Indian automotive component industry is highly competitive with a number of global and Indian companies of different sizes. The Indian automotive component industry in FY 2017-18 witnessed a growth of 18.3% over the previous year, registering a turnover of INR 3,45,635 crore. Over the years, the Indian auto component manufacturers have increased their global footprint; and the export grew at 23.9% during FY 2017-18 to reach INR 90,571 crore (Automotive Component Manufacturers Association of India, 2018). Indian auto components are exported to more than 160 countries (https://www.acma.in, 2019). Europe accounts for the largest share of Indian auto components exports at 38.1%, followed by North America at 21%, and finally Asia at 25% (https://www.ibef.org, 2019). In 1990's, most of the exports were made to the international aftermarkets whereas at present most of the exports are made to the global OEMs or tier I organizations. This reflects that the Indian auto component manufacturers are equipping themselves with the latest manufacturing philosophies and practices to survive in the global competitive market; in addition to the traditional benefit of lower labour cost. The Indian auto component manufacturers need to brace for significantly lean operations to adapt to the changes (https://www.mckinsey.com, 2019).

Therefore, the leanness assessment of an Indian automotive component manufacturing organization (hereafter case organization) is carried out to show the usefulness of the proposed models. The case organization, a leading automotive components manufacturer, was established in 1985. It is a joint venture of Indian and Japanese organizations and has global presence including Europe and USA. It has seven plants in India. The organization produces the steering systems and various driveline components for light commercial utility vehicles and passenger cars for almost all automotive manufacturers in India. The case organization has ISO 9001, ISO 14001, and TS 16949 certifications. It also got the Deming prize in 2003, TPM excellence award in 2007, and *udyog rattan* award in 2012. The case study is conducted at one of the plants of the case organization. Steering shafts, steering gears, idler housings and assemblies, steering column assemblies, case differentials, and differential boxes are produced in the selected plant of case organization. The two core values of the case organization are ‘respect for the individual’ and ‘service to the customer’, and the five guiding principles of the case organization are: ownership, teamwork and self-discipline, aspiration for innovation and for technique, continuous kaizen, and customer first.

1.4 OBJECTIVES OF THE RESEARCH

The objectives of the proposed research are:

- To trace the evolution of leanness assessment approaches and scope of leanness assessment through a literature review
- To develop an outcome based integrated performance measurement framework for leanness assessment and validate it by assessing the leanness of the case organization

- To identify hard and soft lean tools and techniques (practices) and prioritize them using interpretive structural modelling (ISM) and interpretive ranking process (IRP) approaches
- To assess and improve employee ownership (a soft lean practice) of the case organization
- To develop an integrated values stream mapping approach for the leanness assessment and improvement of a complex assembly line at the case organization

1.5 METHODOLOGY

To accomplish the above mentioned objectives of the research, following tasks are performed as per the work plan shown in figure 1.1.

- A systematic literature review is conducted (1998 – 2018) to trace the evolution of various themes of leanness, leanness assessment approaches, and leanness assessment functional areas
- A conceptual literature review is conducted to develop the performance dimensions and key performance indicators (KPIs) for assessing the identified functional areas of an organization. An integrated performance measurement framework is developed for the leanness assessment at KPI, performance dimension, functional area, and organization levels
- A case study is conducted to assess the leanness of an Indian automotive component manufacturing organization by using the proposed integrated performance measurement framework in conjunction with fuzzy and fuzzy ANP methodologies
- 20 hard and 12 soft lean practices are identified from the literature. ISM and IRP models of hard and soft lean practices are developed to prioritize/rank these practices

- A case study is conducted to assess the employee ownership of the case organization by using fuzzy methodology. Managerial interventions are proposed and implemented to improve the employee ownership of the case organization.
- An integrated VSM approach is developed to assess the leanness of a complex assembly line. Continuous *kaizen* concept is used to improve the leanness of a complex assembly line at the case organization

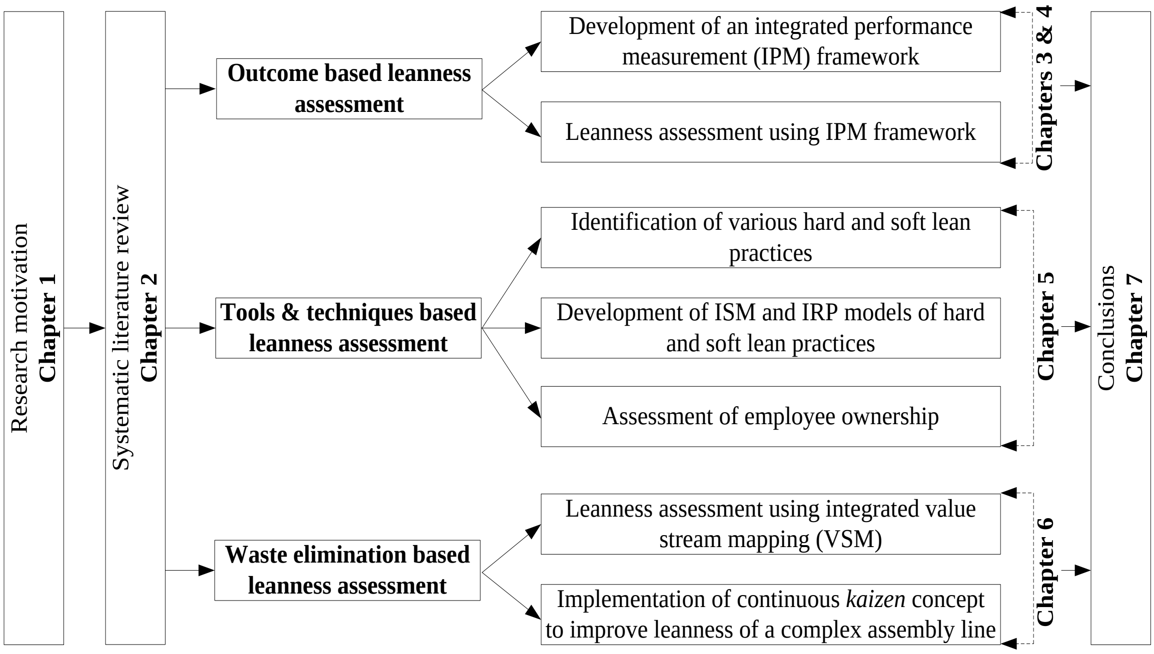


Figure 1.1: Work plan to achieve thesis objectives

1.6 SIGNIFICANCE OF THE STUDY

The thesis contributes to the existent body of knowledge on leanness assessment for academicians, researchers, and practitioners alike. The systematic literature review, one of its kind on leanness assessment, can be a building block for the budding researchers to explore the newer research areas in leanness assessment. The proposed integrated performance measurement framework for lean assessment is comprehensive; it encompasses various functional areas of an organization, unlike the existing frameworks which mainly assess manufacturing process, and to some extent, financial and new product development areas. Important areas like customer management, supplier management, human resource management, and administration are not assessed in an integrated way for leanness by most of the existing frameworks/models. 119 KPIs, identified from the literature for assessing 26 performance dimensions of seven functional areas of an organization, can be used by the practitioners for leanness assessment and improvement of their organizations irrespective of the type of industry. The practitioners can use the leanness assessment score of different levels of the hierarchy to leverage the better performing areas/dimensions and improve the poor performing areas/dimensions. Researchers can also use these KPIs for comparing their research. The thesis also makes a useful lecture material for teaching leanness assessment as the developed models are validated by the case studies.

The identification and prioritization/ranking of the hard and soft lean practices provide leverage to the practitioners to prioritize limited resources for the implementation of lean manufacturing as per the hierarchical models of lean practices developed by using ISM and IRP approaches. The developed ISM and IRP models provide the inter-linkages/dominance of the practices, which lead to a better perspective for the effective implementation. It is expected that the descriptive study on employee ownership will be beneficial to the human resource personnel to improve employee ownership.

It is expected that the developed integrated VSM for a complex assembly line environment can be replicated by the practitioners to leverage numerous advantages of VSM for complex environments. The concept of continuous *kaizen* can be used to improve the leanness of a system.

1.7 ORGANIZATION OF THE THESIS

The thesis is organized into seven chapters. Chapter 2 presents a systematic literature review of the leanness assessment to trace the evolution of various themes of leanness, leanness assessment approaches, and functional areas from 1998 to 2018. Chapter 3 discusses the development of an integrated performance measurement framework to assess the organizational leanness. Chapter 4 describes the leanness assessment of the case organization using the IPM framework. Chapter 5 presents various hard and soft lean practices and their hierarchical models, developed by using interpretive structural modelling (ISM) and interpretive ranking process (IRP) approaches. Chapter 6 demonstrates an integrated value stream mapping (VSM) approach to assess and improve leanness of a complex assembly line in conjunction with the concepts of continuous *kaizen*. Finally, chapter 7 provides the conclusions of the study with limitations and scope for future research.

CHAPTER 2

LEANNESS ASSESSMENT: A SYSTEMATIC LITERATURE REVIEW

In this chapter, a systematic literature review (SLR) of the leanness assessment has been conducted to trace the evolution of various themes of leanness, leanness assessment approaches, and leanness assessment areas of an organization.

2.1 INTRODUCTION

Performance evaluation is a way of evaluating a system about its capability, competence, efficiency, and effectiveness to fulfill certain objectives. The issue of performance evaluation, originated in the 1980s, was thought to be sufficiently matured to measure quality, cost, and delivery until newer non-financial performance dimensions like flexibility, reliability, safety, *etc.* appeared. This led to the non-financial performance measures driven by the core competencies of the organizations. The data about these performance measures are generally multi-dimensional, complex and non-quantitative. Literature shows that early attempts to use these performance measures to measure or evaluate the effectiveness of newer systems like lean manufacturing or lean organizations have failed. There are many studies in recent past which suggest that lean manufacturing has failed to achieve the desired results (Bortolotti, Boscari, and Danese, 2015; Tiwari, Turner, and Sackett, 2007; Bhasin and Burcher, 2006). Liker and Rother (2011) pointed out that the numerous lean programs were not successful due to the superficial approach of the organizations. Several organizations focused on the implementation of hard lean tools and techniques and ignored the soft lean practices (human-related practices) (Liker and Rother, 2011; Bortolotti, Boscari, and Danese, 2015). There have been several reports about the lean failures because of the selection and implementation of various improper tools/techniques in a specific environment (Tiwari, Turner, and Sackett, 2007; Karim and Arif-Uz-Zaman, 2013). Gupta and Kundra (2012) opined that this failure is because of the consideration of the lean as a manufacturing strategy or process, rather than as a long-term philosophy. Some other reasons of lean failure include underestimation of lean by the top management (Ahmad, Mehra, and Pletcher, 2004; Zhu and Lin, 2017), resistance to change and organizational culture (Bhasin, 2011a; Bhasin and Burcher, 2006), lack of management support, inadequate training and resistance to change (Sharma *et al.*, 2015), lack of understanding, use of incorrect tools, application of one tool to solve all the organizational issues, and poor decision-making system (Bhamu and Sangwan, 2014). Susilawati *et al.* (2015) concluded that lean failure is due to the complex nature and improper implementation of the lean philosophy. But, it is also true that more and more organizations are trying to be more competitive by reducing unwanted and unwarranted waste by adopting lean philosophy. Hence, more research needs to be done to know whether the lean manufacturing failed due to the inappropriate performance measures or improper implementation or a combination of both.

The scope of this chapter is to answer the following research questions:

- How have themes, approaches and functional areas of leanness assessment evolved over the period?
- What should be the future direction of leanness assessment?

Lean assessment is a comparatively new area of research; the first publication about lean assessment was published by Harrison (1998) after a decade of the term "lean" coined by John Krafcik in 1988. Lean assessment is a continuous improvement process due to its intrinsically dynamic nature. Doolen and Hacker (2005) developed a survey instrument to measure the degree of implementation of lean practices used by electronics manufacturers.

Wan and Chen (2009) proposed a web-based program to effectively guide the process of lean implementation and presented an adaptive lean assessment model to assess the current status of the organization and to indicate the improvement areas for further action. Vinodh and Chintha (2011a) designed a leanness measurement model and identified probable improvement areas using the multi-grade fuzzy technique. Ramesh and Kodali (2012) proposed a decision framework, by integrating the analytical hierarchy process (AHP) and preemptive goal programming (PGP), to select the appropriate value stream map (VSM) as per organizational priorities. Vimal and Vinodh (2012) applied IF-THEN rules to recognize the weak areas within an organization, provided the solutions to overcome these difficulties to enhance leanness level of an organization. AL-Najem *et al.* (2013) developed a measurement framework of lean systems (processes; human resources; top management and leadership; planning and control; customer relations; and supplier relations) for Kuwaiti small and medium manufacturing industries and found that the quality practices were not very supportive of lean systems. Similarly, Garza-Reyes *et al.* (2018) assessed the lean readiness level of European pharmaceutical manufacturing organizations through six quality practices and found the unsatisfactory level of lean readiness for the participating organizations. Moreover, Garza-Reyes *et al.* (2015) adapted the framework developed by AL-Najem *et al.* (2013) to evaluate the lean readiness of the Turkish automotive suppliers and observed a high level of lean readiness among Turkish automotive suppliers, particularly in the areas of top management and leadership, and customer relations. Pakdil and Leonard (2014) developed a leanness assessment tool (LAT) using qualitative and quantitative aspects of leanness. Costa *et al.* (2014) claimed that the available literature is unable to assess the effect of lean principles on system engineering program performance and identified metrics to measure the lean performance. The literature on lean assessment does not maintain the pace of advancement because a pervasive proportion of the available literature depends upon a rather obsolete vision of lean assessment (Papadopoulou and Özbayrak, 2005).

The existing literature has some papers on "lean assessment", but only few papers on "literature review of lean assessment". Only six review articles were found in the literature which reviews the literature on lean assessment. The first review paper on the leanness assessment was published by Doolen and Hacker (2005). Doolen and Hacker (2005) reviewed 12 different survey instruments and seven industrial assessment tools along with the review of associated literature on the possible limitations of a lean manufacturing strategy. Narayanamurthy and Gurumurthy (2016a) conducted a detailed literature review of leanness assessment by analyzing 31 peer-reviewed journal articles and conference papers and found that leanness assessment literature has evolved from process-level to organization-level. Cocca *et al.* (2018) conducted a SLR of the 31 methods to assess leanness in manufacturing organizations. The results show that less than a third of the methods are capable to measure leanness in a comprehensive way by considering both the implementation level of lean practices and the performance outcomes.

2.2 LITERATURE REVIEW

There are eight types of literature reviews: systematic, state of the art, narrative, realistic, rapid, conceptual, expert, and critical (Thomé, Scavarda, and Scavarda, 2016). A brief review of these literature review techniques is presented in table 2.1. It is proposed to do a systematic literature review of the leanness assessment to provide a meta-analysis and synthesis of the leanness assessment.

Table 2.1: Different types of literature reviews and their scope

Type of review	Scope	Author
Systematic review	• Systematic, transparent, scientific, and most widely accepted process • Well-defined, precise and accurate • Covers all published studies related to the particular topic • Defines the time span of the selected literature. • Emphasizes on specific research questions which draw cause and effect analysis • Provides meta-analysis and synthesis of the selected literature	Petticrew and Roberts, 2006; Morioka and Carvalho, 2016; Adapa, Bhullar, and De Souza, 2016; Thomé, Scavarda, and Scavarda, 2016; Glock, 2017; Costa and Filho, 2016
State of the art review	• Mainly concentrates on current research of selected topic. • Provides new point of view on current issues • Primarily focuses on technical areas	Garza-Reyes, 2015; Butler, 1999; Asiedy and Gu, 1998
Narrative review	• Covers large number of studies which are directly or indirectly related to the selected topic • Draws conclusions of the selected topic • Identifies the gaps in the existing research • Summarizes the information about the methods and results.	Bhamu and Sangwan, 2014; Costa and Filho, 2016; Rowley and Stack, 2004
Realistic review	• Basically used to synthesize individual studies and produce a generalized theory • Helps to refine the existing theories • Rarely used for literature review	Pawson *et al.*, 2005
Rapid review	• This type of literature review is periodic and carried out for a restricted time span (for few months) • Very less number of articles reviewed • Systematic assessment of the existing findings on the selected topic.	Petticrew and Roberts, 2006
Conceptual review	• Examines conceptual knowledge and synthesizes different theories, concepts, and phenomena • Provides a theoretical literature review of existing theories and interrelationship among them • Used to propose a new conceptual framework, model, roadmap or instrument based on the existing literature of the specific topic	Bhamu and Sangwan, 2014; Gupta and Kundra, 2012; Neely, Gregory, and Platts, 2005
Expert review	• Review done by experts of the subject or field • Common approach in basic science, pharmaceutical, and medicine	Petticrew and Roberts, 2006
Critical review	• Focused on extensive literature of a specific topic and deeply evaluates the quality of research • Results are typically presented in the form of a hypothesis or framework • Provides higher degree of analysis and synthesis of the selected topic	Jasti and Kodali, 2015; Rowley and Stack, 2004; Lélé, 1991

A systematic literature review is systematic, transparent, scientific, holistic, and most widely accepted (Thomé, Scavarda, and Scavarda, 2016). Hence, this study systematically reviews the lean assessment literature to find research gaps on lean assessment. This will also help not only to unravel the shift in the themes and leanness assessment approaches but also to highlight the homogeneity and heterogeneity in past leanness assessment methods. The SLR comprises four phases: plan, do, analyze/synthesize, and propose (table 2.2).

Table 2.2: Different phases of a systematic literature review

SLR Phase	Purpose	Description	Article Section
Phase 1: Plan	Identification of problems	Review of lean articles has reported failure of lean philosophy and complexity of leanness assessment. Lack of leanness assessment review articles in the literature.	Section 2.1
Phase 2: Do	Selection of keywords, databases, inclusion/exclusion criteria, *etc.*	Inclusion/ exclusion criteria and keywords were defined to select literature by assuring the relevance of the article for the proposed SLR.	Section 2.2
Phase 3: Analyze/Synthesize	Analysis and synthesis of the literature	Descriptive and content analyses to get insight from the literature.	Section 2.3
Phase 4: Propose	Interpretation of findings and propose the future research direction	Findings of the literature review. Future research direction proposed.	Section 2.4

Planning is the first phase of a SLR, which contains problem identification and research question(s). The planning phase answers: Why is the review required? How to start the review process? What will be the contribution of the work? In the second phase, literature for the review is selected. This is the most important phase of a SLR. If the selected literature is inappropriate or irrelevant, then the subsequent phases will present flawed contribution. Third and fourth phases are used to analyze, interpret and propose the future research directions. The research methodology for SLR is crisply presented in table 2.3.

For any kind of literature search, it is essential to identify what should be included and what should be excluded. First of all, the study restricted the work published in the English language to define the inclusion criteria. The English language is selected because it has a maximum number of research articles and wide readership. Further, the articles on lean assessment published in peer-reviewed journals or conferences are included. The patent and citation were excluded. The Google Scholar (https://scholar.google.co.in) has been used for the literature search. A systematic search commences with the selection of keywords, which is usually done after careful examination of literature and dialogue with peers. The keywords to perform the literature review were picked up by the analysis of the extant literature on the subject. The inclusive keywords used to find out articles related to lean assessment literature were: "lean performance", "leanness" and "lean" with one of the word evaluation, assessment, measurement, indicators, model, framework, metrics, measure, assess, tool, or outcome (table 2.3).

Table 2.3: Research methodology for systematic literature review

Filter Type	**Characterization**	**Result**
Inclusion criteria	Topic: articles related to lean assessment only. Language: English Time span: all articles published until December 2018. Article type: articles published in peer-reviewed journals and conferences.	
Exclusion criteria	Patents and citations.	
Keywords	• Inclusive keywords: "Lean performance" or "Leanness" With at least one of the words: evaluation, assessment, measurement, indicators, model, framework, metrics, measure, assess, tool, outcome • Inclusive keyword: "Lean" With at least one of the words: evaluation, assessment, measurement, indicators, metrics, measure, assess Without the words: performance, implementation, water, body, fat, muscle, tissue, agile, six, catalysts, men, women, combustion, meat, fuel, environment	
Keyword search	Search engine: Google scholar Articles containing at least one of the above-defined keywords in the title of the article. Manual sorting of the article titles to select only those articles which consider industrial or organizational performance.	194
Consolidation I	Articles published in Science Direct, Emerald, Springer, Taylor & Francis, and IEEE databases.	86
Consolidation II	Reading abstracts to assure relevancy of the articles.	71
Consolidation III	Reading complete articles to assure relevancy of articles.	61
Consolidation IV	Forward/backward snowball approach to search the additional relevant articles.	+25
Final sample size		86

Some words (implementation, water, body, fat, muscle, tissue, agile, six, catalysts, men, women, combustion, meat, fuel, and environment) were excluded, because through manual inspection, it was observed that these words provided irrelevant data. The keywords should be adequately broad so as neither to synthetically confine the number of studies nor to miss the studies associated with the topic of research (Thomé, Scavarda, and Scavarda, 2016; Cooper, 2015). All keywords were only searched in the title of the article. Keywords are used to search different articles related to the topic of the research. The time horizon for this literature search is from 1998 to 2018. The first paper on lean assessment appeared in 1998. In the identification step, 194 research articles were identified using the keyword search. The sorting was required since browsing returned a large number of articles. The screening of the articles was done on the basis of databases, relevancy of articles by manual reading of abstracts and then reading full-length articles. It is observed that around 45 percent of the articles have been published in five reputed databases: Science Direct, Emerald, Taylor & Francis, Springer, and IEEE. Saunders, Lewis, and Thornhill, (2012) also argued that these databases are the most reliable and suitable for the literature reviews. The conference papers were also restricted to these databases. Hence, electronic databases of Science Direct (sciencedirect.com), Emerald (emeraldinsight.com), Taylor & Francis (tandfonline.com), Springer (springerlink.com), and IEEE (ieeexplore.ieee.org) were included in the search. This led to the removal of about 55% articles. Articles were further consolidated by reading the abstract and full paper, leading to the removal of 25 articles. The total articles left after consolidation were 61. The final sample size was obtained through snowball approach using forward/backward search. The forward/backward snowball approach was used and this led to the addition of 25 articles, leading to a total of 86 articles for the study as shown in table

2.3. The complete list of reviewed articles and their characteristics are presented in table 2.4. A brief review of articles on leanness assessment is presented here:

Sánchez and Pérez (2001) developed an integrated checklist to assess manufacturing changes with respect to lean production. The model used 36 indicators within six groups comprising team work, continuous improvement, JIT production, suppliers' integration, elimination of zero-value activities, and delivery. The survey of Spanish manufacturing plants is used to identify the lean production indicators, which are more expedient to assess the leanness level within the production systems. The authors found that half of surveyed organization used 60% of the identified indicators. Although this is one of the few studies which used indicators for the first time to assess the leanness.

Taj (2005) evaluated the current state of some electronics manufacturing plants in China. An Excel spreadsheet is used as an assessment tool to evaluate nine essential functional areas of processes, inventory, maintenance, setup, team approach, quality, layout/handling, scheduling/control, and suppliers. Results showed the significant gaps between the actual positions of the organizations and the targets. Most of the identified areas are limited to the shop floor of the manufacturing plant which restricts the usability of the developed assessment tool to integrate the shop floor with the other functional areas of an organization.

Bayou and de Korvin (2008) defined the manufacturing leanness as a strategy to incur less input to attain the organizational goals through generating better output. Authors also compared manufacturing leanness of General Motors and Ford Motors Companies using Honda Motor Company's system as a benchmark. For the comparison, authors selected the lean attributes of JIT, quality controls and *kaizen*, and collected the data from audited financial statements of three years. The benchmarking of these two organizations proved that the manufacturing system of Ford Motors is 17% leaner than that of General Motors.

Bhasin (2008) proposed a robust system that not only concentrates on the intangible and intellectual assets but also embraces various time horizons and the interests of multiple stakeholders. The dynamic multi-dimensional performance (DMP) framework embracing five dimensions is more robust and stresses the need to utilize a smaller set of multidimensional metrics which are closely aligned with an organization's strategies. DMP model provides a good barometer for multiple time horizons and facilitates the examination of a wider view of organizational success. This model does not guide how to deploy enterprise performance management or evaluation, rather it focuses on measurement systems. Many organizations fail to conquer the main difficulty is translating qualitative targets into quantitative metrics.

Behrouzi and Wong (2011) presented a simple and innovative fuzzy methodology to assess the leanness of manufacturing systems. This methodology provided a single unit-less leanness score for the whole manufacturing system. The waste elimination and JIT were identified as two most important lean attributes. Further, authors used a numerical example to illustrate the used fuzzy methodology. However, the limited number of lean attributes and the use of hypothetical case example for the illustration limit its application in actual real time situations.

Ramesh and Kodali (2012) developed a decision framework to maximize the organizational performance with minimum use of resources by the elimination of lean wastes from the production process. Authors proposed an integrated analytical hierarchy process (AHP) – preemptive goal programming (PGP) method for the selection of the most preferred sequence of VSM. The theoretical contribution of the method is the use of iterative PGP strategy, which permits the manager to precisely find out the optimum values of various performance parameters that maximize overall organizational performance.

Sopelana *et al.* (2012) demonstrated the application of lean transformation toolkit (LeanT2) by conducting the exploratory study in five Spanish organizations. Authors proposed a SMART readiness maturity assessment tool which was used for the implementation and measurement of lean manufacturing in the product development process. Results indicate that product development teams are overloaded due to number of non-value added activities. The major limitation of the study is the use of only qualitative module; the use of quantitative module would improve the assessment.

Alsmadi, Almani and Jerisat (2012) empirically analyzed the variation in lean practices as well as their relationship to company performance in manufacturing and service sectors. It was found that the manufacturing sector use hard practices such as TPM and set-up time reduction and the service sector outperforms in soft lean practices related to customer and human resource (HR) management. Empirical study showed a positive relationship between lean practices and company performance in both the sectors. Also, the degree of effect on performance was found to be identical in both the sectors.

Behrouzi and Wong (2013) developed an integrated stochastic-fuzzy model to assess supply chain leanness of an automotive organization. Total 28 performance measures were selected under the four categories of cost, quality, flexibility and delivery, and reliability to assess the leanness level. Total leanness index was calculated to assess current leanness level and identify weak performing categories. Authors also suggested some specific management actions to improve the leanness level.

Cil and Turkan (2013) analyzed the relationship between the lean transformation and the organization's priority to implement and assess the transformation of individual lean elements. The study used an analytic lean enterprise transformation modeling approach to identify the weights of lean transformation components. Authors suggested that for a comprehensive view of lean transformation; this model should be combined with survey based assessment tools.

Karim and Arif-Uz-Zaman (2013) developed a methodology for implementing lean manufacturing strategies and also proposed a leanness evaluation metric using continuous performance measurement (CPM). The methodology is used to identify manufacturing wastes, select suitable lean tools, identify relevant performance indicators, attain significant performance improvement, and setup lean culture in the organization. Authors developed a simplified leanness evaluation metric considering both efficiency and effectiveness attributes and integrated it with the lean implementation methodology. However, the implementation of this method may be costly and time consuming.

Belekoukias, Garza-Reyes and Kumar (2014) investigated the impact of five essential lean methods (i.e. JIT, automation, kaizen, total productive maintenance (TPM), and value stream mapping (VSM)) on contemporary measures of operational performance (i.e. cost, speed, dependability, quality, and flexibility) to provide an enhanced understanding of the relationship between the lean strategy and the operational performance. The study employs a three pronged verification approach by using correlations, regressions and structural equation model (SEM) to justify the findings. The results indicate that JIT and automation have the strong significance on operational performance while kaizen, TPM and VSM have weak or even negative effect on it. Future empirical studies can also follow a mixed method approach involving quantitative and qualitative data-sets that could be tested through rigorous statistical methods. A higher response rate and a mixed quantitative–qualitative approach with strong statistical analysis method may allow the generalization of the findings in similar studies.

Lucato *et al.* (2014) proposed a method to measure the degree of implementation of the lean programs in manufacturing companies. The authors proposed two concepts – the degree of leanness (DOL) of SAE J4000 (standard) and DOL of a company. Results reveal that the DOL for multinational companies is higher than that of the national companies; and it is not possible to establish a relationship between the degree of lean implementation and the size of the company.

Wong, Ignatius, and Soh (2014) developed a lean index to evaluate the leanness level of an organization in sustaining lean transformation. This lean index has been developed from theory, and is quantified using analytic network process (ANP). Performance monitoring using multi criteria tools such as ANP helps in quickly responding to the variations in customer demand with the corresponding cost reduction. The focus of this study is broader but confined to the cross-sectional analysis of the firm. Therefore, extending the present ANP structure to include measures of evaluating lean throughout the organization or in a supply chain will be more useful.

Pakdil and Leonard (2014) developed a comprehensive tool called the leanness assessment tool (LAT), using both quantitative (directly measurable and objective) and qualitative (perceptions of individuals) approaches to assess lean implementation. The LAT measures quantitative and qualitative aspects of leanness through eight (i.e. time effectiveness, quality, process, cost, human resources, delivery, customer, and inventory) quantitative and five (i.e. quality, process, human resources, delivery, and customer) qualitative performance dimensions. The comprehensive nature of the tool and the large data collection process for each performance indicator are deterrents for the organizations to use LAT.

Hadid and Mansouri (2014) proposed a theoretical model establishing the core constructs of lean services, their interrelation and impact on organizational performance. Authors emphasized on the potential impact of lean service on operational and financial performance through the universal theory, socio-technical systems theory and contingency theory. Six significant contextual variables – firm size, firm age, internationalization, process type, business strategy, and cost & management systems – of lean performance were identified based on a review of the management accounting, organizational strategy and diversification literature. Future work can investigate the effectiveness of sequential and simultaneous lean implementations.

Al-Ashaab *et al.* (2016) developed a tool which assists the managers in the identification of actual status of the organization with respect to the lean principles. Authors proposed that the leanness assessment should be carried out before an organization starts the product development transformation. Two case studies in aerospace and automotive organizations were conducted to test and validate the developed tool. The results showed that the application of the developed tool provides a structured way to evaluate the lean product development practices.

Narayanamurthy and Gurumurthy (2016b) described a leanness assessment approach to compute the systemic leanness; and to assist continuous improvement by considering interaction between lean elements. Graph-theoretic approach (GTA) was used to measure the interaction between the elements in the developed framework. Systemic leanness is measured by taking into account the degree of inheritance of sub-elements and the extent of interaction between the elements. Further, different outputs scenarios were calculated by considering the best and worst case outputs to assess the status of the case example.

Teixeira and Salonitis (2017) developed an assessment tool to assess workstation design in automotive assembly lines. A pyramid shaped model was developed to show the concept of the hierarchy of workstation requirements; and the requirements were prioritized to obtain desirable performance at workstations. Seven identified requirements are: waste elimination; flexibility; quality; visual management; health and safety; inventory and material logistics; and work environment cleanliness and orderliness. A checklist was developed based on the best practices in workstation design. The tool was implemented at an automotive assembly line and the results revealed that the areas of waste elimination, and inventory and material logistics need improvement.

Tortorella, Miorando and Marodin (2017) developed a framework to group the lean practices into bundles which need to be analyzed. Authors empirically tested the positive association between lean supply chain bundles and performance. The above-mentioned association were established and validated through a survey of Brazilian organizations and their supply chains.

Pakdil, Toktaş and Leonard (2018) analyzed the reliability and validity of the qualitative aspects of lean assessment tool (LAT) developed by Pakdil and Leonard (2014). Exploratory factor analysis and confirmatory factor analysis were conducted to ascertain validity and reliability of qualitative components of LAT. The results found the used scale reliable and valid throughout sociocultural boundaries. The quantitative component of LAT is ignored.

Garza-Reyes *et al.* (2018) assessed the quality practices of European pharmaceutical manufacturing organizations to identify the level of readiness and to sustain lean performance within the pharmaceutical sector. Six quality practices of processes; human resources; top management and leadership; planning and control; supplier relations; and customer relations were included for the assessment. The results indicate an inadequate lean readiness level of the European pharmaceutical manufacturing organizations. The study is limited to quality practices.

Table 2.4: List of reviewed articles and their characteristics

Author	Journal	Database	Country	Type of organization	Case study/ Survey	Methodology	Qualitative/ Quantitative	Theme	Type of assessment
Harrison (1998)	Int. J. Logist. Res. Appl.	Taylor & Francis	UK	Automotive organization	Case Study	Empirical study	Quantitative	Lean manufacturing	Tool & technique based assessment
Biazzo and Panizzolo (2000)	Integr. Manuf. Syst.	Emerald	Italy	NA	NA	Conceptual	Qualitative	Lean manufacturing	Tool & technique based assessment
Sánchez and Pérez (2001)	Int. J. Oper. Prod. Manag.	Emerald	Spain	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean manufacturing	Outcome based assessment
Soriano--Meier and Forrester (2002)	Integr. Manuf. Syst.	Emerald	UK	Ceramic organizations	Survey	Empirical study	Quantitative	Lean organization	Tool & technique based assessment
Motwani (2003)	Ind. Manag. Data Syst.	Emerald	USA	Automotive organization	Case Study	Empirical study	Qualitative	Lean manufacturing	Tool & technique based assessment
Shah and Ward (2003)	J. Oper. Manag.	Science Direct	USA	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean manufacturing	Tool & technique based assessment
Taj (2005)	Manag. Decis.	Emerald	China	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean manufacturing	Tool & technique based assessment
Papadopoulou and Özbayrak (2005)	J. Manuf. Technol. Manag.	Emerald	UK	Manufacturing organizations*	Multiple case studies	Empirical study	Qualitative	Lean manufacturing	Tool & technique based assessment
Narasimhan, Swink, and Kim (2006)	J. Oper. Manag.	Science Direct	USA	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean manufacturing	Outcome based assessment
Leung *et al.* (2006)	IEEE Int. Conf. on Management of Innovation and Technology	IEEE	China	Apparel organization	Case Study	Empirical study	Quantitative	Lean supply chain	Tool & technique based assessment
Srinivasaraghavan and Allada (2006)	Int. J. Adv. Manuf. Technol.	Springer	USA	Manufacturing organizations*	Survey	Empirical study	Quantitative	Lean organization	Outcome based assessment
Rivera and Frank Chen (2007)	Robot. Comput. Integr. Manuf.	Science Direct	Colombia	NA	NA	Conceptual	Quantitative	Lean manufacturing	Tool & technique based assessment

Table 2.4: List of reviewed articles and their characteristics (Contd.)

Author	Journal	Database	Country	Type of organization	Case study/ Survey	Methodology	Qualitative/ Quantitative	Theme	Type of assessment
Shah and Ward (2007)	J. Oper. Manag.	Science Direct	USA	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean manufacturing	Outcome based assessment
Bayou and de Korvin (2008)	J. Eng. Technol. Manag.	Science Direct	USA	Automotive organizations	Multiple case studies	Empirical study	Qualitative	Lean manufacturing	Tool & technique based assessment
Bhasin (2008)	J. Manuf. Technol. Manag.	Emerald	UK	NA	NA	Conceptual	Quantitative	Lean organization	Outcome based assessment
Wan and Chen (2008)	Int. J. Prod. Res.	Taylor & Francis	USA	NA	NA	Conceptual	Quantitative	Lean manufacturing	Outcome based assessment
Wan and Chen (2009)	Comput. Ind.	Science Direct	USA	NA	NA	Conceptual	Quantitative	Lean manufacturing	Outcome based assessment
Gurumurthy and Kodali (2009)	Benchmarking An Int. J.	Emerald	India	Manufacturing organization*	Case Study	Empirical study	Quantitative	Lean manufacturing	Mixed assessment
Fullerton and Wempe (2009)	Int. J. Oper. Prod. Manag.	Emerald	USA	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean manufacturing	Mixed assessment
Singh, Garg, and Sharma (2010a)	Meas. Bus. Excell.	Emerald	India	Automotive organization	Case Study	Empirical study	Qualitative	Lean organization	Mixed assessment
Niu, Zuo, and Li (2010)	IEEE 17Th Int. Conf. on Industrial Engineering and Engineering Management (IE&EM)	IEEE	China	Automotive component organization	Case Study	Empirical study	Qualitative	Lean organization	Outcome based assessment
Florent and Zhen (2010)	IEEE Int. Conf. on e-Education, e-Business, e-Management and e-Learning	IEEE	China	Manufacturing organizations*	Survey	Empirical study	Qualitative & Quantitative	Lean supplier	Outcome based assessment

Table 2.4: List of reviewed articles and their characteristics (Contd.)

Author	Journal	Database	Country	Type of organization	Case study/ Survey	Methodology	Qualitative/ Quantitative	Theme	Type of assessment
Saurin, Marodin, and Ribeiro (2011)	Int. J. Prod. Res.	Taylor & Francis	Brazil	Automotive component organization	Case Study	Empirical study	Qualitative	Lean manufacturing	Tool & technique based assessment
Vinodh and Chintha (2011a)	Int. J. Prod. Res.	Taylor & Francis	India	Electronics organization	Case Study	Empirical study	Qualitative	Lean organization	Outcome based assessment
Bhasin (2011a)	Int. J. Lean Six Sigma	Emerald	UK	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean organization	Outcome based assessment
Peter and Lanza (2011)	Prod. Eng. Res. Dev.	Springer	Germany	Machine tool organization	Case Study	Empirical study	Quantitative	Lean manufacturing	Outcome based assessment
Vinodh, Prakash, and Selvan (2011)	Int. J. Adv. Manuf. Technol.	Springer	India	Manufacturing organization*	Case Study	Empirical study	Qualitative & Quantitative	Lean manufacturing	Outcome based assessment
Vinodh and Balaji (2011)	Int. J. Prod. Res.	Taylor & Francis	India	Electronics organization	Case Study	Empirical study	Qualitative	Lean organization	Outcome based assessment
Behrouzi and Wong (2011)	Procedia Comput. Sci.	Science Direct	Malaysia	NA	NA	Conceptual	Quantitative	Lean manufacturing	Outcome based assessment
Calarge *et al.* (2011)	IEEE Int. Conf. on Management and Service Science (MASS)	IEEE	Brazil	Automotive organizations	Survey	Empirical study	Qualitative	Lean organization	Tool & technique based assessment
Vinodh and Chintha (2011b)	Int. J. Prod. Res.	Taylor & Francis	India	Electronics organization	Case Study	Empirical study	Qualitative	Lean organization	Outcome based assessment
Ramesh and Kodali (2012)	Int. J. Prod. Res.	Taylor & Francis	India	Manufacturing organization*	Case study	Empirical study	Qualitative & Quantitative	Lean manufacturing	Outcome based assessment
Azevedo *et al.* (2012)	Resour. Conserv. Recycl.	Science Direct	Portugal	Automotive organization	Case Study	Empirical study	Qualitative	Lean organization	Outcome based assessment

Table 2.4: List of reviewed articles and their characteristics (Contd.)

Author	Journal	Database	Country	Type of organization	Case study/ Survey	Methodology	Qualitative/ Quantitative	Theme	Type of assessment
Vinodh and Kumar (2012)	J. Manuf. Technol. Manag.	Emerald	India	Manufacturing organization*	Case Study	Empirical study	Qualitative	Lean organization	Outcome based assessment
Vimal and Vinodh (2012)	Int. J. Adv. Manuf. Technol.	Springer	India	Manufacturing organization	Case Study	Empirical study	Qualitative	Lean organization	Outcome based assessment
Meiling, Backlund, and Johnsson (2012)	Eng. Constr. Archit. Manag.	Emerald	Sweden	Off-site Manufacturing organizations	Survey	Empirical study	Qualitative	Lean management	Tool & technique based assessment
Sopelana *et al.* (2012)	IEEE 18th Int. Conf. on Engineering, Technology and Innovation	IEEE	Spain	Automotive, aeronautic and home appliances organizations	Multiple case studies	Empirical study	Qualitative	Lean product development	Tool & technique based assessment
Vinodh and Vimal (2012)	Int. J. Adv. Manuf. Technol.	Springer	India	Electronics organization	Case Study	Empirical study	Qualitative	Lean organization	Outcome based assessment
Alsmadi, Almani, and Jerisat (2012)	Total Qual. Manag. Bus. Excell.	Taylor & Francis	UK	Manufacturing and service organizations	Survey	Empirical study	Quantitative	Lean organization	Mixed assessment
Anvari, Zulkifli, and Yusuff (2013)	Int. J. Adv. Manuf. Technol.	Springer	Iran	Manufacturing organization*	Case Study	Empirical study	Quantitative	Lean manufacturing	Outcome based assessment
Karim and Arif-Uz-Zaman (2013)	Bus. Process Manag. J.	Emerald	Australia	Electrical organization	Case study	Empirical study	Quantitative	Lean organization	Mixed assessment
Lemieux, Pellerin, and Lamouri (2013)	J. Enterp. Transform.	Taylor & Francis	Canada	Luxury organization	Case study	Empirical study	Qualitative	Lean product development	Tool & technique based assessment
Gupta, Acharya, and Patwardhan (2013)	Int. J. Product. Perform. Manag.	Emerald	India	Tyre manufacturing	Case study	Empirical study	Quantitative	Lean organization	Waste elimination based assessment
Behrouzi and Wong (2013)	Int. J. Adv. Manuf. Technol.	Springer	Malaysia	Automotive organization	Case study	Empirical study	Qualitative & Quantitative	Lean supply chain	Outcome based assessment

Table 2.4: List of reviewed articles and their characteristics (Contd.)

Author	Journal	Database	Country	Type of organization	Case study/ Survey	Methodology	Qualitative/ Quantitative	Theme	Type of assessment
Vimal and Vinodh (2013)	J. Manuf. Technol. Manag.	Emerald	India	Electronics organization	Case study	Empirical study	Qualitative	Lean organization	Tool & technique based assessment
Diaz-Elsayed *et al.* (2013)	CIRP Ann. - Manuf. Technol.	Science Direct	USA	Automotive organization	Case study	Empirical study	Quantitative	Lean manufacturing	Tool & technique based assessment
Camacho-Miñano, Moyano-Fuentes, and Sacristán-Díaz (2013)	Int. J. Prod. Res.	Taylor & Francis	Spain	NA	NA	Conceptual	Qualitative	Lean management	Mixed assessment
Cil and Turkan (2013)	Int. J. Adv. Manuf. Technol.	Springer	Turkey	Manufacturing organization*	Case Study	Empirical study	Qualitative	Lean organization	Tool & technique based assessment
Ghosh (2013)	J. Manuf. Technol. Manag.	Emerald	India	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean manufacturing	Tool & technique based assessment
Lucato *et al.* (2014)	Int. J. Product. Perform. Manag.	Emerald	Brazil	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean manufacturing	Tool & technique based assessment
Belekoukias, Garza-Reyes, and Kumar (2014)	Int. J. Prod. Res.	Taylor & Francis	UK	Manufacturing organizations*	Survey	Empirical study	Quantitative	Lean manufacturing	Mixed assessment
Elnadi and Shehab (2014)	Procedia CIRP	Science Direct	UK	Manufacturing organizations*	Survey	Empirical study	Quantitative	Lean organization	Tool & technique based assessment
Hallam and Keating (2014)	J. Enterp. Transform.	Taylor & Francis	USA	Aerospace organizations	Survey	Empirical study	Qualitative	Lean organization	Tool & technique based assessment
Pakdil and Leonard (2014)	Int. J. Prod. Res.	Taylor & Francis	Turkey	NA	NA	Conceptual	Qualitative & Quantitative	Lean organization	Outcome based assessment
Magenheimer, Reinhart, and Schutte (2014)	Prod. Eng. Res. Dev.	Springer	Germany	NA	NA	Conceptual	Qualitative	Lean management	Waste elimination based assessment

Table 2.4: List of reviewed articles and their characteristics (Contd.)

Author	**Journal**	**Database**	**Country**	**Type of organization**	**Case study/ Survey**	**Methodology**	**Qualitative/ Quantitative**	**Theme**	**Type of assessment**
Arif-Uz-Zaman and Ahsan (2014)	Int. J. Product. Perform. Manag.	Emerald	Bangladesh	Textile organization	Case study	Empirical study	Qualitative & Quantitative	Lean supply chain	Outcome based assessment
Hadid and Mansouri (2014)	Int. J. Oper. Prod. Manag.	Emerald	UK	Service organization	NA	Conceptual	Qualitative	Lean organization	Tool & technique based assessment
Costa *et al.* (2014)	Procedia Comput. Sci.	Science Direct	USA	NA	NA	Conceptual	Qualitative & Quantitative	Lean product development	Outcome based assessment
Wong, Ignatius, and Soh (2014)	Prod. Plan. Control	Taylor & Francis	Malaysia	Electronics organization	Case Study	Empirical study	Quantitative	Lean organization	Outcome based assessment
Greinacher *et al.* (2015)	Procedia CIRP	Science Direct	Germany	Metal processing organization	Case Study	Empirical study	Quantitative	Lean organization	Outcome based assessment
Garza-Reyes, Ates, and Kumar (2015)	Int. J. Product. Perform. Manag.	Emerald	UK	Automotive component organizations	Survey	Empirical study	Quantitative	Lean organization	Tool & technique based assessment
Maasouman and Demirli (2015)	IFAC-PapersOnLine	Science Direct	Canada	NA	Case Study	Empirical study	Qualitative & Quantitative	Lean manufacturing	Outcome based assessment
Liang *et al.* (2015)	IEEE Int. Conf. on Automation Science and Engineering (CASE)	IEEE	China	NA	NA	Conceptual	Quantitative	Lean manufacturing	Tool & technique based assessment
Afonso and Cabrita (2015)	Procedia Eng.	Science Direct	Portugal	Food manufacturing organization	Case Study	Empirical study	Quantitative	Lean supply chain	Outcome based assessment
Susilawati *et al.* (2015)	J. Manuf. Syst.	Science Direct	UK	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean manufacturing	Tool & technique based assessment
Sharma, Dixit, and Qadri (2015)	J. Manuf. Technol. Manag.	Emerald	India	Machine tool organizations	Survey	Empirical study	Qualitative	Lean supply chain	Tool & technique based assessment

Table 2.4: List of reviewed articles and their characteristics (Contd.)

Author	Journal	Database	Country	Type of organization	Case study/ Survey	Methodology	Qualitative/ Quantitative	Theme	Type of assessment
Azadeh *et al.* (2015)	Expert Syst. Appl.	Science Direct	Iran	Packing and printing organization	Case Study	Empirical study	Qualitative & Quantitative	Lean organization	Outcome based assessment
Matawale, Datta, and Mahapatra (2015)	J. Model. Manag.	Emerald	India	Automotive organization	Case Study	Empirical study	Qualitative	Lean supply chain	Tool & technique based assessment
Vidyadhar *et al.* (2016)	J. Eng. Des. Technol.	Emerald	India	Manufacturing organization*	Case Study	Empirical study	Qualitative	Lean organization	Tool & technique based assessment
Al-Ashaab *et al.* (2016)	Int. J. Comput. Integr. Manuf.	Taylor & Francis	UK	Aerospace and automobile organizations	Multiple case studies	Empirical study	Qualitative	Lean product development	Tool & technique based assessment
Omogbai and Salonitis (2016)	Procedia CIRP	Science Direct	UK	Print packaging organization	Case Study	Empirical study	Quantitative	Lean manufacturing	Outcome based assessment
Tekez and Tasdeviren (2016)	Procedia Comput. Sci.	Science Direct	Turkey	NA	NA	Conceptual	Qualitative	Lean manufacturing	Tool & technique based assessment
Wu, Xu, and Xu (2016)	Ann. Oper. Res.	Springer	China	Tobacco manufacturing organization	Case Study	Empirical study	Qualitative	Lean organization	Tool & technique based assessment
Dal Forno *et al.* (2016)	Benchmarking An Int. J.	Emerald	Brazil	Manufacturing organizations*	Multiple case studies	Empirical study	Quantitative	Lean product development	Outcome based assessment
Thanki and Thakkar (2016)	Prod. Plan. Control	Taylor & Francis	India	NA	NA	Conceptual	Quantitative	Lean manufacturing	Waste elimination based assessment
Narayanamurthy and Gurumurthy (2016b)	J. Manuf. Technol. Manag.	Emerald	India	Manufacturing organizations*	Multiple case studies	Empirical study	Qualitative	Lean organization	Mixed assessment
Liu *et al.* (2017)	Int. J. Prod. Res.	Taylor & Francis	China	Manufacturing organizations*	Multiple case studies	Empirical study	Qualitative	Lean organization	Outcome based assessment

Table 2.4: List of reviewed articles and their characteristics (Contd.)

Author	Journal	Database	Country	Type of organization	Case study/ Survey	Methodology	Qualitative/ Quantitative	Theme	Type of assessment
Agrawal, Asokan, and Vinodh (2017)	Benchmarking An Int. J.	Emerald	India	Heavy engineering fabrication	Case study	Empirical study	Qualitative	Lean organization	Outcome based assessment
Teixeira and Salonitis (2017)	Procedia CIRP	Science Direct	UK	Automotive assembly line	Case study	Empirical study	Qualitative	Lean manufacturing	Outcome based assessment
Tortorella, Miorando, and Marodin (2017)	Int. J. Prod. Econ.	Science Direct	Brazil	Not specified	Survey	Empirical study	Qualitative	Lean supply chain	Mixed assessment
Mourtzis *et al.* (2018)	Int. J. Adv. Manuf. Technol.	Springer	Greece	Mold-making organization	Case study	Empirical study	Quantitative	Lean product development	Outcome based assessment
Moyano-fuentes, Bruque-cámara, and Maqueira-marin (2018)	Prod. Plan. Control	Taylor & Francis	Spain	Not specified	Survey	Empirical study	Quantitative	Lean supply chain	Outcome based assessment
Rehman, Alkhatani, and Umer (2018)	IEEE Access	IEEE	Saudi Arabia	Manufacturing organization*	Case study	Empirical study	Quantitative	Lean manufacturing	Outcome based assessment
Pakdil, Toktaş, and Leonard (2018)	J. Manuf. Technol. Manag.	Emerald	USA	Manufacturing organizations*	Survey	Empirical study	Qualitative	Lean organization	Outcome based assessment
Garza-Reyes *et al.* (2018)	Int. J. Product. Perform. Manag.	Emerald	UK	Pharmaceutical manufacturing organizations	Survey	Empirical study	Quantitative	Lean organization	Tool & technique based assessment
Kumar, Dhingra, and Singh (2018)	J. Eng. Des. Technol.	Emerald	India	Automotive component organization	Case study	Empirical study	Quantitative	Lean manufacturing	Waste elimination based assessment

*Either an empirical study of many manufacturing organizations or type of organization not specified.

2.3 ANALYSIS AND SYNTHESIS

The main challenge while conducting a SLR is to disaggregate and aggregate the dataset to depict the trade-off between detailed information and coherent information. Descriptive and content analyses are generally carried out to analyze and synthesize the data for disaggregation and aggregation of data respectively.

2.3.1 Descriptive Analysis

Descriptive analysis has been carried out to get a preliminary overview of the reviewed literature. Figures 2.1 to 2.6 show the number of articles in different databases, proportion of journal and conference papers in the final sample, the number of articles published over time phases, types of methodologies, qualitative or quantitative approaches used, and the articles published in various countries.

In terms of the number of articles per database, Emerald contributes 35% (30 articles), Science Direct 23% (20 articles), Taylor & Francis 21% (18 articles), Springer 13% (11 articles), and IEEE 8% (7 articles) as shown in figure 2.1. 93% articles are from journals and remaining 7% are from conference publications as shown in figure 2.2.

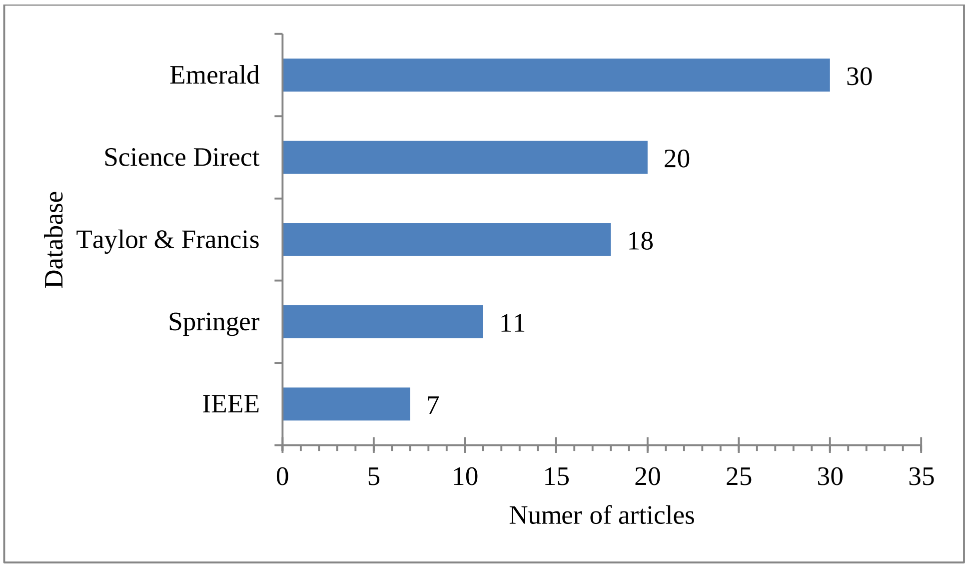


Figure 2.1: Number of articles and databases

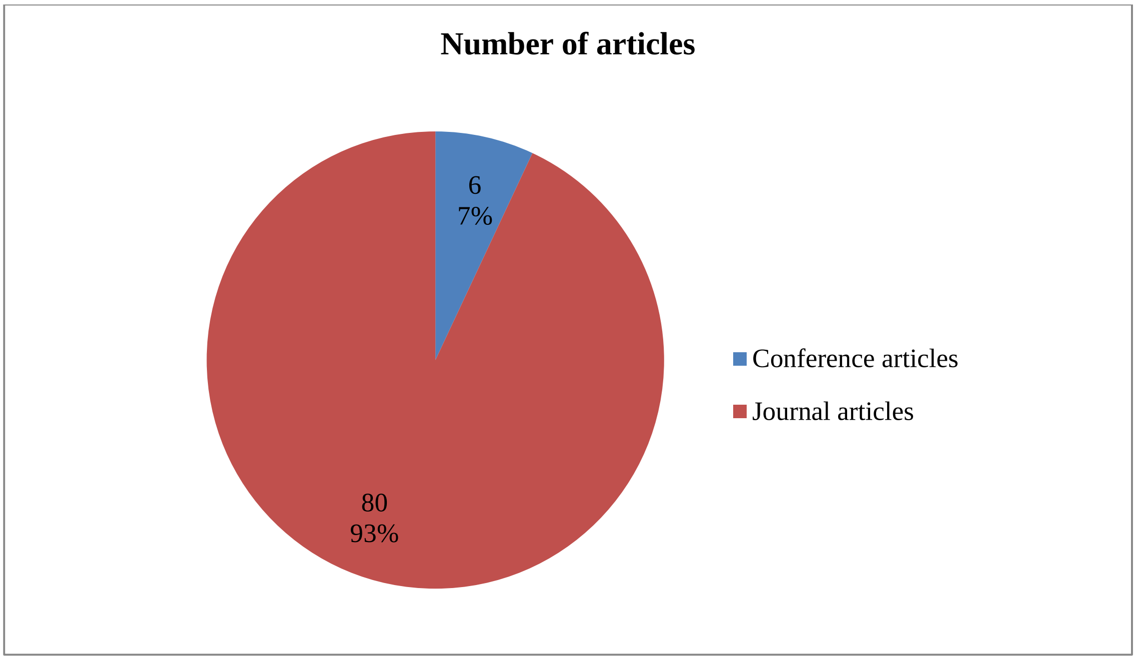


Figure 2.2: Proportion of journal and conference articles

2.3.1.1 Number of published articles over time phases: The literature review timeline (1998 – 2018) is divided into three phases. Each phase consists of seven years. The trend of published articles shows that the number of articles increased drastically in the third phase as shown in figure 2.3. There were only six articles on leanness assessment until 2004. During 2003-2004, some papers highlighting the failure of lean philosophy were published (Del Val and Fuentes, 2003; Hines, Holweg, and Rich, 2004). This may have focused the research on leanness assessment. During 2005-2011, the number of articles increased manifolds (25 articles). 64% (55 articles) of total articles are published during the last phase (2012 – 2018). This trend shows that lean assessment is an emerging area of research. Large number of publications since 2012 could be a sign of the enhancing relevance of a well-organized assessment of lean performance.

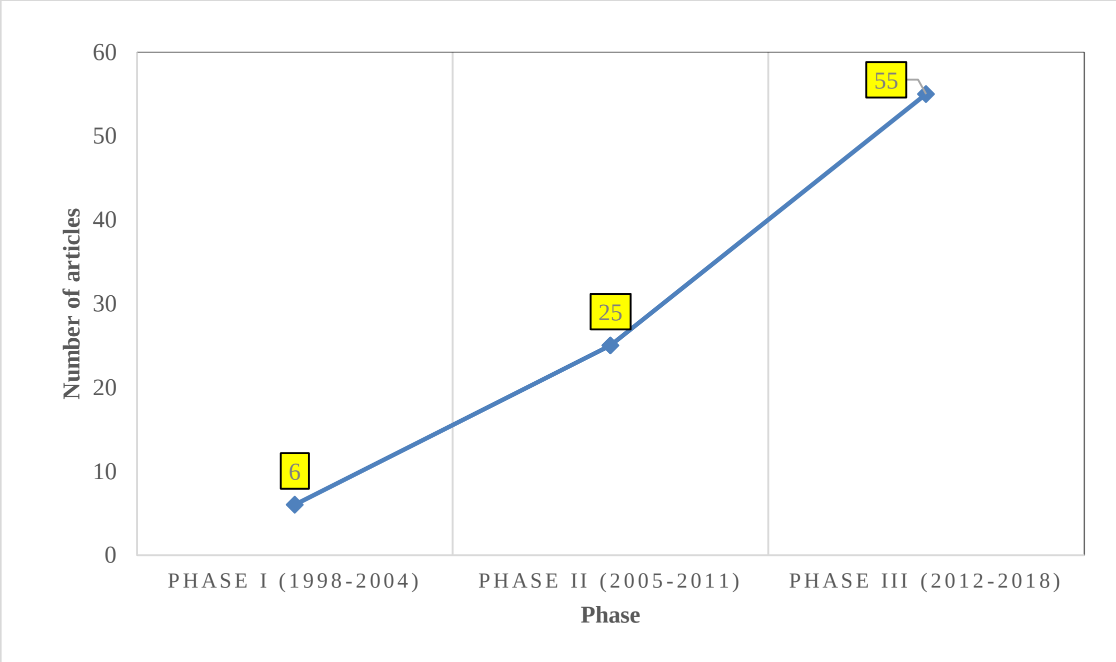


Figure 2.3: Number of articles published on leanness assessment in each phase

2.3.1.2 Types of methodologies: The adopted methodologies in various articles are divided into two groups – conceptual or empirical studies. Only 13 (15%) articles are conceptual, discussing the basic concepts of leanness assessment. 73 (85%) articles consist empirical studies as shown in figure 2.4. Most of the empirical studies involve case studies, (65%) and only 35% are survey based studies.

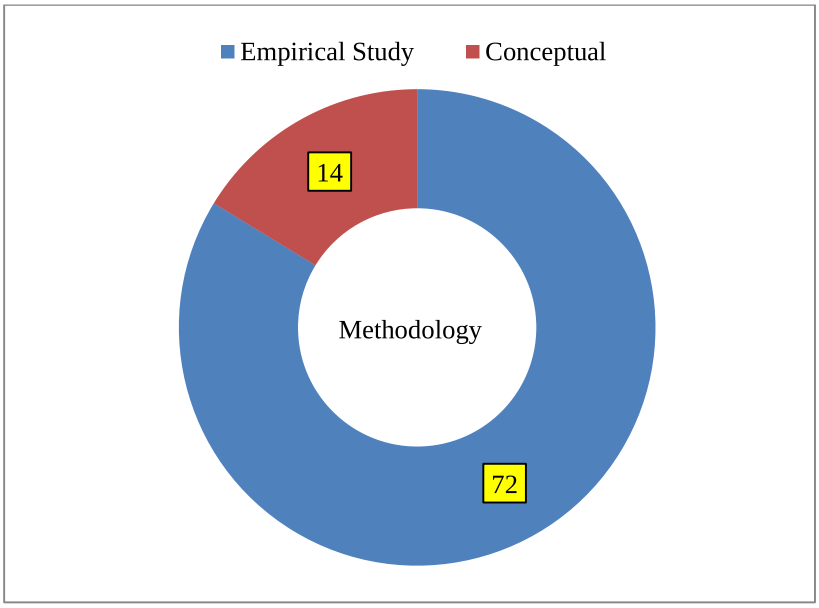


Figure 2.4: Types of methodologies

2.3.1.3 Qualitative and quantitative approaches: The qualitative approach has been widely used for leanness assessment as shown in figure 2.5. Linguistic variables have been used to measure the performance. Linguistic variables are capable to absorb ambiguity/uncertainty in the data and are generally preferred for the lack of crisp data or when the data extraction is complex. The number of qualitative studies from India are 14 out of 20; whereas, for the UK, six studies are qualitative as compared to nine quantitative studies.

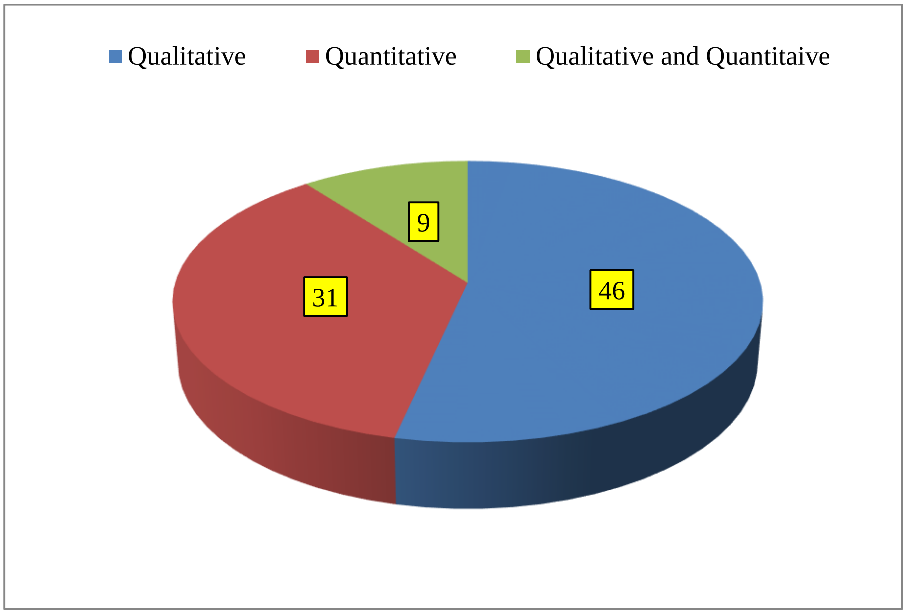


Figure 2.5: Qualitative or quantitative approach

2.3.1.4 Country-wise distribution of articles: The articles are divided country-wise according to the country of the first author or the country of case organization(s). The country of case organization(s) will dominate if the first author belong to different country. The maximum number of articles have been either authored by Indian or about Indian companies as shown in figure 2.6. 19 studies by Indians are empirical and only one study is conceptual. The majority of these articles use empirical research in Indian automotive organizations. This is because of many Indian automotive organizations also faced the pinch of the global slowdown in this sector and lean was extensively adopted for cost reduction by these organizations (Bhamu and Sangwan, 2014). More than half the articles are published from India, UK, and USA. There is no article from Japan, which is surprising because the lean has originated from Japan. There may be two reasons for it: (i) they publish their articles in Japanese language and (ii) they prefer the term "Toyota Production" over lean manufacturing.

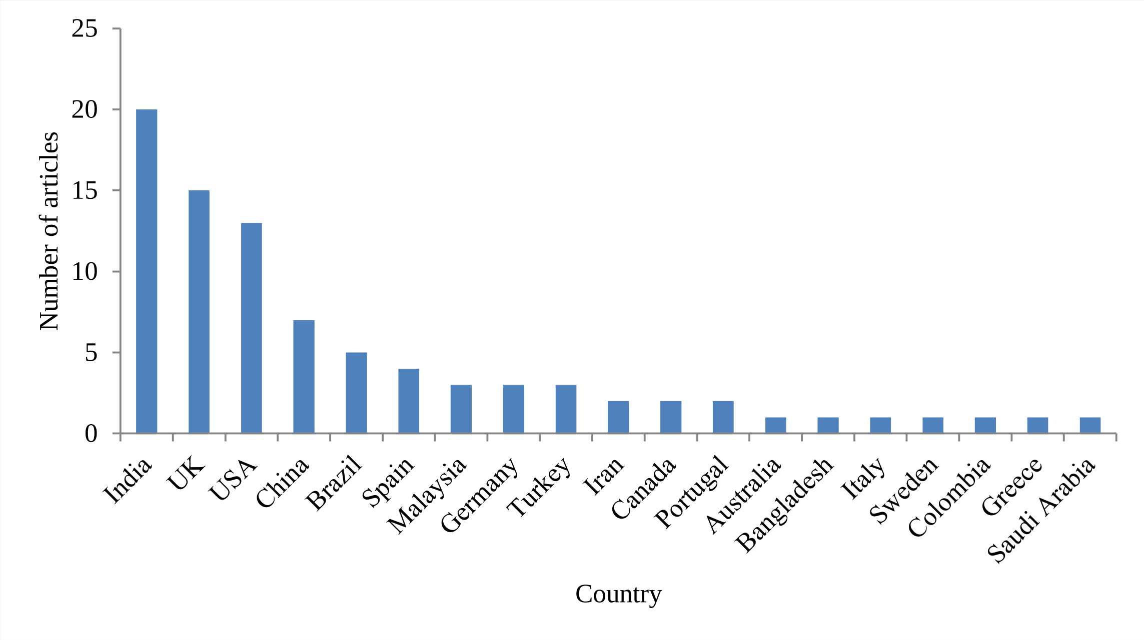


Figure 2.6: Country-wise distribution of research articles

2.3.2 Content Analysis

Content analysis is mainly used to present the coherent information about the subject after going through various research articles. This is a structured way for the aggregation of data, which has been disaggregated during the descriptive analysis.

The research in lean assessment can be broadly classified under the themes of leanness, leanness assessment approaches, and functional areas of assessment as shown in figure 2.7. Based on the existing literature, the themes of leanness can be divided into six groups – lean manufacturing, lean organization, lean supply chain, lean product development, lean management, and lean supplier. There are four types of leanness assessment approaches in the existing literature – outcome based assessment, tool & technique based assessment, mixed assessment, and waste elimination based assessment. The lean assessment has been carried out in seven functional areas. It is essential to assess all the functional areas simultaneously. These seven assessment areas are manufacturing process, new product development, finance, administration, human resource management, customer, and supplier.

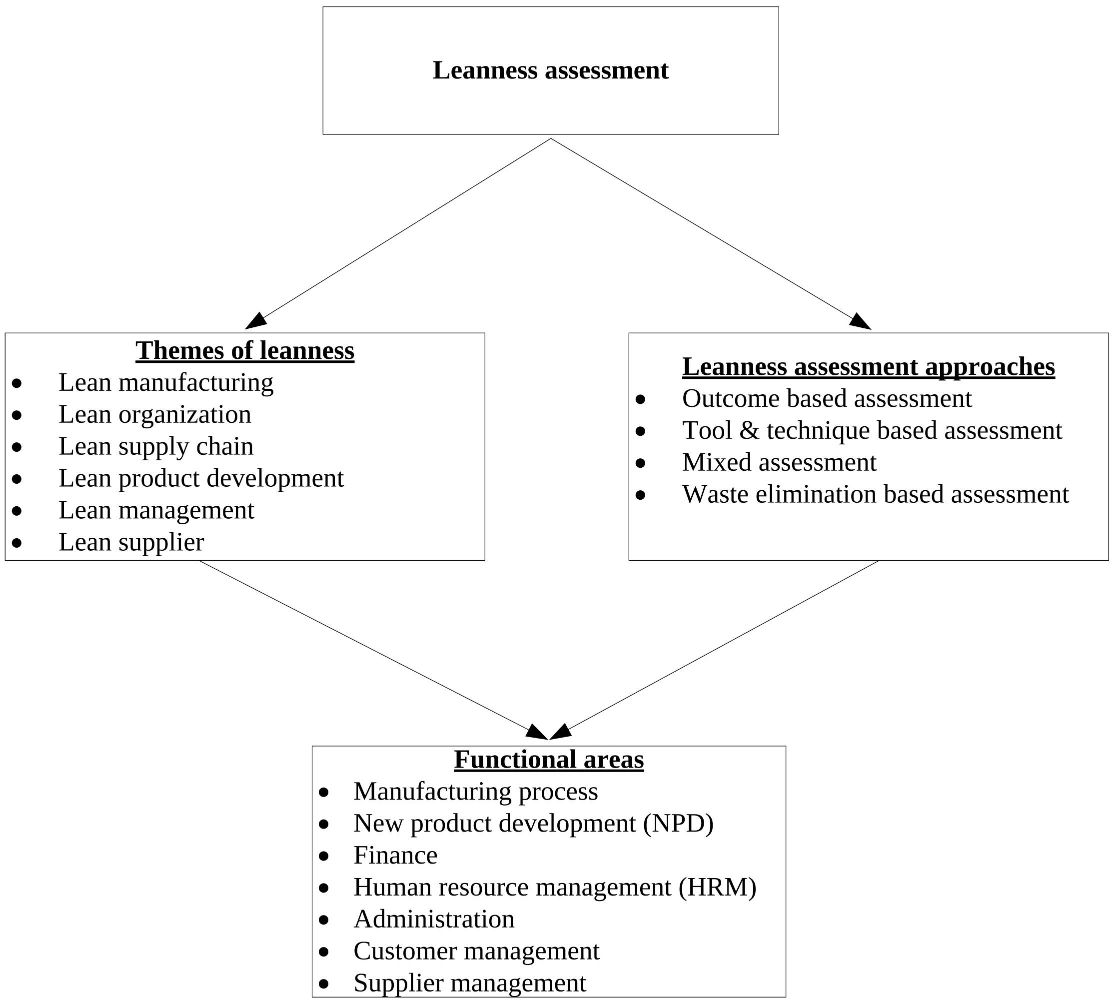


Figure 2.7: Themes, approaches and functional areas of leanness assessment

2.3.2.1 Leanness assessment themes: The process of lean implementation started with shop-floor manufacturing operations and consequently the performance measures were also developed for its leanness assessment. Biazzo and Panizzolo (2000) argued that the process variables play an important role to assess the work organization in lean manufacturing environment. Sánchez and Pérez (2001) developed an integrated checklist of indicators; and tested the manufacturing plants situated in the Spanish region of Aragon to assess manufacturing transformation towards lean production. Taj (2005) developed a spreadsheet-based lean assessment tool which is used to assess nine key areas of manufacturing – inventory; maintenance; processes; quality; team approach; setups; layout/handling; suppliers; and scheduling/control. The results have shown a fairly significant gap between the observed values and the lean manufacturing targets. Meiling, Backlund, and Johnsson (2012) conducted a study to evaluate the degree of implementation of lean management principles in the companies which have their production activities off-site. The Likert scale scores showed similar patterns in the two construction companies demonstrating that the findings can be generalized for an off-site production situation also. Maasouman and Demirli (2015) developed a visual maturity model to continuously measure the manufacturing cell leanness at the shop floor level. Sharma, Dixit, and Qadri (2015) investigated the influence of lean manufacturing practices on performance measures in an Indian machine tool manufacturing industry and found that the two lean criteria – cross-functional cross-organizational design and development teams, and strategic partnership with suppliers – have significant impact on performance measures. Elnadi and Shehab (2014) proposed a conceptual model for the UK manufacturing companies which can be used to assess the degree of leanness of product-service system (PSS). Vinodh, Prakash, and Selvan (2011) conducted a case study for the lean assessment of a manufacturing organization in India and found a measurable improvement in performance of the organization. Vinodh and Chintha (2011b) designed a leanness assessment model using multi-grade fuzzy approach and found that the organization successfully implemented lean manufacturing. In addition, the strong as well as weak areas were identified in order to further enhance the leanness level of the organization. Sopelana *et al.* (2012) proposed a "SMART readiness maturity assessment" tool to measure the leanness level of product development process in a qualitative manner. Behrouzi, Wong, and Kuah (2010) developed a model, which is useful to assess the lean performance of suppliers with six distinguishing characteristics (i.e. easy to use, dimensionless score, flexible, linguistic, dynamic, and continuous improvement). Florent and Zhen (2010) conducted a research on applications and theories of the supply chain management and established a lean assessment index system for the lean supply chains. Behrouzi and Wong (2013) selected major performance categories of cost, quality, delivery, reliability, and flexibility in conjunction with 28 associated measures to systematically quantify the supply chain leanness using stochastic-fuzzy modeling approach. Arif-Uz-Zaman and Ahsan (2014) considered five elements of a supply chain (plan, source, make, delivery, and return) and four major categories of lean metric (flexibility, time, cost, and quality) to develop a fuzzy-based method for the supply chain leanness assessment. Afonso and Cabrita (2015) developed a conceptual framework for overseeing lean supply chain by incorporating an extensive set of financial and non-financial performance measures which can assist the managers in deciding the best-suited performance measures to accomplish the goals.

Lean manufacturing and lean organization are most widely used themes in the research as shown in figure 2.8. Total 68 articles (79%) are related to these two themes. In the first phase of leanness assessment (1998-2004), only six articles (five lean manufacturing and one lean organization) were published but in the second phase (2005-2011), the number of articles on themes of lean manufacturing and lean organizations increased appreciably as shown in figure 2.9. In the third phase, the number of articles on the theme of lean organization increased drastically as compared to the theme of lean manufacturing. It implies that the organizations are working to make the whole organization lean instead of only manufacturing operations at the shop floor.

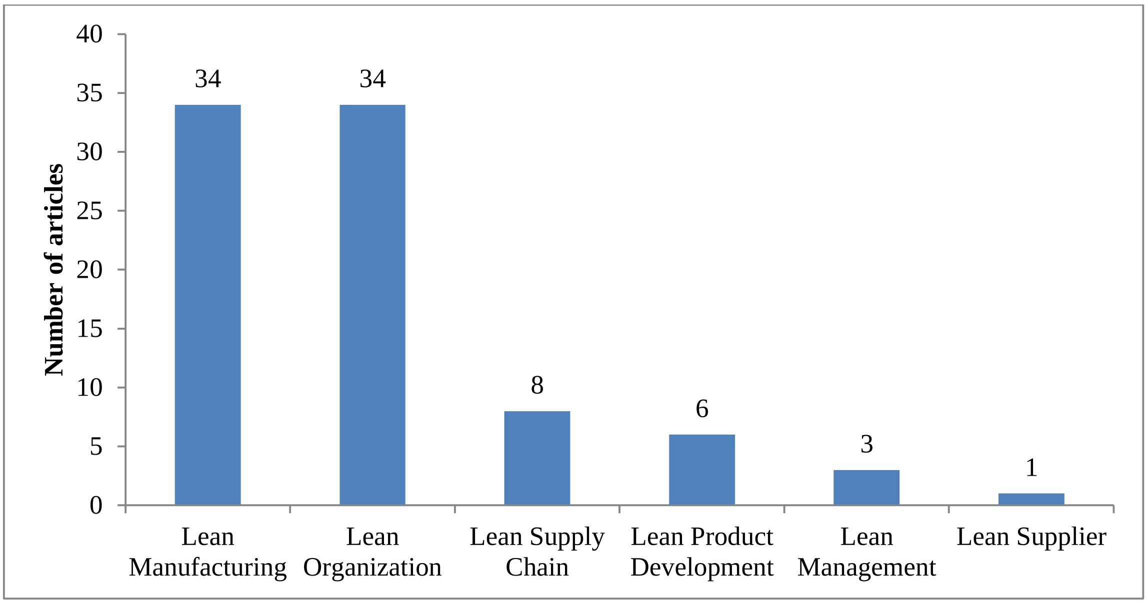


Figure 2.8: Themes of leanness

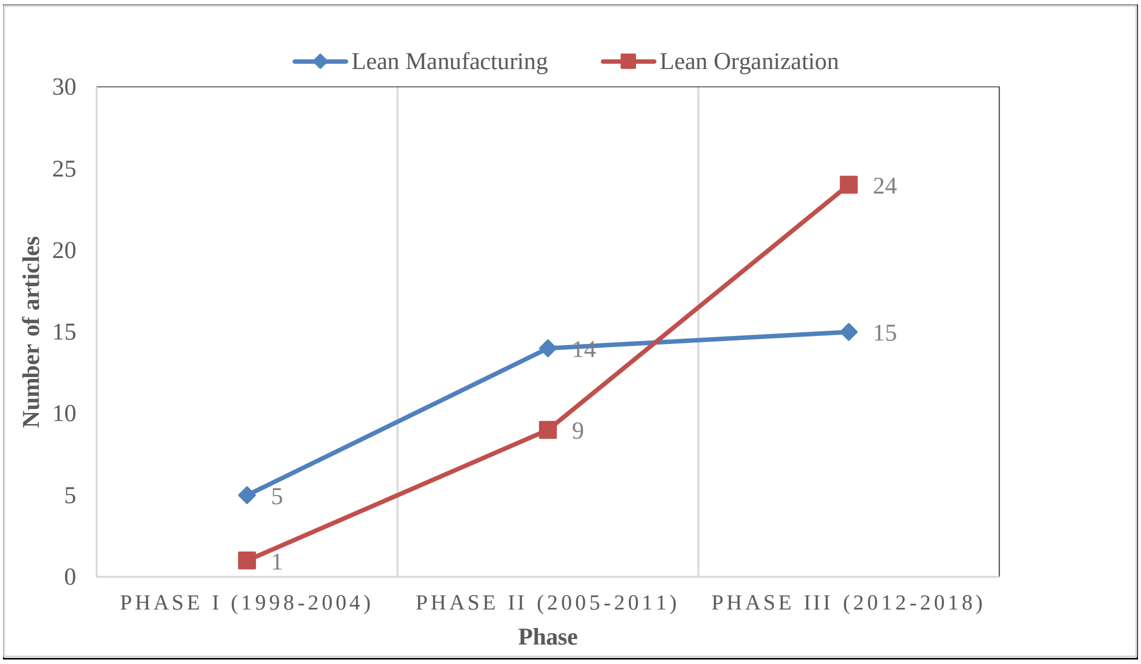


Figure 2.9: Trend of major themes (lean manufacturing and lean organization)

2.3.2.2 Leanness assessment approaches: Afonso and Cabrita (2015) said that there are three main approaches for assessing the lean performance: measuring the degree of implementation of lean tools and techniques, the measurement of outputs resulting from lean implementation, and a combination of the first and second approaches. Behrouzi and Wong (2013) claimed that there are four main approaches to leanness assessment; the additional fourth approach is the waste elimination through value stream mapping. Therefore, on the basis of existing literature, there are four methods/approaches to assess the leanness of an organization: tool & technique based assessment, outcome based assessment, waste elimination based assessment, and a combination of the first and second approaches. The first one is measuring the level of implementation of different lean tools and techniques. This approach is very simple and many academician and practitioners are using this approach from the beginning of lean performance evaluation era. Soriano-Meier and Forrester (2002) constructed a survey instrument to measure the degree of leanness of ceramic tableware manufacturing company in the United Kingdom (UK). Susilawati *et al.* (2015) presented the concept of fuzzy based multi-dimensionality to evaluate the implementation level of lean practices for eliminating the vagueness due to imprecise human judgment. Wan and Chen (2009) presented an adaptive leanness assessment method by using a web-based program to identify the critical targets for the improvement and recognized the suitable tools and techniques for fostering the action plans. The second approach to lean assessment is an outcome based assessment. The outcomes are generally measured in the form of time, cost, quality, flexibility, delivery, customer satisfaction, and continuous improvement (Behrouzi and Wong, 2013; Bayou and de Korvin, 2008; Arif-Uz-Zaman and Ahsan, 2014). Vinodh and Vimal (2012) proposed a leanness assessment model using 30 criteria. Significant improvement was observed in the performance measures in terms of defects per units, overall equipment effectiveness, work in process, first-time yield, changeover time, *etc.* Pakdil and Leonard (2014) developed a leanness assessment tool (LAT) which can be used to measure qualitative and quantitative performance aspects. The third approach of leanness assessment is a mixed approach using both tool & technique based assessment and outcome based assessment. In this approach, both degree of lean implementation and performance metrics have been considered. Gurumurthy and Kodali (2009) used the third approach of lean assessment and identified 65 lean tools and techniques, and 90 lean performance measures to evaluate the lean performance. Karim and Arif-Uz-Zaman (2013) proposed a systematic methodology for the lean implementation and continuous assessment using the leanness evaluation metrics. The fourth approach is waste elimination based assessment. In this approach, value stream mapping (VSM) is used to map a manufacturing process or process chain. The VSM is also used to identify and eliminate the waste by drawing current state and future state maps (Rother and Shook, 2009). Gupta, Acharya, and Patwardhan (2013) used this approach of lean assessment and found that over-processing and excessive defects are critical wastes for a radial tyre manufacturing organization. Magenheimer, Reinhart, and Schutte (2014) also used waste elimination based assessment approach for recognition, quantification, and elimination of waste in indirect business areas.

Most of the research is based on tool & technique based assessment and outcome based assessment; 73 articles (85%) are related to only these two type of leanness assessment approached (figure 2.10). In the first phase of leanness assessment (1998-2004), only six articles (five tools and technique based and one outcome based) have been published but in the second phase (2005-2011), there is a sudden increase in research articles (22 articles) as shown in figure 2.11. The tool & technique based assessment articles have increased from five to seven whereas the outcome based assessment articles have increased from one to 15 during 2005-2011. The similar findings are also observed in the third phase of leanness assessment.

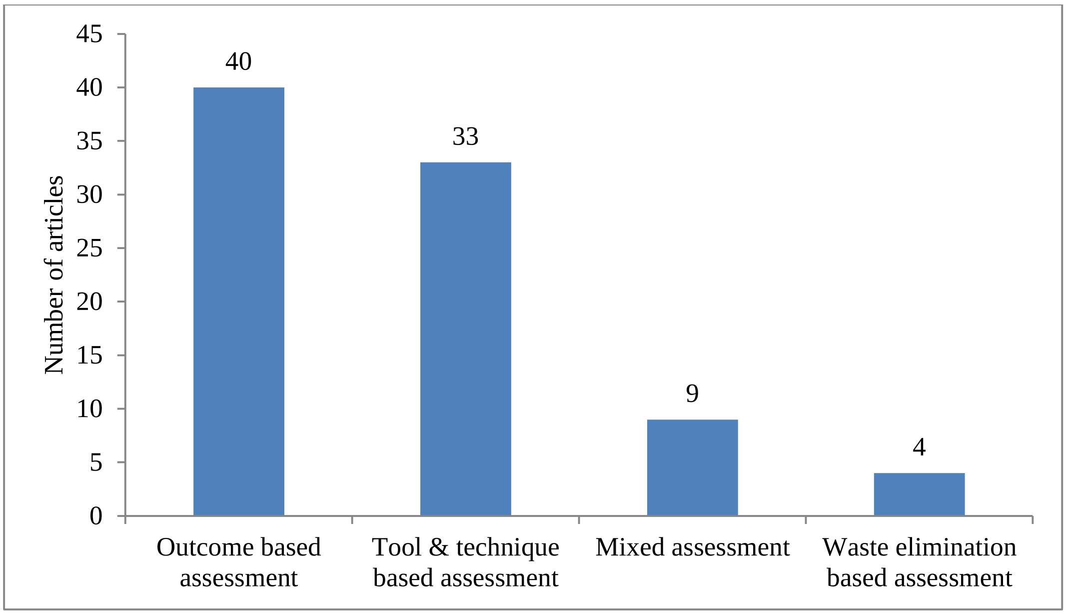


Figure 2.10: Leanness assessment approaches of the reviewed articles

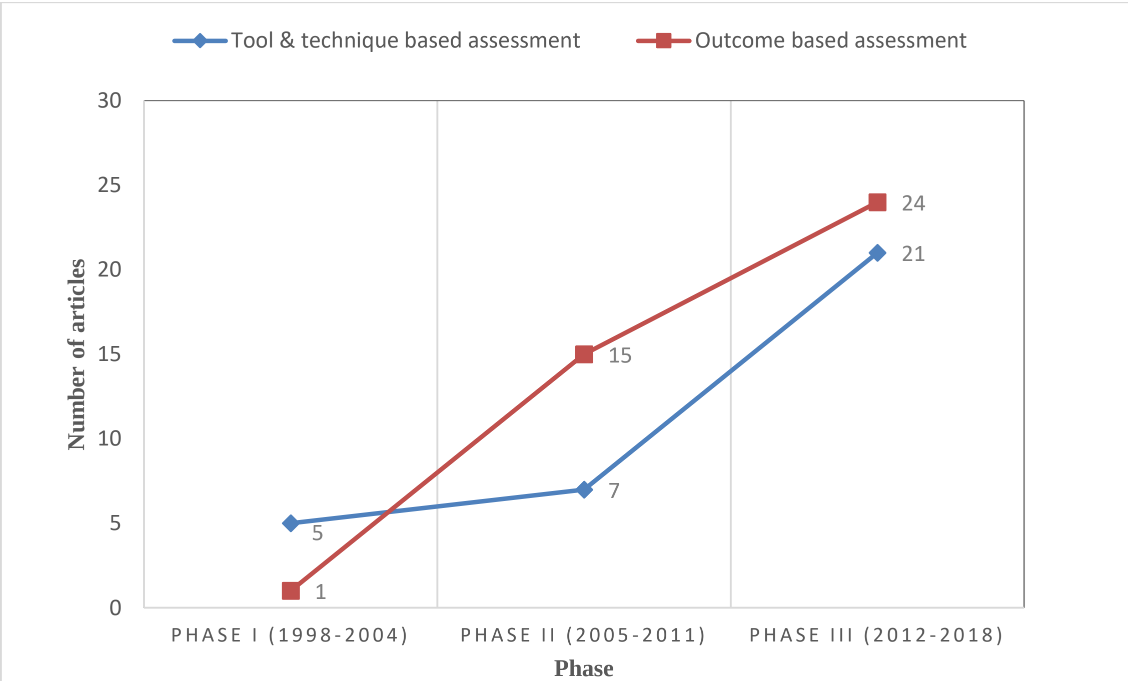


Figure 2.11: Trend of widely used leanness assessment approaches (outcome based and tool & technique based)

2.3.2.3 Functional areas: The philosophy of lean production focuses on respecting the human beings like employees, customers, and suppliers (Shah and Ward, 2003). Panizzolo (1998) presented lean production improvement programs that characterize many areas of lean philosophy such as manufacturing planning and controls; product design; process and equipment; supplier and customer relationship; *etc.* Karim and Arif-Uz-Zaman (2013) opined that lean is intended to eliminate the waste in all aspects of production in partnership with customers, supplier network, product development, and factory management. Arif-Uz-Zaman and Ahsan (2014) concluded that there is a lack of coordination among performance measurement system, modern manufacturing practices and human resource management. The human resource management and organizational culture are essential drivers for enhancing the change management paradigm to improve the performance (Gupta, Acharya, and Patwardhan, 2013).

It is essential to know the potential functional areas of the system to improve leanness level of an organization. This process of identifying the potential functional areas is performed at the micro level. Singh, Garg, and Sharma (2010a) considered five leanness parameters – investment priorities, supplier issues, customer issues, lean practices, and various wastes. Calarge *et al.* (2011) found from the lean implementation and assessment of Brazilian and Spanish organizations that ethics and organization; personnel and human resource; supplier/customer and organizational report; and product development are the high impact areas. Sopelana *et al.* (2012) claimed that manufacturing systems are interdependent on various sub-systems such as the lean product development, which is highly dependent on supplier involvement, cross-functional team, balanced team structure, integrated activities, strategic project management, *etc.* Hadid and Mansouri (2014) presented the socio-technical theory (STS) which implies that the improved performance can be obtained with simultaneous focus on social and technical subsystems. Anvari, Zulkifli, and Yusuff (2013) extracted various leanness criteria from five basic performance areas of manufacturing process, financial, employees, customers, and suppliers. The seven functional areas used for leanness assessment are in the literature (Table 2.5):

manufacturing process, new product development (NPD), finance, human resource management (HRM), administration, customer management, and supplier management.

Table 2.5: Identified functional areas for leanness assessment

Functional area	References
Manufacturing process	Motwani, 2003; Saurin, Marodin, and Ribeiro, 2011; Shah and Ward, 2003; Lucato *et al.*, 2014; Maasouman and Demirli, 2015; Vinodh and Vimal, 2012
New product development (NPD)	Sopelana *et al.*, 2012; Gupta and Kundra, 2012; Behrouzi and Wong, 2013; Anvari, Zulkifli, and Yusuff, 2013; Vimal and Vinodh, 2013; Susilawati *et al.*, 2015; Lemieux, Pellerin, and Lamouri, 2013
Finance	Fullerton and Wempe, 2009; Bayou and de Korvin, 2008; Afonso and Cabrita, 2015; Anvari, Zulkifli, and Yusuff, 2013; Sánchez and Pérez, 2001; Sopelana *et al.*, 2012
Human resource management (HRM)	Shah and Ward, 2003; Biazzo and Panizzolo, 2000; Vinodh, Prakash, and Selvan, 2011; Wong, Ignatius, and Soh, 2014; Hadid and Mansouri, 2014
Administration	Magenheimer, Reinhart, and Schutte, 2014; Handel, 2014; Camacho-Miñano, Moyano-Fuentes, and Sacristán-Díaz, 2013; Karim and Arif-Uz-Zaman, 2013
Customer management	Pakdil and Leonard, 2014; Panizzolo, 1998; Azadeh *et al.*, 2015; Bayou and de Korvin, 2008; Sopelana *et al.*, 2012; Niu, Zuo, and Li, 2010
Supplier management	Behrouzi, Wong, and Kuah, 2010; Florent and Zhen, 2010; Elnadi and Shehab, 2014; Schonberger, 2012; Singh, Garg, and Sharma, 2010a

2.4 INTERPRETATION AND FINDINGS

The leanness assessment is a continuous improvement process due to its intrinsically dynamic nature. The continuous improvement process for lean implementation and assessment can be divided into four steps: problem identification; lean implementation; leanness assessment; and report preparation (Figure 2.12). The process starts with the problem identification followed by application of different tools and techniques to resolve the specified problem(s) followed by the assessment to measure the improvement; and lastly, the report preparation. It can be interpreted from the literature that the problem identification or the cause, which prompts the leadership to think of lean implementation, should be clearly identified and presented. Next, practitioners have to learn "where to start" and "how to proceed" with the available tools and techniques (Wan and Chen, 2009). It is important that focus should be on few tools and techniques to solve the identified problems. One of the reasons of the lean manufacturing failures is the application of single tool/technique to solve all problems or application of many tools/techniques to solve a single problem (Bhamu and Sangwan, 2014). If the identified problems are more than one; then, the special care must be taken to develop the strength of the relationship between the selected lean tools & techniques (practices) and identified problems. At least one tool/technique should be identified having a strong relationship to solve each problem. Next, provide training on the selected tools & techniques to the concerned employees. The proficient employees/suppliers would carry out the leanness assessment to assess the level of implementation and the performance improvement.

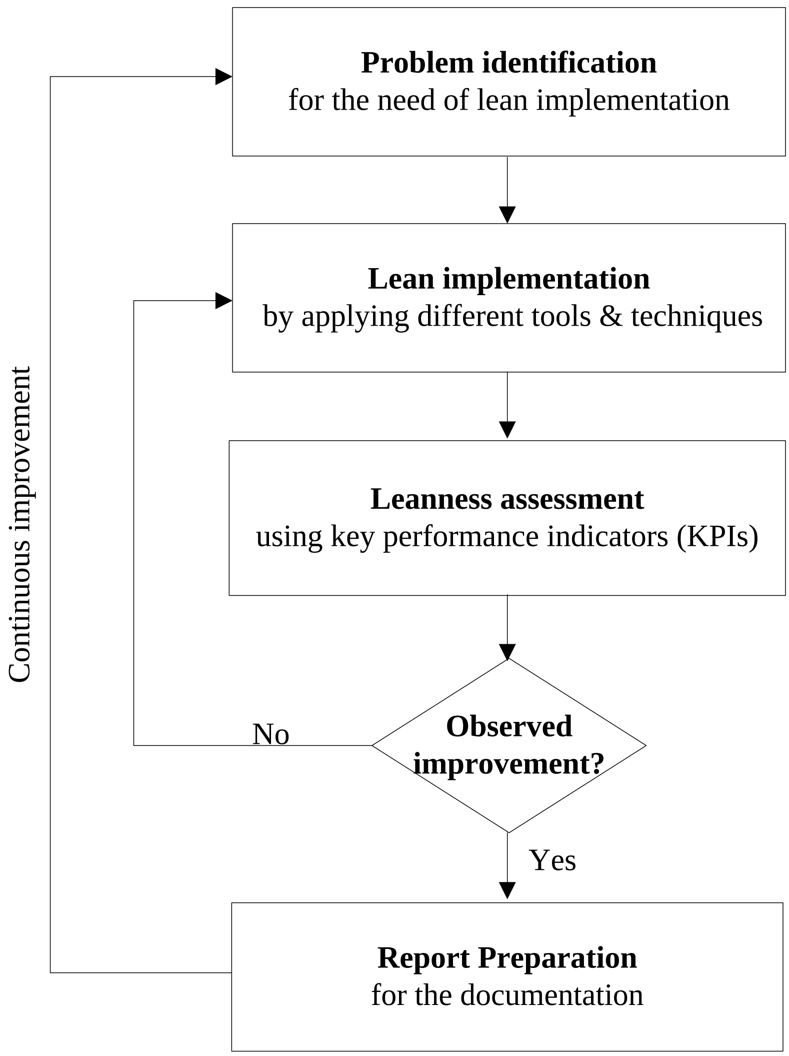


Figure 2.12: Lean implementation and its assessment cycle

These four steps are interrelated with each other, directly or indirectly as given in table 2.6. For example, the problem identification assists leadership not only to select and implement different tools & techniques but also provides the basis for the development of KPIs and helps in developing a structured documentation. Whereas, lean implementation helps to categorize the identified problems under different groups, serves as input for leanness assessment, and establishes the basis for comparing pre and post-implementation status. Similarly, leanness assessment identifies new problem/weak areas for continuous improvement, evaluates the level of implementation (level of success or failure) and the reporting helps in communicating the objectives, targets, strategies, action plans, *etc.* to all stakeholders.

Table 2.6: Summary of the interrelations among problem identification, lean implementation, leanness assessment, and report preparation

<table>
<tr><th></th><th colspan="5">... are interrelated with lean performance</th></tr>
<tr><th></th><th></th><th>Problem identification</th><th>Lean implementation</th><th>Leanness assessment</th><th>Report preparation</th></tr>
<tr><th rowspan="4">How these steps...</th><th>Problem identification</th><td></td><td>Assists leadership to select & implement different tools and techniques</td><td>Various KPIs are developed on the basis of identified problem(s)</td><td>Crystallize KPIs for highly structured documents</td></tr>
<tr><th>Lean implementation</th><td>Helps to categorize problems under different groups</td><td></td><td>adds input for the outcome assessment</td><td>Establishes the basis of comparing pre and post implementation status</td></tr>
<tr><th>Leanness assessment</th><td>Identifies new problems for continuous improvement</td><td>Evaluates the level of implementation</td><td></td><td>Helps in defining objectives, strategies, action plans, and targets for further improvement</td></tr>
<tr><th>Report preparation</th><td>Provides detail examination of the identified problem(s)</td><td>Set the benchmark for further improvement</td><td>Affects what and how lean performance is assessed</td><td></td></tr>
</table>

The existing literature on leanness assessment shows the lack of review based papers on lean assessment. The SLR has identified the evolution of various types of themes of leanness, approaches of leanness assessment and functional areas of the leanness assessment. The review shows that the research on leanness assessment is mainly empirical using qualitative judgment. At the beginning of leanness assessment era, the focus was on assessing the leanness of manufacturing processes; currently the focus has shifted to the assessment of the whole organization along with its supply chain. Similarly, earlier the leanness assessment was done using tool & technique based assessment of manufacturing and financial areas. Now, the leanness assessment also includes non-financial and qualitative parameters of human resource, administration, new product development, supplier management, and customer management using outcome based assessment. The evolution of leanness assessment themes, approaches and assessment areas is shown in table 2.7.

Table 2.7: The evolution of leanness themes, assessment approaches and functional areas

	Brief description	**Phase I (1998-2004)**	**Phase II (2005-2011)**	**Phase III (2012-2018)**
Theme of leanness	Six themes of leanness assessment reflecting the focus	• Focused on lean manufacturing	• Lean manufacturing is still in focus • Lean organization, lean supply chain and lean supplier introduced	• Theme of lean organization evolved drastically • Lean product development, and lean management themes introduced
Leanness assessment approach	Four leanness assessment approaches used to assess the leanness	• Focused on tool & technique based assessment	• Outcome based assessment emerged • Tool & technique based assessment was at second priority • Mixed assessment introduced	• Dominance of outcome based assessment • Tool & technique based assessment emerging • Waste elimination based assessment introduced
Functional area	Functional areas of leanness assessment representing the whole organization	• Mainly manufacturing process and financial assessment	• Human resource management, supplier management and customer management areas introduced in leanness assessment	• Leanness assessment scope became wider and included new product development and administration as functional areas

The SLR investigated the concept of how leanness assessment can be carried out to improve the organizational performance. The most widely assessed areas are manufacturing process and finance, there is need to integrate the NPD, HRM, administration, supplier management and customer management so that the assessment is done for the whole organization.

2.5 CONCLUSIONS

This study presents a systematic literature review of peer-reviewed articles on leanness assessment to know various types of themes, approaches and functional areas to assess the leanness level of an organization. 86 articles were identified for the systematic literature review of leanness assessment (1998 to 2018). The descriptive analysis of these papers shows that the research on leanness assessment is mainly empirical using qualitative judgment. The number of publications on leanness assessment has increased from an average of 0.8 articles per year in the first phase (1998-2004) to an average of 8 articles per year in the third phase (2012-2018). The six thematic areas used for leanness assessment are: lean manufacturing, lean organization, lean supply chain, lean product development, lean management, and lean supplier. In first phase (1998-2004), the focus of leanness assessment was narrow to assess the manufacturing process. In third phase (2012-2018), the scope became wider and includes the whole organization along with its supply chain. Further, the study identifies three basic types of leanness assessment approaches: tool & technique based assessment, outcome based assessment and waste elimination based assessment. Earlier, researchers used tools and techniques based assessment to improve the leanness whereas at present the focus is on the outcome based assessment. Similarly, the focus of leanness assessment shifted from assessing manufacturing process and financial parameters using quantitative measures; to the assessment of non-financial and qualitative parameters related to manufacturing process, human resource, administration, new product development, suppliers, and customers. This study also depicts that the leanness assessment should be carried out in all functional areas of an organization for better results. The scope of leanness assessment in an organization has become wider; from manufacturing process to whole organization.

The SLR raised the issues of leanness assessment in manufacturing sector in light of the following questions: What should be the methodology to assess the leanness level of a manufacturing organization? Which performance dimensions need to be assessed?

Leanness assessment research is predominately through empirical studies devoid of concepts. During last decade, the increase in rate of growth of tool & technique based assessment approach and decrease in rate of growth of outcome based assessment approach articles also show the lack of proper conceptual frameworks/models for leanness assessment. There is a need to develop conceptual frameworks/models for leanness assessment. The practical knowledge gained through the empirical research should be used to develop the theory (conceptual models) for the leanness assessment. The limitation of the SLR is that literature search was focused on peer-reviewed articles published in English language only, therefore some papers in others languages may have been missed.

CHAPTER 3

DEVELOPMENT OF AN INTEGRATED PERFORMANCE MEASUREMENT FRAMEWORK FOR LEANNESS ASSESSMENT

In this chapter, an integrated performance measurement (IPM) framework has been developed to assess the organizational leanness of all functional areas (categories) for a manufacturing organization.

3.1 INTRODUCTION

The subject of performance evaluation of leanness in manufacturing industry has been a matter of great interest and concern for business and academia alike. Researchers have investigated the various dimensions, techniques and organizational requirements for the effective implementation of lean. Fitzgerald *et al.* (1991) identified two types of performance measures in an organization; one related to results while other related to determinant of the results. Bititci, Carrie, and McDevitt (1997) presented two fundamental considerations with regards to the structure and configuration of performance measurement systems – integrity of the system and deployment. Similarly, Neely, Bourne, and Kennerley (2000a) designed the performance measurement systems and reported that there are two basic approaches for designing the performance measurement systems – systems approach and organizational structure approach. The systems approach is an interdisciplinary practice based on scientific theory (Choong, 2014). The system approach is used to measure the horizontal flows of information and materials within the organization (Neely, Bourne, and Kennerley, 2000a). On the other hand, organizational structure approach is based on the hierarchy of the organization; and is used to measure the vertical flows. In this study, the systems approach is used to develop a conceptual framework. However, in practice, this approach is used to measure the determinant of results, integrity of the system, and organizational structure or deployment which is a part of integrity.

Over the past few decades, industries have understood that the continuous assessment of organizational performance is necessary to stay competitive. Performance evaluation is important to know the success of lean implementation. Performance evaluation is the process of evaluating effectiveness, efficiency, and capability of actions and system to obtain the given objectives (Al-Ashaab *et al.*, 2016). Choong (2014) used the systems approach and categorized the fundamental characteristics of a performance measurement system into six aspects – features; systems; stakeholders; measurement and performance; communication and information; and management. The lack of appropriate performance measures has led to the conflicting results of lean implementation. There are reported failures of lean manufacturing in organizations (Bortolotti, Boscari, and Danese, 2015; Behrouzi and Wong, 2011; Tiwari, Turner, and Sackett, 2007; Bhasin and Burcher, 2006). Williams *et al.* (1992) opined that the superiority of Japanese automobile manufacturers over Americans is due to better manufacturability, high capacity utilization, long production hours, and low wage rates in the supplier networks; and not due to lean production. Lack of a clear understanding about lean and its performance evaluation had led to the failure of lean practice. Most of the performance measures of lean have been developed for the manufacturing/production function of the organization. However, the success of the lean implementation depends on many steps in designing, developing and delivering the products to the customer. The lack of integration of manufacturing process lean indicators with other functions of the organization like human resource, finance, administration, supplier management, new product development (NPD), and customer management may be one of the reasons for the failures of lean implementation; as some organizations may be performing poorly in these non-evaluated areas/functions.

Therefore, it becomes important to measure the performance of all functional areas of the organization for the pragmatic evaluation of leanness. During last couple of years, many publications have appeared on the performance measures of lean organizations but to the best of the knowledge, none of the studies has integrated the lean measures related to finance, administration, customer management, supplier management, and human resource management. This chapter primarily aims at fulfilling this major research gap in performance measurement of leanness. It is also important that performance evaluation should be dynamic so that performance measures remain relevant and reflect the current issues of importance. Performance evaluation should focus on results as well as the potential to achieve the goals. The KPIs should be measurable and global in nature otherwise cannot be used for continuous improvement. The complex, interlinked, lagging, inflexible, and financial KPIs which are unrelated to the strategic objectives of the organization cannot be used to measure the modern organizations. The problem of how organizations should assess their performance has been challenging to management commentators and practitioners for many years. The secondary objective of this study is to relate each KPI to lean waste or/and principle. Each KPI has been categorized as strategic or operational, leading or lagging, social or technical, quantitative or qualitative. This study is an attempt to develop appropriate performance measures and their KPIs to evaluate the effectiveness of lean implementation in all functional areas of an organization.

3.2 LITERATURE REVIEW

To develop the IPM framework for the lean organizations, the existing frameworks or models have been studied. The study is conducted on two aspects – the most widely used integrated general performance measurement frameworks and the various frameworks developed for the leanness assessment of organizations.

Performance measurement literature clearly shows that a lot of research activities were happening in late 1990s, which developed the various types of performance measurement systems using multi-dimensional perspective of measurement (Neely, Gregory, and Platts, 2005; Neely, Bourne, and Kennerley, 2000a; Taticchi, Tonelli, and Cagnazzo, 2010; Bezerra and Gomes, 2016). Bititci, Carrie, and McDevitt (1997) presented an integrated performance measurement system as a reference model for the performance measurement; and depicted that a properly designed and structured performance measurement system would give the basis for an effective and accurate performance measurement, which could be used by management at operational, tactical, and strategic levels. Ghalayini, Noble, and Crowe (1997) developed an integrated dynamic performance measurement system which integrates the three major areas of an organization – factory shop floor, process improvement team, and management. Neely, Bourne, and Kennerley (2000a) designed a performance measurement system and argued that although some practitioners discussed the areas in which performance measurement might be useful but no guidelines were given to manage the business performance. Further, they built up the performance prism to strengthen the orientation of internal and external stakeholders as well as the associated processes, capabilities, and strategies. Bititci, Turner, and Begemann (2000) critically reviewed the existing techniques, models and frameworks and concluded that the available techniques and knowledge are mature enough to develop the dynamic performance measurement systems.

Taticchi, Tonelli, and Cagnazzo (2010) argued that although research on the subject of performance measurement and management seems to be reasonably mature in terms of citations and number of publications, but the subject is still vivid because researchers and practitioners have yet to develop integrated performance measurement systems including necessary and vital perspectives of information processing, modern philosophies about measurement, and management. Taticchi, Tonelli, and Cagnazzo (2010) provided a list of integrated performance measurement frameworks or models which are widely used for small, medium and large scales industries. This study reviews these widely used frameworks as presented in table 3.1. The characteristics of frameworks or models are categorized to understand its role in continuous improvement (impede or support); purpose of framework or model (monitoring or improvement); level at which framework or model is used (strategic or operational); coverage of the performance aspects (financial or non-financial); dedication to socio-technical system (social or technical); and nature of framework or model (static or dynamic).

Herzog and Tonchia (2014) identified eight important areas – value concepts & customers; value stream mapping; waste elimination; pull/kanban and flow; just in time (JIT); productive maintenance; employee involvement; and development of excellent suppliers – for evaluating the degree of lean implementation within existing manufacturing systems. Bortolotti, Boscari, and Danese (2015) focused on two crucial success factors for lean implementation – organization culture and adoption of soft practices. Wong, Ignatius, and Soh (2014) developed a lean index and quantified it using analytic network process (ANP) to measure the leanness level of an organization.

If any management system is implemented individually without integrating it with other functions then it results in increased costs, higher chances of failure, extra efforts, the creation of unnecessary bureaucracy, and affects the stakeholders like employees and customers (Rebelo, Santos, and Silva, 2013). Bhasin (2008) proposed a dynamic multi-dimensional performance (DMP) framework which provides a good assessment tool for multiple time horizons and concentrates on the interests of multiple stakeholders.

Table 3.1: A review of most widely used integrated performance frameworks or models

Author	Framework/model	Characteristic of framework/model					
		Impedes/Supports	Monitoring/ Improvement	Strategic/operational	Financial/Non-financial	Social/Technical	Static/Dynamic
Chennell and Dransfield (2000)	A system for organizational performance measurement (OPM)	IMD	MON	S&O	F	T	ST
Laitinen (2002)	Dynamic integrated performance measurement system (DIPMS)	SUP	IMP	S&O	F&NF	T	ST&D
Hudson, Lean, and Smart (2001)	Effective performance measurement (EPM) in SMEs	SUP	IMP	S	F&NF	T&SC	ST&D
Cross and Lynch (1988)	The Strategic Measurement Analysis and Reporting Technique (SMART)	IMD	MON	O	F	T	ST
Keegan, Eiler, and Jones (1989)	The Supportive Performance Measures (SPM)	IMD	MON	O	F	T	ST
Fitzgerald *et al.* (1991)	The Results and Determinants Framework.	IMD	MON	O	F	T	ST
Kaplan and Norton (1992)	The Balanced Scorecard.	SUP	MON	S&O	F&NF	T	ST
Heskett *et al.* (1994)	The Service Profit Chain (SPC)	IMD	MON	O	F	T	ST
Bititci, Carrie, and McDevitt (1997)	The Integrated Performance Measurement System (IPMS)	SUP	IMP	S&O	F&NF	T&SC	ST
Kanji (1998)	The Comparative Business Scorecard (CBS)	SUP	MON	S&O	F	T	ST
Medori and Steeple (2000)	The Integrated Performance Measurement Framework (IPMF)	SUP	IMP	S&O	F&NF	T	ST&D
Bititci, Turner, and Begemann (2000)	The Dynamic Performance Measurement System (DPMS)	SUP	IMP	S&O	F&NF	T&SC	ST&D
Neely, Adams, and Crowe (2001)	The Performance Prism	SUP	IMP	S	F&NF	T&SC	ST&D

Note: Here, IMD= Impedes, SUP= Supports, Mon= Monitoring, IMP= Improvement, S= Strategic, O= Operational, F=Financial, N= Non-financial, T=technical, SC= Social, ST= Static, D= Dynamic

Pakdil and Leonard (2014) developed a leanness assessment tool (LAT) using both quantitative performance dimensions (time effectiveness, quality, process, cost, human resources, delivery, customer, and inventory) and qualitative performance dimensions (quality, process, human resources, delivery, and customer). ISO 22400 describes that the organizations, which seek to improve their financial performance should have well defined KPIs and should also inform their employees to measure, evaluate and display results within the organization (International Standard ISO 22400–2, 2014). Wahab, Mukhtar, and Sulaiman (2013) developed a conceptual model consisting of two main levels – performance dimensions and factors (indicators) – to evaluate leanness in the manufacturing industries. Susilawati *et al.* (2013) proposed a performance measurement and improvement system (PMIS) framework on the basis of the existing literature which comprises process, financial, and customer/market measures. The proposed framework does not consider new product development and other import functions of an organization such as administration, human resource, supplier evaluation, *etc.* (Dombrowski, Schmidtchen, and Ebentreich (2013) argued that organizations which used the lean concepts in their product development process are facing problem of defining KPIs to ensure continuous improvement. Tyagi *et al.* (2015) explained lean thinking concepts for new product development in order to manage, improve and build up the product faster by enhancing the level of performance and quality. Bamber *et al.* (2014) provides good insights into the relationship between process improvement innovations and human resource management (HRM).

Vidyadhar *et al.* (2016) presented a conceptual model for leanness assessment of small and medium enterprises (SMEs) using the application of fuzzy logic. Sajan, Shalij, and Ramesh (2017) investigated the inter-linkage between the lean manufacturing practices in small and medium enterprises (SMEs) and sustainability performance of these practices. The critical success factors for any organization are leadership, employee involvement, training, and motivation of employee (Bhat, Gijo, and Jnanesh, 2014). For any improvement system, the human-based practices such as training, employee involvement and empowerment, team work, multi-skilled or multi-functional workforce, *etc.* are very crucial (Hadid and Mansouri, 2014). Sharma, Dixit, and Qadri (2015) investigated the effect of lean manufacturing practices on the performance metrics for machine tool industry in India and found that two lean manufacturing practices – strategic partnerships with suppliers, and cross-organizational cross-functional design and development teams – extensively affect most of the key performance metrics.

Narayanamurthy and Gurumurthy (2016b) described the methodology of leanness assessment which considers the interaction among lean elements for supporting continuous improvement of lean implementation and systemic leanness evaluation. Ainul Azyan, Pulakanam, and Pons (2017) identified the key success factors as well as failure factors for the implementation of lean manufacturing for the printing industry in Malaysia and found that 'management commitment and support' is the key emerging success factor. Efficiency (process focus) and market (customer focus) drivers provide inspiration for process improvement and better customer service, which results in long term, sustainable and operational improvements (Hadid and Mansouri, 2014). Pietro, Mugion, and Renzi (2013) proposed a mixed approach, which integrates lean principle as internal aspect and customer feedback as external aspect. In Japan, organizations are giving more importance to mutual respect, employee loyalty, teamwork, and professional development for managerial policies (Jaca *et al.*, 2014). Longoni *et al.* (2013) explained the effect of lean production on operational performance, and employee health and safety performance. Hadid and Mansouri (2014) emphasized on the impact of lean services on operational and financial performance through universal theory, socio-technical systems theory and contingency theory. Nawanir, Teong, and Othman (2013) investigated the interrelationship among lean manufacturing, operational performance, and business performance of manufacturing companies in Indonesia and found that the lean manufacturing has a significant and positive impact on both operational performance and business performance. Similarly, Zhu and Lin (2017) also found that the implementation of lean manufacturing has significant and positive effect on achieving the firm value in long run.

Several studies depict that lean manufacturing has improved the operational performance through minimizing inventory and cost; and enhancing quality, delivery service, and productivity (Shah and Ward, 2003; Fullerton and McWatters, 2001; Fullerton and Wempe, 2009); whereas some other studies postulated that the lean manufacturing has improved the business performance in terms of sales, profitability, and customer satisfaction (Yadav, Seth, and Desai, 2017; Kannan and Tan, 2005; Green and Inman, 2007). Karim and Arif-Uz-Zaman (2013) developed a leanness evaluation metric using continuous performance measurement (CPM) considering efficiency and effectiveness attributes.

It has been observed from the existing literature that most of the researchers have focused on lean performance of manufacturing processes and a few researchers have considered new product development for organizational leanness. Some researchers have used few indicators related to human resource or finance or customer in the manufacturing process. Therefore, there is a need for a generalized integrated framework which measures all functional areas of an organization. In this context, the lean organization is defined as an organization that embraces the key lean performance aspects which are appropriate for all organizational functions.

3.3 METHODOLOGY

The main objective of this chapter is to develop an integrated performance measurement framework for lean organizations. The research methodology used for the study is shown in Figure 3.1.

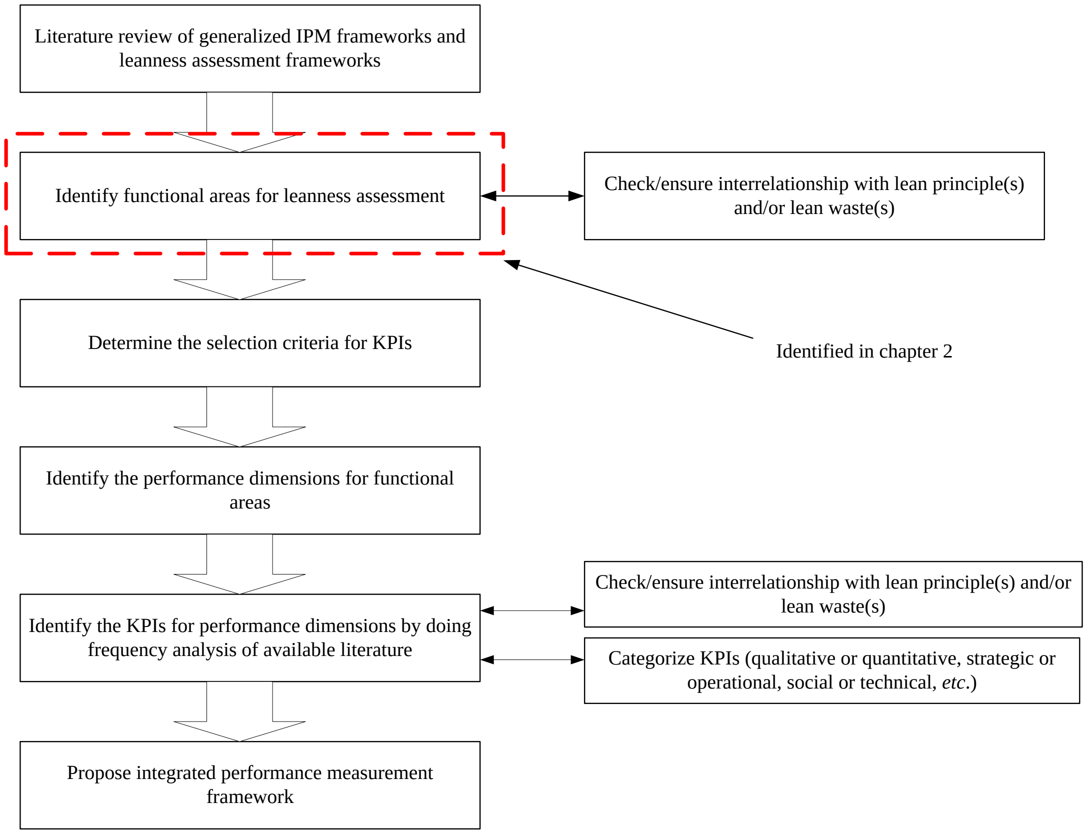


Figure 3.1: Methodology for the development of an IPM framework

First of all, a conceptual literature review (CLR) has been conducted to achieve the research objective. The various functional areas, representing the whole organization, have been identified from the literature review in the last chapter. The interrelationship of each functional area is checked with respect to lean principle(s) and/or lean waste(s). Next, performance dimensions have been developed for each functional area. Further, the study determines the selection criteria for KPIs. The KPIs have been developed using the frequency analysis of available literature. In addition, developed KPIs are categorized with respect to all aspect – qualitative or quantitative; strategic or operational; social or technical; financial or non-financial; leading or lagging; and static or dynamic. The interrelationship of each KPI with lean principle(s) and/or lean waste is identified. Finally, an integrated performance measurement framework has been proposed.

3.4 CRITERIA FOR THE SELECTION OF KPIs

KPIs are simple elements of a complex system which can be easily identified, measured, monitored, and controlled (Kurdve *et al.*, 2014). According to International Standard ISO 22400–1 (2014) and International Standard ISO 22400–2 (2014), KPIs are very crucial to understand and improve the performance of a manufacturing system. Therefore, the selection of KPIs is very crucial. The suitable criteria are required to determine the KPIs for measuring performance (Kanji, 2002; Neely, Bourne, and Kennerley, 2000b). Following eight criteria or guidelines have been identified for the selection of KPIs from the literature and discussion with industry professionals:

3.4.1 Dedicated to Organizational Goals

The improvement of every KPI should reflect the improvement of organizational goals. KPIs should be compatible with the strategic objectives and functional areas of the organization (Neely, Gregory, and Platts, 2005). The performance measurement system cannot be isolated because in order to do performance measurement, an organizational model is needed (Toni and Tonchia, 2001). Grosswiele, Röglinger, and Friedl (2013) also suggested that the indicators of a performance measurement system (PMS) should align with the organizational goals and objectives at the corporate level. If employees understand the linkage of KPIs with organizational goals then chances of lean success are high.

3.4.2 Data Reliability and Complexity

The main purpose behind the creation of KPIs is the collection of suitable and reliable data. The collection of unreliable data means wrong diagnosis and solving wrong problem. The common problem is too much data but too little analysis (Neely, Gregory, and Platts, 2005). The data gathered from surveys are used for reliability and validity analyses, thus, data should be authenticated and reliable for the analysis (Toni and Tonchia, 2001). Higher the complexity of data, higher the chances of unreliability. Further, quality of data is also important in the context of timeliness, correctness, range, completeness, and appropriateness (Grosswiele, Röglinger, and Friedl, 2013).

3.4.3 Consistent to the Hierarchy

The performance measure should be consistent throughout the hierarchical structure of the organizations (Bititci, Carrie, and McDevitt, 1997). Bourne *et al.* (2000) argued that there is an integration between performance measures (indicators) and hierarchy of the organization. Moreover, performance indicators should be aligned with organizational functions throughout organizational hierarchy (Hon, 2005). The performance measurement indicators are hierarchical in orientation (Neely, Bourne, and Kennerley, 2000a). The organization needs to establish the link between performance measure and hierarchical structure (Otley, 1999). The performance measurement system should follow the organizational model; PMS cannot be independent of organizational structure.

3.4.4 Dynamic

The KPIs should be static as well as dynamic depending on the timeline of the measurement. The regular operational performance is measured by static measures. The real time performance, which changes from time to time due to external factors, is measured by dynamic measures (Ferreira *et al.*, 2012). The performance measures should change from time to time as strategies develop (Otley, 1999). The performance measurement systems should grow with and accommodate to the changing internal and external environments (Hon, 2005). The PMS must be dynamic and flexible enough to adapt strategic changes. An integrated dynamic PMS helps managers to discover interface among common areas of success and their allied performance measures (Sousa and

Aspinwall, 2010). The absence of flexibility and lack of structured framework are the main obstacles in the adoption of dynamic performance systems. The PMS must be dynamic and flexible enough to adapt strategic changes.

3.4.5 Time Horizon

The performance indicators must be suitable for short term as well as long term performance strategies. In short term, indicators are used to measure operational performance whereas in long term indicators are used to measure performance at a corporate level. A good performance measurement system has lagging as well as leading indicators. Periodic performance measurement directs the organization to set future performance values (Ferreira *et al.*, 2012). The importance of performance indicators depends on time horizon (Molina-Castillo and Munuera-Alemán, 2009).

3.4.6 Easy to Understand

The performance measurement system should be simple and easy to understand by users (Neely, Gregory, and Platts, 2005). So, KPIs should be defined in such a way that these are simple to understand, measure, monitor, and analyze. Sometimes, it is difficult for the managers to understand some indicators due to technicalities associated with them. The simplicity of measurement system is a useful characteristic of a PMS (Hon, 2005). The complexity of PMS depends upon the number of indicators in it (Grosswiele, Röglinger, and Friedl, 2013).

3.4.7 Socio-technical

A performance measurement system should consider technical as well as social aspects as the socio-technical theory suggests that a superior performance may be accomplished by insisting on both the technical and social subsystems (Hadid and Mansouri, 2014). The technical and social factors collectively stress on production paradigm, health, safety and corporate social responsibility issues (Sousa and Aspinwall, 2010). Generally, technical indicators are related to hard practices such as total productive maintenance (TPM), total quality management (TQM), just in time (JIT), *etc.* and social indicators are related to soft practices based on human resource management (HRM) such as customer satisfaction, employee empowerment, employee involvement, *etc.* The performance measurement system should capture complete picture of the organization in complex modern environments.

3.4.8 Duplication

Duplication means measuring the same indicator in different forms. For example, the defects are measured by defect rate, parts per million (ppm), quality rate, scrap rate, rework rate, defects by sale, failure rate at inspection, *etc.* A performance measurement system should consider existing measures and consolidate new measures to delete duplicate measures (Grosswiele, Röglinger, and Friedl, 2013). The root cause analysis method can be used to identify root causes and counter-measures to avoid duplication (Hadid and Mansouri, 2014).

3.5 IDENTIFICATION OF PERFORMANCE DIMENSIONS AND KPIs

26 performance dimensions have been identified under the seven functional areas. These performance dimensions contain 119 KPIs. The structure of the proposed IPM is shown in figure 3.2. The identification of various performance dimensions and KPIs is as:

3.5.1 Manufacturing Process

This functional area has six performance dimensions – quality, cost, time, inventory, delivery, and process flow. A total of 33 KPIs have been identified on the basis of frequency analysis of 36 research publications as shown in table 3.2. The identified KPIs are further categorized as quantitative or qualitative; strategic or operational; financial or non-financial; technical or social; leading or lagging; static or dynamic (Table 3.3).

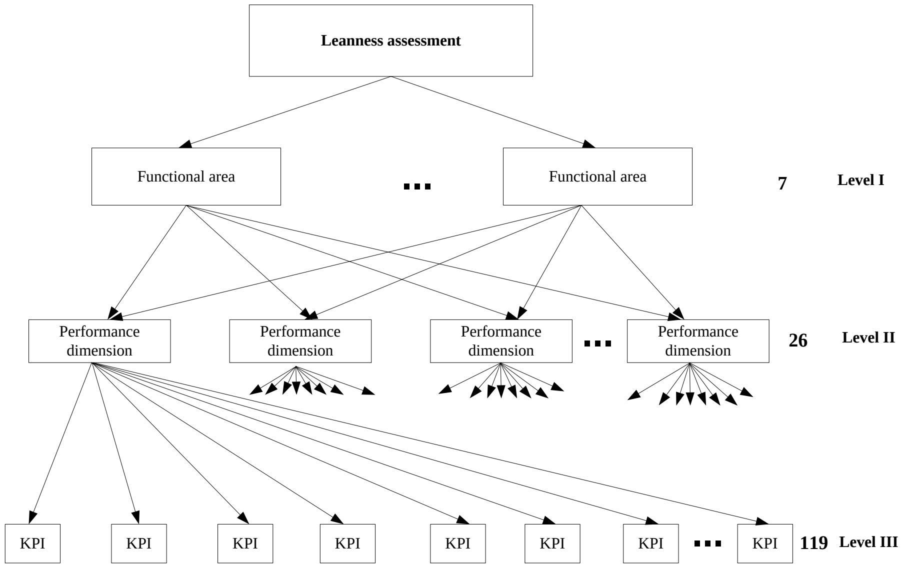


Figure 3.2: Structure of the proposed IPM framework

3.5.1.1 Quality: The economic environment is changing rapidly. Quality is defined as the number of good parts that are produced as a percentage of the total parts produced (Ng, Low, and Song, 2015). Quality can be inferred by defect, rework and scrap rates in the manufacturing organizations (Pakdil and Leonard, 2014). These days, organizations can ill afford defects and rework (Sangwan, Bhamu, and Mehta, 2014). Poka-yoke can drive defects out of processes and significantly improves quality and reliability (Amin *et al.,* 2014). First pass yield (FPY) is defined as the percentage of total parts produced without any rework. Scrap requires excessive rework to recycle into raw materials (if possible) than sent back into the flow (Ramesh and Kodali, 2012). Quality performance dimension is measured using the following KPIs.

- Defect rate
- Poka-yoke
- Scrap ratio
- First pass yield (FPY)

Table 3.2: Frequency analysis of manufacturing process KPIs

KPI	Arif-Uz-Zaman and Ahsan (2014)	Pakdil and Leonard (2014)	Kurdve *et al.* (2014)	Karim and Arif-Uz-Zaman (2013)	Bhasin (2008)	Behrouzi and Wong (2011)	Camacho-Miñano, Moyano-Fuentes, and Sacristán-Díaz (2013)	Susilawati *et al.* (2012)	Panizzolo *et al.* (2012)	Cumbo, Kline, and Bumgardner (2006)	Sánchez and Pérez (2001)	Dora, Kumar, and Gellynck (2016)	Ray *et al.* (2006)	Duque and Cadavid (2007)	Amin and Karim (2012)	Rebelo, Santos, and Silva (2013)	Toni and Tonchia (1996)	Susilawati *et al.* (2013)	Bonavia and Marin-Garcia (2011)	Kilpatrick (2003)	Agus and Hajinoor (2012)	Kumar *et al.* (2006)	Bhasin (2011b)	Saurin, Marodin, and Ribeiro (2011)	Koeijer, Paauwe, and Huijsman (2014)	Sharma and Singh (2015)	Wilson (2009)	Womack and Jones (2003)	Ramesh and Kodali (2012)	Afonso and Cabrita (2015)	Shetty, Hartford, and Ali (2010)	Searcy (2009)	Venkatesh (2007)	Gunasekaran, Patel, and McGaughey (2004)	Bhagwat and Sharma (2007)	Kang *et al.* (2016)	Frequency
Defect rate	√	√	√	√	√					√	√	√		√		√	√	√	√	√			√		√	√		√		√				√			20
Percentage cost of poor quality		√														√							√														3
Overall equipment effectiveness index	√	√	√	√						√												√		√		√	√									√	10
Manufacturing lead time	√	√		√				√		√	√	√	√	√			√	√	√	√	√			√	√		√		√	√							19
Manufacturing cycle time	√	√		√	√			√	√			√		√				√		√			√				√										12
Throughput rate										√			√				√																			√	4
Inventory turns		√			√		√			√		√	√			√			√				√	√	√			√	√						√		14
Scrap ratio		√			√	√	√	√			√		√	√	√			√				√	√	√	√	√			√		√	√			√	√	20
Percentage of work in process (WIP) inventory		√			√		√				√		√	√	√					√			√								√	√			√	√	13
Processing cost per unit	√	√	√	√	√								√			√							√									√		√	√		11
Percentage of maintenance cost		√														√										√											3
Percentage of raw material cost					√								√				√						√														4
Percentage of labor cost										√			√													√	√						√				5
Percentage of inventory cost		√				√																								√			√		√		5
Percentage of in-house material movement cost		√				√							√													√							√				5
Percentage of raw material inventory		√			√			√					√		√			√					√														7

Table 3.2: Frequency analysis of manufacturing process KPIs (contd.)

KPI	Arif-Uz-Zaman and Ahsan (2014)	Pakdil and Leonard (2014)	Kurdve *et al.* (2014)	Karim and Arif-Uz-Zaman (2013)	Bhasin (2008)	Behrouzi and Wong (2011)	Camacho-Miñano, Moyano-Fuentes, and Sacristán-Díaz (2013)	Susilawati *et al.* (2012)	Panizzolo *et al.* (2012)	Cumbo, Kline, and Bumgardner (2006)	Sánchez and Pérez (2001)	Dora, Kumar, and Gellynck (2016)	Ray *et al.* (2006)	Duque and Cadavid (2007)	Amin and Karim (2012)	Rebelo, Santos, and Silva (2013)	Toni and Tonchia (1996)	Susilawati *et al.* (2013)	Bonavia and Marin-Garcia (2011)	Kilpatrick (2003)	Agus and Hajinoor (2012)	Kumar *et al.* (2006)	Bhasin (2011b)	Saurin, Marodin, and Ribeiro (2011)	Koeijer, Paauwe, and Huijsman (2014)	Sharma and Singh (2015)	Wilson (2009)	Womack and Jones (2003)	Ramesh and Kodali (2012)	Afonso and Cabrita (2015)	Shetty, Hartford, and Ali (2010)	Searcy (2009)	Venkatesh (2007)	Gunasekaran, Patel, and McGaughey (2004)	Bhagwat and Sharma (2007)	Kang *et al.* (2016)	Frequency
Percentage of finished goods inventory		√			√		√	√							√			√					√														7
First pass yield (FTY)		√	√							√			√			√						√					√		√							√	9
Machine down time		√						√			√			√	√	√		√								√			√		√						10
Set up rate		√				√	√	√	√				√	√	√			√			√												√			√	12
Utilization efficiency			√		√		√					√				√	√	√	√	√								√	√							√	12
Worker efficiency		√			√			√									√	√					√				√		√			√		√		√	11
Space productivity		√			√		√						√	√						√			√		√		√					√		√	√		12
On-time delivery		√	√			√	√			√		√				√			√								√		√					√	√		12
Lot size reduction								√	√		√		√	√				√	√		√										√						9
Transportation or motion		√		√				√			√			√	√			√								√					√						9
Changeover time											√				√		√	√											√							√	6
Allocation efficiency	√			√	√											√							√			√										√	7
Poka-yoke								√	√	√								√																			4
Pull process	√						√	√			√			√				√			√																7
Number of non-value added activities				√		√		√		√								√									√										6
Process capability index									√									√				√															3
Flexibility	√			√																														√	√		4

Table 3.3: Manufacturing process KPIs and their characteristics

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
Quality	Defect rate	PPM	$\frac{\text{Total defective parts}}{\text{Total parts produced}} \times 1000000$	Defect	QT	O	NF	T	LG	ST
	Scrap ratio	%	$\frac{\text{Scrap quantity}}{\text{Produced quantity}} \times 100$	Defect	QT	O	NF	T	LG	ST
	Poka-yoke		Likert scale	Defect	QL	O	NF	T	LD	ST
	First pass yield (FPY)	%	$\frac{\text{Good parts}}{\text{Inspected parts}} \times 100$	Defect	QT	O	NF	T	LG	ST
Cost	Processing cost per unit	INR		Value	QT	O	F	T	LG	ST
	Percentage cost of poor quality	%	$\frac{\text{Cost of poor quality}}{\text{Total manufacturing cost}} \times 100$	Defect	QT	O	F	T	LG	ST
	Percentage of raw material cost	%	$\frac{\text{Raw material cost}}{\text{Total manufacturing cost}} \times 100$	Value	QT	O	F	T	LG	ST
	Percentage of maintenance cost	%	$\frac{\text{Maintenance cost}}{\text{Total manufacturing cost}} \times 100$	Value	QT	O	F	T	LD & LG	ST
	Percentage of labor cost	%	$\frac{\text{Labor cost}}{\text{Total manufacturing cost}} \times 100$	Value	QT	O	F	T	LG	ST
	Percentage of inventory cost	%	$\frac{\text{Inventory cost}}{\text{Total manufacturing cost}} \times 100$	Value, inventory	QT	O	F	T	LG	ST
	Percentage of in-house material movement cost	%	$\frac{\text{In} - \text{house material movement cost}}{\text{Total manufacturing cost}} \times 100$	Value, transportation	QT	O	F	T	LG	ST
Time	Manufacturing lead time	Months/days		Flow, waiting	QT	O	NF	T	LG	ST
	Manufacturing cycle time	Minutes		Waiting	QT	O	NF	T	LG	ST
	Throughput rate (TPR)	Units/hours	$\frac{\text{Produced quantity}}{\text{Actual order execution time}}$	Flow, waiting	QT	O	NF	T	LG	ST
	Machine down time	Minutes		Waiting	QT	O	NF	T	LG	ST

Table 3.3: Manufacturing process KPIs and their characteristics (Contd.)

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
	Set up rate	%	$\frac{\text{Actual set up time}}{\text{Actual unit processing time}} \times 100$	Waiting	QT	O	NF	T	LG	ST
	Changeover time	Minutes		Waiting	QT	O	NF	T	LG	ST
Inventory	Percentage of work in process (WIP) inventory	%	$\frac{\text{Work in process (WIP) inventory}}{\text{Total inventory}} \times 100$	Inventory	QT	O	NF	T	LD & LG	ST
	Percentage of raw material inventory	%	$\frac{\text{Raw material inventory}}{\text{Total inventory}} \times 100$	Inventory	QT	O	NF	T	LG	ST
	Percentage of finished goods inventory	%	$\frac{\text{Finished goods inventory}}{\text{Total inventory}} \times 100$	Inventory	QT	O	NF	T	LG	ST
	Inventory turns	Hours	$\frac{\text{Throughput}}{\text{Average inventory}}$	Inventory	QT	O	F	T	LG	ST
Delivery	On-time delivery	%	$\frac{\text{Number of order delivered on time}}{\text{Total number of order}} \times 100$	Pull, waiting	QT	O	F	T	LD & LG	ST
	Flexibility		Likert scale	Flow	QL	S	NF	T	LD & LG	D
	Transportation or motion	Meters		Transporta-tion	QT	O	NF	T	LG	ST
Process flows	Overall equipment effectiveness (OEE) index	%	Availability × Effectiveness × Quality rate × 100	Flow, defect	QT	O	NF	T	LG	ST
	Utilization efficiency	%	$\frac{\text{Actual production time}}{\text{Actual busy time}} \times 100$	Value	QT	O	NF	T	LG	ST

Table 3.3: Manufacturing process KPIs and their characteristics (Contd.)

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
	Worker efficiency	%	$\frac{\text{Actual personel work time}}{\text{Actual personel attendance time}} \times 100$	Value	QT	O	NF	T	LG	ST
	Space productivity	%	$\frac{\text{Total space used}}{\text{Total space available}} \times 100$	Value	QT	O	NF	T	LG	ST
	Lot size reduction	Number	$\text{Initial lot size} - \text{Final lot size}$	Flow	QT	S	NF	T	LG	D
	Allocation efficiency	%	$\frac{\text{Actual unit busy time}}{\text{Planned busy time}} \times 100$	Value	QT	O	NF	T	LG	ST
	Pull process		Likert scale	Pull	QL	S	NF	T	LG	D
	Number of non-value added activities	Number		Value	QT	O	NF	T	LG	ST
	Process capability index		$\frac{\text{Upper specification limit} - \text{Lower specification limit}}{6 \times \text{Standard deviation}}$	Value	QT	O	NF	T	LG	ST

Note: Here, QT=Quantitative, QL=Qualitative, S=Strategic, O=Operational, F=Financial, NF=Nonfinancial, T=Technical, LD=leading, LG=Lagging, ST=Static, D=dynamic

3.5.1.2 Cost: Lean is used to reduce cost by eliminating non-value added activities. Elimination of waste lowers variable production costs associated with labor, raw material, inventory, quality, material movement, maintenance, and energy, thereby increasing the unit profitability of products and processes. Lean constantly targets cost, quality and customer service (Alsmadi, Almani, and Jerisat, 2012). Anvari, Zulkifli, and Yusuff (2013) found that the most critical components to leanness are defects, cost, lead time, and value. Processing cost is defined as the total cost incurred while manufacturing any product (Amin *et al.*, 2014). This performance dimension is measured using following KPIs.

- Processing cost per unit
- Percentage cost of poor quality
- Percentage of raw material cost
- Percentage of maintenance cost
- Percentage of labor cost
- Percentage of inventory cost
- Percentage of in-house material movement cost.

3.5.1.3 Time: In the current globalized business environment, time effectiveness is essential for every organization to be competitive. Cycle time is the time required to complete one cycle of an operation. Lead time is defined as the total amount of time between the placing of an order and the receipt of the goods (Drohomeretski *et al.*, 2014). Lead time reduction is an important driver for the implementation of lean in any manufacturing organization (Sangwan, Bhamu, and Mehta, 2014). Panizzolo *et al.* (2012) argued that manufacturing process times have improved after lean implementation. Throughput time is the time required for a product to proceed from concept to launch, order to delivery, or raw materials to product handover to the customer. This includes both processing and queue time. Various parameters such as setup time, changeover time, throughput time, *etc*. directly affect production volume. These parameters have significant scope to improve production volume (Singh, Garg, and Sharma, 2010). Machine down time is directly related to machines effectiveness. The following KPIs have been identified for this performance dimension.

- Manufacturing lead time
- Manufacturing cycle time
- Throughput rate
- Machine down time
- Setup rate
- Changeover time

3.5.1.4 Inventory: Conventionally, inventory has been considered as an asset but lean thinking focuses on elimination of all types of inventory (Ramesh and Kodali, 2012). Main principle of lean manufacturing is to reduce all forms of waste; inventory is one of the important wastes. Pull system enables the production only when the customer asks for it. The pull system minimizes inventory. The total inventory is the sum of raw material inventory, work in process (WIP) inventory and finished goods inventory; and inventory turnover is the ratio of the quantity of sold products to the sum of product inventory and work in process (WIP) inventory (Ray *et al.*, 2006). Manufacturing organizations overcome the effect of the variability in a production system by properly managing the inventory, capacity and time (Bhasin, 2008). The identified KPIs for this performance dimension are:

- Percentage of raw material inventory
- Percentage of work in process inventory

- Percentage of finished goods inventory
- Inventory turnover

3.5.1.5 Delivery: These days, manufacturing organizations build customer centric business strategies. This forces the organizations to maintain their delivery promises. Developing the manufacturing potential to deliver the goods on time requires precise estimation of the delivery time. Organization has to bear additional cost if on-time delivery is extended. Wong, Ignatius, and Soh (2014) argued that improved on-time delivery is an essential market winning criteria. Operational performance is estimated by asking questions about cost, quality, flexibility and delivery relative to main competitors (Longoni *et al.*, 2013). Transportation does not add any value within the organization or between organizations and factories at different places (Karlsson and Åhlström, 1996). The following KPIs have been identified for this performance dimension.

- On-time delivery
- Transportation or motion
- Flexibility

3.5.1.6 Process flow: Continuous improvement, productivity and cost reduction are three essential pillars of a lean manufacturing system (Camacho-Miñano, Moyano-Fuentes, and Sacristán-Díaz, 2013). Toni and Tonchia (1996) emphasized on inter-functional effectiveness, process efficiency and system flexibility. If production repetitively increases than it is essential to measure material productivity instead of material cost. Just in time (JIT) is generally used to implement pull process effectively. JIT conveys what is needed, when it is needed and what amount is needed. Pull system is one of the three elements of JIT. The pull system enables the production of what is needed, based on the signal from the customer. The activities which do not add values to the final product are termed as necessary non-value added (NNVA) activities and wastes (Karim and Arif-Uz-Zaman, 2013). Overall equipment effectiveness (OEE) is product of availability, performance rate and quality rate (Ng, Low, and Song, 2015). To implement lean manufacturing, process stability or capability has to be evaluated using control charts (Wilson, 2009). The following KPIs have been identified for this dimension.

- Utilization efficiency
- Worker efficiency
- Space productivity
- Overall equipment effectiveness (OEE) index
- Lot size reduction
- Allocation efficiency
- Pull process
- Number of non-value added activities
- Process capability index

3.5.2 New Product Development

This functional area has six performance dimensions – quality; research and development; time; market; cost; and rate of return. Under these six performance dimensions, a total of 37 KPIs have been identified on the basis of frequency analysis of 22 research publications as shown in table 3.4. The identified KPIs are further categorized as quantitative or qualitative; strategic or operational; financial or non-financial; technical or social; leading or lagging; static or dynamic (Table 3.5).

3.5.2.1 Quality: Defect, in product development, is defined as a failure in tests, inaccurate data, and warranty costs (Mohammadi, 2010). Tyagi *et al.* (2015) suggested that defined level of quality can be achieved by a large number of iterations during the

Table 3.4: Frequency analysis of new product development KPIs

KPI	Tyagi *et al.* (2015)	Tuli and Shankar (2014)	Bhasin (2008)	Susilawati *et al.* (2012)	Costa *et al.* (2014)	Susilawati *et al.* (2013)	Mohammadi (2010)	Bhasin (2011b)	Koeijer, Paauwe, and Huijsman (2014)	Jasti and Kodali (2014)	Molina-Castillo and Munuera-Alemán (2009)	Toni and Tonchia (1996)	Sánchez and Pérez (2001)	Panizzolo *et al.* (2012)	Agus and Hajinoor (2012)	Ray *et al.* (2006)	Chiesa and Frattini (2007)	Driva, Pawar, and Menon (2000)	Geisler (1994)	Chiesa *et al.* (2007)	Gunasekaran, Patel, and McGaughey (2004)	Bhagwat and Sharma (2007)	Frequency
Rework rate or change requests	√	√	√	√	√	√	√	√		√	√	√		√	√	√	√						15
Quality specifications			√		√			√	√		√	√			√				√				8
Percentage of development cost	√	√		√	√	√	√			√	√	√					√	√	√	√	√		13
Time to market	√	√	√	√	√	√	√	√		√	√	√						√					12
Product design cycle time		√	√							√							√				√	√	6
Product design lead time	√	√	√	√		√				√						√					√	√	9
New market development or growth			√		√			√			√												4
Expected market share	√		√	√		√		√	√	√	√				√								9
Percentage of marketing cost				√		√					√												3
Customer satisfaction	√	√			√		√																4
Part standardization				√		√							√	√									4
Percentage of sales from new products			√		√		√	√															4

Table 3.4: Frequency analysis of new product development KPIs (Contd.)

KPI	Tyagi *et al.* (2015)	Tuli and Shankar (2014)	Bhasin (2008)	Susilawati *et al.* (2012)	Costa *et al.* (2014)	Susilawati *et al.* (2013)	Mohammadi (2010)	Bhasin (2011b)	Koeijer, Paauwe, and Huijsman (2014)	Jasti and Kodali (2014)	Molina-Castillo and Munuera-Alemán (2009)	Toni and Tonchia (1996)	Sánchez and Pérez (2001)	Panizzolo *et al.* (2012)	Agus and Hajinoor (2012)	Ray *et al.* (2006)	Chiesa and Frattini (2007)	Driva, Pawar, and Menon (2000)	Geisler (1994)	Chiesa *et al.* (2007)	Gunasekaran, Patel, and McGaughey (2004)	Bhagwat and Sharma (2007)	Frequency
Number of new product launched in last 5 years					√		√		√		√												4
Number of non-value added activities	√	√								√													3
Return on investment					√		√			√												√	4
On-time delivery	√	√		√	√	√	√			√	√							√					9
Resource utilization		√			√																		2
Number of patents filed					√		√		√		√								√				5
Number of design changes to specification					√		√																2
Life cycle design/assessment				√		√								√									3
Number of bottlenecks					√		√																2
Innovativeness rating			√		√																		2
Strategic competence	√		√		√			√			√												5
Effectiveness of risk management process		√			√					√													3
Design manhours		√										√					√			√	√		5

Table 3.4: Frequency analysis of new product development KPIs (Contd.)

KPI	Tyagi *et al.* (2015)	Tuli and Shankar (2014)	Bhasin (2008)	Susilawati *et al.* (2012)	Costa *et al.* (2014)	Susilawati *et al.* (2013)	Mohammadi (2010)	Bhasin (2011b)	Koeijer, Paauwe, and Huijsman (2014)	Jasti and Kodali (2014)	Molina-Castillo and Munuera-Alemán (2009)	Toni and Tonchia (1996)	Sánchez and Pérez (2001)	Panizzolo *et al.* (2012)	Agus and Hajinoor (2012)	Ray *et al.* (2006)	Chiesa and Frattini (2007)	Driva, Pawar, and Menon (2000)	Geisler (1994)	Chiesa *et al.* (2007)	Gunasekaran, Patel, and McGaughey (2004)	Bhagwat and Sharma (2007)	Frequency
Timeliness					√		√											√					3
Number of processes reduced											√			√									2
Employee training and satisfaction		√		√	√									√									4
Percentage of profit from new product					√					√						√	√				√	√	6
Involvement of suppliers in product development				√		√							√	√									4
Product customization				√		√								√									3
Product performance					√						√	√			√				√				5
Knowledge management		√					√																2
Quality function deployment (QFD)				√		√																	2
Benchmarking							√									√					√	√	4
Life cycle costing																	√						1
Actual project cost to budgeted cost							√											√			√	√	4

Table 3.5: New product development KPIs and their characteristics

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
Quality	Rework rate or change requests	Number	Number of iterations made in the NPD	Defect	QT	O	NF	T	LG	ST
	Quality specifications		Likert scale	Defect	QL	S	NF	T	LD	D
	Part standardization		Likert scale	Perfection	QL	S	NF	T	LD	D
	Benchmarking		Likert scale	Perfection	QL	S	NF	T	LD	D
Research and development	Number of non-value added activities	Number		Value	QT	O	NF	T	LG	ST
	Resource utilization		Likert scale	Value stream	QL	O	NF	T	LG	ST
	Number of patents filed	Number		Value	QT	S	NF	T	LG	ST
	Number of design changes to specification	Number		Flow	QL	S	NF	T	LG	D
	Life cycle design/ assessment		Likert scale	Value	QL	S	NF	T	LD	D
	Number of bottlenecks	Number		Defect	QT	O	NF	T	LG	ST
	Innovativeness rating		Likert scale	Value	QL	S	NF	T	LG	D
	Employee training and satisfaction		Likert scale	Value	QL	S	NF	T	LD & LG	D
	Involvement of suppliers in product development		Likert scale	Value stream	QL	S	NF	T	LD	D

Table 3.5: New product development KPIs and their characteristics (Cond.)

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
	Product customization		Likert scale	Pull	QL	S	NF	T	LD & LG	D
	Knowledge management		Likert scale	Value	QL	S	NF	T	LD	D
	Quality function deployment (QFD)	Number	P chart/ C chart violation	Value stream	QT	S	NF	T	LD & LG	ST
	Number of processes reduced	Number		Over processing	QT	S	NF	T	LG	ST
Time	Design manhours	Hours		Value stream	QT	O	NF	T	LG	ST
	Time to market	Month		Flow	QT	S	NF	T	LG	ST
	Product design cycle time	Minutes		Waiting	QT	O	NF	T	LG	ST
	Product design lead time	Months/ days		Flow, waiting	QT	O	NF	T	LG	ST
	Timeliness	%	$\frac{\text{Target time}}{\text{Actual time}} \times 100$	Flow	QT	O	NF	T	LG	ST
	On-time delivery	%	$\frac{\text{Number of new product delivered on-time}}{\text{Total number of new product delivered}} \times 100$	Pull, waiting	QT	O	NF	T	LD & LG	ST
Market	New market development or growth		Likert scale	Value stream	QL	S	NF	T	LD	D
	Expected market share	%		Value	QT	S	NF	T	LD	D
	Customer satisfaction		Likert scale	Value	QL	S	NF	T	LD & LG	D

Table 3.5: New product development KPIs and their characteristics (Cond.)

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
	Number of new products launched during last five years	Number		Value	QT	S	NF	T	LG	ST
	Strategic competence		Likert scale	Value	QL	S	NF	T	LD	D
	Effectiveness of risk management process		Likert scale	Value	QL	S	NF	T	LD	D
	Product performance		Likert scale	Value	QL	S	NF	T	LD	D
Cost	Percentage of development cost	%	$\frac{\text{Development cost}}{\text{Total project cost}} \times 100$	Value	QT	O	F	T	LG	ST
	Life cycle costing		Likert scale	Value	QL	S	F	T	LD & LG	ST
	Percentage of marketing cost	%	$\frac{\text{Marketing cost}}{\text{Total project cost}} \times 100$	Value	QT	S	F	T	LD & LG	ST
	Actual project cost to budgeted cost	%	$\frac{\text{Actual project cost}}{\text{Total budgeted cost}} \times 100$	Value	QT	O	F	T	LG	ST
Rate of return	Percentage of sales from new products	%	$\frac{\text{Sales from new products}}{\text{Total sales}} \times 100$	Value	QT	S	F	T	LG	ST
	Return on investment	%	$\frac{\text{Total gain from new product} - \text{Total project cost}}{\text{Total project cost}} \times 100$	Value	QT	S	F	T	LG	ST
	Percentage of profit from new product	%	$\frac{\text{Profit from new product}}{\text{Net profit}}$	Value	QT	S	F	T	LG	ST

Note: Here, QT=Quantitative, QL=Qualitative, S=Strategic, O=Operational, F=Financial, NF=Non-financial, T=Technical, LD=leading, LG=Lagging, ST=Static, D=dynamic

product design. Statistical process control (SPC) provides quality control tools in a production process that permits a considerable reduction in testing and inspection while attaining unprecedented quality (Mascitelli, 2011). The following KPIs have been identified for this dimension.

- Rework rate or change requests
- Quality specifications
- Part standardization
- Benchmarking

3.5.2.2 Research and development: Mascitelli (2011) recognized that research is used to investigate non-product specific technologies to provide feasibility for commercialization; and development is used to incorporate the feasible technologies into commercial products. R & D accountability can be measured in terms of its efficiency, effectiveness, internal and external customer focus, and alignment to business strategy (Chiesa and Frattini, 2007).

13 KPIs have been identified for the performance dimension of cost.

- Number of non-value added activities
- Resource utilization
- Number of patents filed
- Number of design changes to specification
- Life cycle design/assessment
- Number of bottlenecks
- Innovativeness rating
- Employee training and satisfaction
- Involvement of suppliers in product development

- Product customization
- Knowledge management
- Quality function deployment (QFD)
- Number of processes reduced

3.5.2.3 Time: The important discriminating factors between the best-performing companies and rest of the companies are short product development cycle times and higher quality (Sobek, Ward, and Sloan, 1999; Tuli and Shankar, 2015). Accelerating innovation requires companies to reduce their development cycle time and time to market (Hoppmann *et al.*, 2011). The following KPIs have been identified to measure this dimension.

- Design manhours
- Time to market
- Product design cycle time
- Product design lead time
- Timeliness
- On-time delivery

3.5.2.4 Market: Product development plays an important role to develop new market as well as to increase the market share, particularly in the market segment where product life cycle is ever decreasing. New product performance can be evaluated on the basis of market, customer and financial performance. Market based performance can be assess by results of the new product in terms of level of success in the market (Molina-Castillo and Munuera-Alemán, 2009). Effectiveness and efficiency are two main targets for product development. Effectiveness means designing the right products to create a high demand; and efficiency means designing the product with the right process (Dombrowski, Schmidtchen, and Ebentreich, 2013). Customer satisfaction and acceptance are vital indicators of market performance (Hines, Francis, and Found, 2006). Seven KPIs have been identified for this dimension.

- New market development or growth
- Expected market share
- Customer satisfaction
- Number of new products launched during last five years
- Strategic competence
- Effectiveness of risk management process
- Product performance.

3.5.2.5 Cost: Manufacturing organizations always try to optimize the costs associated with new product development (Karakulin, 2015). The organization should monitor the deviation of actual cost from the target cost (Mascitelli, 2011). The adherence to schedule, cost, and performance goals are important inputs for a project (Hoppmann *et al.*, 2011). The success of any project can be measured by new product development productivity (sales/profit to R & D expenditure) (Mohammadi, 2010). In this performance dimension, the following KPIs have been identified.

- Percentage development cost
- Percentage marketing cost
- Life cycle costing
- Actual project cost to the budgeted cost

3.5.2.6 Rate of return: R & D return is defined as the amount of profit or net present value expected from a R & D investment (Nixon, 1998). The main objective of a company manager is to maintain high levels of profits by consistently discovering new knowledge that makes something new from the unique combination of existing knowledge (Karakulin, 2015). The product conception contains sales forecasts in terms of quantity and variability (Dombrowski and Zahn, 2011). At the firm level, the performance of NPD can be measured by popular financial indicators such as sales growth, profit, return on investment, *etc.* (Mohammadi, 2010). The following KPIs have been identified for this dimension.

- Percentage of sales from new products
- Return on investment
- Percentage of profit from new product

3.5.3 Human Resource Management

This functional area has four performance dimensions – health and safety; empowerment; skill; and cost. 15 KPIs have been identified on the basis of frequency analysis of 24 research publications as shown in table 3.6. The identified KPIs are further categorized as quantitative or qualitative; strategic or operational; financial or non-financial; technical or social; leading or lagging; static or dynamic (Table 3.7).

3.5.3.1 Health and safety: Bamber *et al.* (2014) emphasized the need to consider the effect of process improvement on occupational health and safety of employees. As per standard norms, organizations are expected to provide a proactive culture of prevention and safety to reduce the risk of occupational accidents, incidents and absenteeism (Rebelo, Santos, and Silva, 2013). The lean production system may fail if there is a high variability in production rates and lower product quality due to the significant level of absenteeism and turnover (Bonavia and Marin-Garcia, 2011). Grosse *et al.* (2015) point out that there is a need for a robust multi-factor study which investigates the effect of human factors such as workload and employee discomfort on their performance.

Table 3.6: Frequency analysis of human resource management KPIs

KPI	Tortorella and Fogliatto (2014)	Bamber *et al.* (2014)	Pakdil and Leonard (2014)	Kurdve *et al.* (2014)	Bhasin (2008)	Wong, Ignatius, and Soh (2014)	Susilawati *et al.* (2012)	Panizzolo *et al.* (2012)	Cumbo, Kline, and Bumgardner (2006)	Dora, Kumar, and Gellynck (2016)	Ray *et al.* (2006)	Duque and Cadavid (2007)	Rebelo, Santos, and Silva (2013)	Susilawati *et al.* (2013)	Bonavia and Marin-Garcia (2011)	Bhasin (2011b)	Martínez-Jurado, Moyano-Fuentes, and Jerez-Gómez (2014)	Sharma nad Singh (2015)	Ramesh and Kodali (2012)	Arif-Uz-Zaman and Ahsan (2014)	Sánchez and Pérez (2001)	Camacho-Miñano, Moyano-Fuentes, and Sacristán-Díaz (2013)	Chapman, Murray, and Mellor (1997)	Geisler (1994)	Afonso and Cabrita (2015)	Frequency
Absenteeism rate			√		√						√		√		√	√			√							7
Health and safety of employees				√	√				√		√					√	√	√	√					√		9
Number of accidents/ incidents per year					√								√			√		√	√					√		6
Training hours per employee per year		√			√		√	√		√	√	√	√	√	√	√		√	√							13
Percentage of skilled or multifunctional workforce			√		√	√	√	√		√		√		√						√	√					10
Labor turnover			√		√				√						√	√									√	6
No of suggestions implemented per worker per month		√	√		√			√				√		√		√			√		√	√	√			11
Employment security					√										√	√			√							4
Number of remuneration policies or incentive schemes	√	√					√		√					√												5
Employee satisfaction	√					√	√	√	√		√		√	√	√				√						√	11
Average cost of training per year			√										√	√												3
Use of multifunctional task forces/teams			√					√				√		√							√	√				6
Respect for people	√			√													√									3
Work-related flexibility			√					√											√							3
Average labor wage rate									√				√		√											3

Table 3.7: Human resource management KPIs and their characteristics

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
Health and safety	Absenteeism rate	Days/ employee/ year	$\frac{\text{Number of days taken off per year}}{\text{Total number of employee}}$	Under-utilization	QT	O	NF	SC	LG	ST
	Health and safety of employees		Likert scale	Value	QL	S	NF	SC	LD & LG	D
	Number of accidents or incidents occurred per year	Number		Value	QT	O	NF	SC	LG	ST
Empowerment	Number of suggestions implemented per worker per month	Number		Value	QT	O	NF	SC	LG	ST
	Employment security		Likert scale	Flow	QL	S	NF	SC	LD	D
	Number of remuneration policies or incentive schemes	Number		Value	QT	S	NF	SC	LD	D
	Employee satisfaction		Likert scale	Value	QL	S	NF	SC	LD & LG	D
	Respect for people		Likert scale	Value	QL	S	NF	SC	LD & LG	D
	Work-related flexibility		Likert scale	Value stream	QL	S	NF	SC	LD & LG	D

Table 3.7: Human resource management KPIs and their characteristics (Contd.)

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
Skill	Training hours per employee per year	Hours/ employee/ year	$\frac{\text{Total Number of training hours per year}}{\text{Total number of employee}}$	Perfection	QT	S	NF	SC	LG	ST
	Percentage of skilled or multifunctional workforce	%	$\frac{\text{Skilled or multifunctional workforce}}{\text{Total workforce}} \times 100$	Perfection	QL	S	NF	SC	LD & LG	D
	Use of multifunctional task forces/teams		Likert scale	Value stream	QL	S	NF	SC	LD & LG	D
Cost	Labor turnover	%	$\frac{\text{Total Number of labor left}}{\text{Total number of labor}} \times 100$	Flow	QT	O	F	SC	LG	ST
	Average cost of training per year	INR		Value	QT	O	F	SC	LG	ST
	Average labor wage rate	INR/ labor	$\frac{\text{Total cost of labor}}{\text{Total number of labor}}$	Value	QT	S	F	SC	LG	ST

Note: Here, QT=Quantitative, QL=Qualitative, S=Strategic, O=Operational, F=Financial, NF=Non-financial, SC= Social, LD=leading, LG=Lagging, ST=Static, D=dynamic

The following KPIs have been identified for the health and safety performance dimension.

- Absenteeism rate
- Health and safety of employees
- Number of accidents/incidents per year

3.5.3.2 Empowerment: Lean production must be a people-driven process because improvement in the existing process and product can be recognized only by employees (Forrester, 1995). Bamber *et al.* (2014) argued that HRM practices which empower or involve employees have a good impact on performance. Employee involvement increases the commitment and ownership of employee through the change process (Tortorella and Fogliatto, 2014). The remuneration system (salary, reward, awards, *etc.*) certainly affect employee loyalty and commitment to lean production (Bonavia and Marin-Garcia, 2011). The following KPIs have been identified for this performance dimension.

- Number of suggestions implemented per worker per month
- Employment security
- Number of remuneration policies or incentive schemes
- Employee satisfaction
- Respect for people
- Work related flexibility

3.5.3.3 Skill: Training is used to improve employee capability of doing work and accepting new skills. Bonavia and Marin-Garcia (2011) suggested that there is a need to consistently promote the development of a multi-skilled and flexible taskforce by arranging training and effective employee development programs. Bamber *et al.* (2014) argued that by adopting lean manufacturing, the skills of employees could be increased. Continuous training programs about lean practices are required to foster an appropriate culture in the organization (Martínez-Jurado, Moyano-Fuentes, and Jerez-Gómez, 2014).

Employee skills and knowledge may impact process quality and capability (Wong, Ignatius, and Soh, 2014). The following KPIs have been identified for this performance dimension.

- Training hours per employee per year
- Percentage of skilled or multifunctional workforce
- Use of multifunctional task forces/teams

3.5.3.4 Cost: Appropriate wage rate and reward are important attributes for the recruitment and retention of employees (Tracey and Flinchbaugh, 2008). The high rate of employee turnover breaks the continuity, which is the key to success for lean implementation programs (Panizzolo *et al.*, 2012; Grosse *et al.*, 2015) Mobility of employees within the organization may improve organizational performance in two ways: directly, through knowledge, experience and satisfaction, and, indirectly, by decreasing recruitment, selection and training costs (Milkovich and Boudreau, 1994). The following KPIs have been identified to measure this dimension.

- Labor turnover
- Average cost of training per year
- Average labor wage rate

3.5.4 Finance

This functional area has three performance dimensions – rate of return, cost and sales. Ten KPIs have been identified for this functional area on the basis of frequency analysis of 13 research publications as shown in table 3.8. The identified KPIs are further categorized as quantitative or qualitative; strategic or operational; financial or non-financial; technical or social; leading or lagging; static or dynamic (Table 3.9).

3.5.4.1 Rate of return: Conventionally, any PMS is based on financial data such as return on investment, earning per share, purchase price variance, *etc.* (Susilawati *et al.*, 2012). Lean techniques are used to generate profits by better utilization of factories, more customized products and enhanced product quality (Panizzolo *et al.*, 2012). Operational indicators and financial indicators (sales, profit, return on sales, *etc.*) are used to assess the lean management models (Camacho-Miñano, Moyano-Fuentes, and Sacristán-Díaz, 2013). A mix strategy proceeds to highest return on investment (ROI) compared to both pure cost and differentiation strategies with significant sales growth (Hadid and Mansouri, 2014). This performance dimension includes following KPIs.

- Return on assets (ROA)
- Return on investment (ROI)
- Return on sales (ROS)
- Current ratio
- Rate of return on capital employed
- Net profit margin

3.5.4.2 Cost: Several organizations insist on external aspects of performance such as customers, competition and market; and others focus on internal aspects of performance like efficiency, processes and costs (Rebelo, Santos, and Silva, 2013). Lean production is used to recognize an extremely effective and efficient production system with minimum resources which results higher quality and lower costs within the organization (Pakdil and Leonard, 2014). Bhasin (2008) suggested that there is a need to evaluate financial growth on the basis of relevant business issues and real cost rather than traditional standard cost methods. It is essential to find the best way to reduce manpower in order to increase profit and decrease overall cost (Sangwan, Bhamu, and Mehta, 2014). The following KPIs have been identified for this performance dimension.

- Total cost per year
- Procurement cost

3.5.4.3 Sales: Performance measures concerning only financial measures are rarely mentioned (Taggart, 2009). A lean organization can increase its sales by decreasing prices, adding features or capabilities to the product, adding services to the existing product to enhance value, enlarging the distribution and service network or getting profit from new products (Womack and Jones, 2003). Two KPIs have been identified for this performance dimension.

- Sales volume or turnover
- Revenue generated

Table 3.8: Frequency analysis of finance KPIs

KPI	Bhasin (2008)	Camacho-Miñano, Moyano-Fuentes, and Sacristán-Díaz (2013)	Cumbo, Kline, and Bumgardner (2006)	Ray *et al.* (2006)	Rebelo, Santos, and Silva (2013)	Agus and Hajinoor (2012)	Bhasin (2011b)	Koeijer, Paauwe, and Huijsman (2014)	Molina-Castillo and Munuera-Alemán (2009)	Searcy (2009)	Pakdil and Leonard (2014)	Sharma and Singh (2015)	Afonso and Cabrita (2015)	Frequency
Net profit margin	√	√	√	√	√	√			√		√		√	9
Total cost of capital employed/ total sales		√		√	√			√	√			√		6
Sales volume or turnover		√	√	√	√			√	√	√				7
Revenue generated					√				√	√				3
Return on assets (ROA)		√				√			√				√	4
Return on investment (ROI)		√		√				√	√				√	5
Return on sales (ROS)		√				√			√				√	4
Current ratio	√	√					√							3
Rate of return on capital employed	√						√		√					3
Procurement cost/ total sales				√										1

Table 3.9: Financial KPIs and their characteristics

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
Rate of return	Return on assets (ROA)	%	$\frac{\text{Net income}}{\text{Total assets}} \times 100$	Flow	QT	S	F	T	LG	ST
	Return on investment (ROI)	%	$\frac{\text{Total revenue generated} - \text{Total cost}}{\text{Total cost}} \times 100$	Flow	QT	S	F	T	LG	ST
	Return on sales (ROS)	%	$\frac{\text{Net income (before interest and tax)}}{\text{Total sales}} \times 100$	Flow	QT	S	F	T	LG	ST
	Current ratio		$\frac{\text{Current assets}}{\text{Current liabilities}}$	Value	QT	S	F	T	LG	ST
	Rate of return on capital employed	%	$\frac{\text{Operating profit}}{\text{Capital employed}}$	Flow	QT	S	F	T	LG	ST
	Net profit margin	%	$\frac{\text{Net profit after tax}}{\text{Total sales}} \times 100$	Value	QT	S	F	T	LG	ST
Cost	Total cost of capital employed/ total sales	%	$\frac{\text{Total cost of capital employed}}{\text{Total sales}} \times 100$	Value	QT	S	F	T	LG	ST
	Procurement cost/ total sales	%	$\frac{\text{Procurement cost}}{\text{Total sales}} \times 100$	Value	QT	S	F	T	LG	ST
Sales	Sales volume or turnover	Number		Value, Flow	QT	S	F	T	LG	ST
	Revenue generated	INR		Value	QT	S	F	T	LG	ST

Note: Here, QT=Quantitative, S=Strategic, F=Financial, T=Technical, LG=Lagging, ST=Static

3.5.5 Administration

Three performance dimensions of communication, decision making, and work performance have been identified under this functional area. Ten KPIs have been identified, under these three dimensions, on the basis of frequency analysis of 21 research publications as shown in table 3.10. The identified KPIs are further categorized as quantitative or qualitative; strategic or operational; financial or non-financial; technical or social; leading or lagging; static or dynamic (Table 3.11).

3.5.5.1 Communication: Lean manufacturing is used to timely transfer proper information down to the shop floor employees by decentralizing responsibility and decreasing the hierarchic levels in the organization. The lean organization requires expansion of information to all levels. Leadership, communication and employee work attitude are main drivers for corporate and intra-organization alignment. Improvement projects (e.g. kaizen, 5S), data accuracy (DA) and means of information (EDI) enable organizations to become lean through conducive and supportive technical environment (Wong, Ignatius, and Soh, 2014). Poor communication affects worker morale and motivation due to poorly managed resources such as time, material, budget, *etc.*, (Sharma and Singh, 2015). At the plant level, visualization of information can play a great role to enable everyone to know the status of the process at a particular time (Duque and Cadavid, 2007). Three KPIs have been identified to measure communication.

- Communication or information loss
- Business relationship with partners
- Visual control of the shop floor

3.5.5.2 Decision making: In an organization, lean is used to set standards to upgrade the competitive policies (Ray *et al.*, 2006). Interdepartmental coordination is essential. The lack of interdepartmental coordination leads to delay and poor decision making. Traditional measures are historical and difficult to correlate with strategic decisions (Bhasin, 2008). Three KPIs have been identified to measure decision making.

- Commitment of top management
- Competitive policy
- Strategic planning

Table 3.10: Frequency analysis of administration KPIs

KPI	Camacho-Miñano, Moyano-Fuentes, and Sacristán-Díaz (2013)	Wong, Ignatius, and Soh (2014)	Susilawati *et al.* (2012)	Panizzolo *et al.* (2012)	Venkatesh (2007)	Sánchez and Pérez (2001)	Dora, Kumar, and Gellynck (2016)	Duque and Cadavid (2007)	Kilpatrick (2003)	Sharma and Singh (2015)	Molina-Castillo and Munuera-Alemán (2009)	Susilawati *et al.* (2013)	Costa *et al.* (2014)	Pakdil and Leonard (2014)	Bhasin (2008)	Mehrsai, Thoben, and Scholz-Reiter (2014)	Arif-Uz-Zaman and Ahsan (2014)	Ray *et al.* (2006)	Bhasin (2011b)	Toni and Tonchia (1996)	Bhagwat and Sharma (2007)	Frequency
Communication/information loss	√	√		√	√	√		√		√											√	8
Percentage of administrative costs					√					√	√											3
Reduction of paper work in office areas			√		√	√		√	√			√										6
Synchronized scheduling		√	√	√							√	√				√				√	√	8
Business relationship with partners											√		√				√				√	4
Commitment of top management		√		√	√	√	√		√			√	√				√					9
Competitive policy											√							√				2
Strategic planning											√		√		√				√			4
Quality control			√			√		√				√		√								5
Visual control of the shop floor			√	√								√										3

Table 3.11: Administrative KPIs and their characteristics

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
Communication	Communication/information loss		Likert scale	Flow	QL	O	NF	T	LG	D
Communication	Business relationship with partners		Likert scale	Flow	QL	S	NF	T	LD	D
Communication	Visual control of the shop floor		Likert scale	Value stream	QL	O	NF	T	LD	D
Decision making	Commitment of top management		Likert scale	Value	QL	S	NF	T	LD	D
Decision making	Competitive policy		Likert scale	Perfection	QL	S	NF	T	LD	D
Decision making	Strategic planning		Likert scale	Value	QL	S	NF	T	LD	D
Work Performance	Percentage of administrative costs	%	$\frac{\text{Administrative cost}}{\text{Total sales}} \times 100$	Value	QT	S	F	T	LG	ST
Work Performance	Reduction of paperwork in office areas		Likert scale	Flow	QL	S	NF	T	LG	ST
Work Performance	Synchronized scheduling		Likert scale	Value stream	QL	O	NF	T	LG	D
Work Performance	Quality control	Number	P chart/ C chart violation	Defect	QT	S	NF	T	LG	ST

Note: Here, QT=Quantitative, QL=Qualitative, S=Strategic, O=Operational, F=Financial, NF=Non-financial, T=Technical, LD=leading, LG=Lagging, ST=Static, D=dynamic

3.5.5.3 Work performance: The specific improvements in administrative work performance are related to organizational functions of streamlining of customer service functions, decreasing paper work in the office, reducing staff demands, documenting and streamlining the processing to reduce losses. The main targets of manufacturing planning and control are to synchronize production and market demand, accelerate the flows and simplify management (Panizzolo *et al.*, 2012). Material planning, effective workers and machine scheduling are necessary to obtain high level of leanness within the organization (Wong, Ignatius, and Soh, 2014). Four KPIs have been identified for this performance dimension.

- Percentage of administrative costs
- Reduction of paperwork in office
- Synchronized scheduling
- Quality control

3.5.6 Customer Management

Two performance dimensions – serviceability and delivery – have been considered under this functional area. Seven KPIs have been identified on the basis of frequency analysis of 21 research publications as shown in table 3.12. The identified KPIs are further categorized as quantitative or qualitative; strategic or operational; financial or non-financial; technical or social; leading or lagging; static or dynamic (Table 3.13).

3.5.6.1 Serviceability: There is a need to exchange information with customer; and to involve customer in product design and planning (Panizzolo *et al.*, 2012). Susilawati *et al.* (2013) suggested that the manufacturing space should be more responsive to customer demand. Pakdil and Leonard (2014) suggested that customer satisfaction, customer complaint rate and customer retention rate should be observed consistently. Bhasin (2008) pointed out a considerable positive correlation between customer satisfaction and financial performance. Five KPIs have been identified for this dimension.

- Customer satisfaction
- Customer retention rate
- Annual customer complaints
- Customer involvement
- Service quality

3.5.6.2 Delivery: Belekoukias, Garza-Reyes, and Kumar (2014) found that JIT has a direct effect on operational performance and demand variability which affect organizational performance in the form of responsiveness and efficiency. Lean manufacturing is aimed at making organizations more responsive to customer demand (Bhamu and Sangwan, 2014), which enables the organizations to quickly respond to market (Bhasin, 2011b). Two KPIs have been identified to measure delivery.

- On-time delivery
- Responsiveness

Table 3.12: Frequency analysis of customer management KPIs

KPI	Pakdil and Leonard (2014)	Mehrsai, Thoben, and Scholz-Reiter (2014)	Kurdve *et al.* (2014)	Bhasin (2008)	Susilawati *et al.* (2012)	Panizzolo *et al.* (2012)	Cumbo, Kline, and Bumgardner (2006)	Sánchez and Pérez (2001)	Ray *et al.* (2006)	Rebelo, Santos, and Silva (2013)	Susilawati *et al.* (2013)	Bhasin (2011b)	Koeijer, Paauwe, and Huisman (2014)	Sharma and Singh (2015)	Womack and Jones (2003)	Ramesh and Kodali (2012)	Molina-Castillo and Munuera-Alemán (2009)	Behrouzi and Wong (2011)	Venkatesh (2007)	Bhagwat and Sharma (2007)	Afonso and Cabrita (2015)	Frequency
Customer satisfaction	√			√	√	√	√			√	√	√	√			√	√				√	12
Customer retention rate	√			√								√					√					4
Annual customer complaints	√		√											√				√	√		√	6
Responsiveness		√		√	√	√					√	√				√				√	√	9
Customer involvement					√	√					√											3
On-time delivery				√	√	√		√	√		√	√									√	8
Service quality				√		√						√			√						√	4

Table 3.13: Customer management KPIs and their characteristics

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
Serviceability	Annual customer complaints	Number		Defect	QT	O	NF	T	LG	ST
	Customer satisfaction		Likert scale	Value	QL	S	NF	T	LD & LG	D
	Customer retention rate		$\frac{\text{Number of current customers}}{\text{Number of all customers transacted in last X days}} \times 100$	Value	QT	S	NF	T	LG	ST
	Customer involvement		Likert scale	Value	QL	S	NF	T	LD & LG	D
	Service quality		Likert scale	Value	QL	S	NF	T	LD & LG	D
Delivery	Responsiveness		Likert scale	Perfection	QL	S	NF	T	LG	ST
	On-time delivery	%	$\frac{\text{Number of orders delivered on-time}}{\text{Total number of order}} \times 100$	Pull, waiting	QT	O	NF	T	LG	ST

Note: Here, QT=Quantitative, QL=Qualitative, S=Strategic, O=Operational, NF=Non-financial, T=Technical, LD=leading, LG=Lagging, ST=Static, D=dynamic

3.5.7 Supplier Management

More and more organizations are concentrating on their core competencies and outsourcing other works. This has made suppliers an integral part of the organizations. There are numerous examples from the automotive industry, during last decade, which show how the poor supplier performance has affected their bottom line. In this functional area, two performance dimensions – supplier interaction and quality – have been considered. Seven KPIs have been identified on the basis of frequency analysis of 12 research publications as shown in table 3.14. The identified KPIs are further categorized as quantitative or qualitative; strategic or operational; financial or non-financial; technical or social; leading or lagging; static or dynamic (Table 3.15).

3.5.7.1 Supplier interaction: Lean organizations require fewer suppliers who can provide quality supplies just in time. These suppliers are also involved in the product development. Suppliers are selected on the basis of quality of their incoming parts/materials; and involved in product development process and quality improvement programs (Koeijer, Paauwe, and Huijsman, 2014). During last decade, there is a growing agreement on the strategic integration of suppliers, manufacturers and customers (Afshan, 2013). Four KPIs have been identified for this dimension.

- Relationship with suppliers
- Contract length with important suppliers
- Percentage of supplier evaluation cost
- Percentage of distant suppliers eliminated

3.5.7.2 Quality: One of the major reasons identified for the failure of lean production is the poor quality supplies from suppliers. Abdollahi, Arvan, and Razmi (2015) suggested that quality is the most important criterion influencing the supplier selection. Three KPIs have been identified for this dimension.

- Percentage of certified suppliers
- Supplier involvement in design
- Incoming parts/materials defect rate

Table 3.14: Frequency analysis of supplier management KPIs

KPI	Arif-Uz-Zaman and Ahsan (2014)	Pakdil and Leonard (2014)	Susilawati *et al.* (2012)	Panizzolo *et al.* (2012)	Cumbo, Kline, and Bumgardner (2006)	Sánchez and Pérez (2001)	Rebelo, Santos, and Silva (2013)	Susilawati *et al.* (2013)	Molina-Castillo and Munuera-Alemán (2009)	Bhagwat and Sharma (2007)	Susilawati *et al.* (2015)	Afonso and Cabrita (2015)	Frequency
Relationship with suppliers	√		√	√		√	√	√	√		√	√	8
Contract length with important suppliers				√		√					√		3
Percentage of certified suppliers		√	√			√		√					4
Percentage of total cost of supplier evaluation			√	√			√	√			√		5
Percentage of distant supplier eliminated			√	√				√			√		4
Supplier involvement in design			√	√		√		√		√	√		6
Incoming parts/materials defect rate			√					√		√			3

Table 3.15: Supplier management KPIs and their characteristics

Performance dimension	KPI	Unit	Formula	Lean Principle/ Waste	Qualitative/ Quantitative	Strategic/ Operational	Financial/ Non-financial	Social/ Technical	Leading/ Lagging	Static/ Dynamic
Supplier interaction	Relationship with suppliers		Likert scale	Flow	QL	S	NF	T	LD	D
	Contract length with important suppliers		Likert scale	Flow	QL	S	NF	T	LD	D
	Percentage of distant supplier eliminated	%	$\frac{\text{Number of distant suppliers eliminated}}{\text{Total number of suppliers}} \times 100$	Flow	QT	S	NF	T	LG	ST
	Percentage of supplier evaluation cost	%	$\frac{\text{Total cost of supplier evaluation}}{\text{Total sales}} \times 100$	Value	QT	S	F	T	LG	ST
Quality	Supplier involvement in design		Likert scale	Value	QL	S	NF	T	LD & LG	D
	Percentage of certified suppliers	%	$\frac{\text{Number of certified suppliers}}{\text{Total number of suppliers}} \times 100$	Value	QT	S	NF	T	LG	ST
	Incoming parts/material defect rate	%	$\frac{\text{Total Number of defective parts}}{\text{Total number of parts received from suppliers}} \times 100$	Defect	QT	O	NF	T	LG	ST

Note: Here, QT=Quantitative, QL=Qualitative, S=Strategic, O=Operational, F=Financial, NF=Non-financial, T=Technical, LD=leading, LG=Lagging, ST=Static, D=dynamic

3.6 PROPOSED INTEGRATED PERFORMANCE MEASUREMENT FRAMEWORK FOR LEANNESS ASSESSMENT

The proposed framework is a conceptual three level framework. The framework, embedded throughout the whole supply chain of an organization, is shown in figure 3.3. The IPM framework which has seven functional areas of a lean organization – manufacturing process, new product development (NPD), human resource management (HRM), financial, administration, customer management and supplier management. In these seven functional areas, 26 performance dimensions have been identified which are assessed by 119 KPIs. All seven functional areas are interlinked with either lean principles or lean wastes or with both.

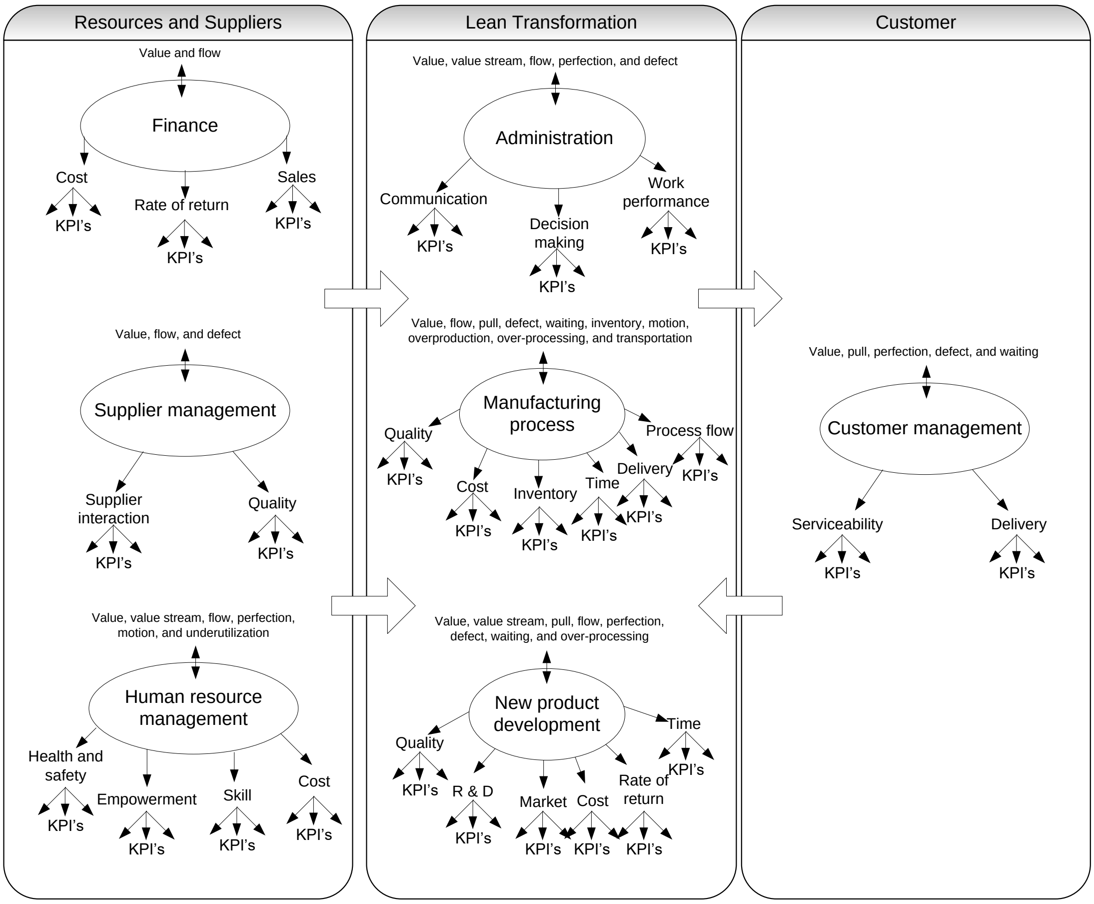


Figure 3.3. Proposed integrated performance measurement framework for the leanness assessment

Further, the developed KPIs are pragmatic in nature and cover all aspects – qualitative or quantitative; strategic or operational; social or technical; financial or non-financial; leading or lagging; and static or dynamic. It is expected that the developed framework will help the managers to justify the implementation of lean in their organizations.

3.7 CONCLUSIONS

This study develops a framework for the leanness assessment of an organization in an integrated way. The organization is divided into seven functional areas, functional areas are divided into 26 performance dimensions and 119 KPIs have been identified to measure these performance dimensions. The study identifies eight criteria, on the basis of literature review and discussion with industry professionals, for the selection of KPIs. These criteria ensure that the KPIs are aligned to the goal of leanness assessment, for strategic and operational assessment covering the socio-technical as well as financial & non-financial aspects of the whole organization for the continuous leanness improvement. KPIs are developed on the basis of selection criteria and frequency analysis of existing literature. Each KPI has been related to either one or more of the eight lean wastes or/and five lean principles. The developed KPIs are categorized as qualitative or quantitative, strategic or operational, social or technical, financial or non-financial, leading or lagging, static or dynamic. The proposed framework is a generic framework for the manufacturing sector. The developed framework is dynamic in nature. So, it is very essential to review the existing KPIs periodically as a part of the target and goal setting. The manager should do the required changes in KPIs as assessment goals change over the period of time. Obsolete KPIs should be deleted and new appropriate KPIs should be introduced. It is expected that the developed framework will help the managers to justify the implementation of lean manufacturing in their organizations.

It is expected that the proposed integrated performance measurement framework; depicting the proper structure and linkages with lean principle/waste will be a good reference for the accurate and effective leanness assessment at different organizational levels irrespective of the industry type. Most of the research papers have considered traditional performance dimensions like quality, cost, delivery, time, rate of return, inventory, *etc.* The performance dimensions like employee empowerment, skill, decision making, communication, health and safety, *etc.*, derived from organizational core values are not in common use.

CHAPTER 4

VALIDATION OF THE INTEGRATED PERFORMANCE MEASUREMENT FRAMEWORK

This chapter presents the leanness assessment of an Indian automotive component manufacturing organization using the IPM framework proposed in the last chapter. First, fuzzy ANP model is used to obtain the importance of various performance dimensions of the proposed IPM framework. Next, fuzzy methodology is used to calculate the leanness score of the case organization.

4.1 INTRODUCTION

One of the real difficulties in leanness assessment is the dynamic nature of business environment. The measured values of some of the KPIs keep on fluctuating; therefore any decision taken based on the fluctuating indices will be vague in nature. The use of fuzzy methodologies is an appropriate approach for handling vagueness and yet to work in mathematically strict and rigorous way (Kickert, 1978). Further, practically, all performance dimensions shall not have equal importance. Since there are number of variables or elements which influence the leanness and some of these elements are interdependent on each other; under such situations, the fuzzy ANP can handle interactions among them as well as can undertake the vagueness associated with the expert judgement during the network building. Therefore, analytic network process (ANP) in combination with fuzzy mathematics is used to assign different weights to different performance dimensions. Qualitative indices must be considered in making transition from a pure model to a practical solution. However, quantitative indices should not be dismissed in favour of totally qualitative indices as quantitative aspects can’t be reckoned with accuracy through intuition alone. Therefore, any practical assessment should have a combination of qualitative and quantitative indices. A combination of both quantitative and qualitative approaches is essential for detailed and large-scale information gathering (Driva, Pawar, and Menon, 2000). Numerous quantitative and qualitative assessment approaches have been offered in literature to evaluate the degree of leanness achieved (Narayanamurthy and Gurumurthy, 2016). Replacing qualitative KPIs with quantitative KPIs results in new indices for lean (Azadeh *et al.*, 2015). The use of both, quantitative and qualitative KPIs gives an inclusive assessment of the organizational leanness efforts (Pakdil and Leonard, 2014). The maximum number of frameworks for leanness assessment are developed using either qualitative or quantitative KPIs. Only few frameworks consider both, qualitative and quantitative KPIs simultaneously to leverage the strengths of each other (Oleghe and Salonitis, 2018).

This chapter demonstrates, through a case study, a fuzzy methodology for the leanness assessment of an organization using quantitative and qualitative KPIs derived for all performance dimensions and functional areas. The case study method is opined to be an appropriate methodology for the exploratory nature of the research (Dora, Kumar, and Gellynck, 2016).

4.2 FUNDAMENTALS OF ANALYTIC NETWORK PROCESS AND FUZZY SET THEORY

The study confers the fuzzy-ANP approach to rank the leanness performance dimensions of an automotive component manufacturing organization. The fuzzy-ANP is the combination of the two approaches: fuzzy set theory and ANP.

4.2.1 Analytic Network Process (ANP)

ANP is a special case of AHP (Saaty, 1996). AHP provides unidirectional hierarchical relations by assuming the independence between the elements of the model. Conversely, the ANP covers the whole network and does not assume independence between elements (Nilashi *et al.*, 2016). The main difference between AHP and ANP is that the ANP can handle negotiations between benchmarking and decision-level by obtaining overall weight through the development of supermatrix (Saaty, 1996). ANP considers the complete network, and there is no need to specify hierarchical levels. ANP based decision making categorises a system into two components: control level and network level (Wang, Liu, and Cai, 2015). The control level consists of the goal and decision criteria whereas the network level includes elements structured by the control level. The elements interrelate with each other to establish a network structure.

4.2.2 Fuzzy Set Theory

The multi-attribute decision making faces some challenges in real life applications due to the vagueness and uncertainty associated with the decision-making process (Nilashi *et al.*, 2016). The fuzzy based decision-making approaches have been developed to provide solutions of the problems arising due to vague and imprecise judgments. The fuzzy sets express human knowledge in mathematical form (Aydin and Pakdil, 2008; Zadeh, 1965). Behrouzi and Wong (2011) stated that the fuzzy methodology contains fuzzy sets to characterize the uncertain, non-statistical and linguistic values. The term ‘‘leanness’’ used in the usual language is typically referred to the multifaceted concepts of vague characterization (Bayou and de Korvin, 2008; Matawale *et al.*, 2014). Behrouzi and Wong (2011) developed a practical and dynamic model for lean performance measurement using the fuzzy methodology. Pakdil and Leonard (2014) also developed a leanness assessment tool using the fuzzy methodology. The fuzzy methodology is well suited to measure qualitative and quantitative data simultaneously. A fuzzy set is used to deal with the uncertainty and vagueness of human judgments in the industry (Nilashi *et al.*, 2016). The basic definition of a fuzzy is:

Definition 1: A fuzzy set Á is defined and characterized by a membership function which links with every element x in Á. The membership function $\mu_{Á}(x)$ is a real number in the interval [0, 1] and expresses the grade of the membership of x in Á.

$$Á = \{(x, \mu_{Á}(x)) \mid x \in Á, \mu_{Á}(x) \in [0,1]\} \qquad (4.1)$$

The fuzzy membership function $\mu_{Á}(x)$ for the fuzzy set Á can be defined in different ways according to its use for a particular problem statement or according to a range of element x in a fuzzy set Á.

Definition 2: The fuzzy membership function $\mu_{Á}(x)$ can be defined as:

$$\mu_{Á}(x_i) = \begin{cases} \frac{(x-l)}{(m-l)}, & l \leq x \leq m \\ \frac{(u-x)}{(u-m)}, & m \leq x \leq u \\ otherwise & 0 \end{cases} \qquad (4.2)$$

where, a triangular fuzzy set can be characterized by (l, m, u) as shown in figure 4.1. The 'l' denotes lower feasible value, 'm' denotes middle value, and 'u' denotes the feasible upper value.

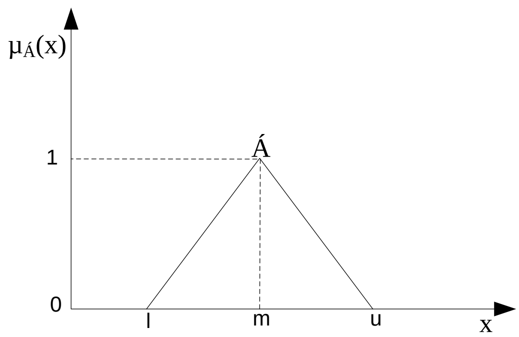


Figure 4.1: A triangle fuzzy number Á where x ranges between 'l' and 'u'

Definition 3: The membership function $\mu_{Á}(x)$ of a triangular fuzzy number can be defined as (Pakdil and Leonard, 2014):

$$\mu_{\acute{A}}(x_i) = \begin{cases} 1 & x_i = a \\ 1 - \frac{(x_i - a)}{(b-a)}; & b < x_i < a \ (direct\ KPIs) \\ 0 & x_i = b \end{cases} \quad (4.3a)$$

$$\mu_{\acute{A}}(x_i) = \begin{cases} 1; & x_i = a \\ 1 - \frac{(x_i - a)}{(b-a)}; & a < x_i < b \ (indirect\ KPIs) \\ 0; & x_i = b \end{cases} \quad (4.3b)$$

where, the element x of the fuzzy set Á ranges between 'a' and 'b' as shown in figure 4.2. 'a' is the best performance and 'b' is the worst performance for each KPI. A direct KPI means more is better (for example employee satisfaction and ROI on capital employed) and an indirect KPI means less is better (for example costs and absenteeism rate).

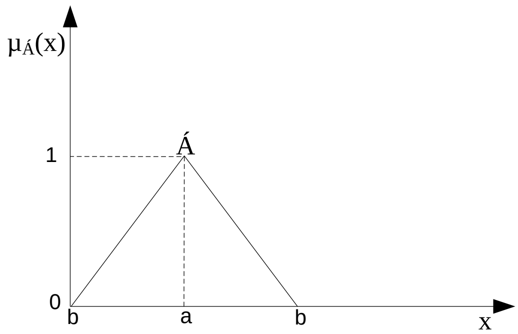


Figure 4.2: A triangle fuzzy number Á where x ranges between 'a' and 'b'

4.2.3 Fuzzy ANP

The fuzzy ANP is very useful multi-criteria decision making (MCDM) technique which determines the importance of various elements of a given data set. Sometimes, it becomes difficult for the experts to give the comparative judgments in the form of exact numerical values. Under these situations, the simple MCDM techniques like AHP, ANP, *etc.* can provide the wrong or inconsistent decisions. So, the decision makers are often censured due to the lack of consistent judgments (Nilashi *et al.*, 2016). Moreover, the assessment of the elements can be influenced by attributes of the decision makers. This kind of situation gives rise to fuzziness during decision making. Thus, the simple ANP seems to be ineffective when it is applied to ambiguous and linguistic problems. The various researchers (Guneri, Cengiz and Seker, 2009; Yazgan, 2011; Chang *et al.*, 2015; Uygun, Kaçamak, and Kahraman, 2015) recommended applying fuzzy ANP as a MCDM technique over conventional ANP for dealing with uncertainty and vagueness during the decision making. The fuzzy ANP provides a pairwise assessment between elements using fuzzy numbers, which deliver more insightful results (Uygun *et al.*, 2015). Thus, the fuzzy ANP is more suitable for this study to conduct the pair-wise comparisons of various performance dimensions with the help of fuzzy numbers.

4.3 DEVELOPMENT OF A FUZZY ANP METHODOLOGY TO FIND PERFORMANCE DIMENSION WEIGHTS

The fuzzy ANP methodology adopted for the study is shown in figure 4.3. Seven functional areas and 26 performance dimensions related to these functional areas have been identified in chapters 2 and 3 respectively. The identified performance dimensions are discussed and finalized with the help of decision makers. A questionnaire is prepared to determine the interdependences among the performance dimensions and conduct the pair-wise comparisons. A group of experts was asked to evaluate the various performance dimensions using the pair-wise comparisons. Based on the pair-wise comparisons, the various matrixes have been formed using triangular fuzzy numbers. The local weight for performance dimensions of a particular functional area with respect to other performance dimensions related to remaining functional areas have been computed. The experts' judgements are checked for consistency. If the judgement are consistent than the un-weighted supermatrix is formed by summarizing the local weights from different matrixes. The weighted supermatrix is obtained by normalizing the weights of various performance dimensions. At last, the limit matrix is obtained and the weights of various performance dimensions are finalized.

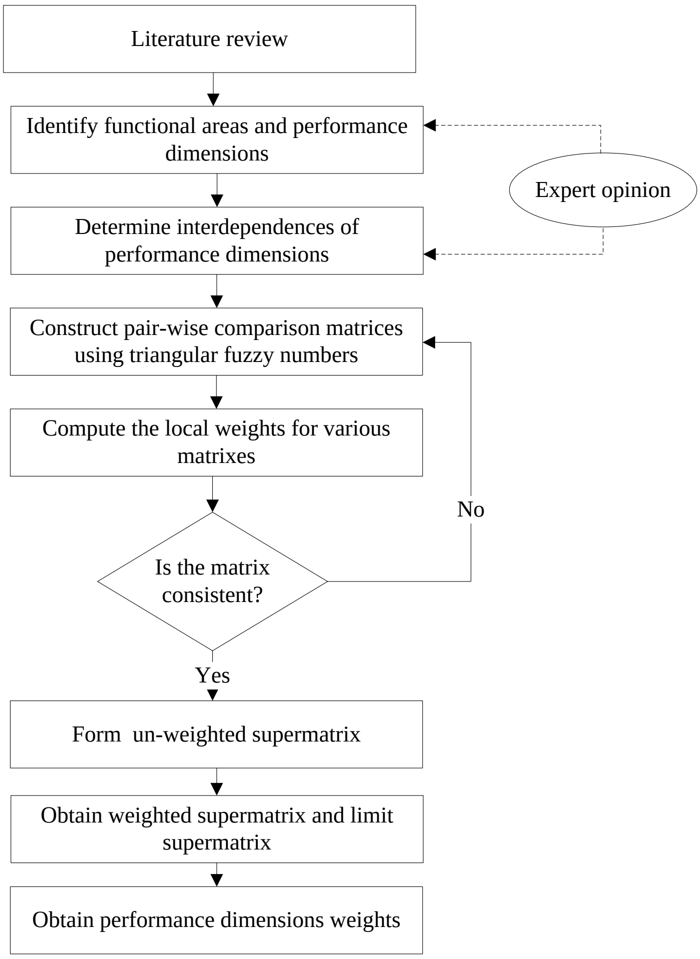


Figure 4.3: Fuzzy ANP methodology

The following steps are used to develop the fuzzy ANP model for an Indian automotive component manufacturing organization.

4.3.1 Identify Functional Areas and Performance Dimensions

The literature review has been conducted to identify the various essential functional areas and performance dimensions for the leanness assessment of a manufacturing organization (chapters 2 and 3). Seven functional areas (manufacturing process, new product development, finance, human resource management, administration, customer management, and supplier management) have been identified. Twenty-six performance dimensions have been identified under these seven functional areas. The descriptions performance dimensions are given in chapter 3. These identified functional areas and performance dimensions are discussed with the experts from an Indian automotive component manufacturing organization. These experts were plant head along with heads of production, manufacturing, new product development, quality, production planning and control, human resource management, and supply chain management departments. One performance dimension of 'supplier interaction' under the functional area of supplier management is replaced with 'serviceability' as per the suggestion given by the experts. The final list of functional areas and their related performance dimensions are presented in table 4.1.

Table 4.1: Functional areas, performance dimensions, and their notations

Functional area	Performance dimension	Notation
Finance (f)	Cost	f1
	Rate of return	f2
	Sales	f3
New product development (n)	Quality	n1
	R&D	n2
	Market	n3
	Cost	n4
	Rate of return	n5
	Time	n6
Manufacturing process (m)	Quality	m1
	Cost	m2
	Inventory	m3
	Time	m4
	Delivery	m5
	Process flow	m6
Human resource management (h)	Health	h1
	Empowerment	h2
	Skill	h3
	Cost	h4
Supplier management (s)	Serviceability	s1
	Quality	s2
Administration (a)	Work performance	a1
	Decision making	a2
	Communication	a3
Customer management (c)	Serviceability	c1
	Delivery	c2

4.3.2 Determine the Interdependence of Performance Dimensions

There are three types of relationships between the various elements of a data set: reflexivity, symmetry, and transitivity. If x, y and z are three elements of a data set X, then, the symmetric and transitive relationship between them can be expressed as shown in figure 4.4. The performance dimensions are interrelated and interdependent with each other. Therefore, the relations between them are symmetric and transitive. In order to establish a relationship among dimensions, the opinions of experts were taken. The direction of the impact relation will be used to calculate the local weights.

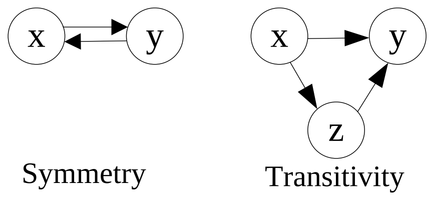


Figure 4.4: Characteristic components of symmetric and transitive relations [Source: Sangwan and Kodali (2004)]

The fuzzy ANP model can be designed as a network as shown in figure 4.5. The model is hierarchical having the goal of leanness assessment at the top and the alternatives, in the form of performance dimensions, at the bottom. In the hierarchical structure, the interdependencies and relationships can exist within each layer which is represented by arc loops.

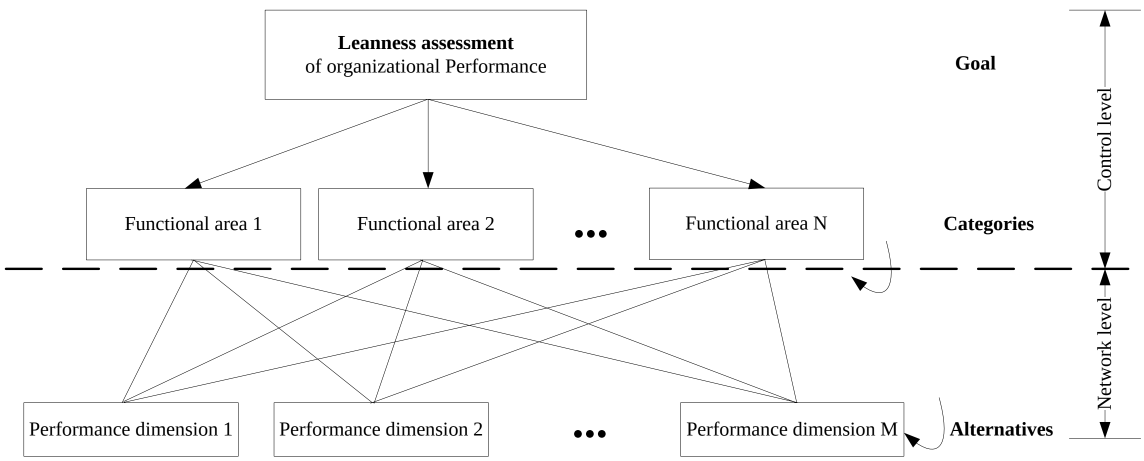


Figure 4.5: A Fuzzy ANP network hierarchy

4.3.3 Construct Pair-wise Comparisons

The pair-wise comparisons were conducted between various performance dimensions. The experts were requested to give single judgment for the various pair-wise comparisons. The elements of a particular group are compared with each other concerning other elements of different groups. For example, a group p have elements p_1, p_2, p_3,…..p_n and other group q have elements q_1, q_2, q_3,….q_n. Then, the elements of groups p are compared with each other for q_1, q_2, q_3,….q_n. To clarify, the following matrix is given for the pair-wise comparisons of elements of p for q_1.

$$p = \begin{bmatrix} p_{11} & p_{12} \cdots & p_{1n} \\ p_{21} & p_{22} \cdots & p_{2n} \\ \vdots & \vdots & \vdots \\ p_{n1} & p_{n2} \cdots & p_{nn} \end{bmatrix} \tag{4.4}$$

As per the structure of the network hierarchy, the relative importance rating is given to each performance dimension by the experts. A discrete scale of 1-9 is provided along the linguistic variables as presented in table 4.2. After the consensus judgments from various experts, it is possible to construct a comparison matrix of functional areas and their related performance dimensions. Based on the experts' judgment, total 156 pair-wise comparison matrixes are developed for 26 performance dimensions of seven functional areas.

Table 4.2.The linguistic variables and triangular fuzzy numbers for the experts

Linguistic variables	Fuzzy number	Triangular fuzzy number	Triangular fuzzy reciprocal number
Extremely important (EXI)	$\tilde{9}$	(7,9, 9)	(1/9, 1/9, 1/7)
Very Important (VI)	$\tilde{7}$	(5, 7, 9)	(1/9, 1/7, 1/5)
Moderately important (MI)	$\tilde{5}$	(3, 5, 7)	(1/7, 1/5, 1/3)
Slightly important (SI)	$\tilde{3}$	(1, 3, 5)	(1/5, /13, 1)
Equally Important (EI)	$\tilde{1}$	(1, 1, 3)	(1/3, 1, 1)

To understand the methodology and calculation of weights, the study takes sample of financial performance dimensions (i.e., f1, f2, f3). The pair-wise comparisons of various financial performance dimensions for performance dimension m1 (manufacturing process quality) are presented in table 4.3.

Table 4.3: Pair-wise comparisons of financial performance dimensions for m1 (manufacturing process quality)

	f1	f2	f3
f1	1.00		
f2	SI	1.00	
f3	EXI	SI	1.00

As described in equation 4.4, the linguistic variables used for the pair-wise comparison (table 4.3) of financial performance dimensions are converted into fuzzy numbers and can be presented in matrix form as:

$$f = \begin{bmatrix} 1 & 0.33 & 0.11 \\ 3 & 1 & 0.33 \\ 9 & 3 & 1 \end{bmatrix}$$

It is quite difficult for the experts to give the exact judgment for different pair-wise comparisons. So, the triangular fuzzy numbers are used for the vague and imprecise judgments. The experts' judgments are converted into triangular fuzzy numbers in terms of l, m and u as given in table 4.4.

Table 4.4: The pair-wise comparison matrix and a triangular fuzzy number for financial performance dimensions for m1

				f1			**f2**			**f3**			**Weight W''**
	f1	**f2**	**f3**	l	m	u	l	m	u	l	m	u	
f1	1.00	0.33	0.11	1.00	1.00	1.00	0.20	0.33	1.00	0.11	0.11	0.14	0.09
f2	3	1.00	0.33	1.00	3.00	5.00	1.00	1.00	1.00	0.20	0.33	1.00	0.26
f3	9	3	1.00	7.00	9.00	9.00	1.00	3.00	5.00	1.00	1.00	1.00	0.66

4.3.4 Calculate Weights for Various Performance Dimensions

The extent analysis method developed by Chang (1992) is used to calculate the weights of various performance dimensions. Let X = {x_1, x_2,..., x_n} be an object set (performance dimensions) and k = {k_1, k_2,...,k_m} be a goal set (functional areas). Each performance dimension x_i is taken, and extent analysis for each functional area k_j is performed. Thus, m extent analysis values for each performance dimension can be obtained with the following signs:

$F^1_{ki}, F^2_{ki}, F^3_{ki} \ldots F^m_{ki}$; (i = 1, 2, 3, 4, 5……., n)

where, all the F^j_{ki} (j=1, 2, 3, 4………, m) are triangular fuzzy numbers (TFNs). The following steps are used for the extent analysis method.

- The value of fuzzy synthetic extent with respect to the i^{th} performance dimension is defined as:

$$S_i = \sum_{j=1}^{m} F_{ki}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} F_{ki}^{j}\right]^{-1} \tag{4.5}$$

- Obtain $\sum^{m}_{j=1} F^j_{ki}$ by performing the fuzzy addition operation of m extent analysis values for a particular matrix as:

$$\sum_{j=1}^{m} F_{ki}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j\right) \tag{4.6}$$

- Obtain $[\sum^{n}_{i=1}\sum^{m}_{j=1} F^j_{ki}]^{-1}$ by performing the fuzzy addition operation of F^j_{ki} (j=1, 2, 3, 4,….., m) values as:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} F_{ki}^{j}\right] = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i\right) \tag{4.7}$$

And then, compute the inverse of the vector $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} F_{ki}^{j}\right]$ given in equation 4.7 as:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} F_{ki}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} l_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} u_i}\right) \tag{4.8}$$

- Compute de-fuzzified weight vector by averaging the values obtained from equation 4.5 as:

$$W' = [\mathrm{d}'(\mathrm{S_{f1}}), \mathrm{d}'(\mathrm{S_{f2}}), \mathrm{d}'(\mathrm{S_{f3}}), \ldots \mathrm{d}'(\mathrm{S_{fn}})] \tag{4.9}$$

where, S_{fi} (i=1, 2, . . ., n) are n performance dimensions.

- Obtain the normalized weight vectors as:

$$W'' = [d(S_{f1}), d(S_{f2}), d(S_{f3}), \dots d(S_{fn})] \quad (4.10)$$

The obtained normalized weights using equation 4.10 can be presented into the matrix form by replacing $d(S_{fi})$ by Wi":

$$W'' = \begin{bmatrix} W_1'' \\ W_2'' \\ \vdots \\ W_n'' \end{bmatrix} \quad (4.11)$$

As described above, the extent analysis method is used to calculate the weights of various performance dimensions. To understand the calculation of the extent analysis method, the weights of financial performance dimensions are calculated using equations 4.5 to 4.11 as follows:

S_{f1}= [(1,1,1) ⊕ (0.2,0.33,1) ⊕ (0.11,0.11,0.14)] ⊗ $[\frac{1}{24.14}, \frac{1}{18.78}, \frac{1}{12.51}]$

S_{f1}= (0.05, 0.08, 0.17)

$d(S_{f1})$ = (0.05+0.08+0.17)/3 = 0.10

S_{f2} =(0.09, 0.23, 0.56)

$d(S_{f2})$= (0.09+0.23+0.56)/3 = 0.29

S_{f3}=(0.37, 0.69, 1.20)

$d(S_{f3})$ (0.37+0.69+1.20)/3 = 0.75

W' = (0.10 , 0.29, 0.75)

By normalizing weights at 1

W" = (0.09,0.26,0.66)

$$W'' = \begin{bmatrix} 0.09 \\ 0.26 \\ 0.66 \end{bmatrix}$$

Thus, the local normalized weights of f1, f2, f3 for m1 are found to be 0.09, 0.26, 0.66 respectively. Similarly, weights for all performance dimensions are calculated and the un-weighted supermatrix is formed.

4.3.5 Check the Consistency of the Judgments

Consistency test is used to ensure that the experts' judgment does not have any contradictions (Saaty 1996). The preferences given by the experts must be checked by consistency tests based on consistency ratios (C.R.) of the various pair-wise comparison matrixes (Lin, Chiu, and Tsai 2008). If C.R. value is less than 0.10 then it is accepted that the judgments of experts are consistent (Saaty 1996). In this study consistency tests are done for every pairwise comparison matrix and when confirmed to be consistent, the process was continued.

$$\text{Consistency index (C.I.)} = (\lambda_{\max} - \text{n})/(\text{n} - 1) \tag{4.12}$$

where, λ_{max} is the largest eigenvalue, and n denotes the number of attributes.

$$\lambda_{\max} = \frac{1}{n}\left[\frac{W_1^1}{W_1''} + \frac{W_2^1}{W_2''} + \cdots + \frac{W_n^1}{W_n''}\right] \tag{4.13}$$

W^1 is calculated by multiplying the matrixes given in equations 4.4 and 4.11.

$$W^1 = [p * W''] \tag{4.14}$$

The C.R. can be calculated as:

$$\text{C.R.} = \frac{\text{C.I.}}{\text{R.I.}} \tag{4.15}$$

Where R.I. is a random index which is derived from a large sample of randomly generated reciprocal matrices using the scale 1/9, 1/8, 1/7,……..3, 4, 5, 6, 7, 8, 9.

Table 4.5: The random index (R. I.) for matrix size (n) [Source: Saaty (1996)]

n	**2**	**3**	**4**	**5**	**6**	**7**	**8**
R. I.	0.00	0.58	0.90	1.12	1.24	1.32	1.41

For example, the consistency of experts' preferences for financial performance dimensions with respect to quality (m1) is checked. For the pair-wise comparison matrix of financial performance dimensions, the order of matrix (n) is 3 and random index (R. I.) is 0.58 as given in table 4.5. The calculation of W^1, λ_{max}, C. I., and C. R. is as:

n=3; R. I. = 0.58

W^1= [f*W"]

W^1= [0.25, 0.75, 2.25)

λ_{max} = 1/3[(0.25/0.09) + (0.75/0.26) + (2.25/0.66)]

λ_{max} = 3.02

$$\text{C.I.} = (3.02 - 3)/(3 - 1) = 0.01$$

$$C.R. = \frac{0.01}{0.58} = 0.02$$

Hence, the given judgment by the expert for the financial performance dimensions with respect to performance dimension m1 is consistent as it is less than 0.1.

4.3.6 Form Un-weighted Supermatrix

The pair-wise comparisons of various performance dimensions provide their local weights. The local weights of financial performance dimensions with respect to manufacturing process quality (m1) are highlighted in table 4.6. Total 156 matrixes are developed for various performance dimensions. The local weights calculated in these 156 matrixes are summarized in the form of a supermatrix. Since the weights are locally normalized for each matrix, so this supermatrix is called un-weighted supermatrix. The size of this un-weighted supermatrix is 26 by 26. When pair-wise comparisons are completed by the experts, the supermatrix is formed by putting the notations of various performance dimensions in both first row and first column of the matrix in the same order as presented in table 4.6. The supermatrix contains the values obtained from evaluations of pair-wise comparison into appropriate columns.

4.3.7 Obtain Weighted Supermatrix and Limit Supermatrix

The weighted supermatrix is calculated by normalizing the weights given in un-weighted supermatrix. For the normalization, the sum of each column should be one as presented in table 4.7.

The matrix multiplication of weighted supermatrix is done to obtain the limit supermatrix. The limit supermatrix is obtained by powering (matrix multiplication with itself) the weighted supermatrix until all the values of each row are stabilized and equal as presented in table 4.8. Every row of the matrix demonstrates the weight of the related performance dimension.

Table 4.6: Un-weighted supermatrix for the 26 performance dimensions

	n1	n2	n3	n4	n5	n6	m1	m2	m3	m4	m5	m6	a1	a2	a3	f1	f2	f3	h1	h2	h3	h4	s1	s2	c1	c2
n1	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.17	0.11	0.09	0.22	0.26	0.17	0.39	0.17	0.28	0.15	0.39	0.17	0.17	0.26	0.15	0.43	0.43	0.22	0.12
n2	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.10	0.11	0.44	0.11	0.41	0.17	0.26	0.17	0.06	0.07	0.26	0.17	0.17	0.39	0.07	0.25	0.25	0.11	0.12
n3	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.11	0.09	0.11	0.08	0.17	0.07	0.17	0.06	0.07	0.15	0.17	0.17	0.07	0.07	0.06	0.06	0.11	0.12
n4	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.37	0.36	0.09	0.11	0.08	0.17	0.15	0.17	0.41	0.26	0.07	0.17	0.17	0.15	0.39	0.06	0.06	0.11	0.12
n5	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.27	0.22	0.09	0.11	0.08	0.17	0.07	0.17	0.13	0.39	0.07	0.17	0.17	0.07	0.26	0.06	0.13	0.11	0.12
n6	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.04	0.11	0.19	0.36	0.08	0.17	0.07	0.17	0.06	0.07	0.07	0.17	0.17	0.07	0.07	0.13	0.06	0.36	0.39
m1	0.37	0.39	0.38	0.12	0.26	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.37	0.12	0.15	0.24	0.26	0.17	0.17	0.39	0.12	0.26	0.39	0.27	0.04
m2	0.27	0.26	0.18	0.34	0.41	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.27	0.12	0.39	0.37	0.39	0.17	0.17	0.12	0.39	0.08	0.07	0.10	0.17
m3	0.04	0.07	0.05	0.22	0.08	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.17	0.12	0.26	0.13	0.07	0.17	0.17	0.12	0.12	0.08	0.07	0.17	0.27
m4	0.17	0.15	0.28	0.22	0.08	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.04	0.12	0.07	0.13	0.07	0.17	0.17	0.12	0.12	0.08	0.15	0.04	0.04
m5	0.10	0.07	0.05	0.05	0.08	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.10	0.12	0.07	0.06	0.15	0.17	0.17	0.12	0.12	0.41	0.26	0.37	0.37
m6	0.09	0.08	0.33	0.09	0.17	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.04	0.39	0.09	0.17	0.33	0.33	0.09	0.09	0.17	0.17	0.17	0.08	0.09
a1	0.68	0.46	0.33	0.23	0.17	0.68	0.68	0.23	0.23	0.68	0.23	0.65	0.00	0.00	0.00	0.23	0.17	0.33	0.33	0.23	0.68	0.17	0.17	0.17	0.46	0.68
a2	0.23	0.46	0.33	0.68	0.65	0.23	0.23	0.68	0.68	0.23	0.68	0.17	0.00	0.00	0.00	0.68	0.65	0.33	0.33	0.68	0.23	0.65	0.65	0.65	0.46	0.23
a3	0.04	0.07	0.05	0.05	0.08	0.06	0.09	0.09	0.09	0.09	0.09	0.17	0.00	0.00	0.00	0.07	0.06	0.07	0.17	0.17	0.12	0.12	0.08	0.07	0.04	0.10
f1	0.09	0.70	0.07	0.70	0.09	0.59	**0.09**	0.63	0.65	0.68	0.27	0.17	0.33	0.30	0.33	0.00	0.00	0.00	0.65	0.65	0.33	0.72	0.33	0.72	0.72	0.27
f2	0.26	0.22	0.35	0.22	0.68	0.11	**0.26**	0.27	0.17	0.09	0.09	0.17	0.33	0.59	0.33	0.00	0.00	0.00	0.17	0.17	0.33	0.14	0.33	0.14	0.14	0.09
f3	0.66	0.08	0.58	0.08	0.23	0.30	**0.66**	0.09	0.17	0.23	0.63	0.65	0.33	0.11	0.33	0.00	0.00	0.00	0.17	0.17	0.33	0.14	0.33	0.14	0.14	0.63
h1	0.09	0.10	0.25	0.10	0.25	0.27	0.09	0.15	0.15	0.27	0.15	0.15	0.14	0.13	0.25	0.05	0.15	0.25	0.00	0.00	0.00	0.00	0.15	0.10	0.15	0.10
h2	0.09	0.22	0.25	0.22	0.25	0.12	0.09	0.15	0.15	0.12	0.15	0.15	0.28	0.13	0.25	0.28	0.15	0.25	0.00	0.00	0.00	0.00	0.15	0.10	0.15	0.10
h3	0.50	0.58	0.25	0.58	0.25	0.49	0.50	0.54	0.54	0.49	0.54	0.54	0.05	0.13	0.25	0.14	0.15	0.25	0.00	0.00	0.00	0.00	0.15	0.22	0.15	0.22
h4	0.33	0.10	0.25	0.10	0.25	0.12	0.33	0.15	0.15	0.12	0.15	0.15	0.53	0.61	0.25	0.53	0.54	0.25	0.00	0.00	0.00	0.00	0.54	0.58	0.54	0.58
s1	0.26	0.16	0.50	0.12	0.16	0.84	0.26	0.16	0.50	0.88	0.74	0.16	0.50	0.26	0.50	0.16	0.16	0.26	0.50	0.50	0.26	0.16	0.00	0.00	0.74	0.84
s2	0.74	0.84	0.50	0.88	0.84	0.16	0.74	0.84	0.50	0.12	0.26	0.84	0.50	0.74	0.50	0.84	0.84	0.74	0.50	0.50	0.74	0.84	0.00	0.00	0.26	0.16
c1	0.88	0.50	0.74	0.84	0.50	0.16	0.74	0.84	0.50	0.12	0.16	0.26	0.26	0.74	0.50	0.74	0.84	0.74	0.50	0.50	0.50	0.74	0.74	0.84	0.00	0.00
c2	0.12	0.50	0.26	0.16	0.50	0.84	0.26	0.16	0.50	0.88	0.84	0.74	0.74	0.26	0.50	0.26	0.16	0.26	0.50	0.50	0.50	0.26	0.26	0.16	0.00	0.00

Table 4.7: Weighted supermatrix for the 26 performance dimensions

	n1	n2	n3	n4	n5	n6	m1	m2	m3	m4	m5	m6	a1	a2	a3	f1	f2	f3	h1	h2	h3	h4	s1	s2	c1	c2
n1	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.02	0.02	0.04	0.04	0.03	0.06	0.03	0.05	0.02	0.06	0.03	0.03	0.04	0.02	0.07	0.07	0.04	0.02
n2	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.02	0.07	0.02	0.07	0.03	0.04	0.03	0.01	0.01	0.04	0.03	0.03	0.06	0.01	0.04	0.04	0.02	0.02
n3	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.01	0.03	0.01	0.03	0.01	0.01	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.02	0.02
n4	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.06	0.02	0.02	0.01	0.03	0.02	0.03	0.07	0.04	0.01	0.03	0.03	0.02	0.06	0.01	0.01	0.02	0.02
n5	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.04	0.02	0.02	0.01	0.03	0.01	0.03	0.02	0.06	0.01	0.03	0.03	0.01	0.04	0.01	0.02	0.02	0.02
n6	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.03	0.06	0.01	0.03	0.01	0.03	0.01	0.01	0.01	0.03	0.03	0.01	0.01	0.02	0.01	0.06	0.07
m1	0.06	0.06	0.06	0.02	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.02	0.02	0.04	0.04	0.03	0.03	0.07	0.02	0.04	0.06	0.05	0.01
m2	0.05	0.04	0.03	0.06	0.07	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.05	0.02	0.06	0.06	0.06	0.03	0.03	0.02	0.07	0.01	0.01	0.02	0.03
m3	0.01	0.01	0.01	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.04	0.02	0.01	0.03	0.03	0.02	0.02	0.01	0.01	0.03	0.05
m4	0.03	0.02	0.05	0.04	0.01	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.01	0.02	0.01	0.03	0.03	0.02	0.02	0.01	0.02	0.01	0.01
m5	0.02	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.03	0.02	0.02	0.07	0.04	0.06	0.06
m6	0.01	0.01	0.06	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.07	0.01	0.03	0.06	0.06	0.01	0.01	0.03	0.03	0.03	0.01	0.01
a1	0.11	0.08	0.06	0.04	0.03	0.11	0.11	0.04	0.04	0.11	0.04	0.11	0.00	0.00	0.00	0.04	0.03	0.06	0.06	0.04	0.11	0.03	0.03	0.03	0.08	0.11
a2	0.04	0.08	0.06	0.11	0.11	0.04	0.04	0.11	0.11	0.04	0.11	0.03	0.00	0.00	0.00	0.11	0.11	0.06	0.06	0.11	0.04	0.11	0.11	0.11	0.08	0.04
a3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.02
f1	0.01	0.12	0.01	0.12	0.01	0.10	0.01	0.11	0.11	0.11	0.05	0.03	0.06	0.05	0.06	0.00	0.00	0.00	0.11	0.11	0.06	0.12	0.06	0.12	0.12	0.05
f2	0.04	0.04	0.06	0.04	0.11	0.02	0.04	0.05	0.03	0.01	0.02	0.03	0.06	0.10	0.06	0.00	0.00	0.00	0.03	0.03	0.06	0.02	0.06	0.02	0.02	0.02
f3	0.11	0.01	0.10	0.01	0.04	0.05	0.11	0.02	0.03	0.04	0.11	0.11	0.06	0.02	0.06	0.00	0.00	0.00	0.03	0.03	0.06	0.02	0.06	0.02	0.02	0.11
h1	0.01	0.02	0.04	0.02	0.04	0.05	0.01	0.03	0.03	0.05	0.03	0.03	0.02	0.02	0.04	0.01	0.03	0.04	0.00	0.00	0.00	0.00	0.03	0.02	0.03	0.02
h2	0.01	0.04	0.04	0.04	0.04	0.02	0.01	0.03	0.03	0.02	0.03	0.03	0.05	0.02	0.04	0.05	0.03	0.04	0.00	0.00	0.00	0.00	0.03	0.02	0.03	0.02
h3	0.08	0.10	0.04	0.10	0.04	0.08	0.08	0.09	0.09	0.08	0.09	0.09	0.01	0.02	0.04	0.02	0.03	0.04	0.00	0.00	0.00	0.00	0.03	0.04	0.03	0.04
h4	0.05	0.02	0.04	0.02	0.04	0.02	0.05	0.03	0.03	0.02	0.03	0.03	0.09	0.10	0.04	0.09	0.09	0.04	0.00	0.00	0.00	0.00	0.09	0.10	0.09	0.10
s1	0.04	0.03	0.08	0.02	0.03	0.14	0.04	0.03	0.08	0.15	0.12	0.03	0.08	0.04	0.08	0.03	0.03	0.04	0.08	0.08	0.04	0.03	0.00	0.00	0.12	0.14
s2	0.12	0.14	0.08	0.15	0.14	0.03	0.12	0.14	0.08	0.02	0.04	0.14	0.08	0.12	0.08	0.14	0.14	0.12	0.08	0.08	0.12	0.14	0.00	0.00	0.04	0.03
c1	0.15	0.08	0.12	0.14	0.08	0.03	0.12	0.14	0.08	0.02	0.03	0.04	0.04	0.12	0.08	0.12	0.14	0.12	0.08	0.08	0.08	0.12	0.12	0.14	0.00	0.00
c2	0.02	0.08	0.04	0.03	0.08	0.14	0.04	0.03	0.08	0.15	0.14	0.12	0.12	0.04	0.08	0.04	0.03	0.04	0.08	0.08	0.08	0.04	0.04	0.03	0.00	0.00

Table 4.8: Limit supermatrix for the 26 performance dimensions

	n1	n2	n3	n4	n5	n6	m1	m2	m3	m4	m5	m6	a1	a2	a3	f1	f2	f3	h1	h2	h3	h4	s1	s2	c1	c2
n1	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
n2	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
n3	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
n4	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
n5	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
n6	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
m1	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
m2	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
m3	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
m4	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
m5	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
m6	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
a1	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
a2	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071
a3	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
f1	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
f2	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
f3	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
h1	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
h2	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
h3	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
h4	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
s1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
s2	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
c1	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091
c2	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052

4.3.8 Obtain Performance Dimension Weights

Various performance dimensions of different functional areas are weighted based on their relative weights obtained by using fuzzy ANP methodology. The relative weights of each performance dimension and its importance rating (priority no.) are presented in table 4.9.

Table 4.9: The importance rating and the corresponding weights of the 26 performance dimensions

Functional area	Performance dimension	Notation	Weight (W)	Priority no.
Finance (f)	Cost	f1	0.067	4
	Rate of return	f2	0.035	13
	Sales	f3	0.040	9
New product development (n)	Quality	n1	0.037	11
	R&D	n2	0.026	15
	Market	n3	0.013	25
	Cost	n4	0.026	15
	Rate of return	n5	0.020	20
	Time	n6	0.021	19
Manufacturing process (m)	Quality	m1	0.037	11
	Cost	m2	0.032	14
	Inventory	m3	0.019	22
	Time	m4	0.016	24
	Delivery	m5	0.026	15
	Process flow	m6	0.019	22
Human resource management (h)	Health	h1	0.020	20
	Empowerment	h2	0.024	18
	Skill	h3	0.039	10
	Cost	h4	0.059	5
Supplier management (s)	Serviceability	s1	0.057	6
	Quality	s2	0.086	2
Administration (a)	Work performance	a1	0.052	7
	Decision making	a2	0.071	3
	Communication	a3	0.012	26
Customer management (c)	Serviceability	c1	0.091	1
	Delivery	c2	0.052	7

The study shows that the performance dimension of serviceability (c1) under the functional area of customer management received the highest importance rating of 0.091. This shows that the case organization gives high importance to the customer services. This is followed by performance dimensions of quality (s2) under the functional area of supplier management. It shows that the experts believe that the quality parts from the supplier are important parameter for the better performance of the organization. The decision making at administrative level, the overall cost incurred and the cost of human resource management are also important performance dimensions. The communication performance dimensions has received the lowest rating. Although the case organization believes in establishing good communication within and outside the organization, but the organization is not measuring the performance related to the communication. This may be the probable reason for low rating. Thus, the developed fuzzy ANP model provides a basis for the assessment of organizational lean performance. The model guides the managers to focus on higher rated performance dimensions.

4.4 LEANNESS ASSESSMENT OF AN INDIAN AUTOMOTIVE COMPONENT MANUFACTURING ORGANIZATION

A fuzzy methodology is used to assess the leanness score of an Indian automotive component manufacturing organization. The assessment methodology is shown in figure 4.6. The initial list of KPIs is obtained from the developed IPM framework. This initial list of KPIs is to be upgraded for the case organization. This up-gradation ensures that KPIs not listed in the initial list, because of any reason, can be added by the case organization. The methodology also guides the case organization to adopt newer KPIs in future. The KPIs are divided into three parts as per the response of the organization: *yes* (if case organization is using the KPI) or *no* (if case organization is not using the KPI) or *would* (if case organization is not using the KPI now, but would like to use it in future) as given in appendix A. Next, the KPI list is enriched by taking into consideration the experience of the organization and the specific requirements of the organization (product/line/industry specific KPIs). The KPI list is upgraded by adding the KPIs as per the case organization response.

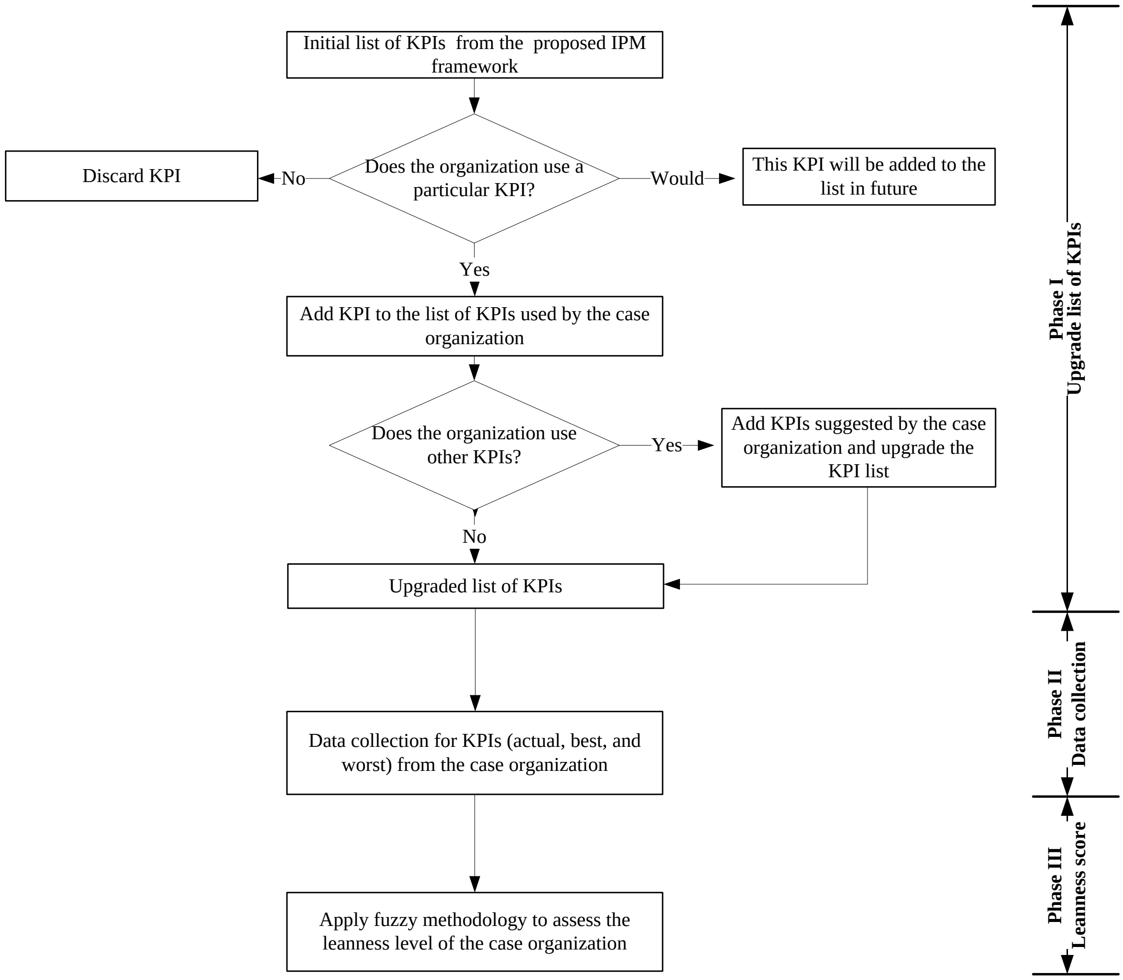


Figure 4.6: Fuzzy methodology for leanness assessment using the IPM framework

The actual performance of the KPIs is obtained from the ERP data of the case organization. If the case organization does not use ERP then the data can be obtained from the records/reports. A mixed model can also be used by obtaining some data from ERP and adding additional data from reports/records.

The fuzzy methodology is used to calculate the leanness scores of the organization at the four levels.

- The leanness score of i^{th} KPI is calculated as (Pakdil and Leonard, 2014):

$$A_i = \mu_{\acute{A}}(x_i) X 100 \qquad (4.16)$$

Where $\mu_{\acute{A}}(x_i)$ is calculated using equation 4.3 (a & b).

- The lean performance of each performance dimension is calculated as (Pakdil and Leonard, 2014):

$$B_j = \sum_{i=1}^{n_j} \frac{\mu_{\acute{A}}(x_i)_j}{n_j} X100 \; ; \qquad j = 1,2,3, \ldots \mathrm{m} \tag{4.17}$$

where $\mu_{\acute{A}}(x_i)_j$ is fuzzy membership value of the i^{th} KPI of the j^{th} dimension. n_j is the number of KPIs in j^{th} performance dimension. m denotes the number of performance dimensions.

- The leanness score for each functional area is computed as (Pakdil and Leonard, 2014):

$$C_k = \frac{1}{m} \sum_{j=1}^{m} \sum_{i=1}^{n_j} \frac{\mu_{\acute{A}}(x_i)_j}{n_j} X100; \qquad k = 1,2,3, \ldots p \tag{4.18}$$

Where k is the functional area.

- The overall leanness score of the case organization is the average leanness score of all functional areas and computed as (Pakdil and Leonard, 2014):

$$L = \frac{1}{p} \sum_{k=1}^{p} C_k \tag{4.19}$$

Based on leanness scores, weak performance areas are identified for the improvement.

4.4.1 Upgrade List of KPIs

The case organization is asked about the use of initial list of 119 KPIs and the responses are recorded into three parts as per the response of the organization: *yes* (if case organization is using the KPI) or *no* (if case organization is not using the KPI) or *would* (if case organization is not using the KPI now, but would like to use it in future). It is pertinent to mention here that at no point of time the performance dimensions and functional areas were mentioned to the respondents, only KPIs were discussed to obtain an unbiased response. The respondent for the administration functional area KPIs was plant head. The respondent for other functional areas were heads of the production, manufacturing, new product development, quality, production planning and control, human resource management, and supply chain management departments. At this stage 40 KPIs were discarded due to ‘no’ response and 21 KPIs were discarded due to ‘would’ response. Further, three KPIs were added as per the suggestions of the respondents. The added KPIs are ‘average supplier rating’, ‘on-time in-full (OTIF) delivery from supplier’, and ‘number of premium freight per year’. The upgraded list contains 61 KPIs; 58 from the proposed framework and three suggested by the case organization.

4.4.2 Data Collection

The performance values for 61 KPIs were extracted from the ERP data. At this stage, it was noticed that the data for the 16 KPIs are different for individual products/production lines. These 16 KPIs are product based or production line based; therefore, these 16 KPIs were not included for further analysis as the lean assessment was done at the plant (organization) level. The best condition for each KPI (a) is selected on the basis of the annual target given by the top management or by doing the benchmarking with the other organizations. Similarly, the worst condition for each KPI (b) is selected on the basis of worst performance of the plant in the past. The collected data is given in table 4.10.

4.4.3 Calculate Leanness Score

The leanness assessment has been conducted for the case organization. For this, the fuzzy methodology is used to calculate the leanness score for each KPI, performance dimension, and functional area using the equations 4.16 to 4.18. The overall leanness score of the case organization is calculated by averaging the leanness scores of the various functional areas as given by equation 4.19.

4.5 RESULTS AND DISCUSSION

The case study has demonstrated the application of the proposed integrated performance measurement framework for the leanness assessment of an Indian automotive component manufacturer.

4.5.1 Number and Types of KPIs used in the Case Organization

The case organization uses 58 KPIs out of 119 KPIs of the selected framework. Later, three KPIs were added as per the suggestions of the case organization. The case organization uses 45 KPIs at the plant (organization) level; and 16 KPIs are product/production line specific. The case organization would like to use the 21 KPIs in future.

Further, it was found that all KPIs used by the case organization are measured in quantitative term as shown in figure 4.7. Some KPIs, which are classified as qualitative KPIs in the selected framework are also measured in quantitative terms in the case organization. For example, 'customer satisfaction' is measured in term of customer satisfaction rating, 'employee satisfaction' is measured in percentage, and 'quality specification' is also measured in percentage. The case organization is not using qualitative KPIs for leanness assessment. The case organization uses a maximum of 70% (23 out of 33) KPIs for the 'manufacturing process' assessment followed by 60% (6 out of 10) KPIs for the 'finance' area assessment. The 'administration' functional area uses only one (administrative cost) KPI out of 10 KPIs (10%) as shown in figure 4.8. Although, the KPIs are used in all functional areas but the proportions of the selected KPIs vary from a minimum of 10% to a maximum of 70%.

Further, the interrelationship of used functional areas with lean principles or lean wastes is checked. It is found that lean wastes of transportation, motion, over processing, and overproduction are not assessed (see figure 4.9).

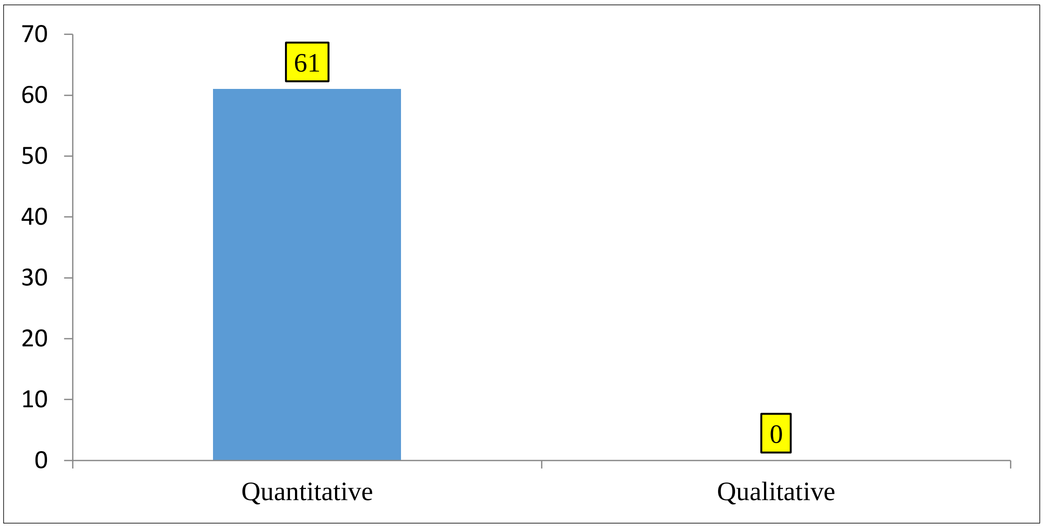


Figure 4.7: Status of used KPIs in terms of quantitative and qualitative

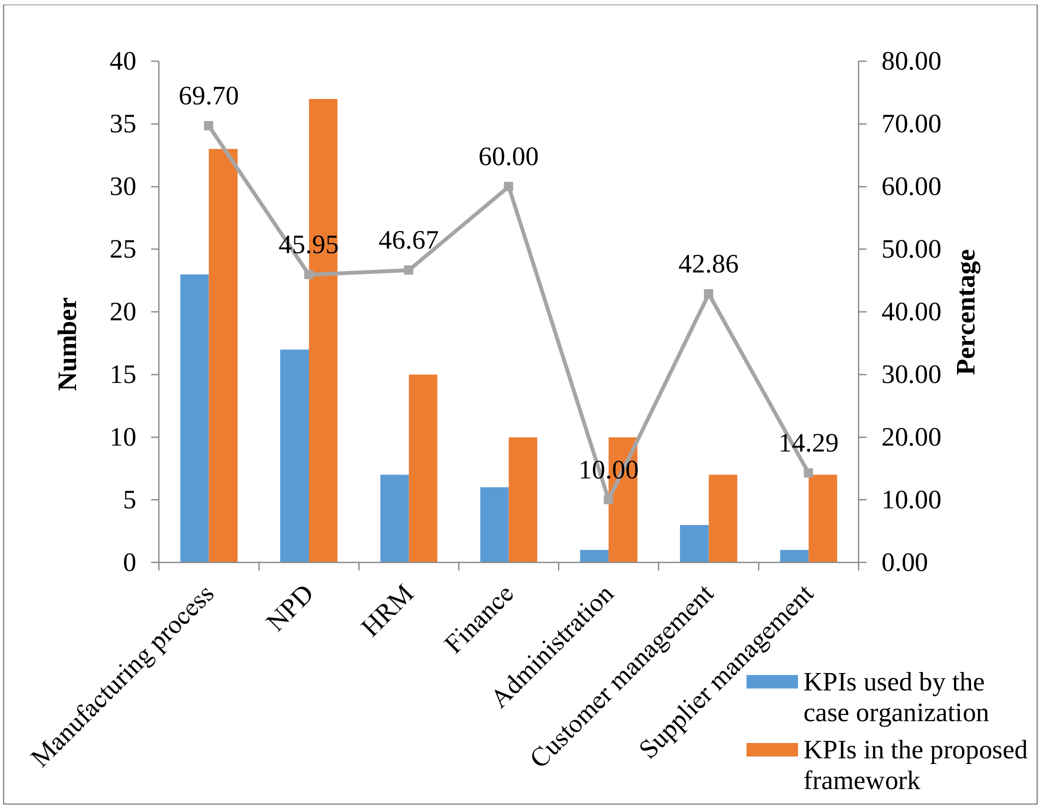


Figure 4.8: Number and percentage of used KPIs in each functional area

4.5.2 Leanness Level of Performance Dimensions in the Case Organization

At the middle level, 24 performance dimensions are used by the case organization to assess leanness. Performance dimensions of 'communication' and 'decision making' are not used in the case organization, whereas, the performance dimension of 'supplier serviceability' is used instead of 'supplier interaction'. The leanness score for the 24 dimensions (Table 4.10) ranges from approximately 33% to 100%, which, reflect the there are opportunities in various dimensions to improve the leanness score.

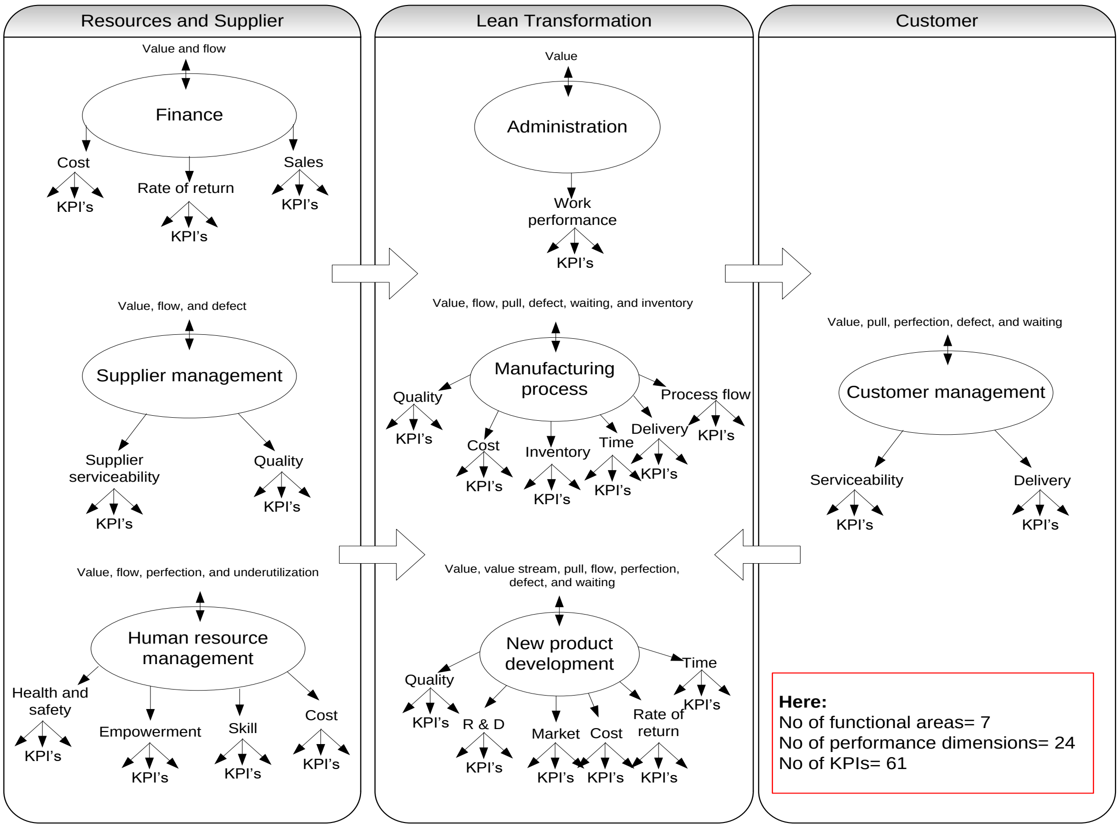


Figure 4.9: Integrated performance measurement framework adopted for the leanness assessment of the case organization

4.5.3 Leanness Level of Different Functional Areas

The overall leanness score of the case organization is 60% as presented in table 4.10. Similarly, the functional area wise leanness scores are shown using the radar chart (Figure 4.10) so that the manager can easily find out the weak performance areas. This helps the managers to visualize the relative performance of all functional areas at one glance. The case organization achieved the best leanness performance in customer management area (leanness score of 90.83%) as shown in figure 4.10. It shows the commitment of the case organization towards its core value of “service to the customer” as discussed in section 1.3 of chapter 1. In addition, the leanness score of the HRM, manufacturing process, and NPD functional area are 65.41%, 61.89%, and 57.47% respectively. The results also show that finance, administration, and supplier management areas need to be improved to enhance the overall organizational lean performance.

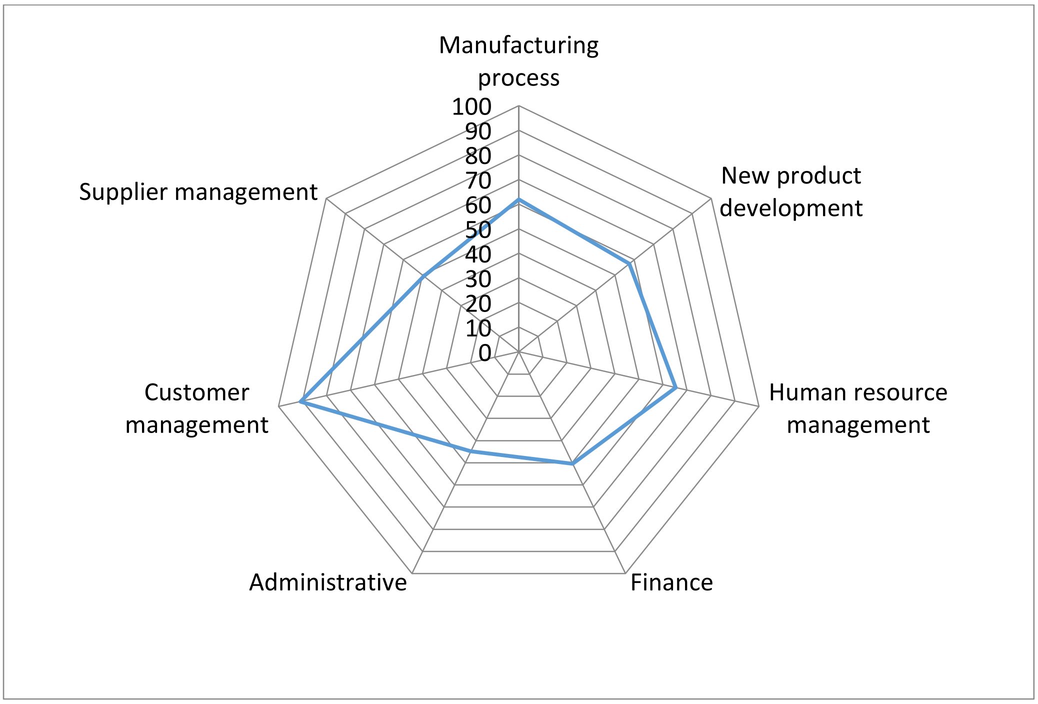


Figure 4.10: Leanness score of the case organization in different functional areas

Table 4.10: Leanness assessment with un-weighted or equally weighted to performance dimensions

Functional area	Performance dimension (PD)	KPI	Best performance value (a)	Worst performance value (b)	Actual (measured)	$\mu(x_i)$	%	Remarks	Leanness score of PD (B_j) %	Leanness score of functional areas (C_k) %
Manufacturing process	Quality	Defect rate in PPM	100	50000	162	0.999	99.88		97.39	61.89
		First time yield (FTY) (Chokko rate)	99.9	95	99.65	0.949	94.90			
		Scrap ratio	–	–	–	–	–	Product specific		
		Poka-yoke	–	–	–	–	–	Product specific		
	Cost	Percentage of cost of poor quality*	0.034	0.652	0.306	0.560	55.99	–	56.21	
		Percentage of raw material cost	60	75	70.15	0.323	32.33	–		
		Percentage of scrap cost*	0	1	0.41	0.590	59.00	–		
		Percentage of manufacturing cost*	2	6	4.09	0.478	47.75	–		
		Percentage of direct labor cost	3	5	3.28	0.860	86.00	–		
		Processing cost per unit	–	–	–	–	–	Not used		
		Percentage of in-house material movement cost	–	–	–	–	–	Not used		
	Time	Total down time*	3	10	7.73	0.324	32.43	–	32.43	
		Set up time	–	–	–	–	–	Product specific		
		Changeover time	–	–	–	–	–	Product specific		
		Manufacturing cycle time	–	–	–	–	–	Product specific		
		Manufacturing lead time	–	–	–	–	–	Would like to use		
		Throughput time (TPT)	–	–	–	–	–	Would like to use		
	Inventory	Total inventory in days*	8.5	28.5	24.5	0.200	20.00	–	32.49	
		Raw material inventory in days*	7	20	18.5	0.115	11.54	–		
		Finished goods inventory in days*	1	5	3.15	0.463	46.25	–		
		Work in process (WIP) inventory in days*	0.5	2.8	1.6	0.522	52.17	–		
	Delivery	On-time delivery (%)	100	90	100	1.000	100.00	–	100.00	
		Transportation or motion	–	–	–	–	–	Would like to use		
		Flexibility	–	–	–	–	–	Not used		
	Process flow	Overall equipment effectiveness (Bekido rate) (%)	95	77	93.62	0.923	92.33	–	95.02	
		Operator efficiency*	99.8	95	99.69	0.977	97.71	–		
		Utilization efficiency	–	–	–	–	–	Product specific		
		Allocation efficiency	–	–	–	–	–	Product specific		
		Process capability index	–	–	–	–	–	Product specific		

Table 4.10: Leanness assessment with un-weighted or equally weighted to performance dimensions (Contd.)

Functional area	Performance dimension (PD)	KPI	Best performance value (a)	Worst performance value (b)	Actual (measured)	μ(x_i)	%	Remarks	Leanness score of PD (B_j) %	Leanness score of functional areas (C_k) %
		Lot size reduction	–	–	–	–	–	Not used		
		Pull process	–	–	–	–	–	Not used		
		Number of non-value added activities	–	–	–	–	–	Not used		
		Space productivity	–	–	–	–	–	Not used		
New product development	Quality	Rework rate or change requests	7	16	12	0.444	44.44	–	48.69	57.47
		Quality specifications	98	55	76	0.488	48.84	–		
		Part standardization (%)	95	70	83.2	0.528	52.80	–		
		Benchmarking	–	–	–	–	–	Product specific		
	Research and development	Quality function deployment (QFD)	–	–	–	–	–	Product specific	–	
		Life cycle design/assessment	–	–	–	–	–	Product specific		
		Product customization	–	–	–	–	–	Would like to use		
		Number of design changes to specification	–	–	–	–	–	Would like to use		
		Employee training and satisfaction	–	–	–	–	–	Would like to use		
		Number of non-value added activities	–	–	–	–	–	Not used		
		Resource utilization	–	–	–	–	–	Not used		
		Number of patents filed	–	–	–	–	–	Not used		
		Number of bottlenecks	–	–	–	–	–	Not used		
		Innovativeness rating	–	–	–	–	–	Not used		
		Number of processing loss reduced	–	–	–	–	–	Not used		
		Product customization	–	–	–	–	–	Not used		
		Involvement of suppliers in product development	–	–	–	–	–	Not used		
	Time	Timeliness (%)	100	70	88.31	0.610	61.03	–	50.39	
		On-time delivery of new products	100	65	78.91	0.397	39.74	–		
		Design man hours	–	–	–	–	–	Product specific		
		Time to market	–	–	–	–	–	Product specific		
		Product design cycle time	–	–	–	–	–	Product specific		
		Product design lead time	–	–	–	–	–	Product specific		

Table 4.10: Leanness assessment with un-weighted or equally weighted to performance dimensions (Contd.)

Functional area	Performance dimension (PD)	KPI	Best performance value (a)	Worst performance value (b)	Actual (measured)	μ(x_i)	%	Remarks	Leanness score of PD (B_j) %	Leanness score of functional areas (C_k) %
	Market	Customer satisfaction rating	300	100	270	0.850	85.00	–	72.50	
		Number of new products launched during last five years	8	3	6	0.600	60.00	–		
		Product performance	–	–	–	–	–	Product specific		
		Effectiveness of risk management process	–	–	–	–	–	Would like to use		
		New market development or growth	–	–	–	–	–	Not used		
		Expected market share	–	–	–	–	–	Not used		
		Strategic competence	–	–	–	–	–	Not used		
	Cost	Actual project cost to budgeted cost (%)	100	90	96.67	0.667	66.70	–	66.70	
		Life cycle costing/assessment	–	–	–	–	–	Would like to use		
		Percentage of development cost	–	–	–	–	–	Not used		
		Percentage of marketing cost	–	–	–	–	–	Not used		
	Rate of return	Percentage of profit from new products	9	2	6.11	0.587	58.71	–	58.71	
		Return on investment	–	–	–	–	–	Would like to use		
		Percentage of sales from new products	–	–	–	–	–	Not used		
Human resource management	Health and safety	Absenteeism rate	10	15.87	11.65	0.719	71.89	–	85.95	65.41
		Number of accidents/incidents per year	0	3	0	1.000	100.00	–		
		Health and safety of employees	–	–	–	–	–	Would like to use		
	Empowerment	No of suggestions implemented per worker per month	3	1.31	2.55	0.734	73.37	–	36.69	
		Employee satisfaction	82	72	72	0.000	0.00	–		
		Respect for people	–	–	–	–	–	Would like to use		
		Number of remuneration policies or incentive schemes	–	–	–	–	–	Not used		
		Work-related flexibility	–	–	–	–	–	Not used		
		Employment security	–	–	–	–	–	Not used		
	Skill	Training hours per employee per year	2.5	0.7	1.95	0.694	69.44	–	69.44	
		Percentage of skilled or multifunctional workforce	–	–	–	–	–	Not used		
		Use of multifunctional task forces/teams	–	–	–	–	–	Not used		

Table 4.10: Leanness assessment with un-weighted or equally weighted to performance dimensions (Contd.)

Functional area	Performance dimension (PD)	KPI	Best performance value (a)	Worst performance value (b)	Actual (measured)	μ(x_i)	%	Remarks	Leanness score of PD (B_j) %	Leanness score of functional areas (C_k) %
	Cost	Labor turnover	1.19	5.26	2.19	0.754	75.43	–	71.58	
		Average cost of training per year	30000	50000	36455	0.677	67.73	–		
		Average labor wage rate	–	–	–	–	–	Would like to use		
Finance	Rate of return	Current ratio	2.5	1	1.78	0.520	52.00	–	47.78	50.52
		Rate of return on capital employed	53	10	35.73	0.598	59.84	–		
		Net profit margin	8	0	2.52	0.315	31.50	–		
		Return on assets (ROA)	–	–	–	–	–	Would like to use		
		Return on investment (ROI)	–	–	–	–	–	Not used		
		Return on sales (ROS)	–	–	–	–	–	Not used		
	Cost	Procurement cost/ total sales (%)	58	85	70.31	0.544	54.41	–	54.41	
		Total cost of capital employed/ total sales	–	–	–	–	–	Not used		
	Sales	Sales volume or turnover in million	42	30.5	36.86	0.553	55.30	–	52.69	
		Revenue generated in million	43.2	30.5	36.86	0.501	50.08	–		
Administration	Work performance	Percentage of administrative costs	0.5	3	1.88	0.448	44.80	–	44.80	44.80
		Reduction of paperwork in office areas	–	–	–	–	–	Would like to use		
		Synchronized scheduling	–	–	–	–	–	Not used		
		Quality control	–	–	–	–	–	Not used		
	Communication	Business relationship with partners	–	–	–	–	–	Would like to use	Not used	
		Visual control of the shop floor	–	–	–	–	–	Would like to use		
		Communication/information loss	–	–	–	–	–	Not used		
	Decision making	Commitment of top management	–	–	–	–	–	Not used	Not used	
		Competitive policy	–	–	–	–	–	Not used		
		Strategic planning	–	–	–	–	–	Not used		

Table 4.10: Leanness assessment with un-weighted or equally weighted to performance dimensions (Contd.)

Functional area	Performance dimension (PD)	KPI	Best performance value (a)	Worst performance value (b)	Actual (measured)	μ(x_i)	%	Remarks	Leanness score of PD (B_j) %	Leanness score of functional areas (C_k) %
Customer management	Serviceability	Customer satisfaction rating	300	100	245	0.725	72.50	–	86.25	90.83
		Annual customer complaints	0	3	0	1.000	100.00	–		
		Service quality	–	–	–	–	–	Would like to use		
		Customer involvement	–	–	–	–	–	Would like to use		
		Customer retention rate	–	–	–	–	–	Not used		
	Delivery	On-time delivery	100	90	100	1.000	100.00	–	100.00	
		Responsiveness	–	–	–	–	–	Would like to use		
Supplier management	Quality	Defect rate of raw material	1486	9665	5146	0.553	55.25	–	55.25	49.31
		Percentage of certified suppliers	–	–	–	–	–	Not used		
		Supplier involvement in design	–	–	–	–	–	Not used		
	Supplier Interaction	Contract length with important suppliers	–	–	–	–	–	Would like to use	Not used	
		Relationship with suppliers	–	–	–	–	–	Not used		
		Percentage of supplier evaluation cost	–	–	–	–	–	Not used		
		Percentage of distant suppliers eliminated	–	–	–	–	–	Not used		
	Serviceability	Average supplier ratting	100	50	80	0.600	60.00	–	47.33	
		On-time in-full (OTIF) delivery from supplier	100	0	62	0.620	62.00	–		
		No of premium freight per year	0	15	12	0.200	20.00	–		
Overall leanness score (L)										**60.03**

Note: "*" KPI name changed as per use in the case organization.

4.6 PRACTICAL IMPLICATIONS

The chapter presents a simple to use yet comprehensive leanness assessment methodology for the practitioners. One of the major drawbacks of many existing leanness assessment methodologies is the data collection for the assessment. The proposed methodology uses data from the ERP system thereby eliminating the torturous data compilation. Direct data from ERP also purges any chance of data manipulation. The study recognizes that when a manager assesses the leanness using an integrated framework, the continuous improvement can be easily accomplished by identifying the strong and weak performance areas of the organization. In addition, it is suggested that the manager should also use the qualitative KPIs as some of the KPIs can be better explained in qualitative terms. The managers at the different levels of hierarchy can use the leanness assessment score at their levels to leverage the well-performing areas/dimensions/KPIs and develop kaizen for improving the poor performing areas/dimensions/KPIs. The proposed methodology supports continuous improvement by providing scope for KPIs addition and deletion, therefore, the study will help practitioners to support their ideas on leanness assessment and will be helpful to deal with organizational performance. The leanness assessment at different levels in different functional areas & different performance dimensions can help organization to give responsibility to different people to improve leanness in different dimensions and/or functional areas.

4.7 CONCLUSIONS

The study presents leanness assessment of an Indian automotive component manufacturing organization at different levels by using the proposed IPM framework and fuzzy methodology. The results show that the case organization is not using all KPIs in the same proportion in different functional areas. However, it is found that the organization covers a large number of performance dimensions at the middle level.

The various performance dimensions from different functional areas are prioritized based on their importance obtained from fuzzy ANP methodology. The study shows that the performance dimension of serviceability received the highest importance rating. This is followed by performance dimensions of supplier quality. The lowest ranking is given to the communication dimension.

It is found that the case organization uses only 61 KPIs. The used KPIs cover all the functional areas of the organization but the level of coverage varies in different areas. The range of used KPIs varies from 10% to 70%. The overall leanness score of the case organization is 60%, which represents the case organization as a lean organization. Finance, administration and supplier management functional areas need to be improved to enhance the overall organizational lean performance as the leanness score in these functional areas is less than or equal to 50%.

The customer management functional area achieved the best leanness score of 90.83%. It shows that the commitment of the case organization towards its core value of ‘service to the customer’ is strong. The leanness level of the case organization in different functional areas is highly variable (ranges from 45% to 91%), which provides the possibility of improvements in the overall organization lean score.

CHAPTER 5

IDENTIFICATION AND PRIORITIZATION OF LEAN PRACTICES

This chapter presents hard and soft lean practices used for tool & technique based leanness assessment. The hierarchical models of lean practices are developed using ISM and IRP techniques.

5.1 INTRODUCTION

Lean thinking has won numerous proponents in the field of manufacturing, and the extent literature on its implementation, in both manufacturing and services proves as a convincing witness of its universality (Rymaszewska, 2014). Lean concept entails a comprehensive system containing many practices aiming at waste reduction and value addition (Zhang, Narkhede, and Chaple, 2017). Many researchers have explored the various hard and soft practices for the successful lean implementation. During the last decade, some researchers (Shah and Ward, 2007; Hadid and Mansouri, 2014; Bortolotti, Boscari, and Danese, 2015) have emphasized the equal importance of hard and soft lean practices for the comprehensive and sustainable lean implementation.

Although lean manufacturing is one of the most potent performance improvement approaches but almost 67% of the lean manufacturing implementations have resulted in failures and less than 20% of those who implemented the lean manufacturing have sustained their results (Jadhav, Mantha, and Rane, 2014). The prominent causes of lean failures are: implementation of lean practices in improper order (sequence) (Jadhav, Mantha, and Rane, 2014), inappropriate implementation of lean practices (Panwar, Jain, and Rathore, 2015; Usta and Serdarasan, 2016) and lack of basic understanding of lean implementation process (Sharma *et al.,* 2015). The lean practices not only influence the effective lean implementation but also affect each other. Some lean practices provide the basis for the implementation of others whereas some are dependent. Thus, it necessitates to comprehend the interrelationship among the various lean practices.

A large number of studies have been conducted on the application of ISM to identify and prioritize the relationship among the various performance parameters (Attri, 2017), but there are limited studies published on the application of ISM for the implementation of lean manufacturing. The studies on lean systems using ISM are related to modelling different variables such as lean enablers (Gupta, Acharya, and Patwardhan, 2013; Sharma, Dixit, and Qadri, 2016), barriers (Upadhye, Deshmukh, and Garg, 2016; Usta and Serdarasan, 2016; Cherrafi *et al.*, 2017), influencing factors (Ravikumar, Marimuthu, and Parthiban, 2015; Vasanthakumar, Vinodh, and Ramesh, 2016), lean practice bundles (Jadhav, Mantha, and Rane, 2014), *etc*. The ISM approach is used to find interrelationship among hard and soft lean practices separately through a hierarchical structure and MICMAC analysis.

Ranking of variables in any context is a central concern of the management process and decision-making. Actions planned are to be ranked with respect to their influence/impact on the performance areas for prioritization and resource allocation. For the selection and prioritization, the management generally prefers the extreme; either intuitive judgment or rational choice. IRP is a novel ranking technique which provides the advantage of both the analytical logic and intuitive process of rational choice (Sushil, 2009). In the IRP-based assessment, a number of matrixes are developed to establish the inter-relationships among one type of variables with the help of other types of variables. In this chapter, IRP is employed to examine the dominance relationship among the various lean practices.

5.2 LITERATURE REVIEW

There is a large spectrum of lean practices in the literature and being practiced by various organizations (Rose *et al.*, 2011; Pavnaskar, Gershenson, and Jambekar 2003). Some organizations have implemented a whole spectrum of lean practices, while others have implemented a few lean practices (Gurumurthy and Kodali, 2009). A literature review is conducted to identify the key lean practices (hard and soft) which are frequently cited by many researchers. The hard lean practices, also called tools & techniques, are generally implemented to enhance the shop floor performance of an organization.

Alukal and Manos (2006) emphasised that value stream mapping (VSM) is the right choice to begin the journey for the implementation of lean manufacturing. The VSM could be pursued by the implementation of more lean tools & techniques such as just-in-time (JIT), *kaizen*, *poka-yoke*, *kanban*, visual ads, 5S, lot size reduction, single minute exchange of dies (SMED), total quality management (TQM), total productive maintenance (TPM), *etc.* (Prashar, 2014). VSM helps to understand the material and information flows along the value stream (Bhamu, Khandelwal, and Sangwan, 2013). 5S leads to a well-organised workplace which results in more productive, efficient and safer operations (Sharma *et al.*, 2015). The SMED helps to reduce the set up times and brings it within a few minutes (within 10 minutes) which improves productivity (Carrizo and Campos, 2011). The literature review on lean manufacturing reveals diverse views regarding the implementation of various hard lean practices (tools & techniques) and the interrelation among them. The detail descriptions of hard lean practices are given by Gurumurthy and Kodali (2009) and Gupta and Jain (2013). Table 5.1 presents the various hard lean practices and their inter-linkages with lean principles and/or waste.

Table 5.1: Hard lean practices and their inter-linkage with lean principles and/or waste

S. No.	Hard lean practice	Inter-linkage with lean principle and/or waste	Reference
1	JIT	Inventory, pull	Shah and Ward, 2007; Elnadi and Shehab, 2014; Nawanir, Lim, and Othman, 2016; Garza-Reyes *et al.*, 2018
2	TQM	Defect, value	Shah and Ward, 2007; Bhamu and Sangwan, 2014; Lucato *et al.*, 2014; Garza-Reyes *et al.*, 2018
3	TPM	Waiting, flow	Kumar *et al.*, 2006; Upadhye, Deshmukh, and Garg, 2010; Zhou, 2012
4	5 S	Waiting, motion, flow, value stream	Zhou, 2012; Rose *et al.*, 2011; Roy, 2011; Kumar *et al.*, 2006; Panwar *et al.*, 2018
5	*Andon*	Waiting, flow	Motwani, 2003; Bortolotti, Boscari, and Danese, 2015; Andreadis, Garza-Reyes, and Kumar, 2017
6	*Kaizen*	Defect, waiting, motion, value stream, flow	Kumar *et al.*, 2006; Anand and Kodali, 2009a; Upadhye, Deshmukh, and Garg, 2010; Rose *et al.*, 2011; Roy, 2011; Zhou, 2012
7	*Takt* time	Waiting, value	Shah and Ward, 2007; Azevedo *et al.*, 2012; Bhamu, Kumar, and Sangwan, 2012
8	*Poka-yoke*	Over-processing, defect, perfection	Kumar *et al.*, 2006; Anand and Kodali, 2009a; Rahman, Laosirihongthong, and Sohal, 2010; Roy, 2011; Panizzolo *et al.*, 2012; Zhou, 2012
9	*Kanban*	Inventory, pull, flow	Rahman, Laosirihongthong, and Sohal, 2010; Rose *et al.*, 2011; Panizzolo *et al.*, 2012; Zhou, 2012; Saboo, Garza-Reyes, and Kumar, 2014
10	Lot size reduction	Inventory, flow	Zhou 2012; Rose *et al.*, 2011; Rahman, Laosirihongthong, and Sohal 2010; Anand and Kodali, 2009a; Panwar *et al.*, 2018
11	Pull production	Over-production, inventory, pull	Gurumurthy and Kodali, 2009; Azevedo *et al.*, 2012; Nawanir, Teong, and Othman, 2013
12	Automation	Defect, waiting, flow	Gurumurthy and Kodali, 2009; Singh, Garg, and Sharma, 2010b; Hadid and Mansouri, 2014
13	Visual aids	Waiting, flow	Rose *et al.*, 2011; Panizzolo *et al.*, 2012; Zhou, 2012; Panwar *et al.*, 2017
14	Work standardization	Waiting, flow	Anand and Kodali, 2009; Rose *et al.*, 2011; Zhou, 2012; Panwar *et al.*, 2017
15	One piece flow	Inventory, pull, flow	Pavnaskar, Gershenson, and Jambekar, 2003; Gurumurthy and Kodali, 2009; Ainul Azyan, Pulakanam, and Pons, 2017; Panwar *et al.*, 2017
16	SMED	Waiting, value stream	Rahman, Laosirihongthong, and Sohal, 2010; Rose *et al.*, 2011; Roy, 2011; Panizzolo *et al.*, 2012; Zhou, 2012; Saboo, Garza-Reyes, and Kumar, 2014; Panwar *et al.*, 2017
17	Load levelling	Waiting, flow	Pavnaskar, Gershenson, and Jambekar, 2003; Abdulmalek and Rajgopal, 2007; Gurumurthy and Kodali, 2009
18	VSM	Over production, motion, transportation, under-utilization of manpower, inventory, value stream, flow	Kumar *et al.*, 2006; Bhamu, Kumar, and Sangwan, 2012; Saboo, Garza-Reyes, and Kumar, 2014
19	Elimination of buffers	Inventory, pull	Pavnaskar, Gershenson, and Jambekar, 2003; Gurumurthy and Kodali, 2009; Jasti and Kodali, 2015; Panwar *et al.*, 2017
20	Synchronization	Waiting, flow	Bhasin and Burcher, 2006; Gurumurthy and Kodali, 2009; Cil and Turkan, 2013

Many organizations implemented only hard lean practices and ignored the human centric practices (soft lean practices) (Bortolotti, Boscari, and Danese, 2015). The ignorance of human related practices could lower the employee motivation resulting in non-lean behaviour. Table 5.2 presents the soft lean practices and their inter-linkages with lean principle and/or waste.

Table 5.2: Soft lean practices and their inter-linkage with lean principle and/or waste

S. No.	Soft lean practice	Inter-linkage with lean principle and/or waste	References
1	Problem solving team	Defect, waiting, flow	Womack and Jones, 2003; Pakdil and Leonard, 2014; Bortolotti, Boscari, and Danese, 2015; Garza-Reyes, Ates, and Kumar, 2015; Tuli and Shankar, 2015
2	Safety improvement program	Value	Amin and Karim, 2013; Longoni *et al.*, 2013; Kurdve *et al.*, 2014; García-Alcaraz, Oropesa-Vento, and Maldonado-Macías, 2017
3	Team work	Flow	Bonavia and Marin-Garcia, 2011; Garza-Reyes, Ates, and Kumar, 2015; Jasti and Kodali, 2015
4	Employee involvement	Value	Bonavia and Marin-Garcia, 2011; Martínez-Jurado, Moyano-Fuentes and Jerez-Gómez, 2014; Garza-Reyes, Ates, and Kumar, 2015
5	Cross-functional team	Defect, motion, waiting, flow, value stream	Leach *et al.*, 2005; Bonavia and Marin-Garcia, 2011; Pakdil and Leonard, 2014
6	Customer involvement	Value	Panizzolo, 1998; Gupta, Acharya, and Patwardhan, 2013; Garza-Reyes, Ates, and Kumar, 2015; Yang, Lee, and Cheng, 2016
7	Supplier relationship	Flow, pull	Afshan, 2013; Elnadi and Shehab, 2014; Garza-Reyes, Ates, and Kumar, 2015
8	Information sharing with suppliers	Flow	Ghobadian and Gallear, 2001; Narasimhan, Swink, and Kim, 2006; Azevedo *et al.*, 2012; Afshan, 2013; Tortorella and Fogliatto, 2014
9	Rewards and recognition	Value	Kerrin and Oliver, 2002; Sousa and Aspinwall, 2010; AL-Najem *et al.*, 2013; Marin-Garcia, Juarez-Tarraga, and Santandreu-Mascarell, 2018
10	Information sharing with employees	Flow, value stream	Bonavia and Marin-Garcia, 2011; AL-Najem *et al.*, 2013; Tuli and Shankar, 2015; Yang, Lee, and Cheng, 2016
11	Supplier involvement	Defect, pull, flow	Tortorella and Fogliatto, 2014; Garza-Reyes, Ates, and Kumar, 2015; Tuli and Shankar, 2015
12	Employee ownership	Value	Ghobadian and Gallear, 2001; Sousa and Aspinwall, 2010; Martínez-Jurado, Moyano-Fuentes, and Jerez-Gómez, 2014; Dora, Kumar, and Gellynck, 2016

Shah and Ward (2007) defined the lean practices which cover the comprehensive nature of the lean system and claimed that the lean system should include people, process, internal, and external (related to customer and supplier) components simultaneously. Hadid and Mansouri (2014) emphasized that lean is deemed as a socio-technical system which contains two constructs – lean technical (hard) practices and lean supportive (soft) practices. The focus of soft lean practices is on human resource management (HRM) (Kaynak, 2003). The soft lean practices support the continuous improvement by imparting a sense of ownership and common responsibility (Ghobadian and Gallear, 2001). The continuous improvement can be achieved by conducting small incremental improvement activities. Cross-functional teams decrease supervision costs and provide the basis for knowledge sharing (Leach *et al.*, 2005). Bonavia and Marin-Garcia (2011) stated that the employment security, and rewards and recognition provide advantages of better internal communication, teams operation and employee retention. The soft lean implementation leads to improved lean manufacturing performance.

5.3 INTERPRETIVE STRUCTURAL MODELLING (ISM) APPROACH

ISM is an interactive learning process used to develop a structural model of variables (Thakkar, Kanda, and Deshmukh, 2008; Mittal and Sangwan, 2014). Similarly, Vasanthakumar, Vinodh, and Ramesh (2016) claimed that ISM is a decision making approach in which a number of variables affecting implementation of a specific system are presented in a structured way. Attri (2017) conducted a literature review of ISM applications and found that the applications of ISM method have been immensely augmented in recent times. The available research on the modelling of lean systems using ISM is related to different variables of lean such as lean enablers, barriers, influencing factors, lean practice bundles, *etc.* as presented in table 5.3.

Table 5.3: Application of ISM in the field of lean manufacturing

Research study	Theme	Variable	Contribution/focus
Cheah, Wong, and Deng (2012)	Lean manufacturing implementation	Challenges	The study applied ISM technique to investigate the complex dynamics among different challenges for the implementation of lean manufacturing at an electrical and electronics organization in Malaysia.
Gupta, Acharya, and Patwardhan (2013)	Lean manufacturing implementation	Enablers	Focus of the study is to identify critical strategic and operational decision making enablers/factors for the successful implementation of lean manufacturing in an Indian tyre manufacturing organization.
Kumar *et al.* (2013)	Lean manufacturing implementation	Influencing variables	Authors developed a structural model of variables for the implementation of lean manufacturing in an Indian automobile industry.
Jadhav, Mantha, and Rane (2014)	Sustainable lean implementation	Lean JIT practice bundles	Focus of the study is to identify and rank the lean JIT practice bundles and their influence on cost reduction.
Ravikumar, Marimuthu, and Parthiban (2015)	Lean manufacturing implementation	Influencing factors	Authors presented a combined approach (combination of ISM and AHP) to evaluate the lean implementation performance of micro, small & medium enterprises (MSMEs) using 11 influencing factors.
Sharma *et al.* (2015)	Lean manufacturing implementation	Lean criteria	Authors investigated interaction among the key lean criteria in a machine tool organization.
Govindan *et al.* (2015)	Supply chain	Lean, green and resilient practices	Authors identified ten critical practices related to lean, green and resilient manufacturing and developed a structural model to improve the automotive supply chain performance.
Keerthana and Suresh (2016)	Lean manufacturing implementation	Drivers	Authors identified the various lean drivers and determined the relationship among them for the street food sector.
Usta and Serdarasan (2016)	Lean manufacturing implementation	Barriers	The study analysed the lean manufacturing implementation barriers to determine the interrelation among each other.
Vasanthakumar, Vinodh, and Ramesh (2016)	Lean remanufacturing practices	Influencing factors	Authors identified 20 influencing factors and developed the structural model describing interrelationships among most dominant and least dominant factors for automotive component remanufacturing companies in India.
Vinodh, Ramesh, and Arun (2016)	Integrated lean sustainable system	Influencing factors	Authors identified the mutual relationship among influencing factors of an integrated lean sustainable manufacturing system at an Indian automotive component manufacturer.
Upadhye, Deshmukh, and Garg (2016)	Lean manufacturing implementation	Barriers	The study developed a relationship among the identified barriers for the successful lean manufacturing implementation.
Kumar and Kumar (2016)	Lean manufacturing implementation	Lean elements	Authors examined the interrelationship among various lean elements and determined their ranks based on driving and dependence powers.
Sharma, Dixit, and Qadri (2016)	Lean manufacturing implementation	Enablers	Authors identified lean manufacturing implementation enablers, developed relationship among them, and ranked them.

Table 5.3: Application of ISM in the field of lean manufacturing (Contd.)

Research study	Theme	Variable	Contribution/focus
Khaba and Bhar (2017)	Lean manufacturing implementation	Barriers	Authors identified, analysed, and prioritized the major barriers to lean implementation for the construction industry
Patidar, Soni, and Soni (2017)	Lean manufacturing implementation	Lean waste	The study identified critical wastes in the lean manufacturing environment and determined the interaction among them to identify the 'driving wastes' and the 'dependent wastes'.
Attri, Singh, and Mehra (2017)	5S implementation	Barriers	Focus of the study is to determine and analyse the relationship among various barriers to 5S implementation in manufacturing organizations.
Cherrafi *et al.* (2017)	Green lean implementation	Barriers	Authors found 15 barriers from a systematic literature review and identified the relationship among these barriers to develop a hierarchical model.

A large number of research articles have been published on the modelling of lean systems using various modelling tools & techniques such as structural equation modelling (SEM), computer simulation, analytic hierarchical process (AHP), analytic network process (ANP), Petri nets, *etc.* Similarly, ISM has also been used to model the various element of lean system. ISM method uses the expert opinions with the help of various managerial tools & techniques such as nominal group techniques, brainstorming, *etc.* to develop the contextual relationships among the identified variables (Azevedo, Carvalho, and Cruz-Machado, 2013). ISM is used to identify the interrelationship among the variables and to develop the hierarchy (Sage, 1977; Warfield, 1974).

This study describes the interrelations among the various lean practices and prioritizes lean practices with the help of contextual relationships among the various lean practices using ISM approach. The ISM methodology used for the study is shown in figure 5.1.

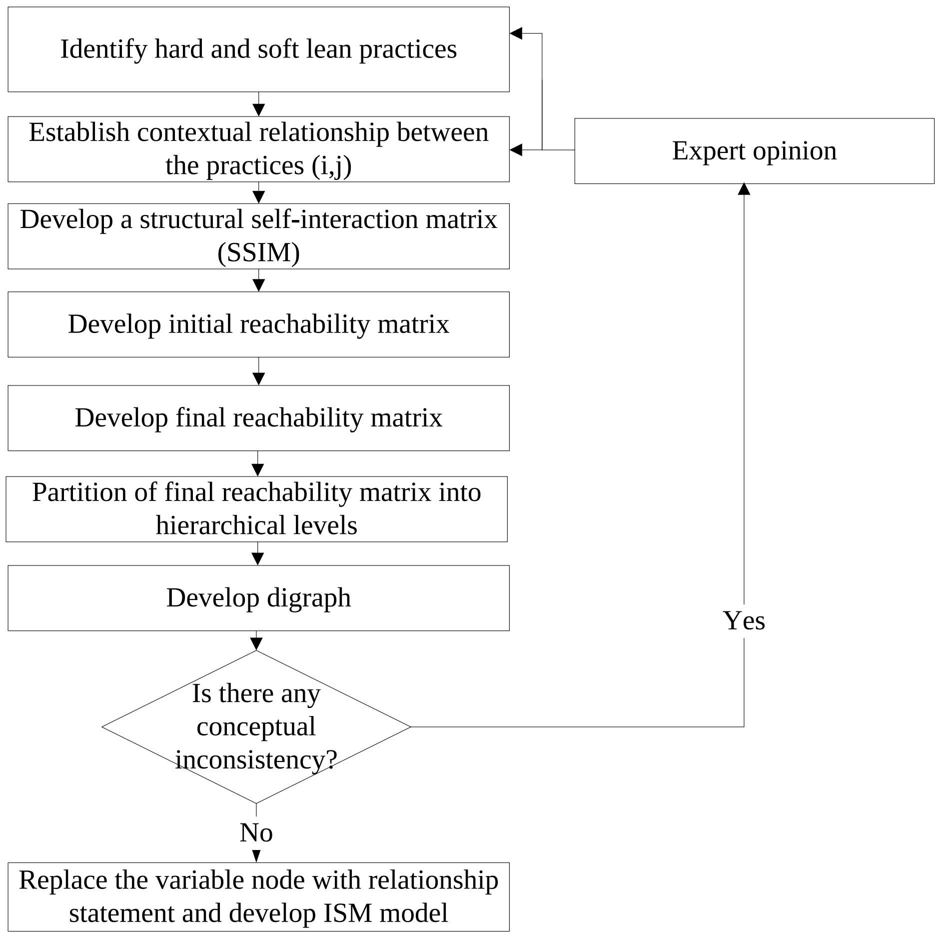


Figure 5.1: ISM methodology for the modelling of lean practices [Adapted from Kannan *et al.* (2008)]

5.3.1 Development of ISM-based Models for Hard and Soft Lean Practices

The ISM models are developed to establish the hierarchy and interrelationship among various lean practices and to prioritize the hard and soft lean practices separately. The methodology is as follows.

5.3.1.1 Identify hard and soft lean practices: A literature review was conducted for the identification of hard and soft lean practices. 20 hard and 12 soft lean practices were identified from the literature. Further, these lean practices are discussed with the top management of the case organization to finalise the list of hard and soft lean practices.

5.3.1.2 Establish contextual relationships among the lean practices: A questionnaire was developed to know the contextual relationships among the lean practices. The questionnaire has two parts. First part is about the hard lean practices whereas second part is related to soft lean practices. This questionnaire is discussed with experts from the case organization. The heads of human resource, supply chain, manufacturing, and production planning and control departments participated in the discussion. All four experts have more than 15 years industrial work experience. The contextual relationship of "influences" is chosen for analysing the lean practices.

5.3.1.3 Develop the structural self-interaction matrix (SSIM): Two structural self-interaction matrixes (SSIM) are developed based on the pair-wise comparison of the hard and soft lean practices. The structural self-interaction matrixes for hard and soft lean practices are presented in tables 5.4 and 5.5 respectively.

Table 5.4: SSIM matrix of hard lean practices

i ↓ / *j* →	**1** JIT	**2** TQM	**3** TPM	**4** 5 S	**5** *Andon*	**6** *Kaizen*	**7** *Takt* time	**8** *Poka-yoke*	**9** *Kanban*	**10** Lot size reduction	**11** Pull production	**12** Automation	**13** Visual aids	**14** Work standardization	**15** One piece flow	**16** SMED	**17** Load levelling	**18** VSM	**19** Elimination of buffers	**20** Synchronization
1 JIT	X	O	A	X	A	A	A	A	A	V	X	A	A	A	X	A	O	O	X	A
2 TQM		X	X	A	O	A	O	A	A	A	O	A	A	A	A	O	A	A	A	A
3 TPM			X	X	A	A	O	A	A	X	A	A	A	X	O	X	X	O	V	X
4 5 S				X	A	A	O	O	A	A	O	A	X	V	A	X	O	O	A	X
5 *Andon*					X	A	A	A	A	X	X	A	X	X	X	X	X	O	X	X
6 *Kaizen*						X	A	X	O	V	V	X	V	X	V	V	V	V	V	V
7 *Takt* time							X	O	O	V	V	V	O	V	V	V	O	O	V	V
8 *Poka-yoke*								X	O	O	O	X	O	X	O	O	O	X	O	O
9 *Kanban*									X	X	V	O	X	X	X	O	O	O	V	O
10 Lot size reduction										X	A	A	O	A	A	A	O	O	A	A
11 Pull production											X	A	O	A	X	A	X	O	A	X
12 Automation												X	O	V	X	A	O	V	V	V
13 Visual aids													X	X	O	O	O	A	O	O
14 Work standardization														X	X	X	X	A	O	X
15 One piece flow															X	X	A	O	O	X
16 SMED																X	O	O	V	V
17 Load levelling																	X	O	O	X
18 VSM																		X	O	O
19 Elimination of buffers																			X	A
20 Synchronization																				X

Table 5.5: SSIM matrix of soft lean practices

i ↓ / j →	1 Problem solving team	2 Safety improvement program	3 Team work	4 Employee involvement	5 Cross-functional team	6 Customer involvement	7 Supplier relationship	8 Information sharing with suppliers	9 Rewards and recognition	10 Information sharing with employees	11 Supplier involvement	12 Employee ownership
1 Problem solving team	X	O	O	X	X	V	O	O	O	A	O	O
2 Safety improvement program		X	O	O	V	V	V	O	O	A	O	O
3 Team work			X	O	O	V	V	X	A	X	X	X
4 Employee involvement				X	X	O	O	O	O	A	O	O
5 Cross-functional team					X	O	O	O	O	X	O	O
6 Customer involvement						X	V	X	O	A	O	A
7 Supplier relationship							X	X	O	A	V	X
8 Information sharing with suppliers								X	A	A	A	X
9 Rewards and recognition									X	O	O	V
10 Information sharing with employees										X	V	X
11 Supplier involvement											X	X
12 Employee ownership												X

The following notations are used:

- V: Practice *i* influences practice j
- A: Practice *j* influences practice *i*
- X: Practice *i* and practice *j* influence each other
- O: Practice *i* and practice *j* are unrelated

5.3.1.4 Develop initial reachability matrix: The initial reachability matrix is developed by replacing the SSIM matrix notation with binary numbers of 0 and 1. The following rules are used to develop the initial reachability matrix.

SSIM (i,j)	V	A	X	O
Initial reachability matrix (i,j)	1	0	1	0
Initial reachability matrix (j,i)	0	1	1	0

The initial reachability matrixes for hard and soft lean practices are presented in tables 5.6 and 5.7 respectively.

Table 5.6: Initial reachability matrix of hard lean practices

i ↓ / *j* →	1 JIT	2 TQM	3 TPM	4 5 S	5 *Andon*	6 *Kaizen*	7 *Takt* time	8 *Poka-yoke*	9 *Kanban*	10 Lot size reduction	11 Pull production	12 Automation	13 Visual aids	14 Work standardization	15 One piece flow	16 SMED	17 Load levelling	18 VSM	19 Elimination of buffers	20 Synchronizatio
1 JIT	1	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0	1	0
2 TQM	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 TPM	1	1	1	1	0	0	0	0	0	1	0	0	0	1	0	1	1	0	1	1
4 5 S	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1
5 *Andon*	1	0	1	1	1	0	0	0	0	1	1	0	1	1	1	1	1	0	1	1
6 *Kaizen*	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
7 *Takt* time	1	0	0	0	1	1	1	0	0	1	1	1	0	1	1	1	0	0	1	1
8 *Poka-yoke*	1	1	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	1	0	0
9 *Kanban*	1	1	1	1	1	0	0	0	1	1	1	0	1	1	1	0	0	0	1	0
10 Lot size reduction	0	1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
11 Pull production	1	0	1	0	1	0	0	0	0	1	1	0	0	0	1	0	1	0	0	1
12 Automation	1	1	1	1	1	1	0	1	0	1	1	1	0	1	1	0	0	1	1	1
13 Visual aids	1	1	1	1	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0
14 Work standardization	1	1	1	0	1	1	0	1	1	1	1	0	1	1	1	1	1	0	0	1
15 One piece flow	1	1	0	1	1	0	0	0	1	1	1	1	0	1	1	1	0	0	0	1
16 SMED	1	0	1	1	1	0	0	0	0	1	1	1	0	1	1	1	0	0	1	1
17 Load levelling	0	1	1	0	1	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1
18 VSM	0	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	1	0	0
19 Elimination of buffers	1	1	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0
20 Synchronization	1	1	1	1	1	0	0	0	0	1	1	0	0	1	1	0	1	0	1	1

Table 5.7: Initial reachability matrix of soft lean practices

i ↓ / *j* →	1 Problem solving team	2 Safety improvement program	3 Team work	4 Employee involvement	5 Cross-functional team	6 Customer involvement	7 Supplier relationship	8 Information sharing with suppliers	9 Rewards and recognition	10 Information sharing with employees	11 Supplier involvement	12 Employee ownership
1 Problem solving team	1	0	0	1	1	1	0	0	0	0	0	0
2 Safety improvement program	0	1	0	0	1	1	1	0	0	0	0	0
3 Team work	0	0	1	0	0	1	1	1	0	1	1	1
4 Employee involvement	1	0	0	1	1	0	0	0	0	0	0	0
5 Cross-functional team	1	0	0	1	1	0	0	0	0	1	0	0
6 Customer involvement	0	0	0	0	0	1	1	1	0	0	0	0
7 Supplier relationship	0	0	0	0	0	0	1	1	0	0	1	1
8 Information sharing with suppliers	0	0	1	0	0	1	1	1	0	0	0	1
9 Rewards and recognition	0	0	1	0	0	0	0	1	1	0	0	1
10 Information sharing with employees	1	1	1	1	1	1	1	1	0	1	1	1
11 Supplier involvement	0	0	1	0	0	0	0	1	0	0	1	1
12 Employee ownership	0	0	1	0	0	1	1	1	0	1	1	1

5.3.1.5 Develop final reachability matrix: After the development of initial reachability matrix, the final reachability matrix is developed by considering the transitivity among the various lean practices. For the transitivity, if practice X influences practice Y; and practice Y influences practice Z; then, practice X will also influence Z. Thus, as per the transitivity rule, the initial reachability matrix is modified to develop the final reachability matrixes for hard and soft lean practices as presented in tables 5.8 and 5.9 respectively.

Table 5.8: Final reachability matrix of hard lean practices

	i ↓ / *j* →	1 JIT	2 TQM	3 TPM	4 5 S	5 *Andon*	6 *Kaizen*	7 *Takt* time	8 *Poka-yoke*	9 *Kanban*	10 Lot size reduction	11 Pull production	12 Automation	13 Visual aids	14 Work standardization	15 One piece flow	16 SMED	17 Load levelling	18 VSM	19 Elimination of buffers	20 Synchronization	Driving power
1	JIT	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1	16
2	TQM	1	1	1	1	0	0	0	0	0	1	0	0	0	1	0	1	1	0	1	1	10
3	TPM	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	18
4	5 S	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	18
5	*Andon*	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	1	1	17
6	*Kaizen*	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	19
7	*Takt* time	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20
8	*Poka-yoke*	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	19
9	*Kanban*	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	18
10	Lot size reduction	1	1	1	1	1	0	0	0	1	1	1	0	1	1	1	1	1	0	1	1	15
11	Pull production	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1	16
12	Automation	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	19
13	Visual aids	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	1	1	0	1	1	16
14	Work standardization	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	19
15	One piece flow	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	19
16	SMED	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	19
17	Load levelling	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	18
18	VSM	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	18
19	Elimination of buffers	1	1	1	1	1	0	0	0	1	1	1	0	1	1	1	1	1	0	1	1	15
20	Synchronization	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	18
	Dependence power	20	20	20	20	19	14	1	15	18	20	19	16	19	20	19	20	20	8	19	20	

Table 5.9: Final reachability matrix of soft lean practices

i ↓ / j →		1 Problem solving team	2 Safety improvement program	3 Team work	4 Employee involvement	5 Cross-functional team	6 Customer involvement	7 Supplier relationship	8 Information sharing with suppliers	9 Rewards and recognition	10 Information sharing with employees	11 Supplier involvement	12 Employee ownership	Driving power
1	Problem solving team	1	0	0	1	1	1	1	1	0	1	0	0	7
2	Safety improvement program	0	1	0	0	1	1	1	1	0	1	1	1	8
3	Team work	1	1	1	1	1	1	1	1	0	1	1	1	11
4	Employee involvement	1	0	0	1	1	1	0	0	0	1	0	0	5
5	Cross-functional team	1	1	1	1	1	1	1	1	0	1	1	1	11
6	Customer involvement	0	0	1	0	0	1	1	1	0	0	1	1	6
7	Supplier relationship	0	0	1	0	0	1	1	1	0	1	1	1	7
8	Information sharing with suppliers	0	0	1	0	0	1	1	1	0	1	1	1	7
9	Rewards and recognition	0	0	1	0	0	1	1	1	1	1	1	1	8
10	Information sharing with employees	1	1	1	1	1	1	1	1	0	1	1	1	11
11	Supplier involvement	0	0	1	0	0	1	1	1	0	1	1	1	7
12	Employee ownership	1	1	1	1	1	1	1	1	0	1	1	1	11
	Dependence power	6	5	9	6	7	12	11	11	1	11	10	10	

5.3.1.6 Perform level partition: The next step is to perform partition of the final reachability matrix into various hierarchical levels as presented in table 5.10 and table 5.11. The reachability and antecedent sets for each practice are obtained from the final reachability matrix. The reachability set of a practice consists of the practice itself and the other practices, which it may support to achieve. The antecedent set of a practice consists of the practice itself and the other practices, which support its implementation. Intersection set is the intersection of the reachability and antecedent sets for each practice.

Table 5.10: Level partition of hard lean practices

Variable	Reachability set	Antecedent set	Intersection	Level
1	1,2,3,4,5,9,10,11,12,13, 14,15,16,17,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20	1,2,3,4,5,9,10,11,12,13, 14,15,16,17,19,20	I
2	1,2,3,4,10,14,16,17,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20	1,2,3,4,10,14,16,17,19,20	I
3	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17, 19,20	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,19,20	I
4	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17, 19,20	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,19,20	I
5	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,19,20	1,3,4,5,6,7,8,9,10,11,12,13,14, 15,16,17,18,19,20	1,3,4,5,6,8,9,10,11,12,13, 14,15,16,17,19,20	II
6	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17, 18,19,20	3,4,5,6,7,8,9,12,14,15,16,17, 18,20	3,4,5,6,8,9,12,14,15,16, 17,18,20	III
7	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20	7	7	V
8	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17, 18,19,20	3,4,5,6,7,8,9,12,13,14,15,16, 17,18,20	3,4,5,6,8,9,12,13,14,15, 16,17,18,20	III
9	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,19,20	1,3,4,6,7,8,9,10,11,12,13,14,1 5,16,17,18,19,20	1,3,4,6,8,9,10,11,12,13, 14,15,16,17,19,20	III
10	1,2,3,4,5,9,10,11,13,14, 15,16,17,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20	1,2,3,4,5,9,10,11,13,14, 15,16,17,19,20	I
11	1,2,3,4,5,9,10,11,12,13, 14,15,16,17,19,20	1,3,4,5,6,7,8,9,10,11,12,13,14, 15,16,17,18,19,20	1,3,4,5,9,10,11,12,13,14, 15,16,17,19,20	II
12	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,18,19,20	1,3,4,5,6,7,8,9,11,12,14,15,16, 17,18,20	1,3,4,5,6,8,9,11,12,14,15, 16,17,18,20	III
13	1,2,3,4,5,6,8,9,10,11,13, 14,15,16,17,19,20	1,3,4,5,6,7,8,9,10,11,12,13,14, 15,16,17,18,19,20	1,3,4,5,6,8,9,10,11,13,14, 15,16,17,19,20	II
14	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,18,19,20	I
15	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,18,19,20	1,3,4,5,6,7,8,9,10,11,12,13,14, 15,16,17,18,19,20	1,3,4,5,6,8,9,10,11,12,13, 14,15,16,17,18,19,20	II
16	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,18,19,20	I
17	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,19,20	I
18	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,18,20	6,7,8,12,14,15,16,18	6,8,12,14,15,16,18	IV
19	1,2,3,4,5,9,10,11,13,14, 15,16,17,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16, 17,19,20	1,2,3,4,5,9,10,11,13,14, 15,16,17,19,20	I
20	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16, 17,18,19,20	1,2,3,4,5,6,8,9,10,11,12, 13,14,15,16,17,19,20	I

Table 5.11: Level partition of soft lean practices

Variable	Reachability set	Antecedent set	Intersection	Level
1	1,4,5,6,7,8,10	1,3,4,5,10,12	1,4,5,10	II
2	2,5,6,7,8,10,11,12	2,3,5,10,12	2,5,10,12	II
3	1,2,3,4,5,6,7,8,10,11,12	3,5,6,7,8,9,10,11,12	3,5,6,7,8,10,11,12	III
4	1,4,5,6,10	1,3,4,5,10,12	1,4,5,10	II
5	1,2,3,4,5,6,7,8,10,11,12	1,2,3,4,5,10,12	1,2,3,4,5,10,12	II
6	3,6,7,8,11,12	1,2,3,4,5,6,7,8,9,10,11,12	3,6,7,8,11,12	I
7	3,6,7,8,10,11,12	1,2,3,5,6,7,8,9,10,11,12	3,6,7,8,10,11,12	I
8	3,6,7,8,10,11,12	1,2,3,5,6,7,8,9,10,11,12	3,6,7,8,10,11,12	I
9	3,6,7,8,9,10,11,12	9	9	IV
10	1,2,3,4,5,6,7,8,10,11,12	1,2,3,4,5,7,8,9,10,11,12	1,2,3,4,5,7,8,10,11,12	II
11	3,6,7,8,10,11,12	2,3,5,6,7,8,9,10,11,12	3,6,7,8,10,11,12	I
12	1,2,3,4,5,6,7,8,10,11,12	2,3,5,6,7,8,9,10,11,12	2,3,5,6,7,8,10,11,12	III

If the reachability set and the intersection set are identical, then the practice is counted to be in first level and is allotted the top position in the ISM hierarchy. This means that this practice does not influence the other practices except at the same level (level I). After the identification of the top-level practices, these are eliminated from the remaining sets.

5.3.1.7 Develop ISM-based models: After level partition, the digraph is developed using the different levels obtained from the partition matrix. The digraph represents various nodes of lean practices and also shows their interrelations. Next, the diagraph is checked for any conceptual inconsistency. If no conceptual inconsistency exists, then the final ISM models of hard and soft lean practices are developed by removing the transitivity links from the digraph. The developed ISM models of hard and soft lean practices are shown in figures 5.2 and 5.3 respectively.

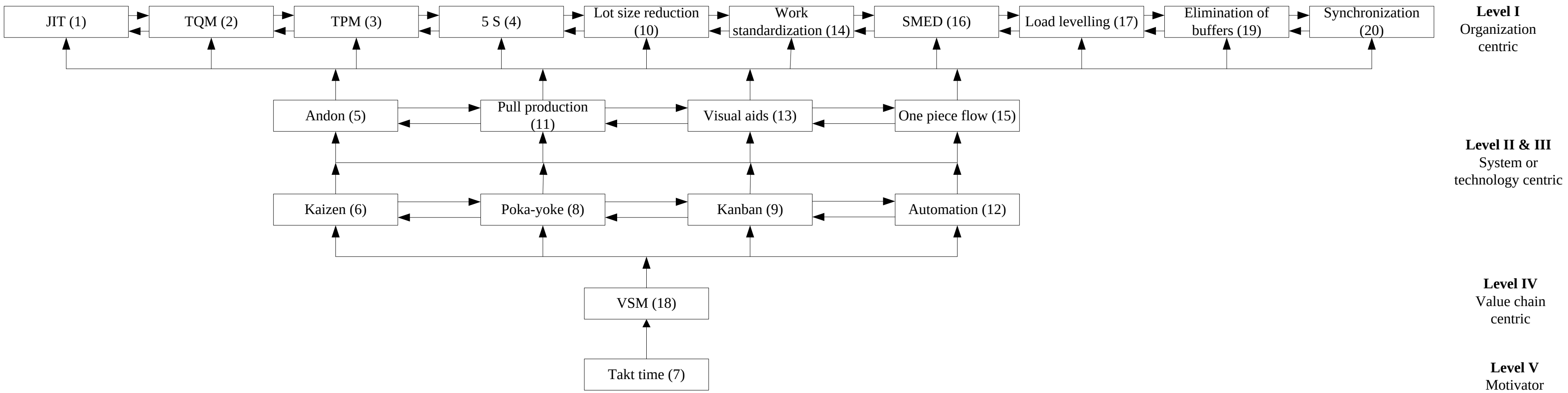


Figure 5.2: ISM-based model of hard lean practices

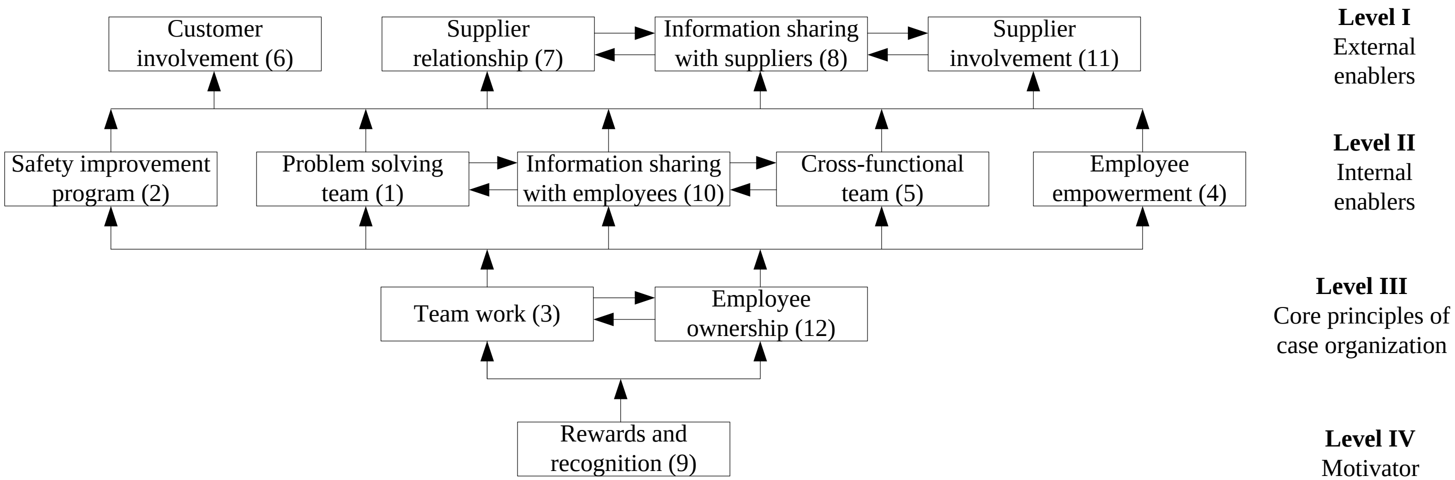


Figure 5.3: ISM-based model of soft lean practices

5.3.2 MICMAC Analysis

Matrice d’Impacts croises-multipication applique´ an classment (cross-multiplication matrix impact applied to classification) is abbreviated as MICMAC. The MICMAC analysis of hard and soft lean practices are shown in figures 5.4 and 5.5 respectively. The driving power as well as dependence power of each practice is calculated in the last section (see tables 5.8 and 5.9). The driving power of a practice is the total number of practices which are supported by this practice. The dependence power is the total number of practices supporting its implementation. The MICMAC analysis is conducted using driving power and dependence power to categorize the lean practices into four clusters: autonomous, dependent, linkage, and driver practices. The practices in the autonomous cluster are having low driving and dependence powers. The practices in the autonomous cluster remain isolated from the rest of the system. The practices in the dependent cluster are having low driving power and high dependence power. Only one lean practice of employee involvement is on the verge of both autonomous and dependent clusters as shown in figure 5.5 which implies that it has moderate dependence power.

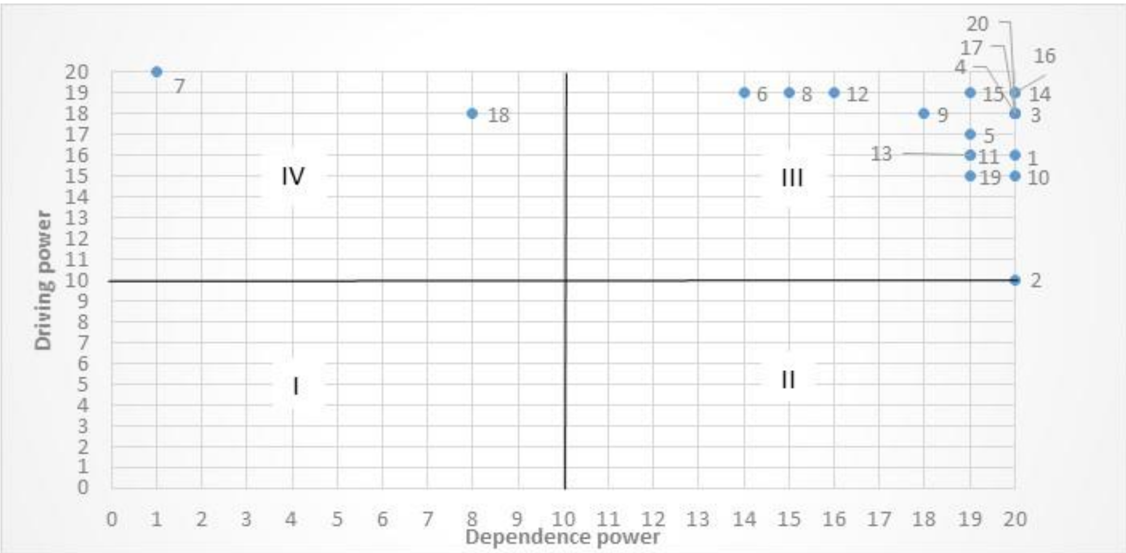


Figure 5.4: MICMAC analysis of hard lean practices

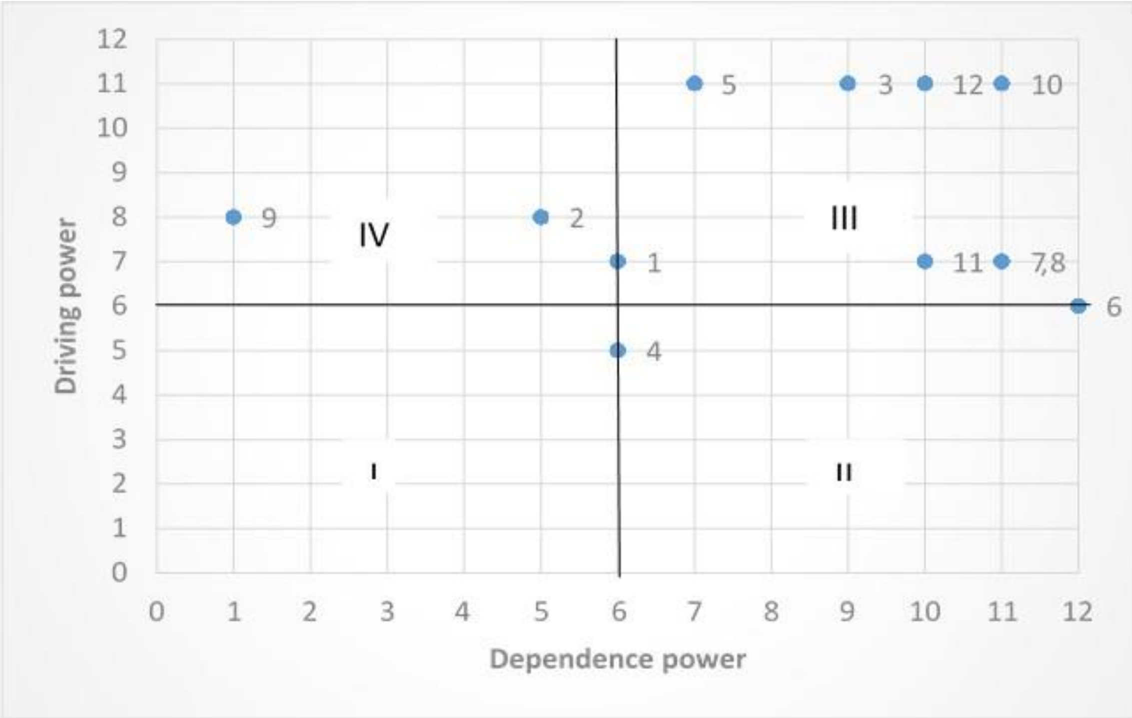


Figure 5.5: MICMAC analysis of soft lean practices

The practices in the linkage cluster are having high driving and dependence powers. The practices of linkage cluster are very sensitive and the slight change in these practices will influence the other practices. Most of the lean practices from both categories are located in the linkage clusters.

5.3.3 Interpretations of ISM-based Models

The study presents an ISM approach to identify and prioritize the interrelationships among the various hard and soft lean practices for an Indian automotive component manufacturing organization. It is found that most of the lean practices are interrelated with each other and none of the practices is isolated or autonomous as shown in figures 5.4 and 5.5. This finding is supported by Jadhav, Mantha, and Rane (2014) who stated that the function of an individual practice as a distinct tool or technique for the organizational enhancement may hinder the objective of lean philosophy. The implementation of lean practices as autonomous practices may lead to lean failures.

The lean hard practices at five levels (Figure 5.2) can be categorised as: organization centric, system/technology centric, value chain centric, and motivators. The soft lean practices are human centric and the four levels can be categorised as: external enablers, internal enablers, organization core principles, and motivators.

The ISM approach determined the influence of the various lean practices on each other so that managers can differentiate the dependent practices, which are at the top of the hierarchical structure and the driving practices, which are at the root of the hierarchical structure. The *takt* time, which is derived from the customer demand, is the main hard practice which drives other hard practices. In other words, other hard practices are used to meet the *takt* time. If the customer demand is satisfied by implementing various lean practices then the lean implementation can be termed as successful. VSM is placed at level IV (value chain centric) in the ISM model of hard lean practices (Figure 5.2). The VSM is also a key driving practice for the effective lean implementation. Other hard practices are adopted to eliminate the wastes identified from the value stream. The levels II & III practices are system or technology centric. The practices of *poka-yoke*, automation, *andon* are technology centric whereas others are system centric. These practices are mutually interrelated and help each other to achieve the leanness. Ten organization centric practices are located at the top of the hierarchy. These practices do not support any other practice and are only supported by the other practices.

The ISM model of soft lean practices is shown in figure 5.3. The rewards and recognition is the motivator and the main driver for the other soft lean practices. Koval *et al.* (2018) also concluded that rewards system encourages employees for the involvement in the continuous improvement activities which facilitate customer satisfaction enhancement. The case organization started different types of rewards and recognition systems such as best *kaizen* award, best employee of the month, attendance award, *Hokai* award to capture the defective parts, best suggestion award, *etc.* These types of reward systems encourage the employees for better work and to improve the ownership spirits among the employees. Thus, rewards and recognition is the motivator for other soft lean practices and positioned at the root of hierarchy (level IV) as shown in figure 5.3. Two soft practices, namely team work and employee ownership are positioned at the third level. These practices are the two core principles of the case organization. The team work leads to self-discipline and better suggestions for the improvement, whereas the employee ownership helps to achieve employee satisfaction; employee morale; commitment and involvement; and accountability for the work. The second level is labelled as internal enablers. Total five soft practices, namely safety improvement program, problem solving team, information sharing with employees, cross-function team, and employee involvement are considered under the domain of internal enablers. Problem solving team, information sharing with employees, cross-function team are interrelated with each other (see figure 5.3) and the slight variation in performance of one practice affects the performance of the others. Four soft lean practices of customer involvement, supplier relationship, information sharing with suppliers, and supplier involvement are positioned at the top level and labelled as external enablers. Apart from the customer involvement, other three soft lean practices of top level are interrelated with each other as shown in figure 5.3. The MICMAC analysis shows that most of the soft practices are interrelated with each other. Any performance variation in any practice will influence the performance of other lean practices. The implementation of lean practices in wrong sequence or order may leads to lean failure.

5.4 INTERPRETIVE RANKING PROCESS (IRP) APPROACH

IRP utilizes an interpretative matrix as a basic tool and performs a pair-wise comparison between the variables (Zhang, Narkhede, and Chaple 2017). Haleem, Qadri, and Kumar (2012) stated that the IRP constructs the robust pair-wise comparison which makes light of the cognitive overload. IRP, developed by Sushil (2009), provides new knowledge for the ranking process since it establishes the interrelationship among one type of variables with respect to other types of variables, whereas other ranking techniques such as AHP, ANP, ISM, *etc.* use only one type of variables to determine the contextual relationships.

In conventional AHP, the interpretation of judgements remains obscure for the practitioners, which is overcome by IRP. In IRP, the experts determine the interpretive logic for dominance of one variable over the other for each pair-wise comparison (Haleem, Qadri, and Kumar 2012). Further, IRP does not entail the statistics regarding the extent of dominance. It also provides consistency check by developing dominance system graphs using the vector logic of the dominance relationships (Zhang, Narkhede, and Chaple 2017). IRP takes two groups of variables; one group of variables is used for ranking whereas other group provides the basis or reference for ranking. In this study, lean practices are used as first group of variables, which need to be ranked; and performance dimensions are considered as second group of variables as basis for the ranking. The IRP methodology is shown in figure 5.6.

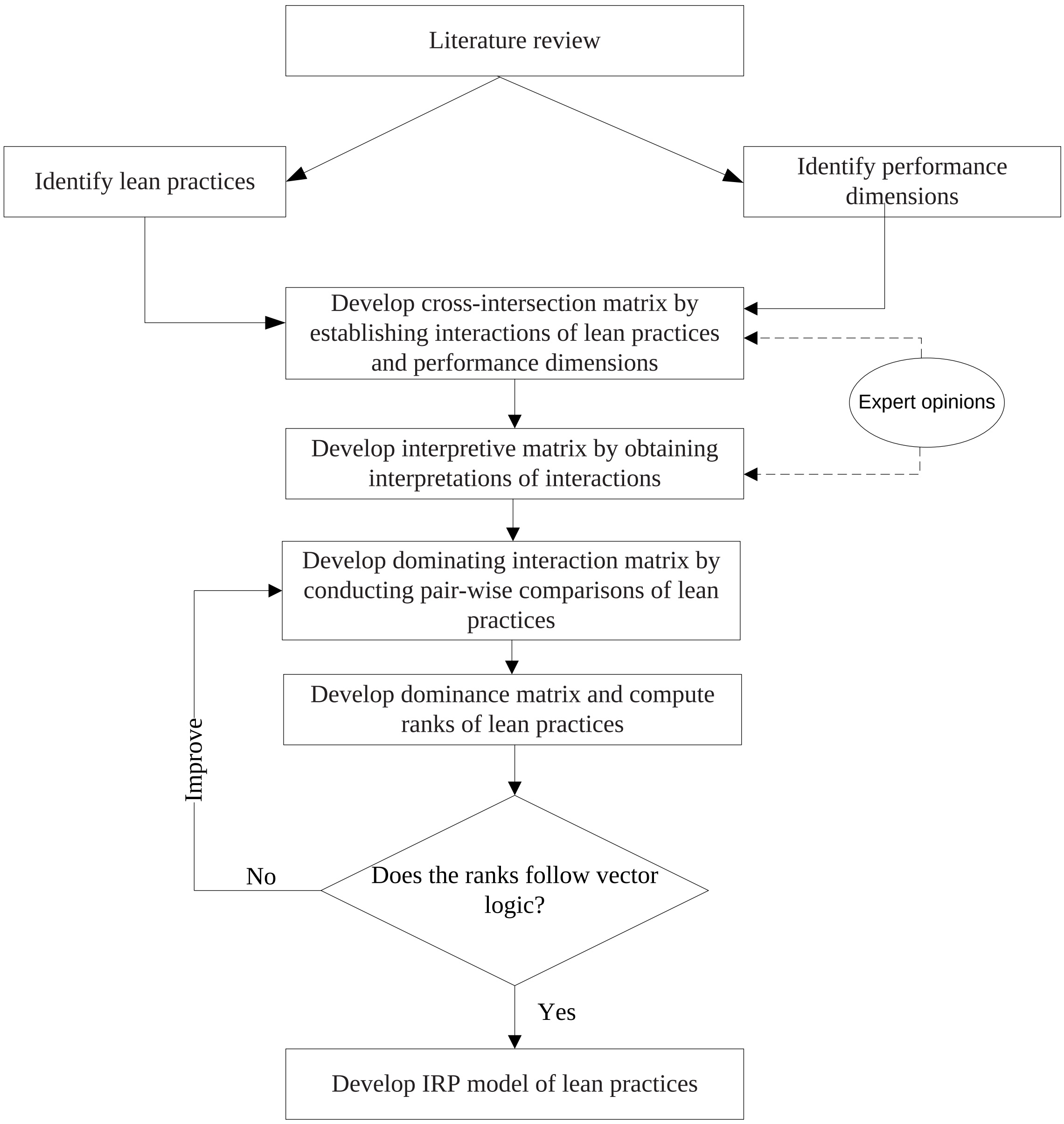


Figure 5.6: IRP methodology [Adapted from Zhang, Narkhede, and Chaple (2017)]

5.4.1 Develop IRP Models of Hard and Soft Lean Practices

5.4.1.1 Identify lean practices and performance dimensions: A literature review was conducted for the identification of lean practices and performance dimensions. 20 hard and 12 soft lean practices were identified from the literature as presented in tables 5.1 and 5.2 respectively. Total 26 performance dimensions are identified under seven functional areas of an organization. Detail description of identified performance dimensions are given in chapter 3. Some performance dimensions such as cost, quality, time, *etc.* are used to measure different functional areas, so those performance dimensions are considered as same. Total 17 different performance dimensions are used as reference to rank 32 lean practices. 20 hard practices are ranked on the basis of 11 related performance dimensions and 12 soft practices are ranked on the basis of 6 related performance dimensions.

5.4.1.2 Develop cross-interaction matrix: A group discussion session was conducted with four industrial experts to establish the interaction between lean practices and performance dimensions. These experts are heads of human resource, supply chain, manufacturing, and production planning and control departments of the case organization. The cross-interaction matrixes show the existence or nonexistence of relationship between lean practices and performance dimensions. For this, the binary numbers are used, where, '1' indicates the existence of relationship and '0' indicates nonexistence of relationship. The cross interaction matrixes for hard and soft lean practices are presented in tables 5.12 and 5.13 respectively.

5.4.1.3 Interpret interactions: The cross-interaction matrixes are converted into cross interaction-interpretive matrixes by interpreting all the interactions with entry '1' in terms of contextual relationships. The experts are also asked to interpret the meaning of "existence of relationship". For example, (P1, D3) is interpreted as 'JIT assures on-time delivery of products', (see table 5.14). The interpretive matrixes for hard and soft lean practices are presented in tables 5.14 and 5.15 respectively.

Table 5.12: Cross-interaction matrix of hard lean practices

	Cost (D1)	Quality (D2)	Delivery (D3)	Time (D4)	Inventory (D5)	Process flow (D6)	Work performance (D7)	Research and development (D8)	Market (D9)	Rate of return (D10)	Sales (D11)
JIT (P1)	0	0	1	1	1	1	0	0	1	0	0
TQM (P2)	0	1	0	0	0	1	1	1	0	0	0
TPM (P3)	0	0	0	1	1	1	0	0	0	0	0
5 S (P4)	0	0	0	1	0	1	1	0	0	0	0
Andon (P5)	0	1	1	1	0	1	0	0	0	0	0
Kaizen (P6)	1	1	1	1	0	1	1	0	0	0	0
***Takt* time (P7)**	1	1	1	1	1	1	1	0	1	0	1
Poka-yoke (P8)	1	1	0	1	0	1	1	0	0	1	1
Kanban (P9)	0	0	1	1	1	1	1	0	0	0	0
Lot size reduction (P10)	1	0	1	0	1	1	0	0	0	0	0
Pull production (P11)	0	0	1	1	1	1	0	0	0	0	0
Automation (P12)	1	1	1	1	0	1	1	0	0	1	0
Visual aids (P13)	0	0	0	1	1	1	1	1	0	0	0
Work standardization (P14)	1	1	1	1	0	1	0	0	0	0	0
One piece flow (P15)	0	0	1	1	1	1	1	0	0	0	0
SMED (P16)	1	0	1	1	0	0	0	0	0	0	0
Load levelling (P17)	0	0	0	1	0	1	1	0	0	0	0
VSM (P18)	1	1	1	1	1	1	1	0	0	1	0
Elimination of buffers (P19)	1	0	0	0	1	0	0	0	0	1	0
Synchronization (P20)	0	0	1	1	0	1	0	0	0	0	0

Table 5.13: Cross-interaction matrix of soft lean practices

	Health and safety (D12)	Empowerment (D13)	Skill (D14)	Serviceability (D15)	Communication (D16)	Decision making (D17)
Problem solving team (P21)	0	0	1	0	1	1
Safety improvement program (P22)	1	1	0	0	0	0
Cross-functional team (P23)	0	1	1	0	1	1
Employee involvement (P24)	0	1	1	0	0	1
Employee ownership (P25)	0	1	1	0	1	1
Customer involvement (P26)	0	0	0	1	1	1
Supplier relationship (P27)	0	0	0	1	1	0
Information sharing with suppliers (P28)	0	0	0	1	1	0
Rewards and recognition (P29)	1	1	1	1	0	1
Information sharing with employees (P30)	1	0	1	0	1	0
Supplier involvement (P31)	0	0	0	1	1	1
Team work (P32)	1	1	1	0	0	1

Table 5.14: Interpretive matrix of hard lean practices

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
P1			Assures on-time delivery	Reduces waiting time	Reduces inventory level	Improves material flow			Increases market presence		
P2		Reduces defect rate				Reduces defect rate, improves process capability index	Enhances quality control	Reduces number of processing losses			
P3				Reduces machine down time and waiting time	Reduces WIP inventory due to sudden breakdowns	Improves overall equipment effectiveness (OEE)					
P4				Improves throughput time		Improves space productivity	Reduces paperwork in office areas				
P5		Assures the quality by facilitating stop-call-wait practice	Improves delivery performance by reducing unwanted delays	Decreases machine down time		Reduces number of non-value added activities					
P6	Reduces cost of poor quality	Increases first pass yield (FPY)	Reduces transportation or motion	Reduces cycle time		Improves worker efficiency	Improves quality control				

Table 5.14: Interpretive matrix of hard lean practices (Contd.)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
P7	Reduces processing cost per unit	Reduces defect rate	Assures on-time delivery	Reduces lead time	Reduces inventory level	Reduces number of non-value added activities	Enhances synchronized scheduling		Enhances market value		Increases sales
P8	Reduces cost of poor quality	Prevents mistakes during working		Improves throughput time		Reduces number of non-value added activities	Improves quality control			Increases return on investment	Increases turnover
P9			Reduces transportation or motion	Reduces waiting time	Reduces WIP inventory	Reduces push process	Improves work performance at shop floor				
P10	Reduces manufacturing cost		Improves delivery performance		Reduces WIP inventory	Improves material flow					
P11			Assures on-time delivery	Reduces waiting time	Establishes material pull	Improves utilization efficiency					
P12	Reduces manufacturing cost	Reduces defect rate	Improves delivery performance	Improves throughput time		Improves OEE	Improves quality control			Increases return on investment	
P13				Reduces non-value added time	Reduces inventory level	Reduces number of non-value added activities	Improves work performance	Reduces number of processing losses			

Table 5.14: Interpretive matrix of hard lean practices (Contd.)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
P14	Reduces cost of poor quality	Reduces scrap ratio	Reduces transportation or motion	Improves throughput time		Reduces number of non-value added activities					
P15			Improves material flow	Reduces lead time	Reduces WIP inventory	Reduces number of non-value added activities	Improves work performance				
P16	Reduces manufacturing cost		Improves delivery performance	Reduces changeover time							
P17				Reduces cycle time		Improves OEE	Enhances synchronized scheduling				
P18	Reduces manufacturing cost	Reduces defect rate	Assures on-time delivery	Reduces cycle time	Reduces WIP inventory	Improves material and information flows	Improves quality control			Increases return on investment	
P19	Reduces inventory cost				Reduces inventory level					Increases return on investment	
P20			Improves delivery performance	Improves throughput time		Reduces number of non-value added activities					

Table 5.15: Interpretive matrix of soft lean practices

	D12	D13	D14	D15	D16	D17
P21			Improves skills by facing challenges together		improves communication through discussion	enhances decision making
P22	Reduces absenteeism	Empowers employees				
P23		Provides new opportunities	Enhances employees skills		Provides better communication platform	Supports decision making
P24		Improves employee progress	Increases commitment towards work			Improves decision making
P25		Transforms the mind-set and behaviour of employees	Helps to get better opportunities to enhance skills		Strengthen employee psychology	Pushes decision making downward
P26				Improves serviceability of the organization	Reduces communication gap	Makes decision making robust and quick
P27				Strengthen buyer-supplier relation and serviceability	Reduces communication gap	
P28				Helps to identify bottlenecks	Improves communication among buyers and suppliers	
P29	Enhances employee morale and mental health	Increases job satisfaction and reduces stresses	Motivates to learn more	Improves employee commitment		Increases participation in suggestion systems
P30	It aware the employees about health and safety		Sharing knowledge enhances skills		It improves organizational culture	
P31				Improves inventory to improve serviceability	Improves communication	Supports decision making
P32	Creates healthy working environment	Support weak employees	Enhances employee skills			Provides better and faster decisions

5.4.1.4 Conduct pair-wise comparisons: The developed interpretive matrixes are used to compare the lean practices with respect to the reference variables of performances dimensions. For this, the pair-wise comparisons between various lean practices are conducted. For example, the lean practice P1 is compared with practice P2 with respect to various performance dimensions D1, D2, D3, *etc.* In this kind of paired comparisons, the ranking variables are compared with the help of their interaction with respect to reference variable(s). The pair-wise comparisons for hard and soft lean practices are given in tables 5.16 and 5.17 respectively. Next, dominating interaction matrixes are developed by summarizing the information of pair-wise comparisons. The dominating interaction matrixes of hard and soft lean practices are given in tables 5.18 and 5.19 respectively.

Table 5.16: Pair-wise comparisons of hard lean practices

Pair-wise comparison of hard lean practices	Performance dimension w.r.t. which dominance holds true	Pair-wise comparison of hard lean practices	Performance dimension w.r.t. which dominance holds true
P1 dominating P2	D3,D4,D5,D6,D9	P11 dominating P6	D3,D5,D6
P1 dominating P3	D3,D4,D5,D6,D9	P11 dominating P7	D5
P1 dominating P4	D3,D4,D5,D6,D9	P11 dominating P8	D3,D5,D6
P1 dominating P5	D3,D4,D5,D9	P11 dominating P9	D3,D4,D6
P1 dominating P6	D3,D5,D9	P11 dominating P10	D3,D4,D5
P1 dominating P7	D5	P11 dominating P12	D3,D5,D6
P1 dominating P8	D3,D4,D5,D9	P11 dominating P13	D3,D4,D5,D6
P1 dominating P9	D3,D4,D9	P11 dominating P14	D5,D6
P1 dominating P10	D3,D4,D9	P11 dominating P15	D3,D4,D5
P1 dominating P11	D3,D9	P11 dominating P16	D3,D5,D6
P1 dominating P12	D3,D5,D9	P11 dominating P17	D3,D5
P1 dominating P13	D3,D4,D5,D9	P11 dominating P18	D5
P1 dominating P14	D3,D5,D9	P11 dominating P19	D3,D4,D6
P1 dominating P15	D3,D9	P11 dominating P20	D5,D6
P1 dominating P16	D3,D5,D6,D9	P12 dominating P1	D1,D2,D4,D6,D7,D10
P1 dominating P17	D3,D5,D9	P12 dominating P2	D1,D3,D4,D6,D7,D10
P1 dominating P18	D3,D9	P12 dominating P3	D1,D2,D3,D4,D6,D7,D10
P1 dominating P19	D3,D4,D6,D9	P12 dominating P4	D1,D2,D3,D4,D6,D7,D10
P1 dominating P20	D3,D5,D9	P12 dominating P5	D1,D2,D3,D4,D7,D10
P2 dominating P1	D2,D7,D8	P12 dominating P6	D1,D3,D4,D10
P2 dominating P3	D2,D6,D7,D8	P12 dominating P7	D1,D2,D10
P2 dominating P4	D2,D6,D7,D8	P12 dominating P8	D1,D3,D4,D6,D10
P2 dominating P5	D2,D7,D8	P12 dominating P9	D1,D2,D3,D4,D6,D7,D10
P2 dominating P6	D2,D8	P12 dominating P10	D1,D2,D3,D4,D7,D10
P2 dominating P7	D2,D8	P12 dominating P11	D1,D2,D4,D7,D10
P2 dominating P8	D2,D8	P12 dominating P13	D1,D2,D3,D4,D6,D10
P2 dominating P9	D2,D8	P12 dominating P14	D1,D2,D4,D7,D10

Table 5.16: Pair-wise comparisons of hard lean practices (Contd.)

Pair-wise comparison of hard lean practices	Performance dimension w.r.t. which dominance holds true	Pair-wise comparison of hard lean practices	Performance dimension w.r.t. which dominance holds true
P2 dominating P10	D2,D7,D8	P12 dominating P15	D1,D2,D4,D7,D10
P2 dominating P11	D2,D7,D8	P12 dominating P16	D1,D2,D3,D6,D7,D10
P2 dominating P12	D2,D8	P12 dominating P17	D1,D2,D3,D10
P2 dominating P13	D2,D6,D8	P12 dominating P18	D1,D10
P2 dominating P14	D2,D7,D8	P12 dominating P19	D1,D2,D3,D4,D6,D7,D10
P2 dominating P15	D2,D8	P12 dominating P20	D1,D2,D7,D10
P2 dominating P16	D2,D6,D7,D8	P13 dominating P1	D7,D8
P2 dominating P17	D2,D8	P13 dominating P2	D4,D5,D7
P2 dominating P18	D2,D8	P13 dominating P3	D7,D8
P2 dominating P19	D2,D6,D7,D8	P13 dominating P4	D5,D7,D8
P2 dominating P20	D2,D7,D8	P13 dominating P5	D5,D7,D8
P3 dominating P2	D4,D5	P13 dominating P6	D5,D8
P3 dominating P4	D4,D5,D6	P13 dominating P7	D7,D8
P3 dominating P5	D5	P13 dominating P8	D5,D7,D8
P3 dominating P6	D5	P13 dominating P9	D7,D8
P3 dominating P7	D5	P13 dominating P10	D4,D7,D8
P3 dominating P8	D5	P13 dominating P11	D7,D8
P3 dominating P9	D4	P13 dominating P12	D5,D7,D8
P3 dominating P10	D4	P13 dominating P14	D5,D7,D8
P3 dominating P11	D4	P13 dominating P15	D7,D8
P3 dominating P12	D5	P13 dominating P16	D5,D6,D7,D8
P3 dominating P13	D4,D5,D6	P13 dominating P17	D5,D7,D8
P3 dominating P14	D5	P13 dominating P18	D7,D8
P3 dominating P15	D4	P13 dominating P19	D4,D6,D7,D8
P3 dominating P16	D5,D6	P13 dominating P20	D5,D7,D8
P3 dominating P17	D5	P14 dominating P1	D1,D2,D4,D6
P3 dominating P19	D4,D6	P14 dominating P2	D1,D3,D4,D6
P4 dominating P1	D7	P14 dominating P3	D1,D2,D3,D4,D6
P4 dominating P2	D4	P14 dominating P4	D1,D2,D3,D4,D6
P4 dominating P3	D7	P14 dominating P5	D1,D2,D3,D4,D6
P4 dominating P5	D7	P14 dominating P6	D1,D3,D4,D6
P4 dominating P6	D7	P14 dominating P7	D1,D2
P4 dominating P9	D4,D7	P14 dominating P8	D3,D4,D6
P4 dominating P10	D4,D7	P14 dominating P9	D1,D2,D3,D4,D6
P4 dominating P11	D4,D7	P14 dominating P10	D1,D2,D3,D4
P4 dominating P13	D4,D6	P14 dominating P11	D1,D2,D3,D4
P4 dominating P14	D7	P14 dominating P12	D3,D6
P4 dominating P15	D4	P14 dominating P13	D1,D2,D3,D4,D6
P4 dominating P16	D6,D7	P14 dominating P15	D1,D2,D4
P4 dominating P19	D4,D6,D7	P14 dominating P16	D1,D2,D3,D6
P4 dominating P20	D7	P14 dominating P17	D1,D2,D3
P5 dominating P1	D2,D6	P14 dominating P18	D1,D2
P5 dominating P2	D3,D4,D6	P14 dominating P19	D2,D3,D4,D6
P5 dominating P3	D2,D3,D4	P14 dominating P20	D1,D2,D3
P5 dominating P4	D2,D3,D4	P15 dominating P1	D5,D6,D7
P5 dominating P6	D4,D6	P15 dominating P2	D3,D4,D5,D6,D7
P5 dominating P8	D3,D6	P15 dominating P3	D3,D5,D6,D7
P5 dominating P9	D4	P15 dominating P4	D3,D5,D6,D7

Table 5.16: Pair-wise comparisons of hard lean practices (Contd.)

Pair-wise comparison of hard lean practices	**Performance dimension w.r.t. which dominance holds true**	**Pair-wise comparison of hard lean practices**	**Performance dimension w.r.t. which dominance holds true**
P5 dominating P10	D2,D4	P15 dominating P5	D3,D5,D6,D7
P5 dominating P11	D2	P15 dominating P6	D3,D5,D6,D7
P5 dominating P12	D6	P15 dominating P7	D5
P5 dominating P13	D2,D3,D4,D6	P15 dominating P8	D3,D5,D6
P5 dominating P15	D2,D4	P15 dominating P9	D3,D4,D6
P5 dominating P16	D2,D6	P15 dominating P10	D3,D4,D6,D7
P5 dominating P17	D2,D3	P15 dominating P11	D6,D7
P5 dominating P19	D2,D3,D4,D6	P15 dominating P12	D3,D5,D6
P5 dominating P20	D2	P15 dominating P13	D4,D5,D6
P6 dominating P1	D1,D2,D6,D7	P15 dominating P14	D3,D5,D6,D7
P6 dominating P2	D1,D3,D4,D6	P15 dominating P16	D3,D5,D6,D7
P6 dominating P3	D1,D2,D3,D4,D6,D7	P15 dominating P17	D3,D5
P6 dominating P4	D1,D2,D3,D4	P15 dominating P18	D5,D7
P6 dominating P5	D1,D2,D3,D7	P15 dominating P19	D3,D4,D6,D7
P6 dominating P7	D2	P15 dominating P20	D3,D5,D6,D7
P6 dominating P8	D1,D2,D3,D4	P16 dominating P1	D1,D4
P6 dominating P9	D1,D2,D4,D7	P16 dominating P2	D1,D3,D4
P6 dominating P10	D2,D4,D7	P16 dominating P3	D1,D3,D4
P6 dominating P11	D1,D2,D4,D7	P16 dominating P4	D1,D3,D4
P6 dominating P13	D1,D2,D3,D4,D6,D7	P16 dominating P5	D1,D4
P6 dominating P14	D2,D7	P16 dominating P6	D3,D4
P6 dominating P15	D1,D2,D4	P16 dominating P8	D3,D4
P6 dominating P16	D1,D2,D6,D7	P16 dominating P9	D1,D4
P6 dominating P17	D1,D2,D3	P16 dominating P10	D3,D4
P6 dominating P18	D2	P16 dominating P11	D1,D4
P6 dominating P19	D2,D3,D4,D6,D7	P16 dominating P12	D4
P6 dominating P20	D1,D2,D7	P16 dominating P13	D1,D3,D4
P7 dominating P1	D1,D2,D3,D4,D6,D7,D9,D11	P16 dominating P14	D4
P7 dominating P2	D1,D3,D4,D5,D6,D7,D9,D11	P16 dominating P15	D1,D4
P7 dominating P3	D1,D2,D3,D4,D6,D7,D9,D11	P16 dominating P17	D1,D3
P7 dominating P4	D1,D2,D3,D4,D5,D6,D7,D9, D11	P16 dominating P18	D1
P7 dominating P5	D1,D2,D3,D4,D5,D6,D7,D9, D11	P16 dominating P19	D3,D4
P7 dominating P6	D1,D3,D4,D5,D6,D7,D9,D11	P16 dominating P20	D1
P7 dominating P8	D1,D3,D4,D5,D6,D7,D9,D11	P17 dominating P1	D6,D7
P7 dominating P9	D1,D2,D3,D4,D6,D7,D9,D11	P17 dominating P2	D4,D6,D7
P7 dominating P10	D2,D3,D4,D6,D7,D9,D11	P17 dominating P3	D6,D7
P7 dominating P11	D1,D2,D3,D4,D6,D7,D9,D11	P17 dominating P4	D4,D6
P7 dominating P12	D3,D4,D5,D6,D7,D9,D11	P17 dominating P5	D4,D6,D7
P7 dominating P13	D1,D2,D3,D4,D5,D6,D9,D11	P17 dominating P6	D4,D6,D7
P7 dominating P14	D3,D4,D5,D6,D7,D9,D11	P17 dominating P7	D6
P7 dominating P15	D1,D2,D3,D4,D6,D7,D9,D11	P17 dominating P8	D4,D6
P7 dominating P16	D1,D2,D3,D4,D5,D6,D7,D9, D11	P17 dominating P9	D4,D6,D7
P7 dominating P17	D1,D2,D3,D4,D5,D7,D9,D11	P17 dominating P10	D4,D6,D7
P7 dominating P18	D1,D3,D4,D7,D9,D11	P17 dominating P11	D4,D6,D7
P7 dominating P19	D2,D3,D4,D6,D7,D9,D11	P17 dominating P12	D4,D6,D7

Table 5.16: Pair-wise comparisons of hard lean practices (Contd.)

Pair-wise comparison of hard lean practices	Performance dimension w.r.t. which dominance holds true	Pair-wise comparison of hard lean practices	Performance dimension w.r.t. which dominance holds true
P7 dominating P20	D1,D2,D3,D4,D5,D6,D7,D9, D11	P17 dominating P13	D4,D6
P8 dominating P1	D1,D2,D6,D7,D10,D11	P17 dominating P14	D4,D6,D7
P8 dominating P2	D1,D4,D6,D7,D10,D11	P17 dominating P15	D4,D6,D7
P8 dominating P3	D1,D2,D4,D6,D7,D10,D11	P17 dominating P16	D4,D6,D7
P8 dominating P4	D1,D2,D4,D7,D10,D11	P17 dominating P18	D4,D7
P8 dominating P5	D1,D2,D7,D10,D11	P17 dominating P19	D4,D6,D7
P8 dominating P6	D6,D7,D10,D11	P17 dominating P20	D4,D6,D7
P8 dominating P7	D2,D10	P18 dominating P1	D1,D2,D4,D5,D6,D7,D10
P8 dominating P9	D1,D2,D6,D7,D10,D11	P18 dominating P2	D1,D3,D4,D5,D6,D7,D10
P8 dominating P10	D2,D4,D7,D10,D11	P18 dominating P3	D1,D2,D3,D4,D5,D6,D7, D10
P8 dominating P11	D1,D2,D7,D10,D11	P18 dominating P4	D1,D2,D3,D4,D5,D6,D7, D10
P8 dominating P12	D2,D7,D11	P18 dominating P5	D1,D2,D3,D4,D5,D6,D7, D10
P8 dominating P13	D1,D2,D4,D6,D10,D11	P18 dominating P6	D1,D3,D4,D5,D6,D10
P8 dominating P14	D2,D10,D11	P18 dominating P7	D2,D5,D10
P8 dominating P15	D1,D2,D7,D10,D11	P18 dominating P8	D2,D3,D4,D5,D6,D10
P8 dominating P16	D1,D2,D6,D7,D10,D11	P18 dominating P9	D1,D2,D3,D4,D6,D7,D10
P8 dominating P17	D1,D2,D7,D10,D11	P18 dominating P10	D2,D3,D4,D6,D7,D10
P8 dominating P18	D1,D11	P18 dominating P11	D1,D2,D3,D4,D6,D7,D10
P8 dominating P19	D2,D4,D6,D7,D11	P18 dominating P12	D2,D3,D4,D5,D6
P8 dominating P20	D1,D2,D7,D10,D11	P18 dominating P13	D1,D2,D3,D4,D5,D6,D10
P9 dominating P1	D5,D6,D7	P18 dominating P14	D3,D4,D5,D6,D7,D10
P9 dominating P2	D3,D4,D5,D6	P18 dominating P15	D1,D2,D3,D4,D6,D10
P9 dominating P3	D3,D5,D7	P18 dominating P16	D2,D3,D4,D5,D6,D7,D10
P9 dominating P4	D3,D5,D6	P18 dominating P17	D1,D2,D3,D5,D6,D10
P9 dominating P5	D3,D5,D7	P18 dominating P19	D2,D3,D4,D6,D7
P9 dominating P6	D3,D5,D6	P18 dominating P20	D1,D2,D3,D4,D5,D6,D7, D10
P9 dominating P7	D5	P19 dominating P1	D1,D5,D10
P9 dominating P8	D3,D5	P19 dominating P2	D1,D5,D10
P9 dominating P10	D3,D4,D5,D7	P19 dominating P3	D1,D5,D10
P9 dominating P11	D5,D7	P19 dominating P4	D1,D5,D10
P9 dominating P12	D5	P19 dominating P5	D1,D5,D10
P9 dominating P13	D3,D4,D5	P19 dominating P6	D1,D5,D10
P9 dominating P14	D5,D7	P19 dominating P7	D1,D5,D10
P9 dominating P15	D5	P19 dominating P8	D1,D5,D10
P9 dominating P16	D3,D5,D6,D7	P19 dominating P9	D1,D5,D10
P9 dominating P17	D3,D5	P19 dominating P10	D1,D5,D10
P9 dominating P18	D5	P19 dominating P11	D1,D5,D10
P9 dominating P19	D3,D4,D6,D7	P19 dominating P12	D5
P9 dominating P20	D5,D7	P19 dominating P13	D1,D5,D10
P10 dominating P1	D1,D5,D6	P19 dominating P14	D1,D5,D10
P10 dominating P2	D1,D3,D5,D6	P19 dominating P15	D1,D5,D10
P10 dominating P3	D1,D3,D5,D6	P19 dominating P16	D1,D5,D10
P10 dominating P4	D1,D3,D5,D6	P19 dominating P17	D1,D5,D10

Table 5.16: Pair-wise comparisons of hard lean practices (Contd.)

Pair-wise comparison of hard lean practices	Performance dimension w.r.t. which dominance holds true	Pair-wise comparison of hard lean practices	Performance dimension w.r.t. which dominance holds true
P10 dominating P5	D1,D3,D5,D6	P19 dominating P18	D1,D5,D10
P10 dominating P6	D1,D3,D5,D6	P19 dominating P20	D1,D5,D10
P10 dominating P7	D1,D5	P20 dominating P1	D6
P10 dominating P8	D1,D3,D5,D6	P20 dominating P2	D3,D4,D6
P10 dominating P9	D1,D6	P20 dominating P3	D3,D6
P10 dominating P11	D1,D6	P20 dominating P4	D3,D4
P10 dominating P12	D5,D6	P20 dominating P5	D3,D4,D6
P10 dominating P13	D1,D3,D5,D6	P20 dominating P6	D3,D4,D6
P10 dominating P14	D5,D6	P20 dominating P8	D3,D4,D6
P10 dominating P15	D1,D5	P20 dominating P9	D3,D4,D6
P10 dominating P16	D1,D5,D6	P20 dominating P10	D3,D4
P10 dominating P17	D1,D3,D5	P20 dominating P11	D4
P10 dominating P18	D1,D5	P20 dominating P12	D3,D4,D6
P10 dominating P19	D3,D6	P20 dominating P13	D3,D4,D6
P10 dominating P20	D1,D5	P20 dominating P14	D4,D6
P11 dominating P1	D5,D6	P20 dominating P15	D4
P11 dominating P2	D3,D4,D5,D6	P20 dominating P16	D3,D4,D6
P11 dominating P3	D3,D5,D6	P20 dominating P17	D3
P11 dominating P4	D3,D5,D6	P20 dominating P19	D3,D4,D6
P11 dominating P5	D3,D5,D6		

Table 5.17: Pair-wise comparisons of soft lean practices

Pair-wise comparison of soft lean practices	Performance dimension w.r.t. which dominance holds true	Pair-wise comparison of soft lean practices	Performance dimension w.r.t. which dominance holds true
P21 dominating P22	D14,D16,D17	P27 dominating P22	D15,D16
P21 dominating P24	D16,D17	P27 dominating P23	D15
P21 dominating P26	D14	P27 dominating P24	D15,D16
P21 dominating P27	D14,D17	P27 dominating P25	D15
P21 dominating P28	D14,D17	P27 dominating P26	D15
P21 dominating P29	D14,D16	P27 dominating P28	D15
P21 dominating P30	D14,D17	P27 dominating P29	D15,D16
P21 dominating P31	D14	P27 dominating P30	D15
P21 dominating P32	D14,D16	P27 dominating P31	D15,D16
P22 dominating P21	D12,D13	P27 dominating P32	D15,D16
P22 dominating P23	D12	P28 dominating P21	D15,D16
P22 dominating P24	D12	P28 dominating P22	D15,D16
P22 dominating P25	D12	P28 dominating P23	D15,D16
P22 dominating P26	D12,D13	P28 dominating P24	D15,D16
P22 dominating P27	D12,D13	P28 dominating P25	D15,D16
P22 dominating P28	D12,D13	P28 dominating P26	D16
P22 dominating P29	D12	P28 dominating P27	D16
P22 dominating P30	D12,D13	P28 dominating P29	D15,D16
P22 dominating P31	D12,D13	P28 dominating P30	D15
P22 dominating P32	D12	P28 dominating P31	D15,D16
P23 dominating P21	D13	P28 dominating P32	D15,D16
P23 dominating P22	D13,D14,D16,D17	P29 dominating P21	D12,D13,D15,D17
P23 dominating P24	D14,D16,D17	P29 dominating P22	D13,D14,D15,D17
P23 dominating P25	D13,D16,D17	P29 dominating P23	D12,D13,D15
P23 dominating P26	D13,D14,D16	P29 dominating P24	D12,D15,D17
P23 dominating P27	D13,D14,D17	P29 dominating P25	D12,D13,D15

Table 5.17: Pair-wise comparisons of soft lean practices (Contd.)

Pair-wise comparison of soft lean practices	Performance dimension w.r.t. which dominance holds true	Pair-wise comparison of soft lean practices	Performance dimension w.r.t. which dominance holds true
P23 dominating P28	D13,D14,D17	P29 dominating P26	D12,D13,D14
P23 dominating P29	D14,D16,D17	P29 dominating P27	D12,D13,D14,D17
P23 dominating P30	D13,D14,D17	P29 dominating P28	D12,D13,D14,D17
P23 dominating P31	D13,D14,D17	P29 dominating P30	D12,D13,D14,D15,D17
P23 dominating P32	D14,D16	P29 dominating P31	D12,D13,D14,D15
P24 dominating P21	D13,D14	P29 dominating P32	D12,D13,D14,D15
P24 dominating P22	D13,D14,D17	P30 dominating P21	D12,D16
P24 dominating P23	D13	P30 dominating P22	D14,D16
P24 dominating P25	D13	P30 dominating P23	D12,D16
P24 dominating P26	D13,D14	P30 dominating P24	D12,D16
P24 dominating P27	D13,D14,D17	P30 dominating P25	D12,D16
P24 dominating P28	D13,D14,D17	P30 dominating P26	D12,D14,D16
P24 dominating P29	D13,D14	P30 dominating P27	D12,D14,D16
P24 dominating P30	D13,D14,D17	P30 dominating P28	D12,D14,D16
P24 dominating P31	D13,D14	P30 dominating P29	D16
P24 dominating P32	D13	P30 dominating P31	D12,D14,D16
P25 dominating P21	D13,D14,D16,D17	P30 dominating P32	D16
P25 dominating P22	D13,D14,D16,D17	P31 dominating P21	D15,D16,D17
P25 dominating P23	D14	P31 dominating P22	D15,D16,D17
P25 dominating P24	D14,D16,D17	P31 dominating P23	D15
P25 dominating P26	D13,D14,D16,D17	P31 dominating P24	D15,D16,D17
P25 dominating P27	D13,D14,D16,D17	P31 dominating P25	D15
P25 dominating P28	D13,D14,D17	P31 dominating P27	D17
P25 dominating P29	D14,D16,D17	P31 dominating P28	D17
P25 dominating P30	D13,D14,D17	P31 dominating P29	D16,D17
P25 dominating P31	D13,D14,D16,D17	P31 dominating P30	D15,D17
P25 dominating P32	D14,D16	P31 dominating P32	D15,D16
P26 dominating P21	D15,D17	P32 dominating P21	D12,D13,D17
P26 dominating P22	D15,D16,D17	P32 dominating P22	D13,D14,D17
P26 dominating P23	D15,D17	P32 dominating P23	D12,D13,D17
P26 dominating P24	D15,D16	P32 dominating P24	D12,D17
P26 dominating P25	D15	P32 dominating P25	D12,D13,D17
P26 dominating P27	D16,D17	P32 dominating P26	D12,D13,D14,D17
P26 dominating P28	D15,D17	P32 dominating P27	D12,D13,D14,D17
P26 dominating P29	D15,D16	P32 dominating P28	D12,D13,D14,D17
P26 dominating P30	D15,D17	P32 dominating P29	D17
P26 dominating P31	D15,D16,D17	P32 dominating P30	D12,D13,D14,D17
P26 dominating P32	D15,D16	P32 dominating P31	D12,D13,D14,D17
P27 dominating P21	D15,D16		

Table 5.18: Dominating interaction matrix of hard lean practices

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
P1	-	D3,D4, D5,D6, D9	D3,D4, D5,D6, D9	D3,D4, D5,D6, D9	D3,D4, D5, D9	D3,D5, D9	D5	D3,D4, D5,D9	D3,D4, D9	D3,D4, D9	D3,D9	D3,D5, D9	D3,D4, D5,D9	D3,D5, D9	D3,D9	D3,D5, D6,D9	D3,D5, D9	D3,D9	D3,D4, D6,D9	D3,D5, D9
P2	D2,D7, D8	-	D2,D6, D7,D8	D2,D6, D7,D8	D2,D7, D8	D2,D8	D2,D8	D2,D8	D2,D8	D2,D7, D8	D2,D7, D8	D2,D8	D2,D6, D8	D2,D7, D8	D2,D8	D2,D6, D7,D8	D2,D8	D2,D8	D2,D6, D7,D8	D2,D7, D8
P3	-	D4,D5	-	D4,D5, D6	D5	D5	D5	D5	D4	D4	D4	D5	D4,D5, D6	D5	D4	D5,D6	D5	-	D4,D6	-
P4	D7	D4	D7	-	D7	D7	-	-	D4,D7	D4,D7	D4,D7	-	D4,D6	D7	D4	D6,D7	-	-	D4,D6, D7	D7
P5	D2,D6	D3,D4, D6	D2,D3, D4	D2,D3, D4	-	D4,D6	-	D3,D6	D4	D2,D4	D2	D6	D2,D3, D4,D6	-	D2,D4	D2,D6	D2,D3	-	D2,D3, D4,D6	D2
P6	D1,D2, D6,D7	D1,D3, D4,D6	D1,D2, D3,D4, D6,D7	D1,D2, D3,D4	D1,D2, D3,D7	-	D2	D1,D2, D3,D4	D1,D2, D4,D7	D2,D4, D7	D1,D2, D4,D7	-	D1,D2, D3,D4, D6,D7	D2,D7	D1,D2, D4	D1,D2, D6,D7	D1,D2, D3	D2	D2,D3, D4,D6, D7	D1,D2, D7
P7	D1,D2, D3,D4, D6,D7, D9, D11	D1,D3, D4,D5, D6,D7, D9, D11	D1,D2, D3,D4, D6,D7, D9, D11	D1,D2, D3,D4, D5,D6, D7,D9, D11	D1,D2, D3,D4, D5,D6, D7,D9, D11	D1,D3, D4,D5, D6,D7, D9, D11	-	D1,D3, D4,D5, D6,D7, D9, D11	D1,D2, D3,D4, D6,D7, D9, D11	D2,D3, D4,D6, D7,D9, D11	D1,D2, D3,D4, D6,D7, D9, D11	D3,D4, D5,D6, D7,D9, D11	D1,D2, D3,D4, D5,D6, D9, D11	D3,D4, D5,D6, D7,D9, D11	D1,D2, D3,D4, D6,D7, D9, D11	D1,D2, D3,D4, D5,D6, D7,D9, D11	D1,D2, D3,D4, D5,D7, D9, D11	D1,D3, D4,D7, D9, D11	D2,D3, D4,D6, D7,D9, D11	D1,D2, D3,D4, D5,D6, D7,D9, D11
P8	D1,D2, D6,D7, D10, D11	D1,D4, D6,D7, D10, D11	D1,D2, D4,D6, D7, D10, D11	D1,D2, D4,D7, D10, D11	D1,D2, D7, D10, D11	D6,D7, D10, D11	D2, D10	-	D1,D2, D6,D7, D10, D11	D2,D4, D7, D10, D11	D1,D2, D7, D10, D11	D2,D7, D11	D1,D2, D4,D6, D10, D11	D2, D10, D11	D1,D2, D7, D10, D11	D1,D2, D6,D7, D10, D11	D1,D2, D7, D10, D11	D1, D11	D2,D4, D6,D7, D11	D1,D2, D7, D10, D11
P9	D5,D6, D7	D3,D4, D5,D6	D3,D5, D7	D3,D5, D6	D3,D5, D7	D3,D5, D6	D5	D3,D5	-	D3,D4, D5,D7	D5,D7	D5	D3,D4, D5	D5,D7	D5	D3,D5, D6,D7	D3,D5	D5	D3,D4, D6,D7	D5,D7
P10	D1,D5, D6	D1,D3, D5,D6	D1,D3, D5,D6	D1,D3, D5,D6	D1,D3, D5,D6	D1,D3, D5,D6	D1,D5	D1,D3, D5,D6	D1,D6	-	D1,D6	D5,D6	D1,D3, D5,D6	D5,D6	D1,D5	D1,D5, D6	D1,D3, D5	D1,D5	D3,D6	D1,D5

Table 5.18: Dominating interaction matrix of hard lean practices (Contd.)

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
P11	D5,D6	D3,D4,D5,D6	D3,D5,D6	D3,D5,D6	D3,D5,D6	D3,D5,D6	D5	D3,D5,D6	D3,D4,D6	D3,D4,D5	-	D3,D5,D6	D3,D4,D5,D6	D5,D6	D3,D4,D5	D3,D5,D6	D3,D5	D5	D3,D4,D6	D5,D6
P12	D1,D2,D4,D6,D7,D10	D1,D3,D4,D6,D7,D10	D1,D2,D3,D4,D6,D7,D10	D1,D2,D3,D4,D6,D7,D10	D1,D2,D3,D4,D7,D10	D1,D3,D4,D10	D1,D2,D10	D1,D3,D4,D6,D10	D1,D2,D3,D4,D6,D7,D10	D1,D2,D3,D4,D7,D10	D1,D2,D4,D7,D10	-	D1,D2,D3,D4,D6,D10	D1,D2,D4,D7,D10	D1,D2,D4,D7,D10	D1,D2,D3,D6,D7,D10	D1,D2,D3,D10	D1,D10	D1,D2,D3,D4,D6,D7,D10	D1,D2,D7,D10
P13	D7,D8	D4,D5,D7	D7,D8	D5,D7,D8	D5,D7,D8	D5,D8	D7,D8	D5,D7,D8	D7,D8	D4,D7,D8	D7,D8	D5,D7,D8	-	D5,D7,D8	D7,D8	D5,D6,D7,D8	D5,D7,D8	D7,D8	D4,D6,D7,D8	D5,D7,D8
P14	D1,D2,D4,D6	D1,D3,D4,D6	D1,D2,D3,D4,D6	D1,D2,D3,D4,D6	D1,D2,D3,D4,D6	D1,D3,D4,D6	D1,D2	D3,D4,D6	D1,D2,D3,D4,D6	D1,D2,D3,D4	D1,D2,D3,D4	D3,D6	D1,D2,D3,D4,D6	-	D1,D2,D4	D1,D2,D3,D6	D1,D2,D3	D1,D2	D2,D3,D4,D6	D1,D2,D3
P15	D5,D6,D7	D3,D4,D5,D6,D7	D3,D5,D6,D7	D3,D5,D6,D7	D3,D5,D6,D7	D3,D5,D6,D7	D5	D3,D5,D6	D3,D4,D6	D3,D4,D6,D7	D6,D7	D3,D5,D6	D3,D4,D5,D6	D5,D6,D7	-	D3,D5,D6,D7	D3,D5	D5,D7	D3,D4,D6,D7	D3,D5,D6,D7
P16	D1,D4	D1,D3,D4	D1,D3,D4	D1,D3,D4	D1,D4	D3,D4	-	D3,D4	D1,D4	D3,D4	D1,D4	D4	D1,D3,D4	D4	D1,D4	-	D1,D3	D1	D3,D4	D1
P17	D6,D7	D4,D6,D7	D6,D7	D4,D6	D4,D6,D7	D4,D6,D7	D6	D4,D6	D4,D6,D7	D4,D6,D7	D4,D6,D7	D4,D6,D7	D4,D6	D4,D6,D7	D4,D6,D7	D4,D6,D7	-	D4,D7	D4,D6,D7	D4,D6,D7
P18	D1,D2,D4,D5,D6,D7,D10	D1,D3,D4,D5,D6,D7,D10	D1,D2,D3,D4,D5,D6,D7,D10	D1,D2,D3,D4,D5,D6,D7,D10	D1,D2,D3,D4,D5,D6,D7,D10	D1,D3,D4,D5,D6,D10	D2,D5,D10	D2,D3,D4,D5,D6,D10	D1,D2,D3,D4,D6,D7,D10	D2,D3,D4,D6,D7,D10	D1,D2,D3,D4,D6,D7,D10	D2,D3,D4,D5,D6	D1,D2,D3,D4,D5,D6,D10	D3,D4,D5,D6,D7,D10	D1,D2,D3,D4,D6,D10	D2,D3,D4,D5,D6,D7,D10	D1,D2,D3,D5,D6,D10	-	D2,D3,D4,D6,D7	D1,D2,D3,D4,D5,D6,D7,D10
P19	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	D5	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	D1,D5,D10	-	D1,D5,D10
P20	D6	D3,D4,D6	D3,D6	D3,D4	D3,D4,D6	D3,D4,D6	-	D3,D4,D6	D3,D4,D6	D3,D4	D4	D3,D4,D6	D3,D4,D6	D4,D6	D4	D3,D4,D6	D3	-	D3,D4,D6	-

Table 5.19: Dominating interaction matrix of soft lean practices

	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32
P21	-	D14,D16, D17	-	D16,D17	-	D14	D14,D17	D14,D17	D14,D16	D14,D17	D14	D14,D16
P22	D12,D13	-	D12	D12	D12	D12,D13	D12,D13	D12,D13	D12	D12,D13	D12,D13	D12
P23	D13	D13,D14, D16,D17	-	D14,D16, D17	D13,D16, D17	D13,D14, D16	D13,D14, D17	D13,D14, D17	D14,D16, D17	D13,D14,D17	D13,D14, D17	D14,D16
P24	D13,D14	D13,D14, D17	D13	-	D13	D13,D14	D13,D14, D17	D13,D14, D17	D13,D14	D13,D14,D17	D13,D14	D13
P25	D13,D14, D16,D17	D13,D14, D16,D17	D14	D14,D16, D17	-	D13,D14, D16,D17	D13,D14, D16,D17	D13,D14, D17	D14,D16, D17	D13,D14,D17	D13,D14, D16,D17	D14,D16
P26	D15,D17	D15,D16, D17	D15,D17	D15,D16	D15	-	D16,D17	D15,D17	D15,D16	D15,D17	D15,D16, D17	D15,D16
P27	D15,D16	D15,D16	D15	D15,D16	D15	D15	-	D15	D15,D16	D15	D15,D16	D15,D16
P28	D15,D16	D15,D16	D15,D16	D15,D16	D15,D16	D16	D16	-	D15,D16	D15	D15,D16	D15,D16
P29	D12,D13,D 15,D17	D13,D14, D15,D17	D12,D13, D15	D12,D15, D17	D12,D13, D15	D12,D13, D14	D12,D13, D14,D17	D12,D13, D14,D17	-	D12,D13,D14, D15,D17	D12,D13, D14,D15	D12,D13, D14,D15
P30	D12,D16	D14,D16	D12,D16	D12,D16	D12,D16	D12,D14, D16	D12,D14, D16	D12,D14, D16	D16	-	D12,D14, D16	D16
P31	D15,D16, D17	D15,D16, D17	D15	D15,D16, D17	D15	-	D17	D17	D16,D17	D15,D17	-	D15,D16
P32	D12,D13, D17	D13,D14, D17	D12,D13, D17	D12,D17	D12,D13, D17	D12,D13, D14,D17	D12,D13, D14,D17	D12,D13, D14,D17	D17	D12,D13,D14, D17	D12,D13, D14,D17	-

5.4.1.5 Develop dominance matrix: The dominating interaction matrixes are converted into dominance matrixes. The number of variables in each cell of dominance matrixes are counted and replaced with numbers (total number of performance dimensions in the cell) as presented in tables 5.20 and 5.21 for hard and soft lean practices respectively. These matrixes give the number of cases, where one variable dominates or is being dominated by other variables. The net dominance (D-B) is calculated for each ranking variable, where D is the total number of cases where particular variable dominates other variables and B is the total number of cases, where particular variable is being dominated by the other variables. The variables are ranked according to their net dominance values (D-B) as presented in tables 5.20 and 5.21 for hard and soft lean practices respectively.

Table 5.20: Dominance matrix of hard lean practices

		Being dominated variables																					
		P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**	**P14**	**P15**	**P16**	**P17**	**P18**	**P19**	**P20**	**D**	**D-B**	**Rank**
Dominating variables	**P1**	-	5	5	5	4	3	1	4	3	3	2	3	4	3	2	4	3	2	4	3	63	1	**VIII**
	P2	3	-	4	4	3	2	2	2	2	3	3	2	3	3	2	4	2	2	4	3	53	-25	**XV**
	P3	-	2	-	3	1	1	1	1	1	1	1	1	3	1	1	2	1	-	2	-	23	-57	**XIX**
	P4	1	1	1	-	1	1	-	-	2	2	2	-	2	1	1	2	-	-	3	1	21	-60	**XX**
	P5	2	3	3	3	-	2	-	2	1	2	1	1	4	-	2	2	2	-	4	1	35	-39	**XVII**
	P6	4	4	6	4	4	-	1	4	4	3	4	-	6	2	3	4	3	1	5	3	65	3	**VII**
	P7	8	8	8	9	9	8	-	8	8	7	8	7	8	7	8	9	8	6	7	9	150	124	**I**
	P8	6	6	7	6	5	4	2	-	6	5	5	3	6	3	5	6	5	2	5	5	92	32	**IV**
	P9	3	4	3	3	3	3	1	2	-	4	2	1	3	2	1	4	2	1	4	2	48	-19	**XII**
	P10	3	4	4	4	4	4	2	4	2	-	2	2	4	2	2	3	3	2	2	2	55	-11	**XI**
	P11	2	4	3	3	3	3	1	3	3	3	-	3	4	2	3	3	2	1	3	2	51	-8	**X**
	P12	6	6	7	7	6	4	3	5	7	6	5	-	6	5	5	6	4	2	7	4	101	57	**III**
	P13	2	3	2	3	3	2	2	3	2	3	2	3	-	3	2	4	3	2	4	3	51	-29	**XVI**
	P14	4	4	5	5	5	4	2	3	5	4	4	2	5	-	3	4	3	2	4	3	71	19	**V**
	P15	3	5	4	4	4	4	1	3	3	4	2	3	4	3	-	4	2	2	4	4	63	8	**VI**
	P16	2	3	3	3	2	2	-	2	2	2	2	1	3	1	2	-	2	1	2	1	36	-41	**XVIII**
	P17	2	3	2	2	3	3	1	2	3	3	3	3	2	3	3	3	-	2	3	3	49	-6	**IX**
	P18	7	7	8	8	8	6	3	6	7	6	7	5	7	6	6	7	6	-	5	8	123	92	**II**
	P19	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	-	3	55	-20	**XIII**
	P20	1	3	2	2	3	3	-	3	3	2	1	3	3	2	1	3	1	-	3	-	39	-21	**XIV**
	B	62	78	80	81	74	62	26	60	67	66	59	44	80	52	55	77	55	31	75	60	**1244**	**0**	

Table 5.21: Dominance matrix of soft lean practices

		Being dominated variables													
		P21	**P22**	**P23**	**P24**	**P25**	**P26**	**P27**	**P28**	**P29**	**P30**	**P31**	**P32**	**D**	**D-B**	**RANK**
Dominating variables	**P21**	-	3	-	2	-	1	2	2	2	2	1	2	17	-10	**VIII**
	P22	2	-	1	1	1	2	2	2	1	2	2	1	17	-16	**XI**
	P23	1	4	-	3	3	3	3	3	3	3	3	2	31	14	**III**
	P24	2	3	1	-	1	2	3	3	2	3	2	1	23	-2	**V**
	P25	4	4	1	3	-	4	4	3	3	3	4	2	35	17	**II**
	P26	2	3	2	2	1	-	2	2	2	2	3	2	23	-1	**IV**
	P27	2	2	1	2	1	1	-	1	2	1	2	2	17	-12	**X**
	P28	2	2	2	2	2	1	1	-	2	1	2	2	19	-9	**VII**
	P29	4	4	3	3	3	3	4	4	-	5	4	4	41	20	**I**
	P30	2	2	2	2	2	3	3	3	1	-	3	1	24	-4	**VI**
	P31	3	3	1	3	1	-	1	1	2	2	-	2	19	-11	**IX**
	P32	3	3	3	2	3	4	4	4	1	4	4	-	35	14	**III**
	B	**27**	**33**	**17**	**25**	**18**	**24**	**29**	**28**	**21**	**28**	**30**	**21**	**301**	**0**	

5.4.1.6 Check the validity of ranks: The expert interpretation of relationships between lean practices and performance dimensions is used for pair-wise comparisons of lean practices. These pair-wise comparisons are summarized into dominating interaction matrixes, which are further used to calculate the ranks of various lean practices. Therefore, if the expert interpretations are wrong, then the ranks are also wrong. Thus the ranks need to be validated.

Individual dominance system graph is developed for each performance dimension which are used to validate the ranks (see figures 5.7 to 5.23). In these graphs, two lean practices are joined by an arrow. The direction of the arrow shows the dominance of particular lean practice over the other. Unidirectionlity and transitive relationships among arrows means the interpreted pair-wise comparisons are correct. And, if the arrows form loops or cycles in the graph, then, the pair-wise comparisons need to be modified as shown in figure 5.7.

For example, the dominance system graph for cost shows the dominance of lean practices over each other with respect to the cost (see figure 5.7). The arrows (vectors) are unidirectional except one, from P8 to P14. It means *poka-yoke* (P8) practice dominates work standardization (P14) with respect to cost as represented by red arrow. This judgment is inconsistent and violates the transitivity principle. Therefore, this link is removed from the dominance system graph and the corresponding pair-wise comparison (table 5.16) and dominating interpretation matrix (table 5.18) are modified. All other judgments are consistent and follow the transitivity principle. Similarly, the transitivity violations are removed from all other dominance system graphs; and the corresponding pair-wise comparisons (tables 5.16 and 5.17) and dominating interpretation matrixes (tables 5.18 and 5.19) are modified. Also, according to Sushil (2009), if the sum of net dominance is zero, then the ranks are validated. The sum of net dominance [∑(D-B)] for both hard and soft lean practices is zero as presented in tables 5.20 and 5.21 respectively, thereby validating the updated ranks.

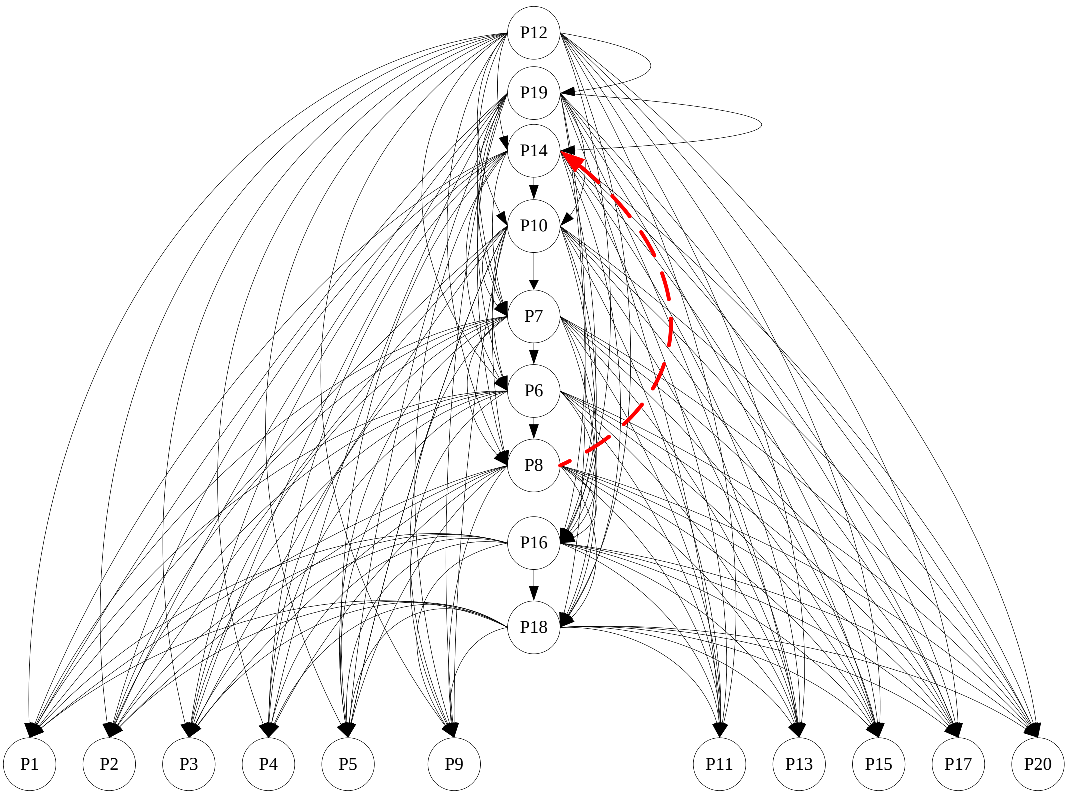


Figure 5.7: Dominance system graph for cost (D1)

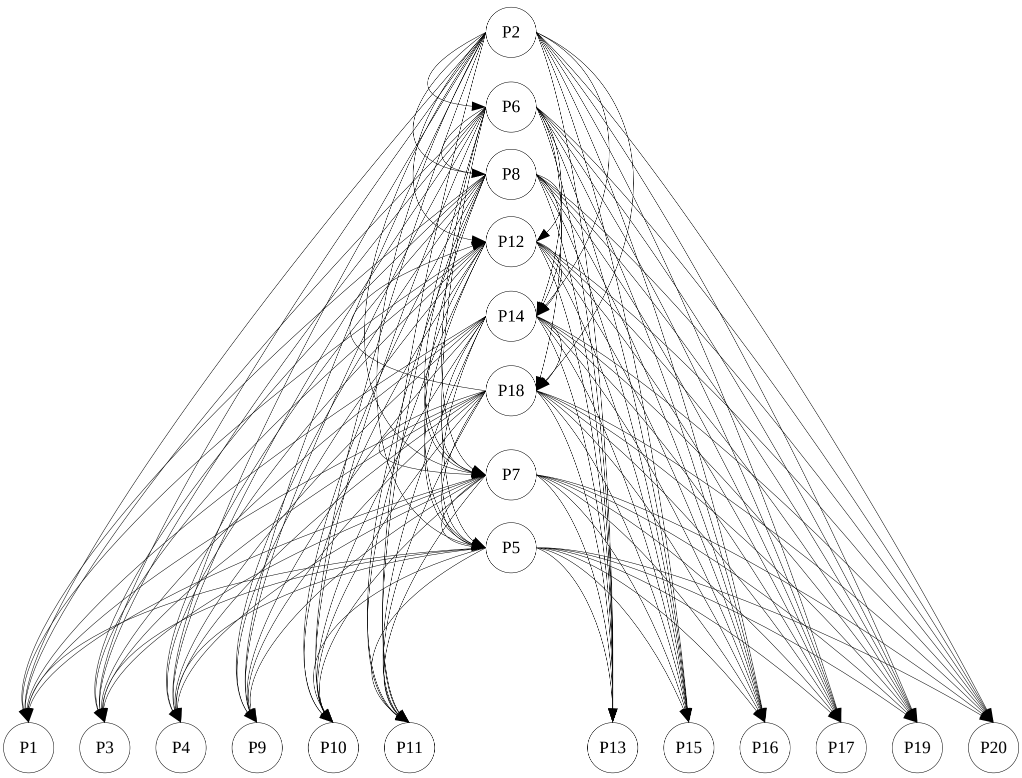


Figure 5.8: Dominance system graph for quality (D2)

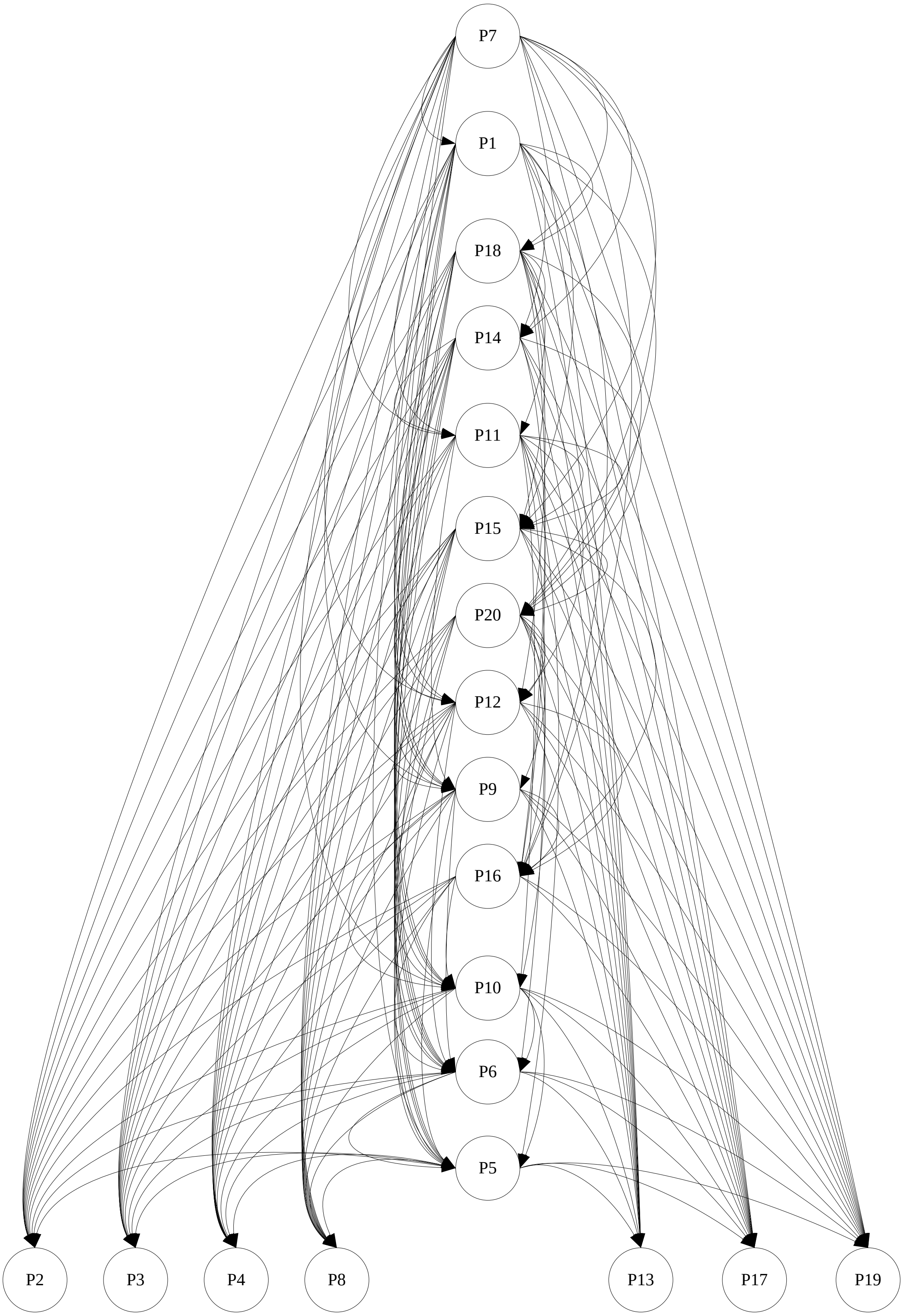


Figure 5.9: Dominance system graph for delivery (D3)

Figure 5.10: Dominance system graph for time (D4)

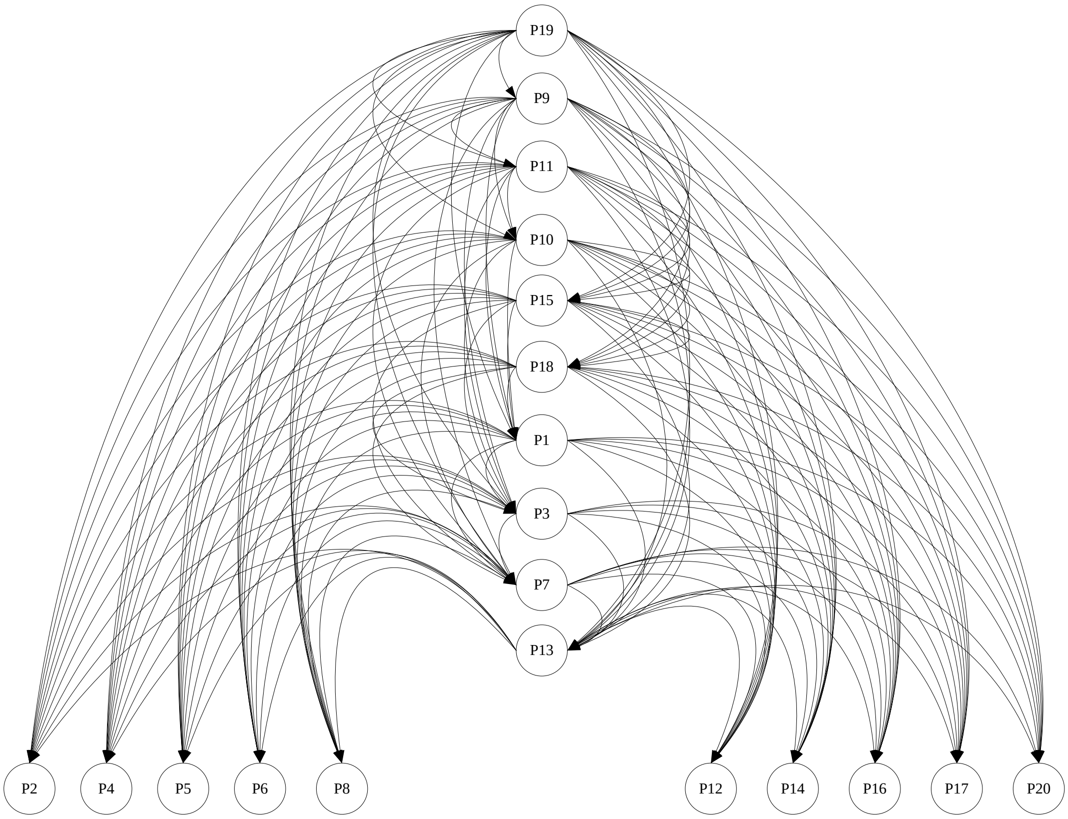


Figure 5.11: Dominance system graph for inventory (D5)

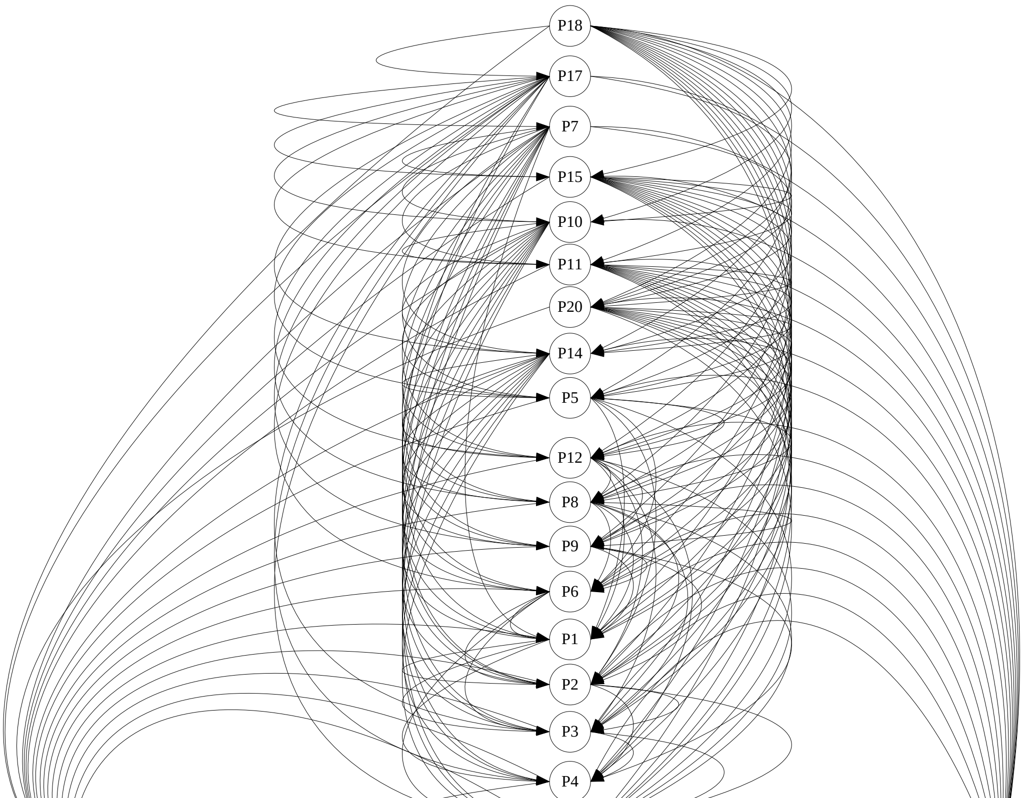


Figure 5.12: Dominance system graph for process flow (D6)

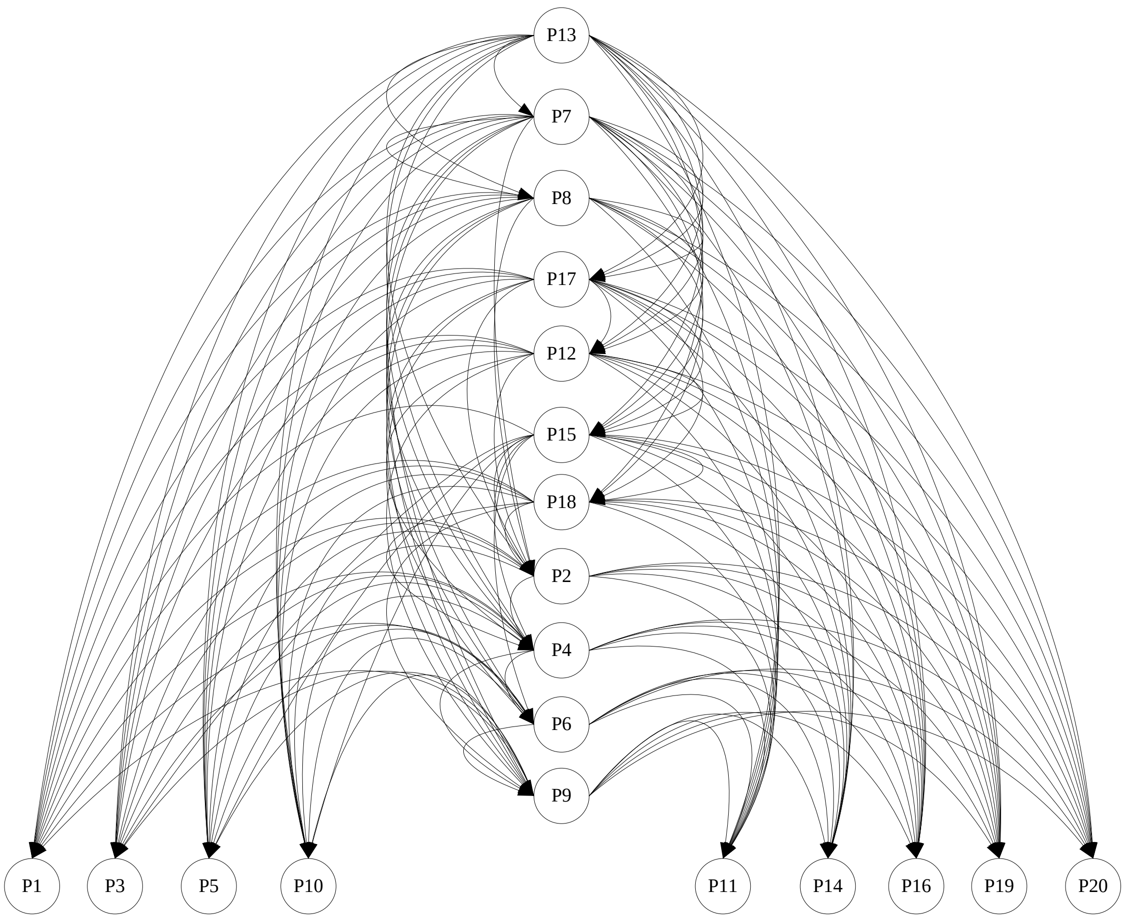


Figure 5.13: Dominance system graph for work performance (D7)

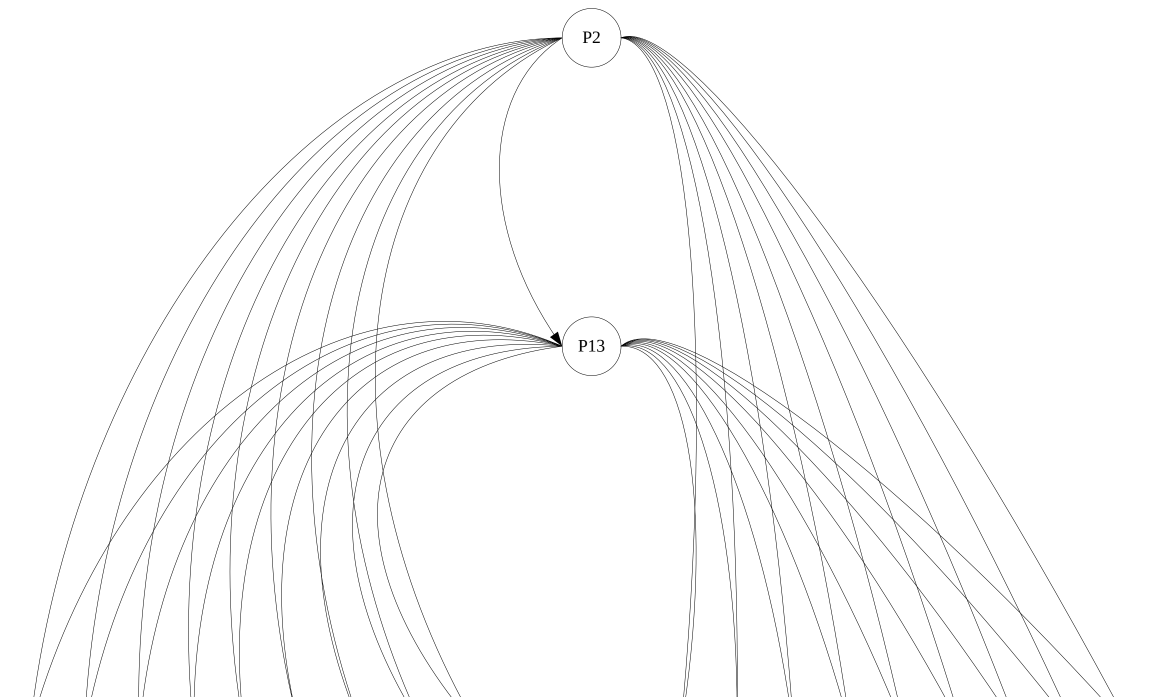


Figure 5.14: Dominance system graph for research and development (D8)

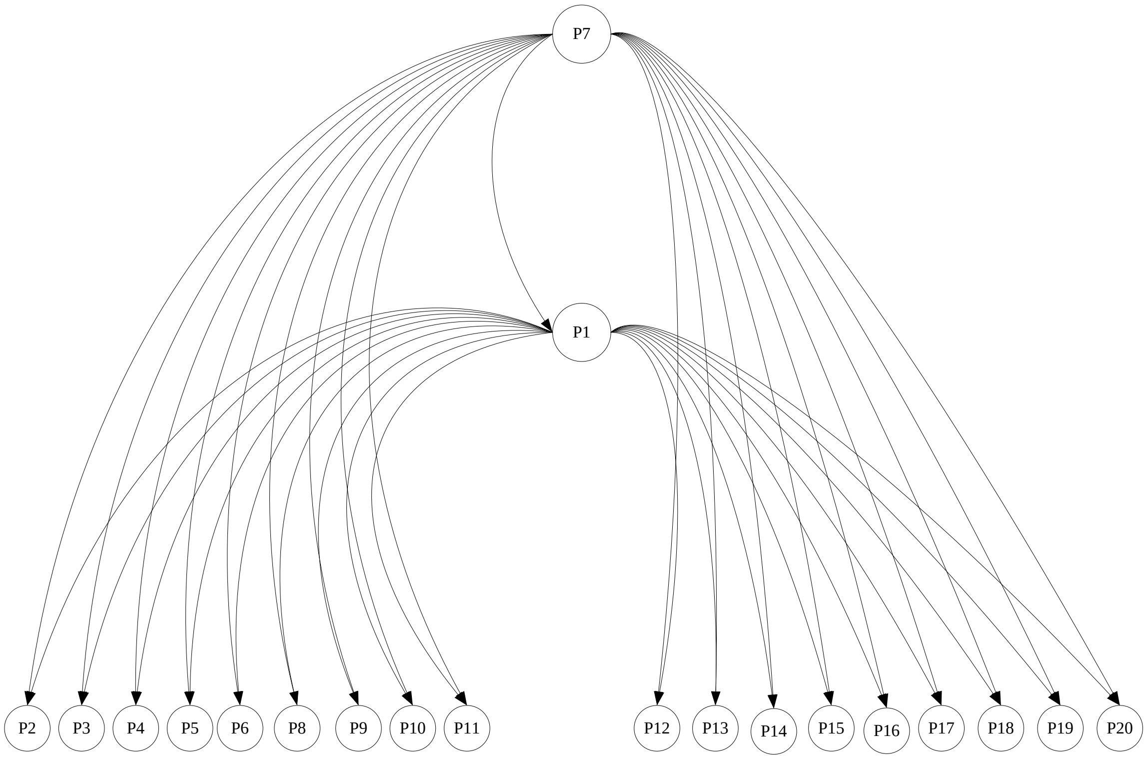


Figure 5.15: Dominance system graph for market (D9)

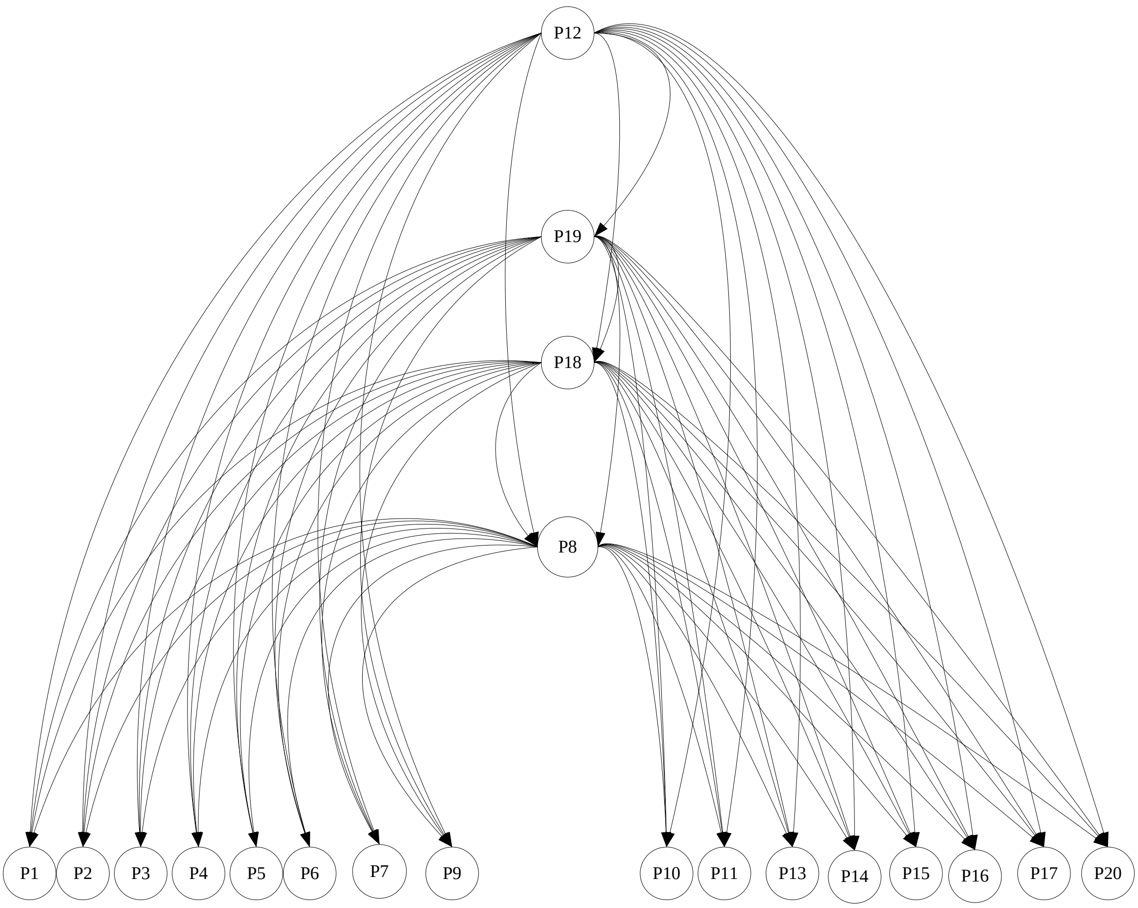


Figure 5.16: Dominance system graph for rate of return (D10)

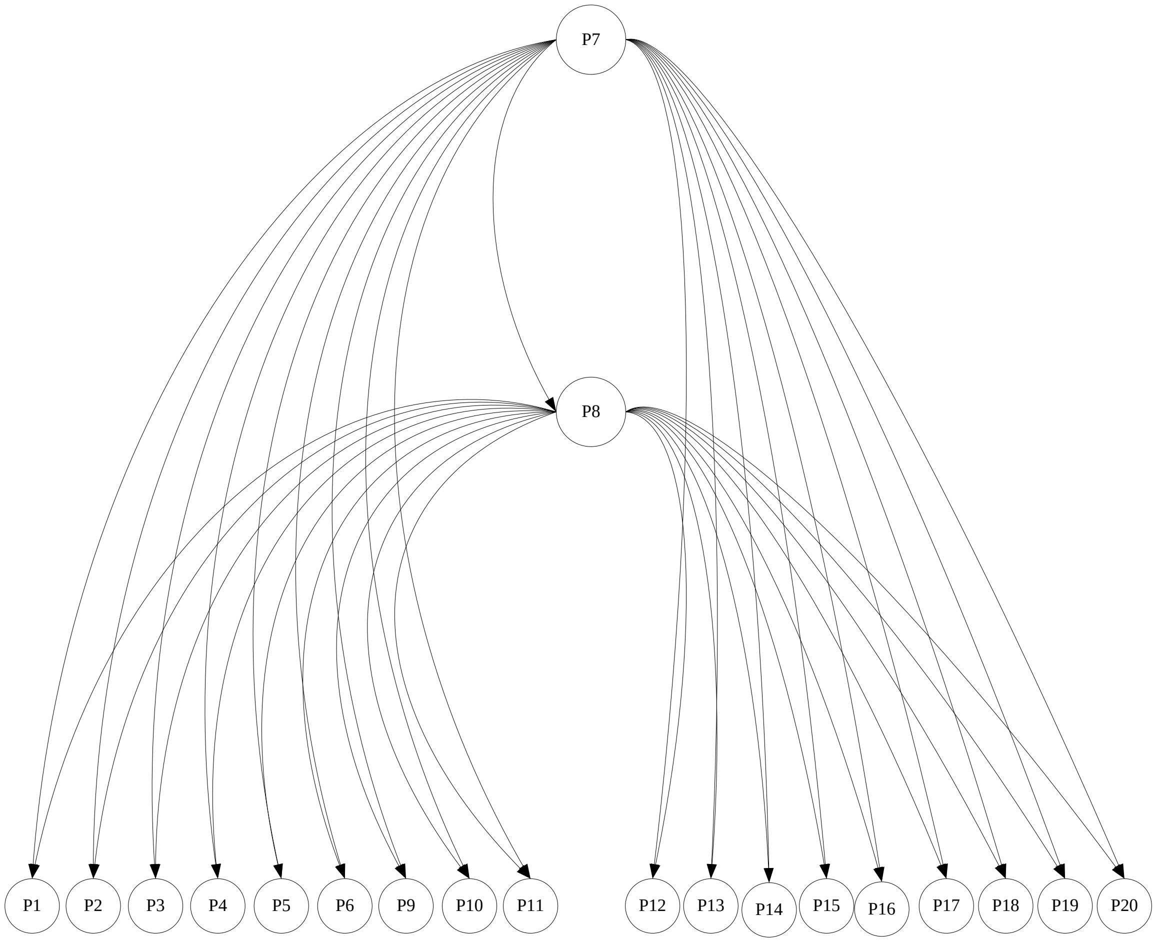


Figure 5.17: Dominance system graph for sales (D11)

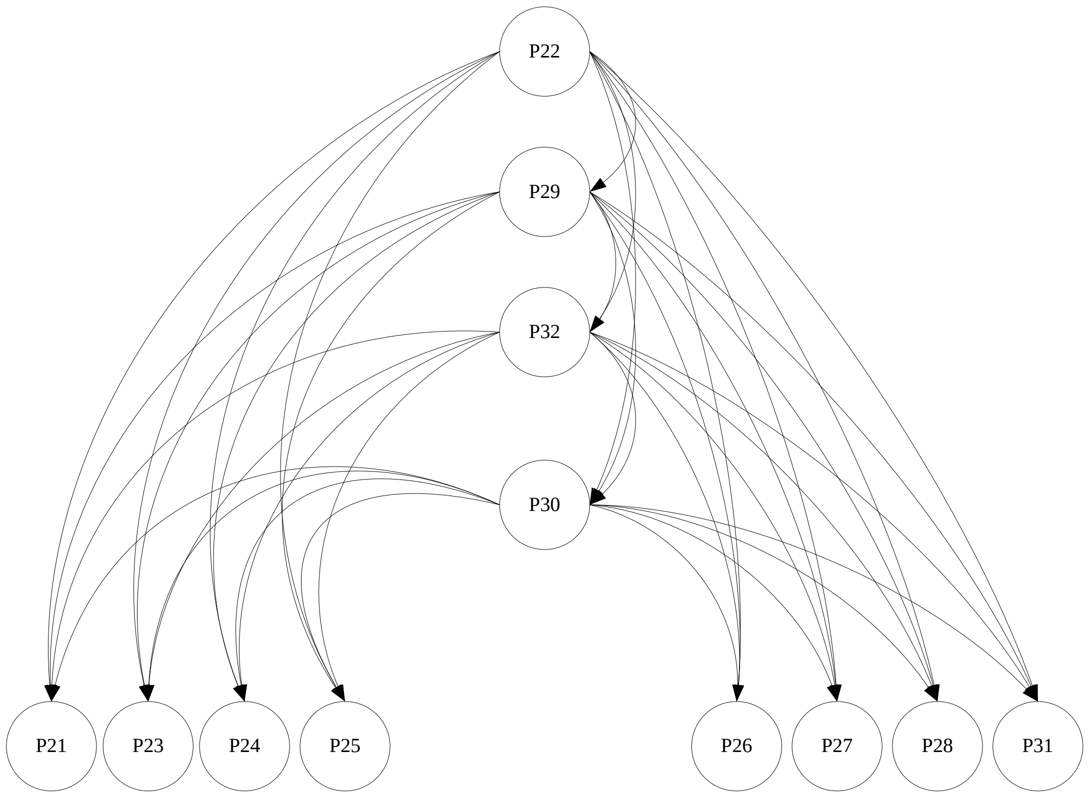


Figure 5.18: Dominance system graph for health and safety (D12)

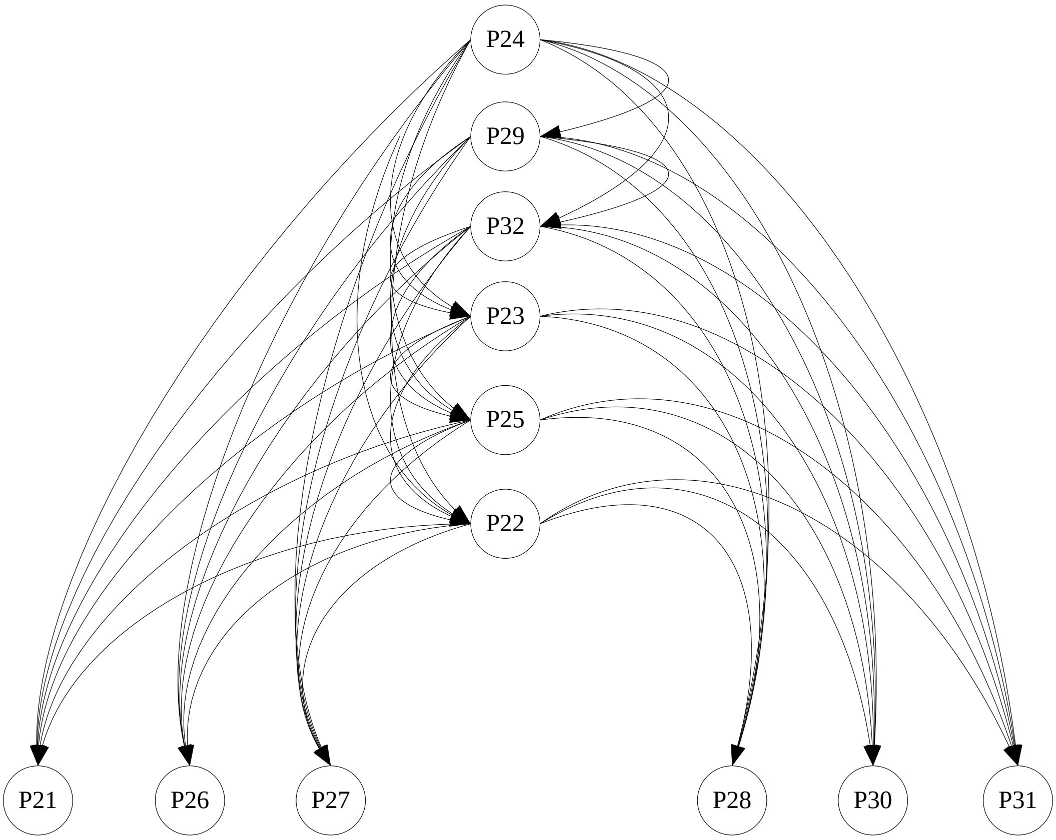


Figure 5.19: Dominance system graph for empowerment (D13)

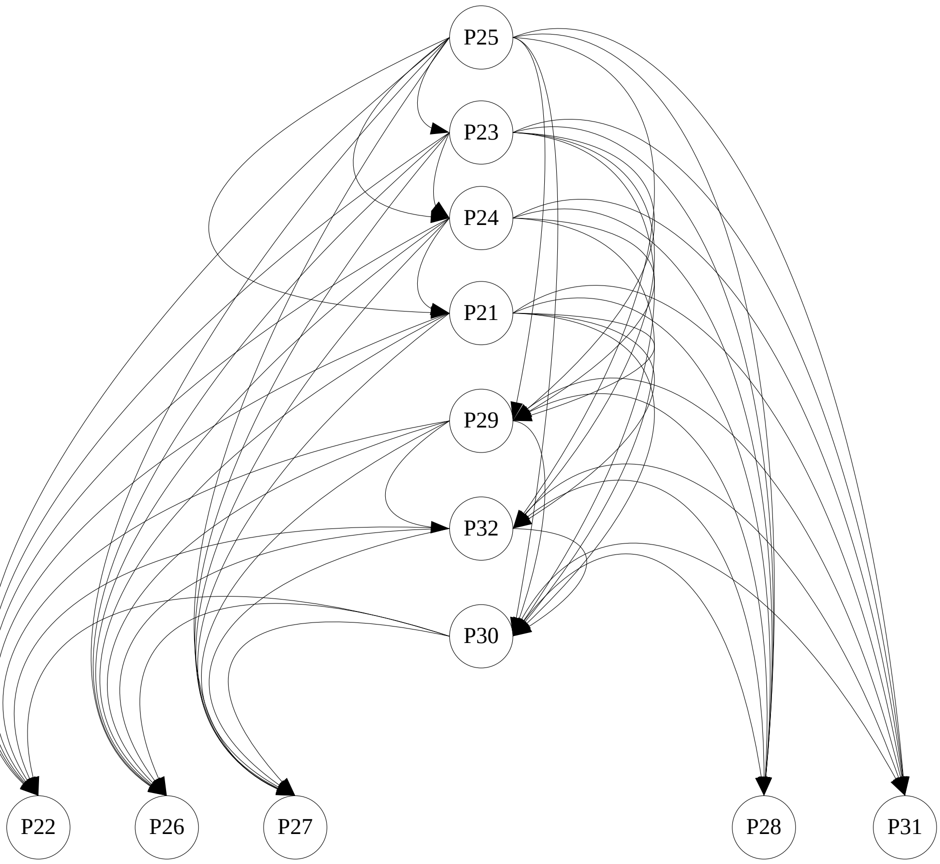


Figure 5.20: Dominance system graph for skill (D14)

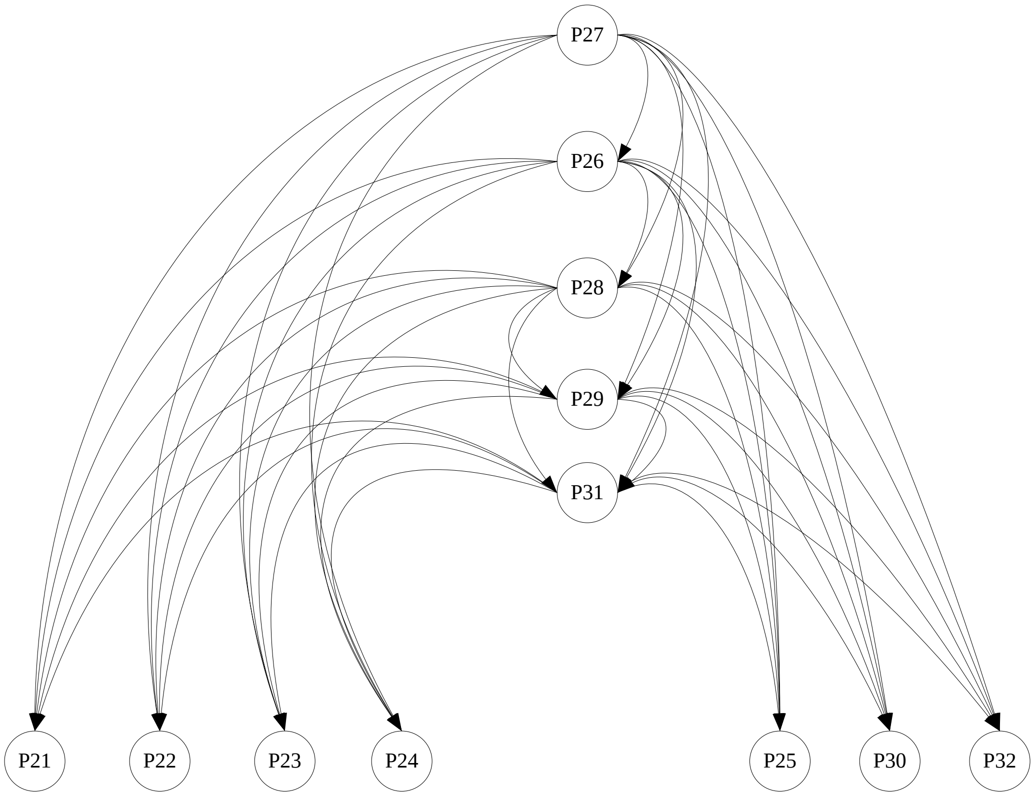


Figure 5.21: Dominance system graph for serviceability (D15)

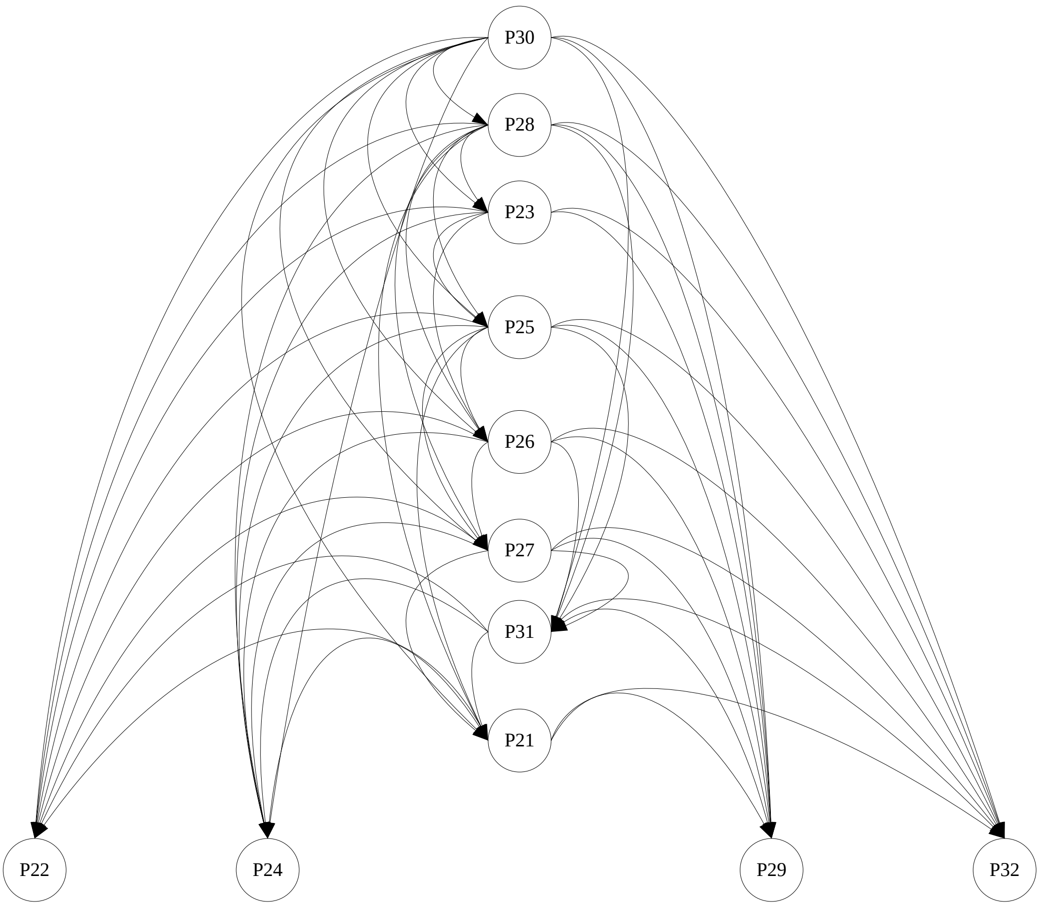


Figure 5.22: Dominance system graph for Communication (D16)

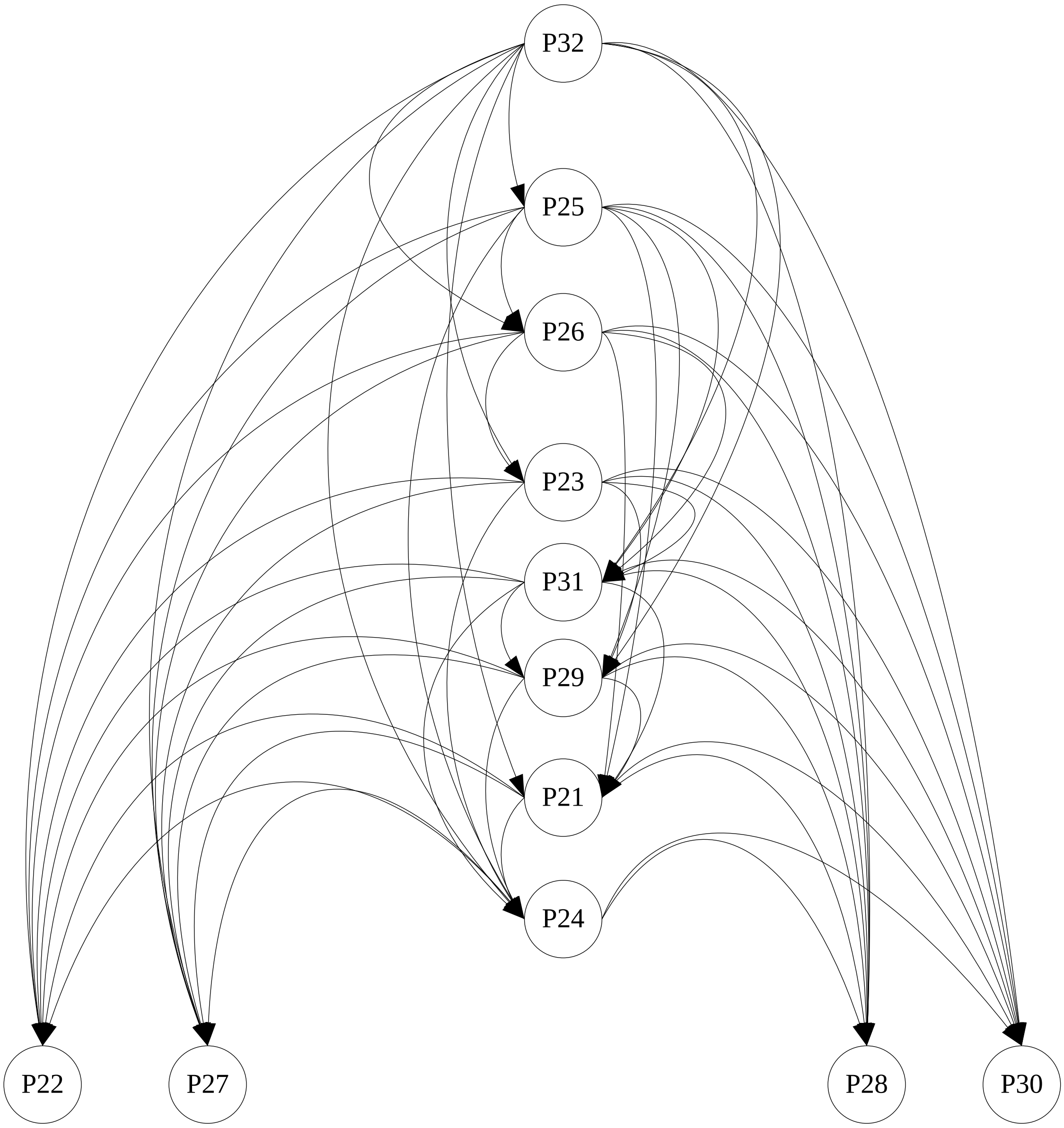


Figure 5.23: Dominance system graph for decision making (D17)

5.4.1.7 Develop IRP models: Finally, IRP models of hard and soft lean practices with respect to performance dimensions are developed as shown in figures 5.24 and 5.25 respectively.

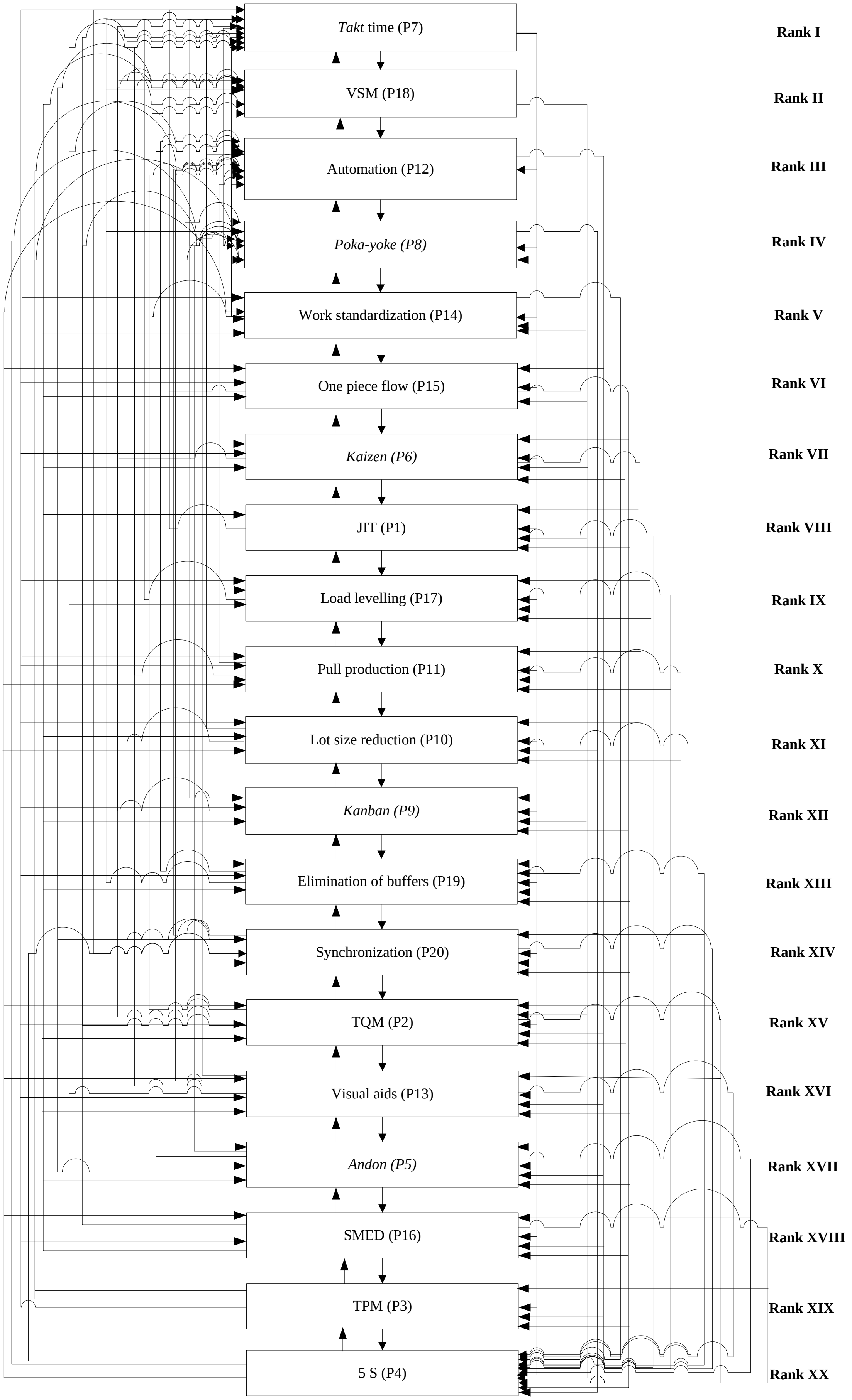


Figure 5.24: IRP model of hard lean practices w.r.t. performance dimensions

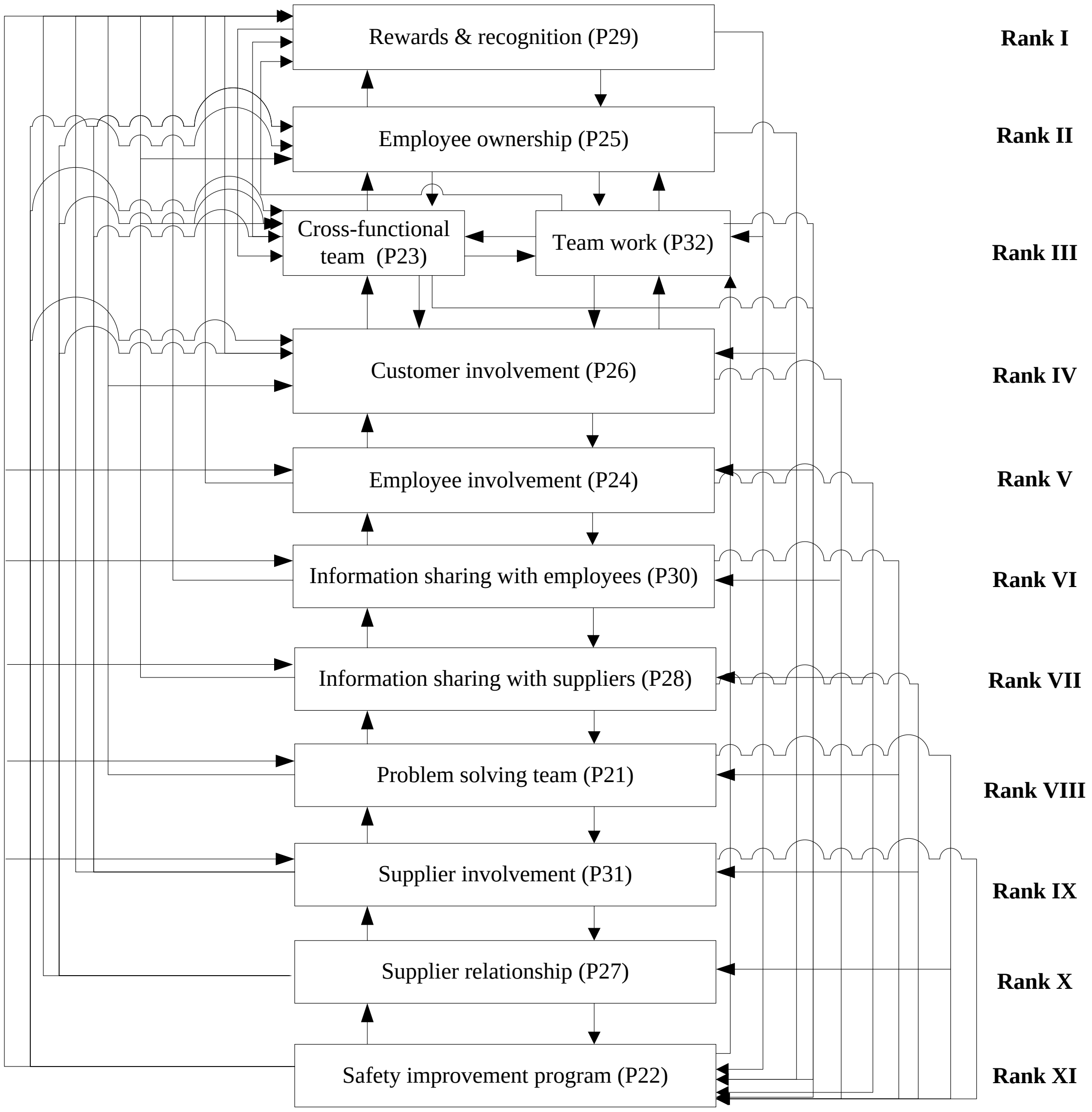


Figure 5.25: IRP model of soft lean practices w.r.t. performance dimensions

5.4.2 Interpretation of IRP Models

Figure 5.24 shows that the takt time dominates the other hard lean practices, therefore management should start the lean journey with the introduction of takt time concept. The takt time is followed by VSM which shows that the case organization is focused towards value stream at various assembly lines. Alukal and Manos (2006) also emphasize that VSM is the right choice to begin the journey for the implementation of lean manufacturing. The third rank of automation indicates that the case organization is concerned about the technology changes and believes to adapt the new technologies. Figure 5.25 shows that the most dominating soft lean practice is rewards and recognition. This is followed by employee ownership, which is one of five core principles of the case organization. The team work and cross functional team mutually received the third rank in IRP model. The safety improvement program has received the last priority.

The developed models clearly shows that the IRP gives more detailed and hierarchical representation than the ISM. The IRP also prioritize the variables based on reference variables which reduces the cognitive load of the managers during the judgment or interpretation of contextual relationship between the variables.

5.5 EMPLOYEE OWNERSHIP

The human resources are the most valuable among all the resources of an organization; since it is the employee who carry forward the organization (Poduval, Pramod, and Raj, 2015). Human resource management (HRM) transforms the mind-set and behaviour of employees with regard to the organization (Kokkaew and Koompai, 2012), for better employee performance. Buick *et al.* (2015) stated that the high performance organizations are portrayed by the proficiency to anticipate and reflect upon the human psychological changes. One critical factor for successful organizations is the employee involvement for longer times. The employees are willing to work with dedication in those organizations which have established working culture. It also improves the organization as well as performance of employees. The organizations should promote a work culture where-in the employees are satisfied, motivated, committed, and have enough autonomy to expand their competencies.

The soft lean practices support the continuous improvement by imparting a sense of ownership and common responsibility (Ghobadian and Gallear, 2001). Employee ownership is an approach to push decision making downward (Bartkus, 1997). Empowered employees are satisfied with their jobs and psychologically attached with their organizations (Uslu, 2014). Poduval, Pramod, and Raj (2015) stated that the bottom level employees (operator level) are generally not involved in decision making process in many Indian organizations. Unhappy employees either create negative “voice” in the organization or “exit”; both the options are not good for an organization. The management should promote rewards and recognition for the encouragement of employees and enhancement of team work activities to improve employee satisfaction, morale, involvement & commitment, and accountability.

The objectives of this study is to determine the kind of action(s) required to enhance the employee ownership through improved employee satisfaction, employee morale, employee commitment & involvement, and employee accountability.

5.5.1 Identification of Human Resource Factors for Employee Ownership

The empirical research shows that the employee ownership analysis can be categorized at macro level and micro level analyses (Thompson, 2005). The macro level analysis is used to show the relationship between employee ownership and organizational outcomes such as profitability, productivity, *etc.* Whereas, micro level analysis emphasises on individual-level variables and establishes a relationship between employee ownership and individual human resource factors such as employee satisfaction, commitment & involvement, motivation, morale, accountability, participation, *etc.* It is observed that sense of ownership is vital to employees than the financial ownership provided by stock sharing (Buchko, 1992; Bartkus, 1997). O’Reilly (2002) classified ownership into two types: financial and psychological ownerships. Psychological ownership is a feeling of accountability to make decisions focused on the company’s long term goals.

Employee ownership improves the employees' morale and motivates them to work in a better way to enhance organizational performance (Thompson, 2005). Similarly, Böckerman (2015) stated that the high employee involvement ascertains employee responsibility to do work well whereas high employee control lowers the employee satisfaction. Srinivasan and Kurey (2014) reported that the quality culture can be established well, if the organizations focus on employee involvement and employee ownership. Uslu (2015) opined that the organizational culture which fortifies its employees improves employee performance substantially. Empowered employees are psychologically dedicated to its organization and are satisfied with their jobs which improves the sense of ownership (Uslu, 2014). The sense of ownership is developed in employees by recognizing and appreciating the good work done by them (Uslu, 2015). Mayhew *et al.* (2007) stated that there is a positive correlation among employee ownership, job satisfaction and employee commitment, while employee ownership acts as an intermediate between job satisfaction and employee autonomy. Dormann and Zapf (2001) stated that job satisfaction has become one of the most prominent research conceptions in organizational psychology. Several studies (Naz and Liaquat, 2015; Dormann and Zapf, 2001) reported remarkable interrelationships among job satisfaction, self-esteem, and employee ownership.

Kaizens impart the sense of employee ownership in the organization (Poduval, Pramod, and Raj, 2015). Relationship building and ownership are critical factors for employee participation to improve the organizational performance (Wendt, 2014). Numerous studies have been conducted on stock ownership (financial involvement of employee) but a few studies are available on psychological ownership (Naz and Liaquat, 2015). Therefore, a case study is conducted at an automotive component manufacturing organization to assess and improve the employee ownership.

5.5.2 Employee Ownership Assessment and Improvement – a Case Study

Although employee ownership is one of the five core principles of the case organization but there is no process to assess the level of ownership. Some annual surveys are conducted by the case organization with the help of some external agencies or consultants but these surveys are generic in nature and not focussed on employee ownership. A quasi-experimental case study is conducted to assess and improve the employee ownership of the case organization. The steps of the case study are given below:

5.5.2.1 Develop survey instrument: A questionnaire is developed to get the data from the employees. The factors of the employee ownership are identified from the literature as above. This was discussed with the organization top leadership to get their expert opinion. Several *gemba* walks were conducted to understand the shop floor environment and employee feelings regarding the employee ownership. Various informal discussion sessions were held at individual employee level by the author (external expert). It is found, through the informal discussion, that the managerial and supervisory level employees have more sense of ownership because of their distinct decision making roles, better information access, better knowledge of organizational structure, and better knowledge of norms and targets. Therefore, it is decided to conduct the employee ownership survey among the operators. A mixed sense of ownership was observed during the informal discussion with operators. Some of the operator comments are:

"Case organization is a very good company and the main thing is "respect for people" which I like most. I am fully satisfied & always try to accomplish my work in a better way."

"Case organization provides stability to my career because the company don't believe in hiring & firing which other companies do. So, I do the assigned work."

"Case organization is a good company, but I am not happy with present scenario. So, I am doing the job just to pass the time till I get another opportunity."

Such comments reflect low employee ownership. The findings of the informal discussion were shared with top leadership (plant head). Mixed reactions strengthened the decision of conducting the survey to know the level of employee ownership. To make things easier, the term "employees" is used in this study to describe the operators.

The proposed questionnaire contains 20 questions under four factors. The questionnaire was refined on the basis of a detailed discussion with the top management about each component of the proposed questionnaire. The final questionnaire contains 15 questions under four factors of employee morale, satisfaction, commitment & involvement, and accountability as given in table 5.22.

Table 5.22: Final survey questionnaire (English version)

Please tick (√) the appropriate answers to following questions (1 = Not at all; 2 = Slightly; 3 = Average; 4 = Fairly; 5 = Very much)		**Not at all**	**Slightly**	**Average**	**Fairly**	**Very much**
Factor	**Question**					
Accountability	How important is ownership for you?	1	2	3	4	5
	Are you interested in the status of the company's profit or loss?	1	2	3	4	5
	Do you think this is your own company?	1	2	3	4	5
	Do you rely on company plans and understand your role in making value?	1	2	3	4	5
Commitment & involvement	Do you think that the company is providing opportunities for career development?	1	2	3	4	5
	Do you think the company gives you the opportunity to do cross-functional work?	1	2	3	4	5
	Do you think the company provides training to you to improve skills?	1	2	3	4	5
Morale	Does the company respect people?	1	2	3	4	5
	Do you think the company provides incentive plans for employees?	1	2	3	4	5
	Do you think that your employment is safe in this company?	1	2	3	4	5
Satisfaction	Are you satisfied with the company policies?	1	2	3	4	5
	Does the company take care of the health and safety of employees?	1	2	3	4	5
	Are you working under pressure?	1	2	3	4	5
	Do you take leave because of more work?	1	2	3	4	5
	Do you see your future in this company?	1	2	3	4	5

Two questions are indirect questions, where 1 means best answer and 5 means worst answer. Personal information of respondents is not captured on questionnaire. Since the focussed or selected group of employees consists of operators, so the questionnaire is developed in Hindi language for easy understanding of the operators. The final questionnaire presented in table 5.22 is English version of the final questionnaire used for the study.

5.5.2.2 Data collection and analysis: A printed questionnaire is used to collect data from the employees. These questionnaire were distributed to 27 respondents, the employees who are working on a group of three assembly lines. The group of assembly lines is chosen because of peculiar problems which will be discussed in the next chapter. The data was collected on a 5-point Likert scale. The Likert scale is chosen for the study as it provides equal spacing between the single scoring numbers and enforces the respondents to make an exclusive and decisive choice. The respondents were briefed by the HR head in the presence of production department head at the beginning of the regular shift. The HR head told about the objective of the study and assured the respondents about the confidentiality of the data. The two heads left the room after orientation. The questionnaires were filled by the respondents simultaneously in the presence of external member only (author). The author explained the factors and the importance of their judgement without personal prejudice. 15 minutes were given to fill the questionnaire. The time limit also impeded the influence of other employees' thoughts.

The collected data is qualitative in nature and measured on the Likert scale. Therefore, fuzzy methodology is applied to convert these qualitative data into quantitative form. The fuzzy methodology, its need and advantages are described in detail in section 4.2.2 of chapter 4.

The membership function $\mu_{\acute{A}}(x)$ for the employee ownership is defined as:

$$\mu_{\acute{A}}(\mathrm{x_i}) = \begin{cases} 1; & \mathrm{x_i} = a \\ 1 - \frac{(\mathrm{x_i}-a)}{(b-a)}; & b < \mathrm{x_i} < a \ (direct\ questions) \\ 0; & \mathrm{x_i} = b \end{cases} \quad (5.1a)$$

$$\mu_{\acute{A}}(\mathrm{x_i}) = \begin{cases} 1; & \mathrm{x_i} = a \\ 1 - \frac{(\mathrm{x_i}-a)}{(b-a)}; & a < \mathrm{x_i} < b \ (indirect\ questions) \\ 0; & \mathrm{x_i} = b \end{cases} \quad (5.1b)$$

where 'a' characterizes the best answer and 'b' characterizes the worst answer for each question (Pakdil and Leonard 2014; Behrouzi and Wong 2011). Direct question means more is better (for example, importance of ownership) and indirect question means less is better (for example, take leave due to more work).

- The score of each question (i^{th}) is calculated as:

  $$\mathrm{Q_i} = \mu_{\acute{A}}(\mathrm{x_i}) X100 \quad (5.2)$$

  where $\mu_{\acute{A}}(x_i)$ is calculated using equation 5.1.

- The score of each factor (P_j) is calculated as:

  $$F_j = \sum_{i=1}^{n_j} \frac{\mu_{\acute{A}}(\mathrm{x_i})_j}{n_j} X100 \ ; \quad j = 1,2,3, \ldots \mathrm{m} \quad (5.3)$$

where $\mu_{\acute{A}}(x_i)_j$ is fuzzy membership value of the i^{th} question of the j^{th} factor. n_j is the number of questions in j^{th} factor. m denotes the number of factors.

- The overall employee ownership score (O_k)is the average score of factors and computed as:

  $$O_k = \frac{1}{m} \sum_{j=1}^{m} \sum_{i=1}^{n_j} \frac{\mu_{\acute{A}}(\mathrm{x_i})_j}{n_j} X100; \quad (5.4)$$

The individual performance scores and overall employee ownership score are shown in figure 5.26. The overall ownership score is 55.44%, which is low as per the expectation of the top management. The top management suggested HR department to analyse the poor employee ownership score with the help of the author. The commitment & involvement, morale, and satisfaction obtained less than average scores, whereas accountability obtained the score of 59.26 %.

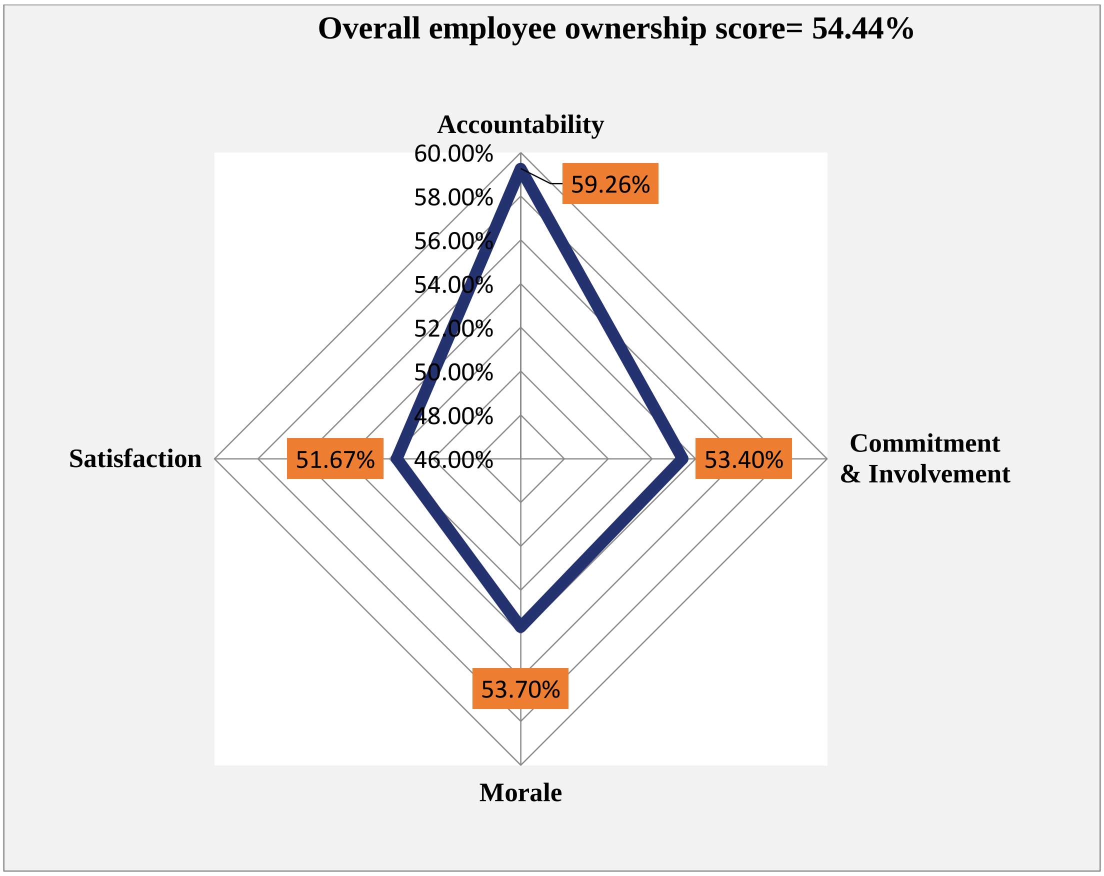


Figure 5.26: Radar chart showing employee ownership scores of various factor

The HR head formed a team comprising personnel from HR department along with author to do the analysis. The team did why-why analysis to find the root cause(s) of poor employee ownership score as shown in figure 5.27. The team found that “lack of opportunities to enhance their skills & knowledge” is the root cause for poor employee ownership score.

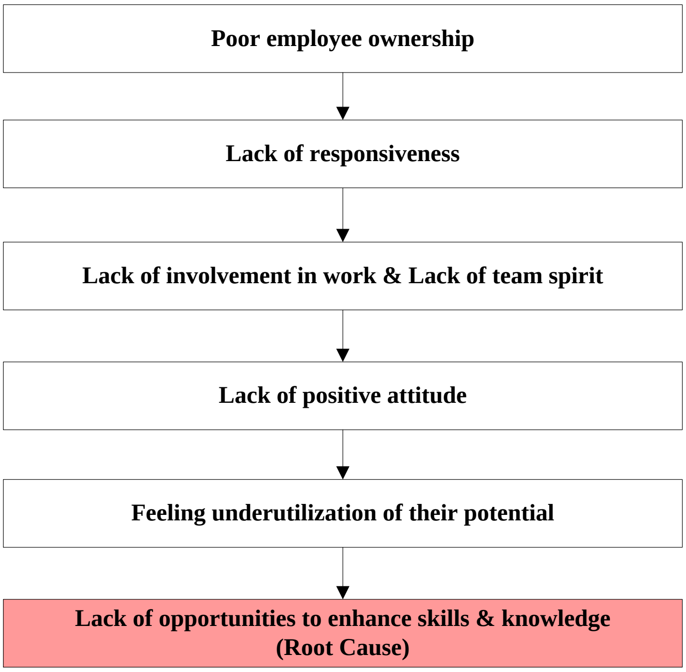


Figure 5.27: Why-why analysis of poor employee ownership

5.5.2.3 Corrective action: After identification of root cause, the team decided to take corrective actions to improve the employee ownership level. The team conducted a brainstorming session to find out the feasible and effective corrective actions. The team reached to the consensus that the employees should be assigned the role of assistant supervisor or supervisor on daily rotation basis depending upon their seniority (work years). There are three assembly lines in the column assembly group and the three lines have 10, 10 and 7 employees. Every day, three operators were assigned the role of supervisor or assistant supervisor; one for each line. Therefore, each operator got an opportunity to act as supervisor or assistant supervisor. After one month, the data is collected again from the same respondents using same questionnaire.

5.5.2.4 Results and discussion: The results after the corrective action are presented in table 5.23 and figure 5.28. The results show that there is an improvement in employee ownership by 4.54%. The employee accountability improved from 59.26% to 63.02%. The highest improvement of 7% is observed for commitment & involvement (from 53.40% to 60.42%). The final employee ownership score is 58.98% as presented in table 5.23.

Table 5.23: Employee ownership scores after corrective action

Factor	Question	Question score (Q_i)	Factor score (F_j)
Accountability	How important is ownership for you?	66.67	63.02
	Are you interested in the status of the company's profit or loss?	70.83	
	Do you think this is your own company?	58.33	
	Do you rely on company plans and understand your role in making value?	56.25	
Commitment & involvement	Do you think that the company is providing opportunities for career development?	43.75	60.42
	Do you think the company gives you the opportunity to do cross-functional work?	64.58	
	Do you think the company provides training to you to improve skills?	72.92	
Morale	Does the company respect people?	58.33	58.33
	Do you think the company provides incentive plans for employees?	64.58	
	Do you think that your employment is safe in this company?	52.08	
Satisfaction	Are you satisfied with the company policies?	52.08	54.17
	Does the company take care of the health and safety of employees?	68.75	
	Are you working under pressure?	47.92	
	Do you take leave because of more work?	50.00	
	Do you see your future in this company?	52.08	
Overall ownership score (O_k)			**58.98%**

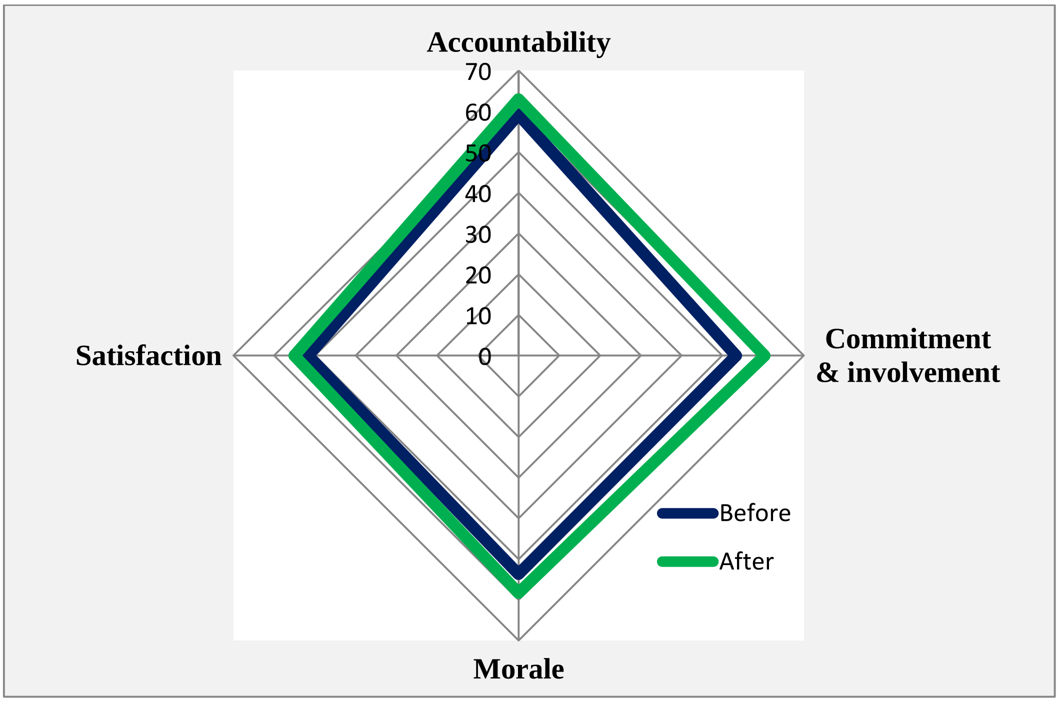


Figure 5.28: Radar chart to compare before and after scores of various factors

The study shows that the employee ownership can be improved by involving the lower level employee in decision making process. Takaki (2005) also stated that the organizations can effectively transit their employees by involving them in decision making or by promoting them according to their skills to embrace a culture of ownership and accountability. The corrective action improved employees' skills and morale as well as accountability. The operators understood the responsibility and accountability of their supervisors, which improved their involvement in their duties. This approach of involving the operator in decision making can also benefit the organization by reducing the number of supervisors in the long run. Bartkus (1997) also opined that the increasing autonomy and decision making at lower levels of an organization can reduce the number of managers and supervisors.

5.6 CONCLUSIONS

This chapter presents 20 hard lean practices and 12 soft lean practices from the literature. The hierarchical models of hard and soft lean practices are developed by using ISM and IRP approaches. Employee ownership, a soft lean practice, is assessed and improved using a case study. Both the models provide almost similar results; however, IRP models are more detailed than the ISM models. Chapter delineates that hard and soft lean practices are two major paradigms for the successful lean implementation. The ISM based model finds that the hard lean practices can be categorised as organization centric, system/technology centric, value chain centric, and motivators. The organization should first focus on motivational practices, than value chain practices, than the system and technology related practices, and finally organization wide practices. Similarly, the organization should first focus on rewards and recognitions (motivators), than practices which are important for its core competencies, than internal enablers, and finally external enablers. *Takt* time and VSM have high dominance or driving power as compared to other hard lean practices in both the approaches. It shows that the lean implementation should start with mapping of organizations' value streams after finding the takt time to fulfil the customer demand. The rewards and recognition, and employee ownership have high dominance or driving power as compared to other soft lean practices in both the approaches.

The developed hierarchical structures of hard and soft lean practices facilitates stepwise implementation of lean manufacturing. It is expected that the structuring of hard and soft lean practices into hierarchies will enable the organization to concentrate the limited resources as per the priority provided by the developed models. It can be concluded that for an effective and efficient implementation of lean practices, an organization should prioritize the lean practices for sequential implementation. The structural models also assist the top management to assign proper roles to employees/departments for the effective lean implementation. The assessment results support the organization with a realistic framework to deal with many challenges, especially, challenge of resource allocation during lean implementation. The developed IRP models help practitioners to prioritize lean practices with respect to their performance targets. The key message from the case study is that the organization must focus on *takt* time achievement; VSM development for all lines; and rewards & recognition announcements.

Chapter also presents a case study of an Indian automotive component manufacturing organization to assess and improve the employee ownership. The case study shows the improvements in employee ownership based on simple managerial interventions. Simple managerial intervention led to the improvements in employee accountability, commitment & involvement, satisfaction, and morale. It is expected that this study will be beneficial to HR personnel to improve the sense of ownership in the employees.

CHAPTER 6

LEANNESS ASSESSMENT OF A COMPLEX ASSEMBLY LINE USING INTEGRATED VALUE STREAM MAPPING

This chapter demonstrates the use of an integrated value stream map for the leanness assessment of a complex assembly line. The concept of continuous kaizen is also introduced to achieve the improvement at value chain level.

6.1 INTRODUCTION

Researchers have investigated the various tools and techniques for the real-time implementation of lean and VSM has appeared as a desired tool for the implementation of lean manufacturing (Rother and Shook, 1999). Rother and Shook (2009) proposed a holistic design approach for VSM in their book ‘‘learning to see’’. The title of the book aptly enunciates the purpose of VSM in such a way that it should succour the systematic identification and elimination of waste in premeditated production processes and institutes the potentials for the improvement.

VSM has been used in numerous manufacturing and service industries including textile, ceramic, sugar, cement, oil extraction, electronics and electrical, furniture, automotive, hospital operations, food preparation, banking operations, educational institutes, public services, *etc.* (Bhamu and Sangwan, 2014). VSM is extensively used to map the material and information flows throughout the value chain of the industry to identify the low performing areas for potential improvements.

However, the biggest drawback of VSM is its limited application under complex material/information flow. Generally, VSMs are developed for a production line or a work cell, which produce a single product or a product family with almost similar products.

VSM can be challenging to apply if the processes are complex like an automotive assembly line where the number of processes involves a large number of components and sub-assemblies to make the final product (Salzman, 2002). It has even said that VSM can be used only if products have at least 80% similarity (Nielsen, 2008). Few papers in the extant literature (Seth, Seth, and Dhariwal, 2017; Ben Fredj-Ben Alaya, 2016; Matt, 2014; Bertolini *et al.*, 2013; Serrano, Ochoa, and Castro, 2008) highlight the challenges in adopting VSM for complex production environments. Under such situations, researchers (Bhamu, Khandelwal, and Sangwan, 2013; Özkan *et al.*, 2005; Lasa, Castro, and Laburu, 2009; Seth, Seth, and Dhariwal, 2017; Ben Fredj-Ben Alaya, 2016) picked one product from the product family and developed a VSM assuming that this VSM will provide similar benefits for the other parts of the family. And, if the similarity among the products is low then researchers (Singh and Singh, 2013; Seth and Gupta, 2005) used different VSMs for different products. This provides theoretical applications of VSM but in actual practice, this leads to higher complexity and lower adoption of VSM. The application of VSM for the improvement of assembly lines is less. The improper and incomplete application of VSM leads to the misapprehensions and misconceptions. This mystifies the identification of waste leading to poor leanness assessment and dents the continuous improvement in future (Dal Forno *et al.*, 2014). The application of VSM for assembly lines is highly challenging because of merging flows, a large number of child parts in the lines and assembly of more than one product on the same line. This is the motivation to develop an integrated VSM for complex assembly lines where the similarity between the products to be assembled on the same line is less than 60%.

6.1.1 VSM as a Tool to Improve the Leanness

It is true that VSM is only a tool, generally, first diagnostic tool to find the inefficiencies in a production system. VSM has become highly popular because it provides a kaleidoscopic view of whole production system at micro level, unlike time and method studies.

VSM has been very efficacious in identifying the wastes and enhancing the processes owing to the diaphanous nature of measures and flows (Tyagi *et al.*, 2015). Further, VSM is a widespread and verified approach which facilitates the mapping and exploration of value chains and helps to identify improvement possibilities (Meudt, Metternich, and Abele, 2017). Huang and Liu (2005) adopted the rough set theory and VSM to show the current state of manufacturing processes; identify and improve inventory levels and logistics cost. VSM has been widely used as a preferred tool to unravel the wastes and bottleneck processes in the value chains because it is a transparent visual kaleidoscopic snapshot of value chains. Therefore, it is convenient to visualize the flow, value addition, cycle time, *etc.* to reduce the non-value added activities and wastes for achieving the required takt time as per customer demand. VSM has become synonymous with the lean application and authors like Dinis-Carvalho *et al.* (2015) consider VSM as a benchmark for the new visual tools & techniques. However, VSM is only a visualization tool and it is used in conjunction with other lean tools & techniques to improve the leanness. The limitations of VSM such as its incapability to detail dynamic nature of manufacturing processes, time-consuming, and inability to comprehend the complexity have led to its integration with simulation (Anand and Kodali, 2009b). However, VSM improves efficiency and effectiveness of other lean tools & techniques as compared to the standalone applications of these tools & techniques. Pingale and Vani (2010) highlights the operational, administrative, and strategic advantages of VSM.

Anand and Kodali (2009b) found that the use of simulation with VSM significantly enhances the quality and productivity as well as reduces cycle time, inventory and floor space. Seth, Seth, and Goel (2008) addressed the different wastes in an Indian cottonseed oil industry supply chain using the VSM approach to ensure proper utilization of capacity to enhance the productivity of the organization. Chen and Meng (2010) proposed a VSM centric lean production system to reorganize whole value stream to upturn the competitiveness of Chinese enterprises. Hodge *et al.* (2011) developed a model for the implementation of lean tools & techniques and lean principles to identify suitable lean principles for the textile industry. The VSM has evolved as a modest, easy to comprehend, amalgamated, and practical tool for identification of wastes in production processes. VSM assists to understand the workstation-level as well as cycle level process enhancements. It establishes linkages between these two levels (Dal Forno *et al.*, 2014). Dal Forno *et al.* (2014) identified that low/lack of clarity of procedures, low/lack of product modularity, low-skilled people, process too intuitive, poor/lack of process stability, small batches with highly mixed production, problems/difficulties in measuring data in processes, low/lack of integration between processes, obsolescence of the current state map, and more flexible production are the main challenges during the application of VSM.

A generic methodology is adopted for the leanness assessment and improvement using VSM as shown in figure 6.1. The methodology covers current state map, 3 M (i.e. *Muda, Mura*, and *Muri*), different lean wastes, lean principles, and future state map. The outer layer represents the development of current value stream map. Next, using 3M, identify the waste (*Muda*), unevenness (*Mura*) and overburden (*Muri*) in the system. The next layer shows the different types of lean wastes and the arrow represent the identification of waste. After identification of different wastes, the next step is to apply the five lean principles to eliminate wastes from the system. Finally, the core represents the established improvement in the form of future value stream map.

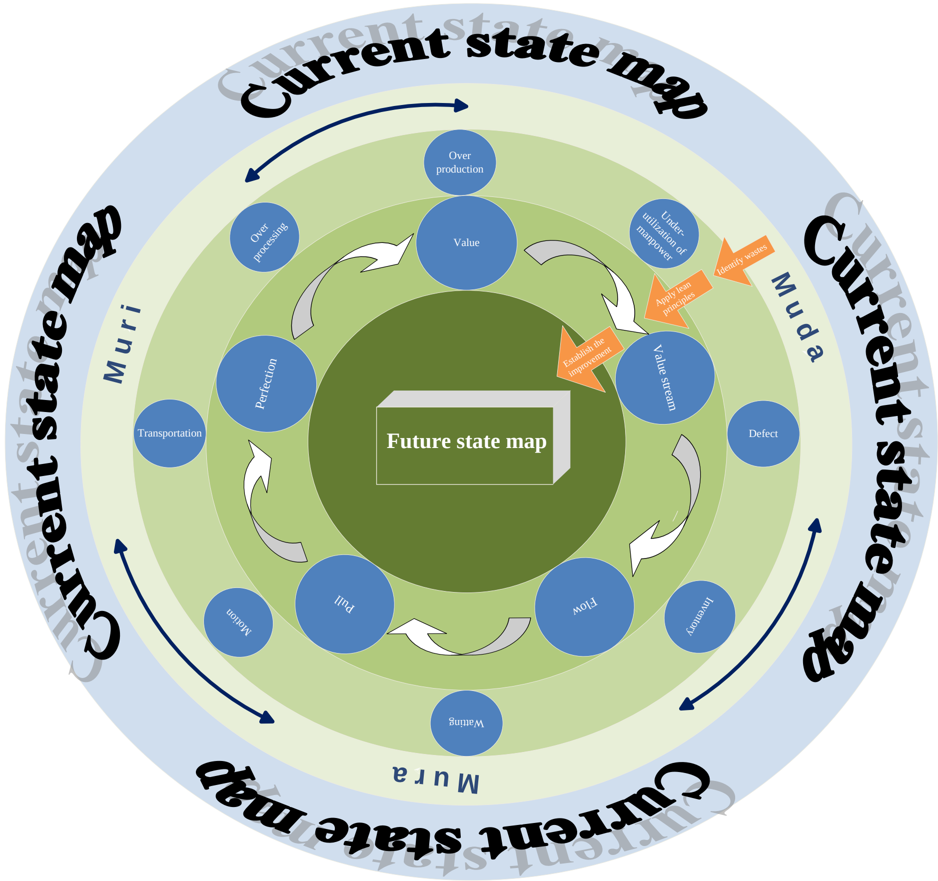


Figure 6.1: Methodology for leanness assessment and improvement using VSM

6.1.2 Application of VSM in Complex Environments

In recent times, the complexity in the production environment has been an extensively researched subject. Numerous researchers have expressed the difficulty in defining the concept of complexity due to the ambiguity linked with the concept (Fredendall and Gabriel, 2003). Toni *et al.* (2005) stated that it is challenging to define a complex production system but the development of complexity measures by considering different aspects of complexity is much more difficult. Calinescu *et al.* (1998) defined the complexity in a production environment as the expected amount of information required to explain the state of the production system. ElMaraghy, Kuzgunkaya, and Urbanic (2005) defined the complex production environment by the uncertainty present within the system. Fernandes (2001) stated that the term “complex” is normally used to express the level of difficulty linked with the manufacturing or assembly of a part. Complexity is a "subjective difficulty" deployed to explain the context of the representation of complex processes, products, assemblies, or the whole production system. In general, the complex production environment is described by its products, resources, and queues that constitute the state of the production system (Smart, Calinescu, and Huatuco, 2013).

These days, the complexities are broadly categorised as static and dynamic. The static complexity means the expected amount of information required to describe the state of a production system whereas dynamic complexity means the deviation of expected amount of information from the scheduled due to uncertainty. The complex assembly line is the example of static complexity where uncertainty about its products and the resources is not high but the complexity occurs due to large number of child parts, occurrence of several processes and sub-processes for different child parts, parallel and merging flows, *etc.* Conversely, the engineers to order (ETO), high-mix low-volume (HMLV) production environment and job shop production are examples of dynamic complexity where the complexity is due to the high uncertainty of product orders, their resources, sequences, routings, *etc.*

Most of the applications of the VSM have been reported in simple production environments where the material and information flows are easily identifiable and straightforward. The increase in complexity of production processes increases the challenges in collecting data for VSM preparation (Dal Forno *et al.*, 2014). There are few papers in the literature, which have used VSM under complex production environments of high mix low volume and merging flows. Marangoni, Romagnoli, and Zammori (2013) introduced a novel-mapping tool called multiple-value stream mapping (M-VSM) for analyzing of high-variety low-volume (HVLV) job shops. The M-VSM did not get practitioners' attention since it was just a theoretical draft and not an in-depth industrial application (Bertolini, Romagnoli, and Zammori, 2017).

Khaswala and Irani (2001) developed a new mapping tool – value network mapping (VNM) – for the improvement of a complex welding job-shop facility. VNM is an integration of production flow analysis and simplification toolkit (PFAST) and VSM. The results show the improvements in the current material handling methods and in the creation of manufacturing cells. But, this method is not linked to the basic concept of VSM – identification and elimination of lean waste from production process. The study has also not used the micro concepts of takt time and pacemaker process which hampers the advantages of full VSM.

McDonald, Van Aken, and Rentes (2002) prescribed application of VSM for an assembly line. This paper mainly focuses on the production control strategy by introducing constant work in process (CONWIP) concept. The non-value added time is reduced by reducing the inventory levels. This paper uses takt time and pacemaker process to fulfil the customer demand. However, the load in different cells is highly unbalanced; and other wastes are not identified & reduced. The assembly line has 14 variants but the processes are same, therefore the material flow is similar for all variants. This means the complexity of the line is comparatively low.

Braglia, Carmignani, and Zammori (2006) presented an innovative framework by integrating VSM with industrial engineering tools for complex bill of materials within a refrigerator assembly line. Although the lead time is reduced using this approach, but this requires a buffer WIP inventory. Further, this approach is difficult to use for multiple merging flows in the complex production or assembly processes.

Serrano, Ochoa, and Castro (2008) evaluated the applicability of VSM to redesign disconnected flow lines with diverse logistic complications. The basic purpose of the study is to check and validate the applicability of VSM in discrete parts manufacturing and to provide the guideline for the VSM application in these type of industries. However, the study is theoretical.

Álvarez *et al.* (2009) described the application of VSM as a lean implementation tool in an assembly line to redesign the operations by decreasing the intermediary stocks and eliminating non-value added time. Authors used the *kanban* and milkrun techniques to reduce dock-to-dock time and improve lean rate. The paper does not provide any insight regarding the identification and elimination of other wastes such as defect, motion, waiting, *etc.*

Bertolini *et al.* (2013) presented an extended VSM, using synchro-MRP system, for an electro-injector manufacturing plant. This synchro-MRP system is used to get the advantages of hybrid push-pull system over pure *kanban* or CONWIP system. Only one VSM was drawn to focus on the reduction of WIP inventory using hybrid push-pull system. The identification and elimination of other wastes are not considered.

Araya (2012) applied VSM in a high-mix low-volume (HMLV) engineer to order environment. The paper merges the processes into cells to create a simple material flow. The timeline data and cell load are not shown, which restrict the application of VSM for identification and elimination of wastes to meet the customer demand.

Schmidtke, Heiser, and Hinrichsen (2014) developed an enhanced VSM method using discrete event simulation (DES). The DES provides trade-off analysis leading to customer demand fulfilment and the monetary benefit quantification. This approach overcomes the limitations of complex production environments where complex routing and significant demand variability are involved. Authors focussed to fulfil the customer demand; however, wastes of inventory, transportation, defect, *etc.* were ignored. The method is not applicable when the system has large WIP inventory, unnecessary motion and transportation due to parallel and merging flows.

Matt (2014) adapted VSM for a steel construction organization under engineer to order environment. The various VSMs are superimposed on each other to get a simplified VSM. This paper combined various manufacturing processes into cells for the superimposition and simplification. However, the value stream maps only show the material flow through various cells. The basic visual depictions on the VSM like inventory, lead time, cycle time, takt time, value added and non-value added time, *etc.* are not shown.

Seth, Seth, and Dhariwal (2017) demonstrated the application of VSM for a complex high-mix low-volume (HMLV) engineer to order environment. The macro concept of VSM is used with approximation and simplification. Due to the use of macro concept for simplification, this paper does not use the basic concepts of takt time and pacemaker process which restricts the application of VSM to identify the various lean wastes. This paper also applied the VSM only for one variant assuming the other variants as similar.

Literature has large number of value stream mapping (VSM) papers but the number of papers on VSM application in complex production environments are limited. Complex production environments have a few VSM applications but complex assembly lines have only few VSM applications. None of the existing VSM papers on complex environments show full VSM; wherein various wastes, non-value added activities, cycle time, uptime, takt time, and the material and information flows are generally shown. The drawbacks of the existing few VSM papers for complex environments are: (i) either developed VSM for one variant or drawn different VSMs for different variants or superimposed VSMs of different variants to develop cells to simplify material flow between cells without considering the load levelling of cells, (ii) did not use the basic concepts of VSM; like takt time, pacemaker, cycle time, value added and non-value added times, *etc.* which inhibits the utility of VSM for practitioners to improve cycle time, customer demand fulfilment, elimination of non-value added activities, *etc.*, and (iii) most of the papers focused on WIP inventory thereby not utilizing the VSM for identification and elimination of other lean wastes. This chapter proposes an integrated VSM for assembly line wherein the above drawbacks of the VSM application under complex environments are taken care of.

6.1.3 Overview of Continuous *Kaizen*

A *kaizen* is a project having the potential for the improvement of worker involvement and the organizational performance at the same time (Farris *et al*,. 2008). Suárez-Barraza, Ramis-Pujol, and Kerbache (2011) identified two interpretations of *kaizen*: the western explanation of *kaizen* as "continuous improvement" and the Japanese interpretation of *kaizen* as improvement by involving everyone alike. In western countries, the continuous improvement is termed as the *kaizen* and seen as a corporate proficiency that is practised as a part of either TQM or various other innovation and improvement programs (Bessant 2003). Whereas in Japan, the *kaizen* is described as a philosophy of conducting improvement activities at the workplace by involving everyone alike (Imai, 1986). Imai (2013) says that *kaizen* should not be interpreted as continuous improvement only, because this interpretation does not include the commitment and self-discipline, two aspects required by everyone for *kaizen* implementation. Aoki (2008) highlights the need to comprehend not only the execution of *kaizen* activities but also the spirit of *kaizen* in more depth. Chung (2018) claimed that *kaizen* is not similar to "improvement" in its usual sense. Thus, present study proposes a new delineation of *kaizen* – 'continuous *kaizen* (CK)'. The study defines 'continuous *kaizen*' as continuous and comprehensive improvement for the completeness at the global or whole value chain level instead of just 'change for better' at local or single workstation, so as to imply the value of integration in *kaizen* activities.

Kaizen should improve leanness level of the organization by systematic identification and elimination of various lean wastes. The 'continuous *kaizen*' focuses on two key aspects:

- *Kaizen* should be throughout the value chain. The *kaizen* should be small, incremental, continuous, and comprehensive throughout the value chain.
- *Kaizen* should involve everyone from everywhere. The multi-hierarchical cross-functional team should perform *kaizen* activities in a specified timeframe to achieve pre-defined goal(s).

The literature suggests that organizations are facing difficulties either to achieve initial results or to sustain the results while adapting the *kaizen* in practice. Laraia, Moody, and Hall (1999) stated that 50 percent of the companies are suffering from the problems of upholding their improvements achieved by conducting the *kaizen* events. The UK organizations also faced similar problems and confirmed poor results of continuous improvement programs (Mackle, 2000). Bateman (2005) conducted a continuous improvement program and found that the organizations obtained lopsided results in the form of process improvements. Tseng, Chiu, and Chinag (2006) showed that continuous improvement was incapable to directly enhance the operational performance in Taiwan manufacturing organizations. The probable reasons for the *kaizen* failures are lack of knowledge about the scope of the *kaizen* philosophy (Oropesa *et al.*, 2016), resistance to change (Marin-Garcia, Garcia-Sabater, and Bonavia, 2009), and isolated attempts for the *kaizen* implementation at local or workstation level (Suárez-Barraza, Ramis-Pujol, and Kerbache, 2011). Irrespective of the increasing manifestation of *kaizen* failures, the organizations are still implementing *kaizen* events to attain the higher customer satisfaction (Koval *et al.,* 2018).

Soltero and Waldrip (2002) stated that lean manufacturing is a set of tools & techniques tied together by *kaizen*. The organizations can implement lean tools & techniques to improve organizational performance, but these endeavours will be sub-optimal without the use of *kaizen* (Prashar, 2014). *Kaizen* is defined as a process-oriented key building block (Womack and Jones, 2003) or philosophy (Chung, 2018) of lean thinking for incremental and continuous improvement of the system. The continuous improvement may be defined as a systematic effort to pursue and employ new methods to consistently obtain the process enhancements (Anand *et al.*, 2009). Generally, *kaizen* is studied in relation to various quality strategies, initiatives and perspectives such as total quality control, TQM, six sigma, *etc*. (Carnerud, Jaca, and Bäckström, 2018; Maurer, 2012; Sanchez and Blanco, 2014).

A k*aizen* focuses on problem identification and its root causes and provides the creative solutions (Vonk, 2005). The *kaizen* activities are used for the value addition to products and/or services (Marin-Garcia, Juarez-Tarraga, and Santandreu-Mascarell, 2018). The *kaizen* implementation attracts many organizations since it provides several qualitative and quantitative benefits to the organizations. The qualitative benefits are often related to human resources such as improvement in worker skills and commitment (Marin-Garcia, Garcia-Sabater, and Bonavia, 2009); self-esteem and motivation (Alukal and Manos, 2006); staff participation, training, communication, teamwork, and greater job satisfaction (Alvarado-Ramírez *et al.*, 2018; Suárez-Barraza and Ramis-Pujol, 2010). The quantitative benefits are linked to the economic factors such as increased productivity, profit, and inventory turnover (Oropesa *et al.*, 2016); reduced lead times, cost, defects, and number of stages in production processes (Ramadani and Gerguri, 2011).

The numerous tools, techniques and methods for *kaizen* implementation exist in the literature (Marin-Garcia, Juarez-Tarraga, and Santandreu-Mascarell, 2018). Typically, *kaizen* tools & techniques are human-based and process-oriented, while *kaizen* itself is continuous, incremental, and hands-on in nature (Alvarado-Ramírez *et al.*, 2018; Suárez-Barraza, Ramis-Pujol, and Kerbache, 2011). Lillrank, Shani, and Lindberg (2001) have categorized the *kaizen* implementation in four dimensions: one, activities by individuals or groups; two, group activities comprising multi-functional or mono-functional and involving persons from the same or different hierarchical levels; three, activities either parallel or integrated into operators' daily work; and four, permanent or temporary working team (for particular projects only). Suárez-Barraza and Lingham (2008) also identified four dimensions of *kaizen* – office *kaizen*, *gemba kaizen*, *kaizen* blitz, and *kaizen teian*. Marin-Garcia, Juarez-Tarraga, and Santandreu-Mascarell (2018) identified eight different types of tools & techniques for the implementation of *kaizen* activities – quality circles, ad hoc groups, suggestion systems in permanent teams, *kaizen* blitz, improvement teams, self-regulated work teams, and *kaizen* event. Table 6.1 presents the salient points of *kaizen* tools & techniques.

Continuous *kaizen* is a distinct approach, which mainly focusses on the leanness improvement by the elimination of various types of lean wastes throughout the value chain. The continuous *kaizen* can be used to improve productivity, line balancing, and line efficiency by improving the cycle time, whereas other tools & techniques of *kaizen* implementation are either part of TQM or six sigma and focus only on quality improvement. Generally, continuous *kaizen* is conducted by a top management defined multi-hierarchical cross-functional team using various methods/tools like g*emba* walk, 3M analysis, ECRS (eliminate, combine, reduce, or shift) studies, *etc.* to systematically identify and analyze the problems at micro level.

Table 6.1: Different types of *kaizen* tools & techniques and their description

Type of *kaizen* tool	Salient points	References
Quality circles	• Quality circle is a small group of workers. • The group members work willingly and meet cyclically to identify, examine and suggest alternative solutions to the problems. • The group can only propose ideas; committee of managers evaluates these ideas and choses the appropriate one to implement. • Generally, the group members implement the selected idea(s).	Kerrin and Oliver, 2002; Rapp and Eklund, 2007
Improvement teams	• In improvement teams, the management choses the participatory persons rather than the voluntarily participation. • The team members are usually from different working areas or from different hierarchy levels of the organization. • This structure supports complementary perspectives and the examination of problems influencing different areas of the organization. • Typically, these structures are unstable as compared to quality circles in terms of time duration and team members.	García-Lorenzo and Carlos Prado, 2003; Lawler, Mohrman, and Benson, 2001
Self-regulated work teams	• Team members judge work distribution, working methods, *etc.* • Generally, multi-faceted employees who accomplish interconnected tasks with differed and skilled work formed the work team. • The team is accountable for support services such as quality control, maintenance, materials supply, *etc.* • Sometimes, the team also performs staff management roles such as training, payment, hiring, firing, *etc.* • The team has less autonomy in comparison to other types of *kaizen* teams.	Kerrin and Oliver, 2002
Ad hoc groups	• Also known as short-term project teams, task forces, *etc.* • Specifically, these groups are formed to handle the critical problems or issues within organization. • Usually, these groups are cross-functional and created for specified duration. • The assigned work is not frequent and the group is disbanded after finishing the assigned work.	García-Lorenzo and Carlos Prado, 2003
Suggestion systems in permanent teams	• Team involves employees giving improvement suggestions on regular basis. • This type of team is also called suggestion box team (*kaizen* teian). • The team plays an important role in those organizations, where the innovation is compulsory factor to survive and grow in the market.	Buech, Michel, and Sonntag, 2010; Amabile, 2012; Gressgård, 2011
Kaizen blitz	• *Kaizen* blitz is a short-term improvement program (3-5 days). • Generally, this is based on the suggestions or ideas given by the technicians, managers, outside experts or consultants. • The cross-functional team makes efforts for the significant improvement in few specified areas.	Chakravorty and Franza 2012; Marin-Garcia, Bonavia Martin, and Miralles, 2008; Terziovski and Sohal, 2000
Kaizen event	• This is a dedicated and well-defined improvement project. • The *kaizen* event uses a committed cross-functional team to improve a targeted work area in a defined time duration with certain goals. • *Kaizen* event acts on a top-down methodology for the improvement activities. • The scope of a *kaizen* event concentrates on the part of a particular value chain. • This is a low or minimum capital investment project. • The team has the sole authority to implement the required changes for the improvements without any approval from the top management. • Generally, the goals are defined and measurable.	Van Aken *et al.*, 2010; Letens, Farris, and Van Aken, 2006; Melnyk *et al.*, 1998

Table 6.1: Different types of *kaizen* tools & techniques and their description (Contd.)

Type of *kaizen* tool	Salient points	References
Continuous *kaizen*	• Team mainly focusses on the reduction of various lean wastes throughout the value chain to enhance the leanness level of the organization. • A dedicated multi-hierarchical cross-functional team along with external experts or consultants work for small and incremental improvement activities in a time bound project. • The team systematically identifies and analyzes different lean wastes using series of *gemba* walks, 3M analysis, ECRS studies, *etc*. • The goals are global, measurable and pre-defined by the top management for the whole value chain. • The team has the autonomy to conduct various *kaizen* activities.	Present study

6.2 CASE STUDY

This study depicts the application of VSM at the case organization, where top management is concerned for the challenges of higher cycle time and lower productivity. The top management recognized the vigour of VSM for the leanness and was willing to apply the VSM to reduce WIP, cycle time, and waste to improve the productivity. However, few managers were cynical of the application of VSM in this complex environment, particularly who had some prior experience of VSM development. The methodology used for the case study is shown in figure 6.2. The first step of the VSM is to decide the goal(s) of VSM. The goal is to improve productivity by elimination of various wastes from the assembly line. Next, a cross-functional team was formed involving persons from different hierarchies of the case organization. The team commenced the discussion about the shop floor activities such as number of product variants, number of machining and assembly lines, customer demands for various products, delivery, actual versus target values of various parameters – rejections, machine downtime, *etc.*, and types of difficulties/problems which have influence on cycle time and create wastes. After examination of previous records, the team members selected the column assembly 2 for the study. Next, the team performed the *gemba* walk along the selected assembly line and collected the necessary data. *Gemba walks* were conducted to establish the concept of *'walk the flow, create the flow'* along the assembly line. Basically, the *gemba* is used to emboldens the principle of "go and see" (Tyagi *et al.,* 2015). Further, the team developed the current value stream map to know the "as-is" state. Then, the team analyzes the current VSM and proposes the future VSM for "to-be" state. The team also defined the work plan for the execution of suggested improvements in the future VSM in terms of short-term (0-3 months) and long-term (up to 1 year) improvement plans. Lastly, implement continuous *kaizen* concept to accomplish the suggested improvement.

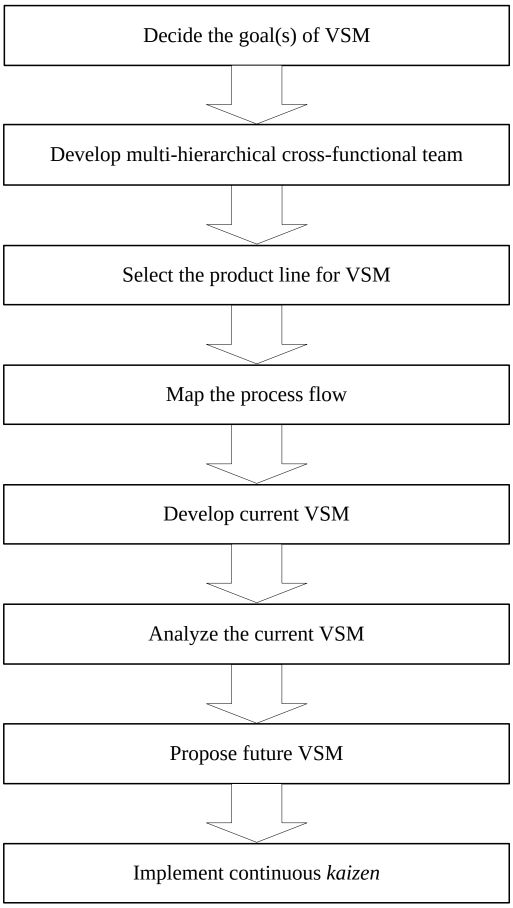


Figure 6.2: VSM implementation methodology

6.2.1 Develop a Multi-hierarchical Cross-functional Team

To apply lean instruments, it is essential to comprise the people from all departments as well as from all organizational levels (Dal Forno *et al.*, 2014; Pettersen, 2009). A multi-hierarchical cross-functional team consisting of 10 internal members and two external experts was formed as shown in figure 6.3. The cross-functional team comprised the heads of production, manufacturing engineering, quality, and production planning and control departments; two team leaders (TLs) at the manager level from manufacturing engineering, and production planning and control departments; two assistant team leaders (ATLs) at the assistant manager and supervisor level from production and quality departments; two operators at the operational level; and two external experts from academia.

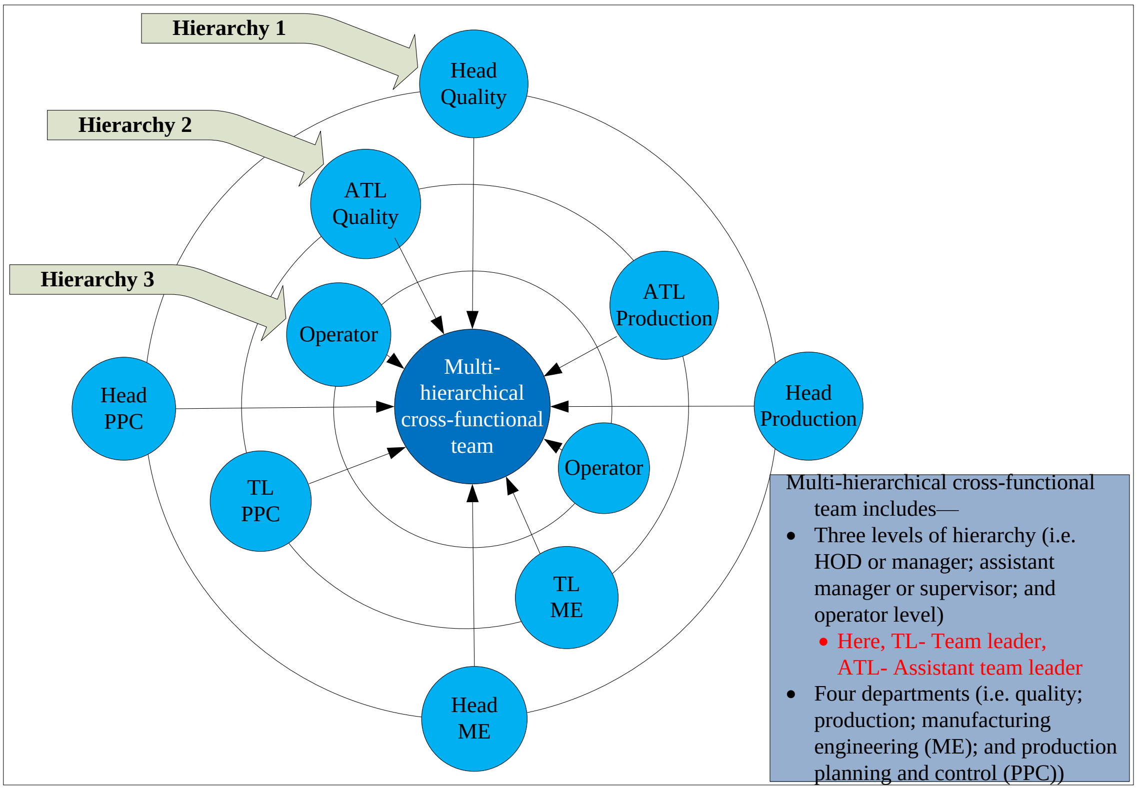


Figure 6.3: Multi-hierarchical cross-functional team for the study

6.2.2 Select the Product Line for VSM

The external experts studied all the eight lines in the plant and the operational data was sought from the heads of various departments. The rejection targets, actual rejections and percent rejections for each line were tabulated (Table 6.2). It is clear that steering column assembly line 2 has the maximum percentage rejections. It was a probable candidate for the VSM. The management also agrees with the selection of this line as it is one of the bottleneck lines for the plant having long lead-time, high cycle time and high customer demand. Therefore, steering column assembly line 2 was selected for the case study. Here after, it will be called as steering column assembly line.

The selected line is a semi-automatic assembly line (i.e. a combination of assembly by man and machine) as shown in figure 6.4(a). In this line, two types of products are being assembled: W-501 guided (Figure 6.4 (b)), and W-501 non-guided models (Figure 6.4 (c)) (product names are changed for the confidentiality). Generally, the changeover in the line takes place 1-2 times in a week. Total 49 child parts from 30 different suppliers are used to assemble these two products.

Table 6.2: The monthly average rejection at the various lines of the case organization

S. No.	Line	Rejection target	Actual rejection	Percentage of actual rejection to target
1	Idler machining	3937.0	3842.3	97.60%
2	Rack housing	1220.7	1517.7	124.33%
3	Steering column assembly 1	158.3	41.0	25.89%
4	Rack & pinion sub-assembly	26.3	11.0	41.77%
5	Steering column assembly 2	69.0	138.0	200.00%
6	Intermediate shaft	42.7	31.7	74.22%
7	Universal joint (UJ) assembly	61.3	63.7	103.80%
8	Idler assembly	232.7	144.3	62.03%

6.2.3 Map the Process Flow

The process sequence is exhibited in figures 6.5 and 6.6. The production of W-501 guided model requires 18 processes, whereas the W-501 non-guided model requires only 16 processes to make the complete assembly. Figures 6.5 and 6.6 clearly depict that a number of processes are carried out in parallel, which make it difficult to understand the process flow. Each process is either an operation or a group of operations. For example, the operations of plastic sleeve insertion, notching and greasing of male shaft is called as process no. 5. If one operator is handling two or more number of processes at different workstations then it is considered as a work cell. Ten operators are used to assemble the guided model, whereas nine operators are used to assemble the non-guided model. Since the number of operators are less than the number of processes, therefore multi-machine activities (one operator is performing two or more processes) are considered as a work cell. For example, processes 1, 2 and 3 are carried out by one operator, therefore it is represented by one work cell and the cycle time is calculated for the work cell rather than the individual processes.

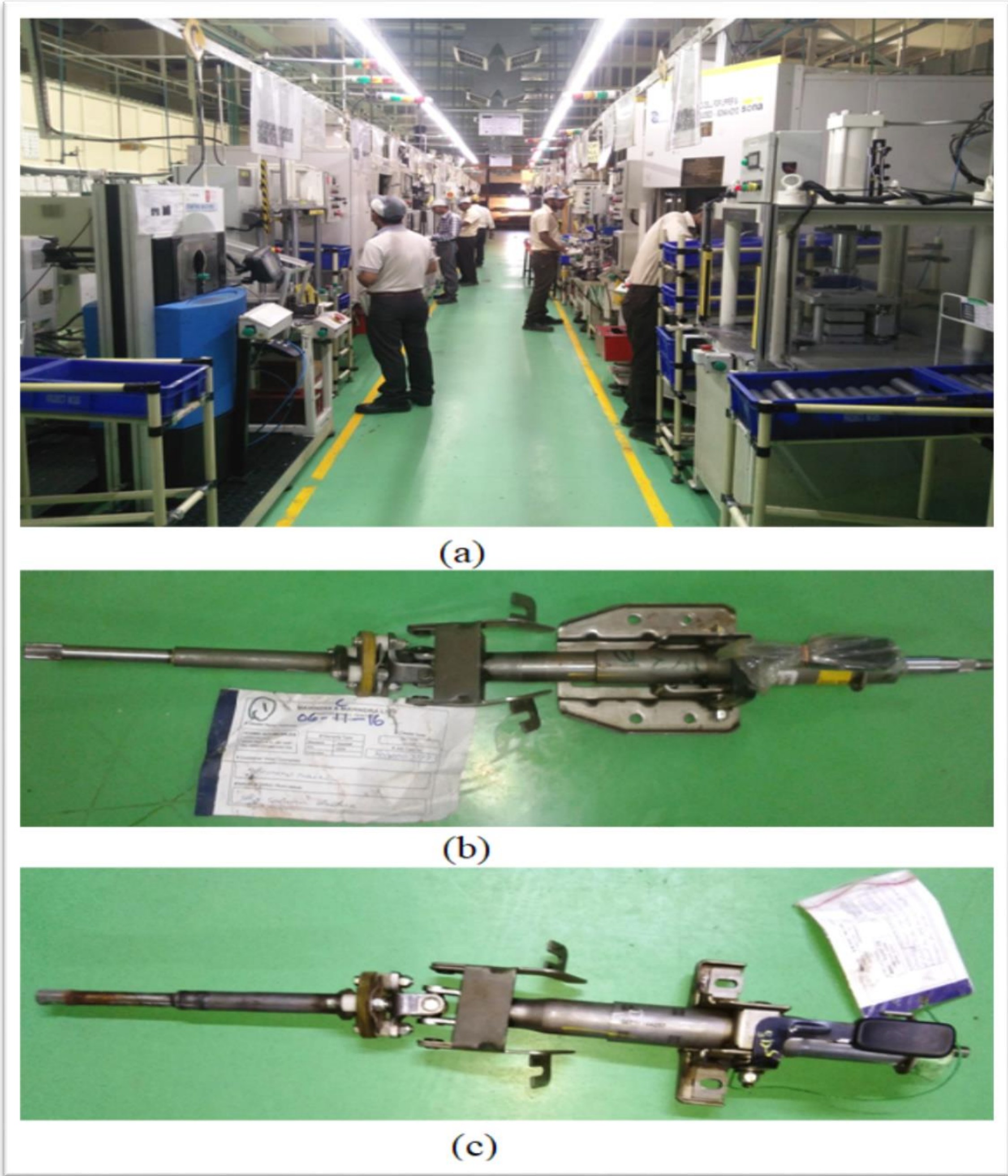


Figure 6.4: Assembly line and product family for the study

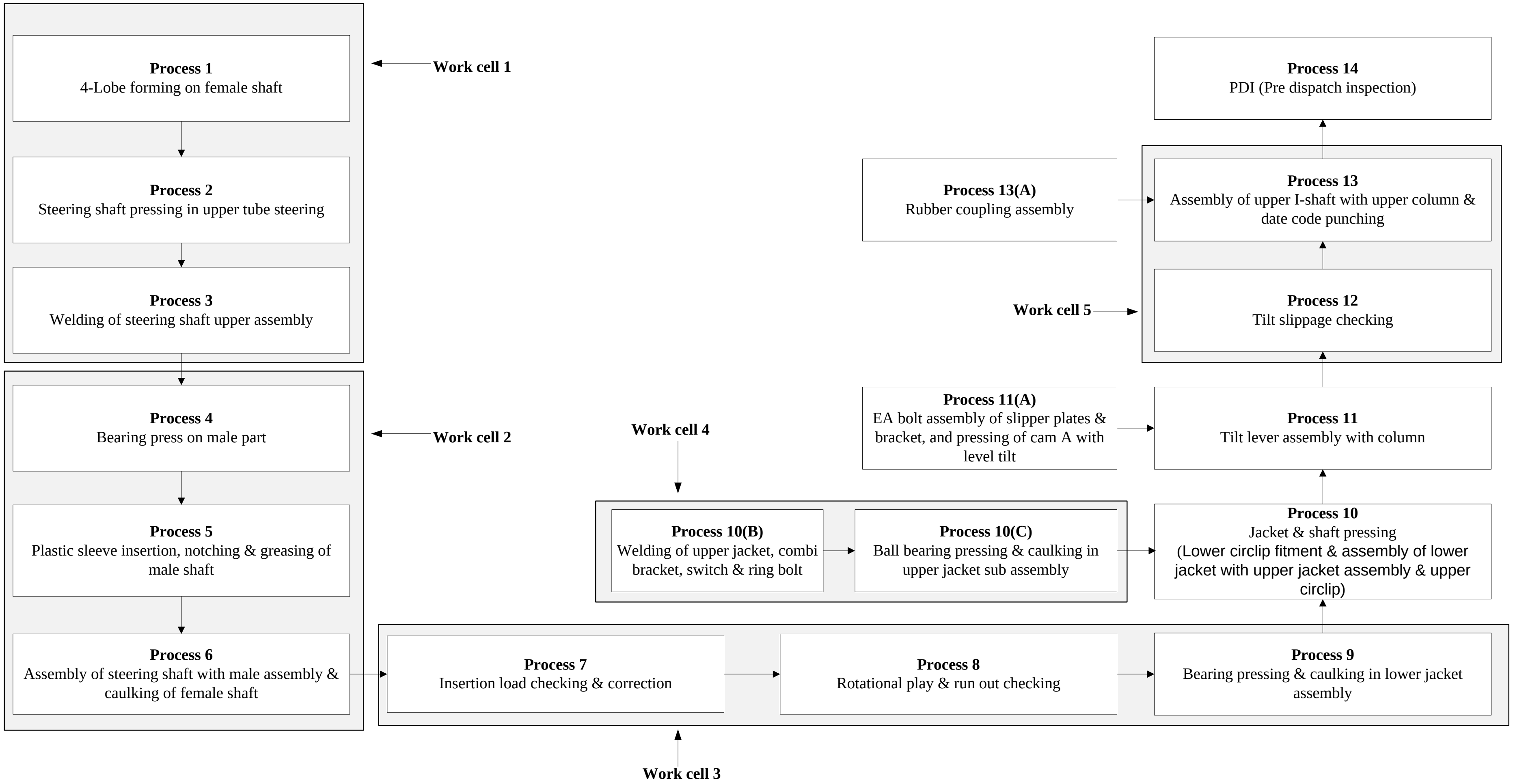


Figure 6.5: Process flow diagram for W-501 guided model

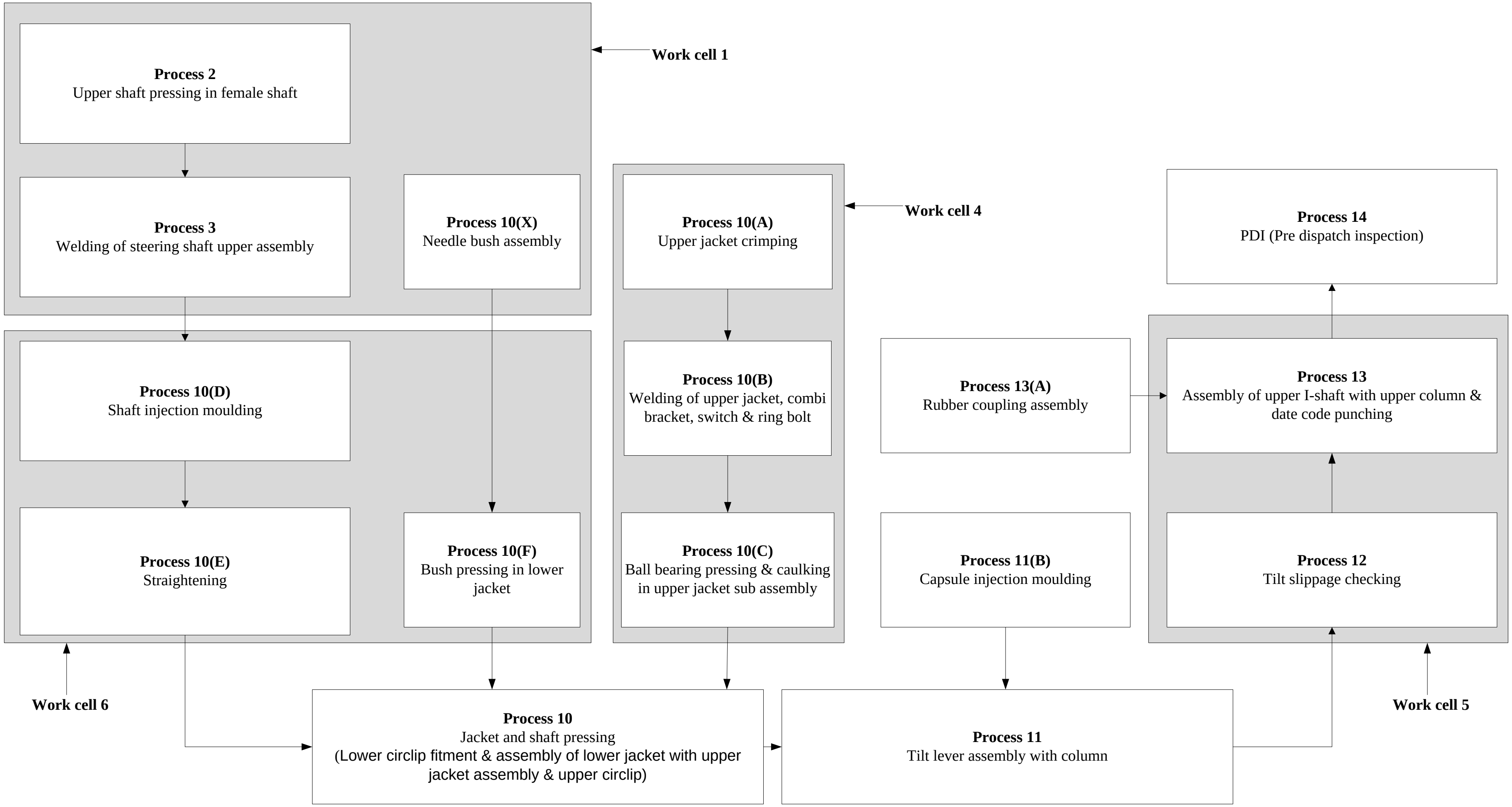


Figure 6.6: Process flow diagram for W-501 non-guided model

6.2.4 Develop Current VSM

The current value stream map is developed (figure 6.7) to know the "as-is" state of the steering column assembly line. The standard symbols of VSM are used to draw the current state map. These symbols represent the flow of information and the flow of materials along the value stream. The production planning and control (PPC) department receives monthly orders and two-month forecasts from the customer. Correspondingly, the PPC department sends the monthly orders and two-month forecasts to the suppliers. Various child parts are sent by the suppliers through the weekly milkrun activities. After the inward quality inspection, the parts are sent to the line. The processes are carried out to make the final assembly of the products. Lastly, the packaging of the finished parts is carried out in the packaging section and the finished part is sent to the warehouse from where it goes to the customer. The following assumptions are made to simplify and unveil the whole activities of the complex environment on a single value stream map.

- There are no changes in the customer and supplier orders, the production rhythm (takt time) is stable and supply of the products is consistent.
- Multi-machine activities (MMAs) operated by one operator are considered as a work cell.
- All raw materials and child parts are received from a single supplier.
- The flow in the line is single piece and the work in process inventory is only due to child parts at the various workstations.
- There are no packaging issues of child parts, especially for B and C types of child parts. Therefore, these child parts can be easily supplied to the line in loose conditions in the desired quantities.
- The cycle time for various processes is taken as the average of the number of readings.

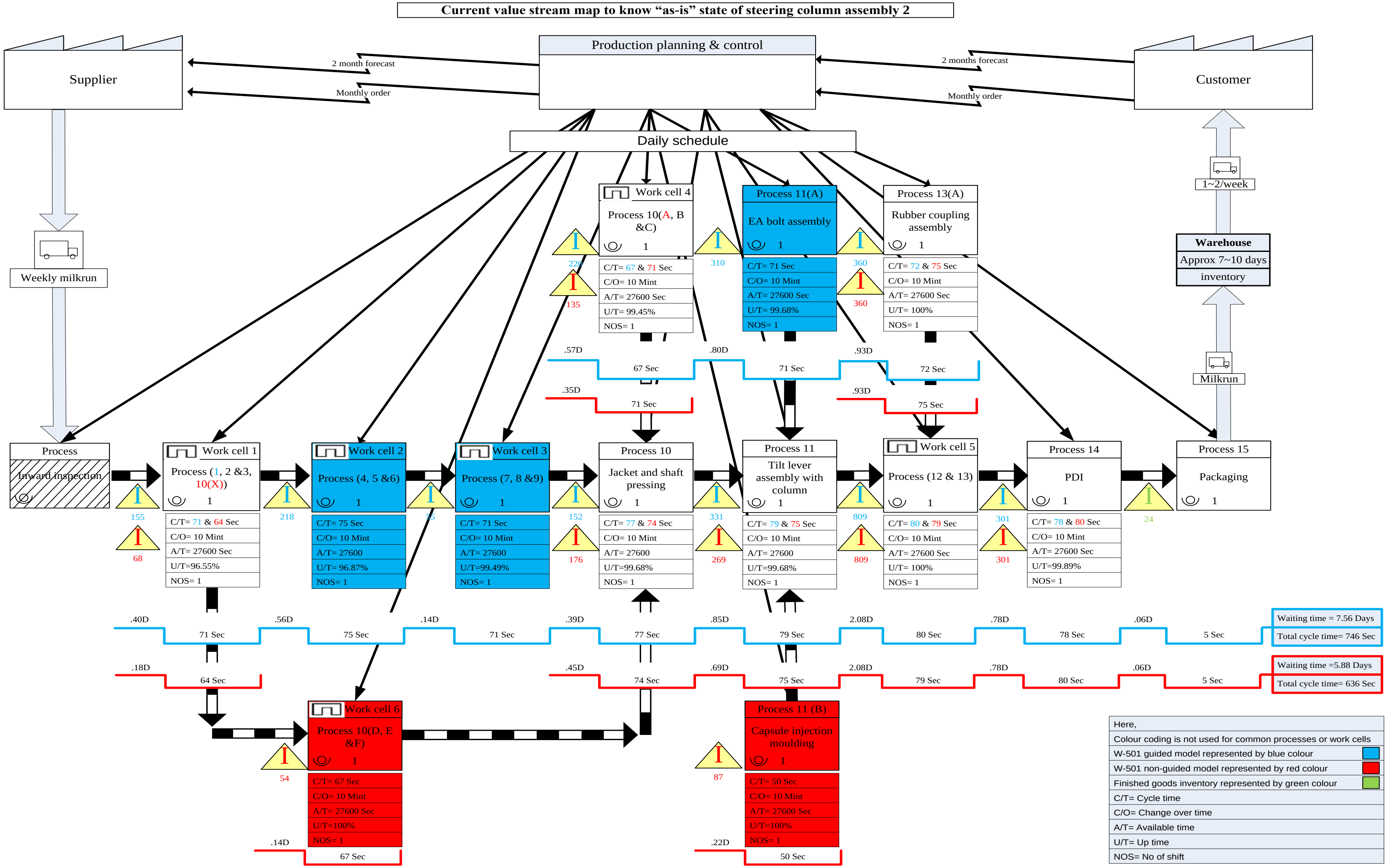


Figure 6.7: Current value stream map

6.2.5 Analyze the Current VSM

The current value stream map shows that flow of information and flow of material are not adequate and a number of weak areas exist, which require the improvements. The current value stream map can be summarized as:

- The total cycle time is 746 seconds for the guided model and 636 seconds for the non-guided model.
- There is a large waiting time of 7.56 days for the guided model and 5.88 days for the non-guided model. This is due to the push system employed for the child parts.
- Some processes are poorly designed such as process 10, process 11, process 12, process 13(A), and process 14.
- The movement of materials between various workstations is not consistent and involves a lot of repetitive, backtrack and zigzag movements.
- The various types of lean wastes are noticed at the shop floor: transportation waste, large WIP inventory at different stations, motion waste due to poor workstation design, waiting due to the unbalanced line and child parts, and defect waste due to rejections.

From the analysis, it is clear that there is an opportunity for the improvement in the current state. The takt time for the customer demand of 388 products per day is:

$$Takt\ \text{time} = \frac{27600}{388} = 71.13 \approx 71\ sec$$

The takt time shows the heartbeat of the selected assembly line. One steering column assembly should be manufactured every 71 seconds. The comparison of the cycle time with the takt time shows that the six processes have higher cycle time than the takt time. Therefore, these six processes require improvements to meet the customer demand. The long distance traveled in the existing layout is one of the factors for the transportation waste and high cycle time. There are a number of zigzag movements of material and operators in the existing layout as shown in figures 6.8 and 6.9.

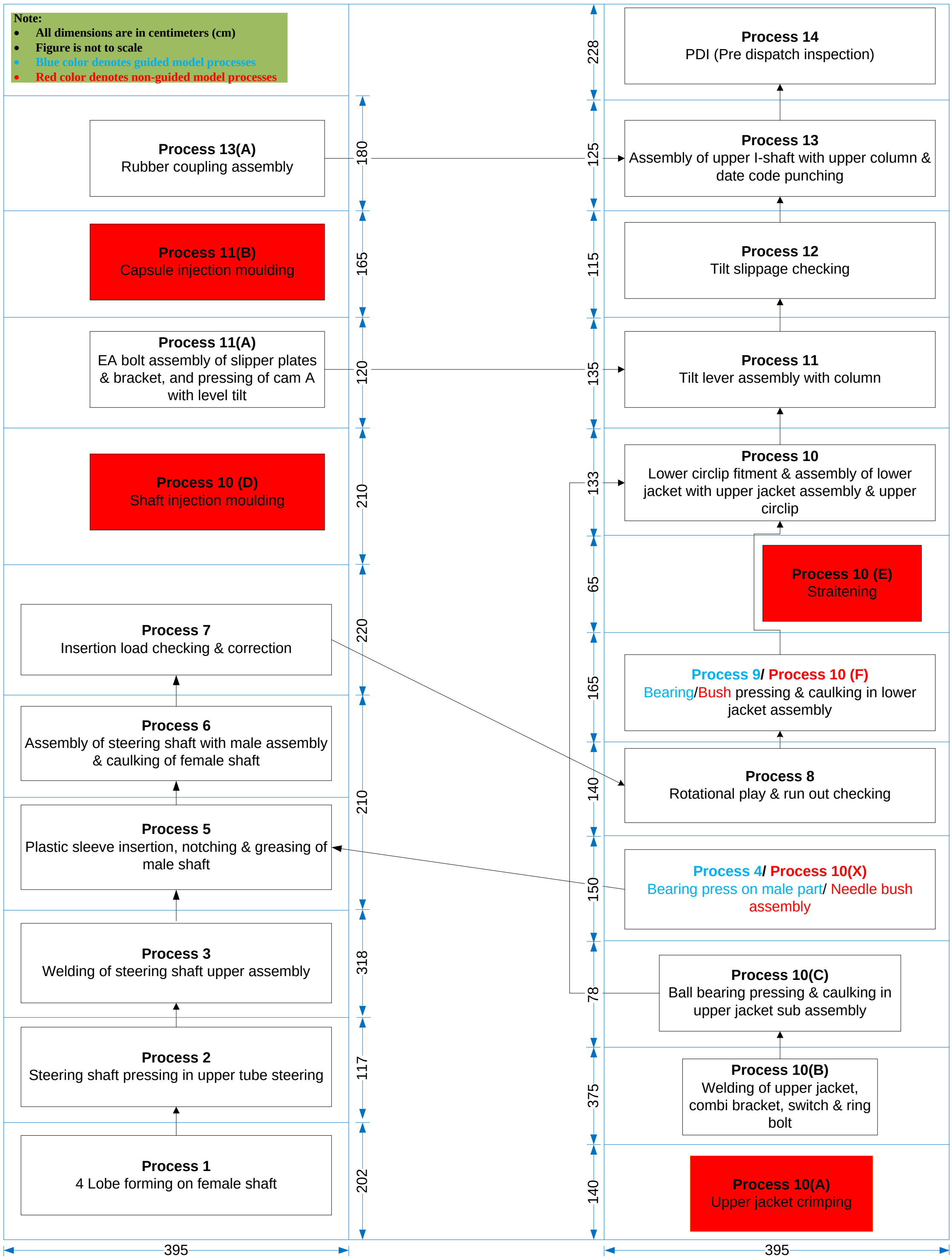


Figure 6.8: Existing machine positions and material flow for W-501 guided model

The concept of “walk the flow, create the flow” is followed by the team for the minute analysis of the current state map. The team conducted *gemba* walks to identify problems from the shop floor perspective. Various brainstorming sessions were conducted to know the problems and their root causes. Brainstorming builds a constructive and worthwhile environment for problem unraveling and enriches attachment among team members. After analyzing the current VSM, the team found that five major types of wastes distressing the line are: transportation, defect, waiting, motion, and WIP inventory.

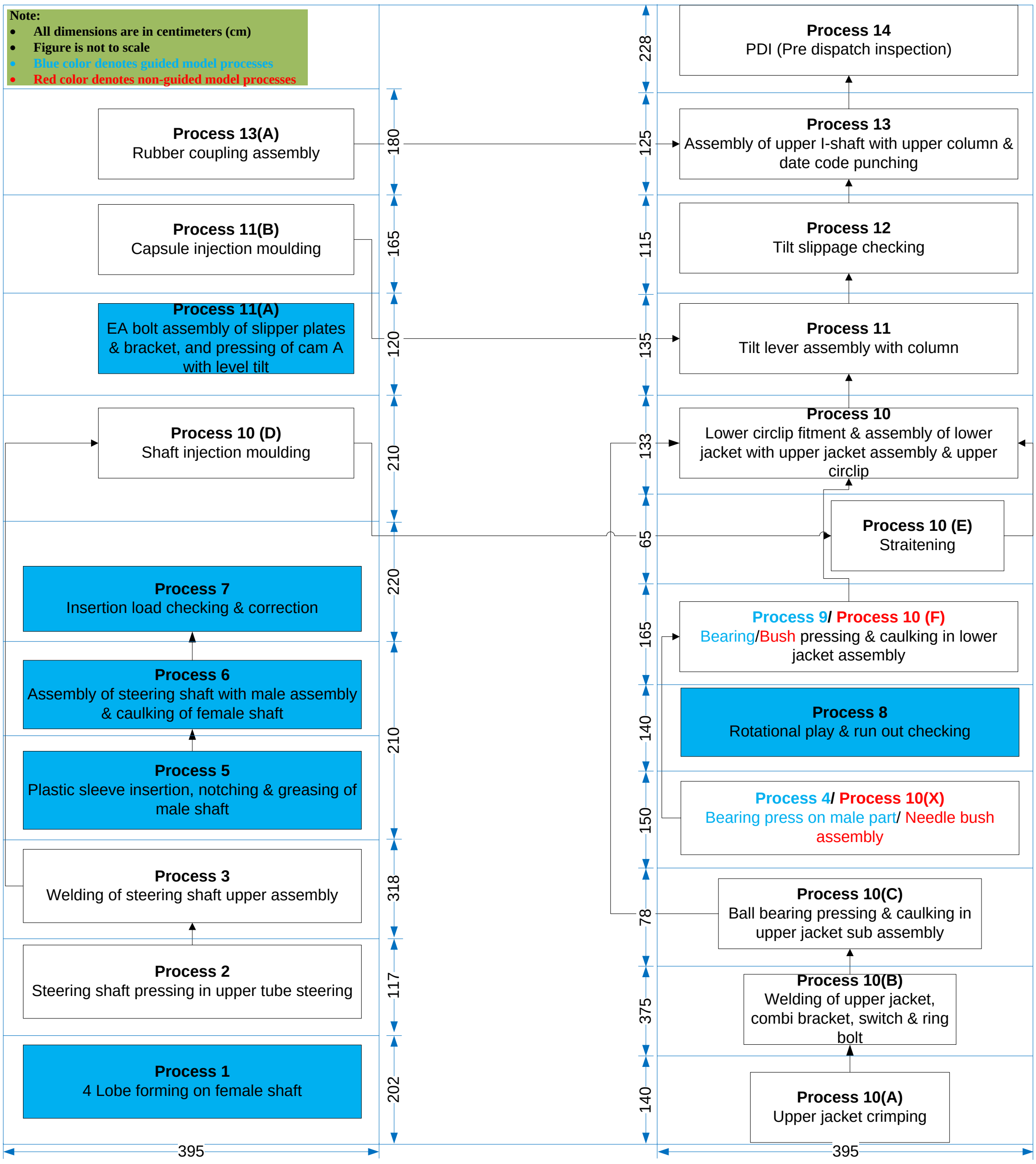


Figure 6.9: Existing machine positions and material flow for W-501 non-guided model

- **Transportation waste**

The cross-functional team conducted a separate session to discuss the possible causes of transportation waste. After the preliminary conversation, the possible causes of transportation waste are presented in table 6.3. The team came to the consensus that the poor line layout is the root cause of the transportation waste. There are a number of zigzag movements of material and operators due to the poor layout design.

Table 6.3: Possible causes of transportation waste after brainstorming session

S. No.	Possible cause
1.	Wrong routing for child part feeding
2.	More space required due to high WIP
3.	Improper bin sizes
4.	Poor line layout
5.	Poor trolley design
6.	Poor material handling
7.	Single storage location
8.	Complex working environment due to large no of child parts
9.	Poor consideration to material flow

- **Defect waste**

The team considered the defect waste due to the different types of rejections at the various workstations. The team listed all types of rejections and developed a Pareto diagram (Figure 6.10). Pareto diagrams are used to examine a problem with a changed viewpoint, to emphasize problems in primacy order, and to construct a cumulative line (Tyagi *et al.* 2015). An Ishikawa diagram is also developed to identify the root causes of the defects. Causes due to man and method are common for all processes, whereas machine and material causes are identified as process specific. Only one Ishikawa diagram (Figure 6.11) is developed for the defects instead of the usual practice of one diagram for each defect. This is due to the fact that the team wanted to focus on the major causes of the defects instead of the focus on the defects. This was possible because of the experienced members in the team. A large number of rejections are due to high sliding force; and the poor load cell is the root cause of the high sliding force.

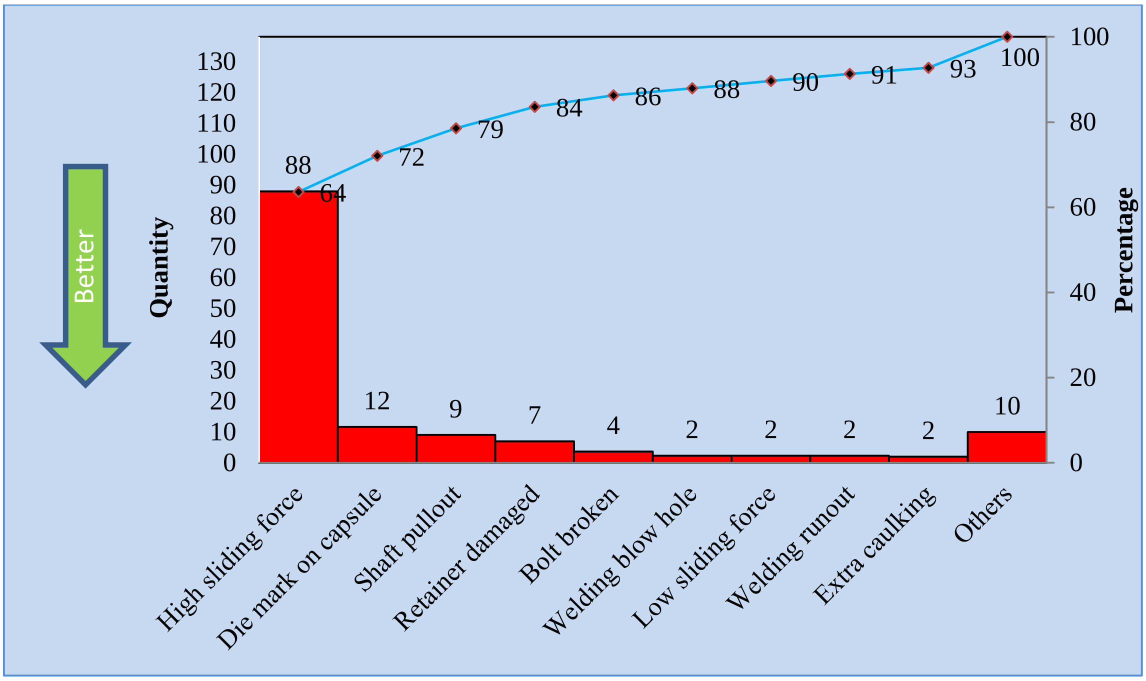


Figure 6.10: Monthly average rejection Pareto of column assembly line

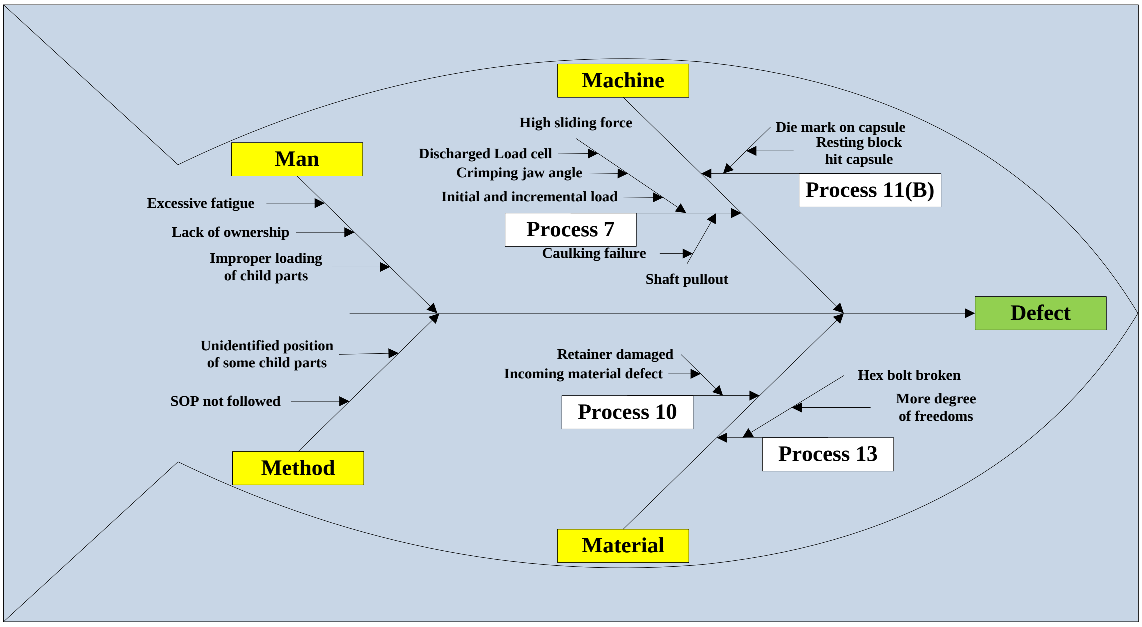


Figure 6.11: Ishikawa diagram for defect waste

- **Waiting waste**

Two major reasons for the waiting waste are machine breakdown and unavailability of bought out parts (BOP). It is found that a large number of breakdowns occurred at various workstations in the first quarter of the financial year 2017-18 (Figure 6.12). The Pareto diagram of brought-out parts (BOP) downtime due to unavailability of material at various processes is shown in figure 6.13. Ishikawa diagram has been developed to show the possible causes of waiting waste (Figure 6.14). The long-distance travel and unbalanced line loading also result in waiting waste.

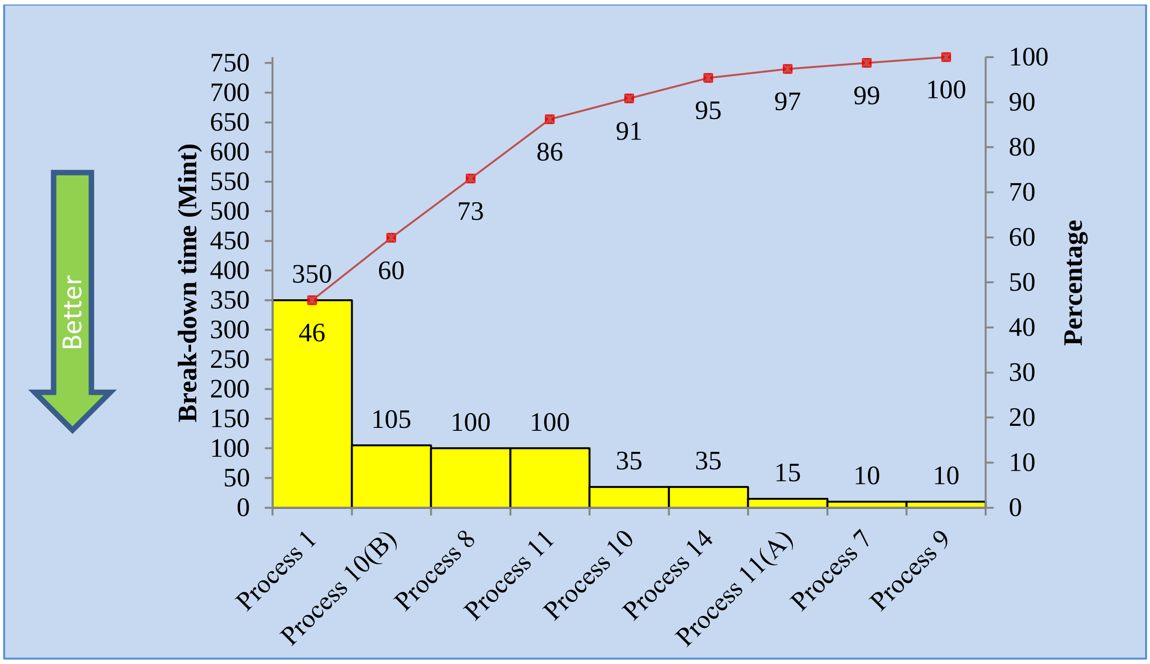


Figure 6.12: Machine break-down time Pareto of column assembly line

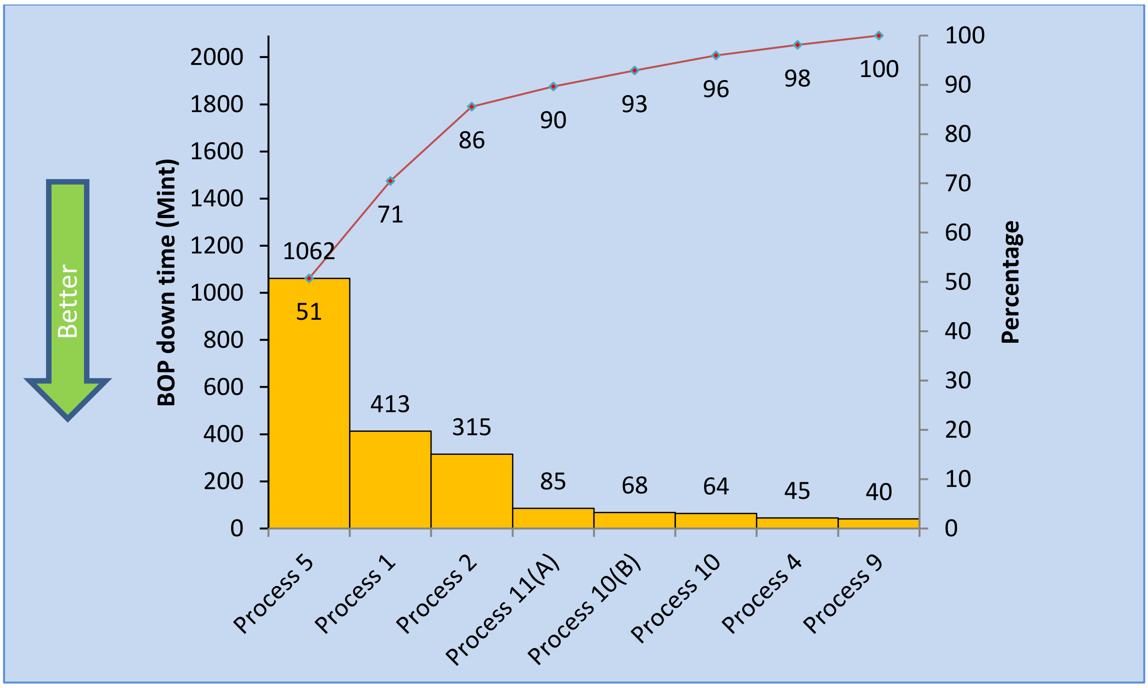


Figure 6.13: BOP downtime Pareto of column assembly line

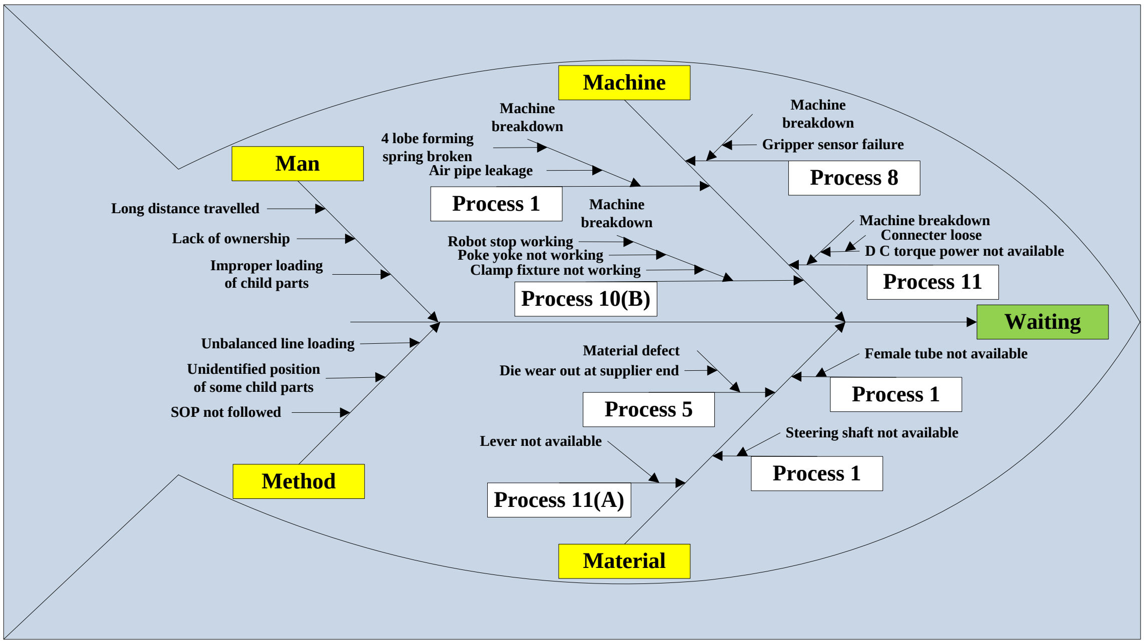


Figure 6.14: Ishikawa diagram for waiting waste

- **Motion waste**

The high cycle time at some workstations is mainly due to motion waste. The possible causes of motion waste are shown in figure 6.15. The poor workstation design and poor line layout are found as the root causes of the motion waste.

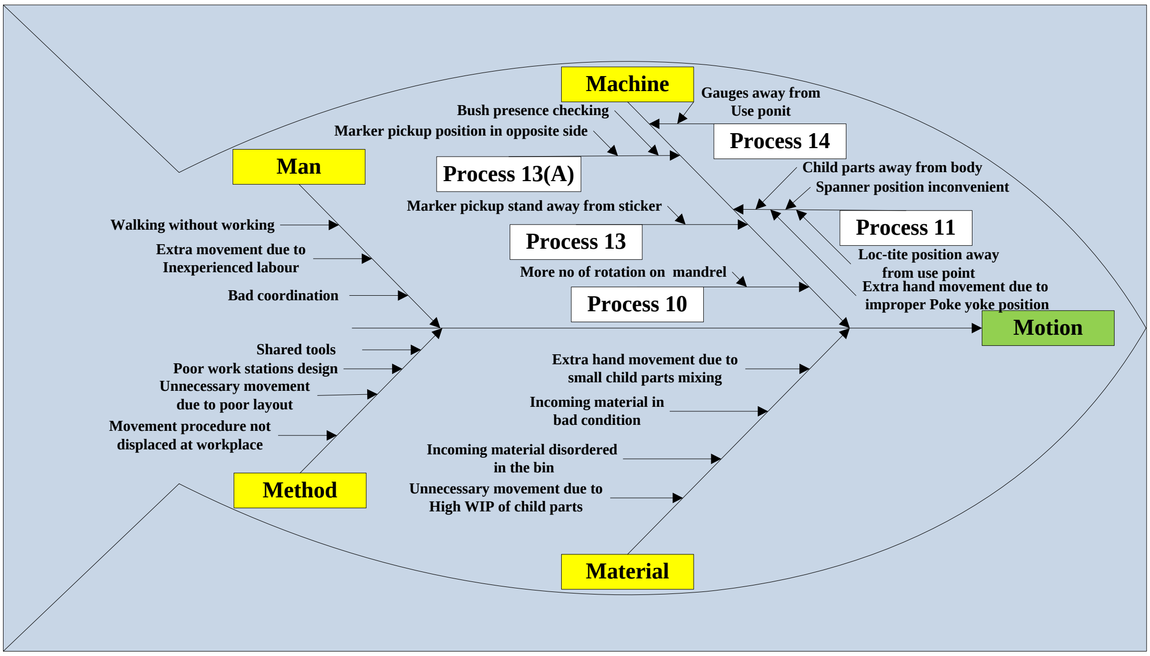


Figure 6.15: Ishikawa diagram for motion waste

- **WIP inventory**

The possible causes of WIP inventory are shown in Figure 6.16. In the current state, the case organization used the push system (root cause) to place the child parts at the various workstations, which resulted in the excessive WIP inventory of child parts.

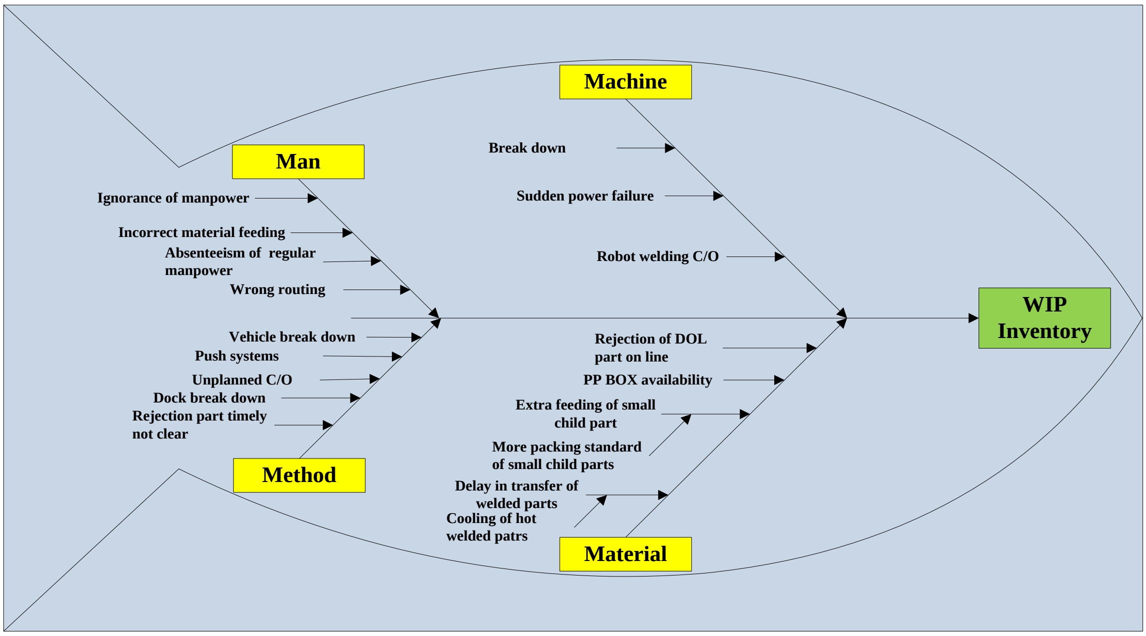


Figure 6.16: Ishikawa diagram for WIP inventory waste

6.2.6 Proposed Future VSM

The analysis of current VSM signals leanness improvement potentials by waste elimination. The micro-concepts of takt time and pacemaker are handy to start the improvement process. Here, the takt time is 71 seconds and process 14 (PDI) is the pacemaker, which decides the heartbeat of the assembly line.

The future state map has been developed (Figure 6.17) using the lean principles. 20 *kaizen*, shown as *kaizen* bursts on figure 6.17, are proposed to eliminate the various types of wastes to improve leanness of the assembly line. In the current layout, the machines for both W-501 non-guided and W-501 guided models are mixed with each other. This creates zigzag movements of material and operators as well as the obstacle for the movement of operators and material. For example, there are eight cross movements from left side to right side or right side to left side of the line in the existing layout (Figures 6.8 and 6.9). A new layout is proposed to smoothen the flow. The proposed layout has only six cross movements as shown in figures 6.18 and 6.19. The advantages of the reduction of two cross movements are very high because these reduced movements are for the guided model, which has high demand as compared to the non-guided model. Further, the information and material flows are improved by redesigning the workplace layout and incorporating the *kanban* card.

The suggestion for the leanness improvement are presented in table 6.4. The type of improvements, proposed improvement initiatives, and their interrelationship with lean manufacturing are also presented in table 6.4. The proposed improvement initiatives can reduce cycle time and accelerate the production to meet the high customer demand. The team summarised lean wastes in terms of occurrence of these wastes at individual processes, their root causes, possible solutions, and the improvement plans as presented in table 6.5. The required improvements are divided into short term and long-term phases. The short-term phase (0-3 months activities) accomplishes the improvements at the local level (individual workstation or process level). In the long-term phase, major improvement activities such as *kanban* implementation, line re-layout, *etc.* should be carried out to achieve the improvements at the global level (line level). These activities take upto one year to accomplish the required improvements.

Table 6.5 shows that motion waste due to poor workstation design can be reduced by implementing the continuous *kaizen* at various workstations in the project duration of three months. Thus, the team decided to implement the continuous *kaizen* to reduce or eliminate the motion waste at various workstations.

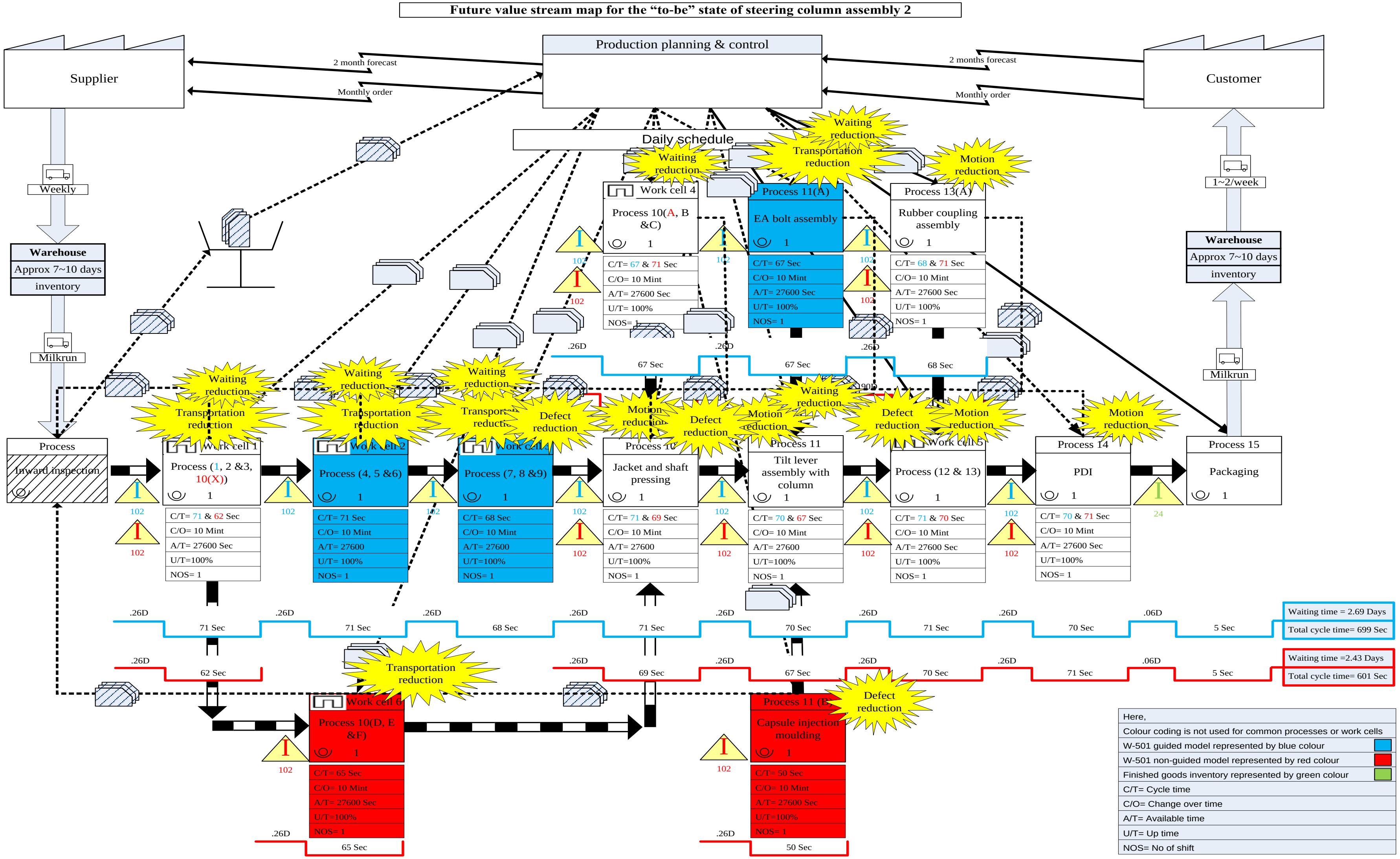


Figure 6.17: Future value stream map

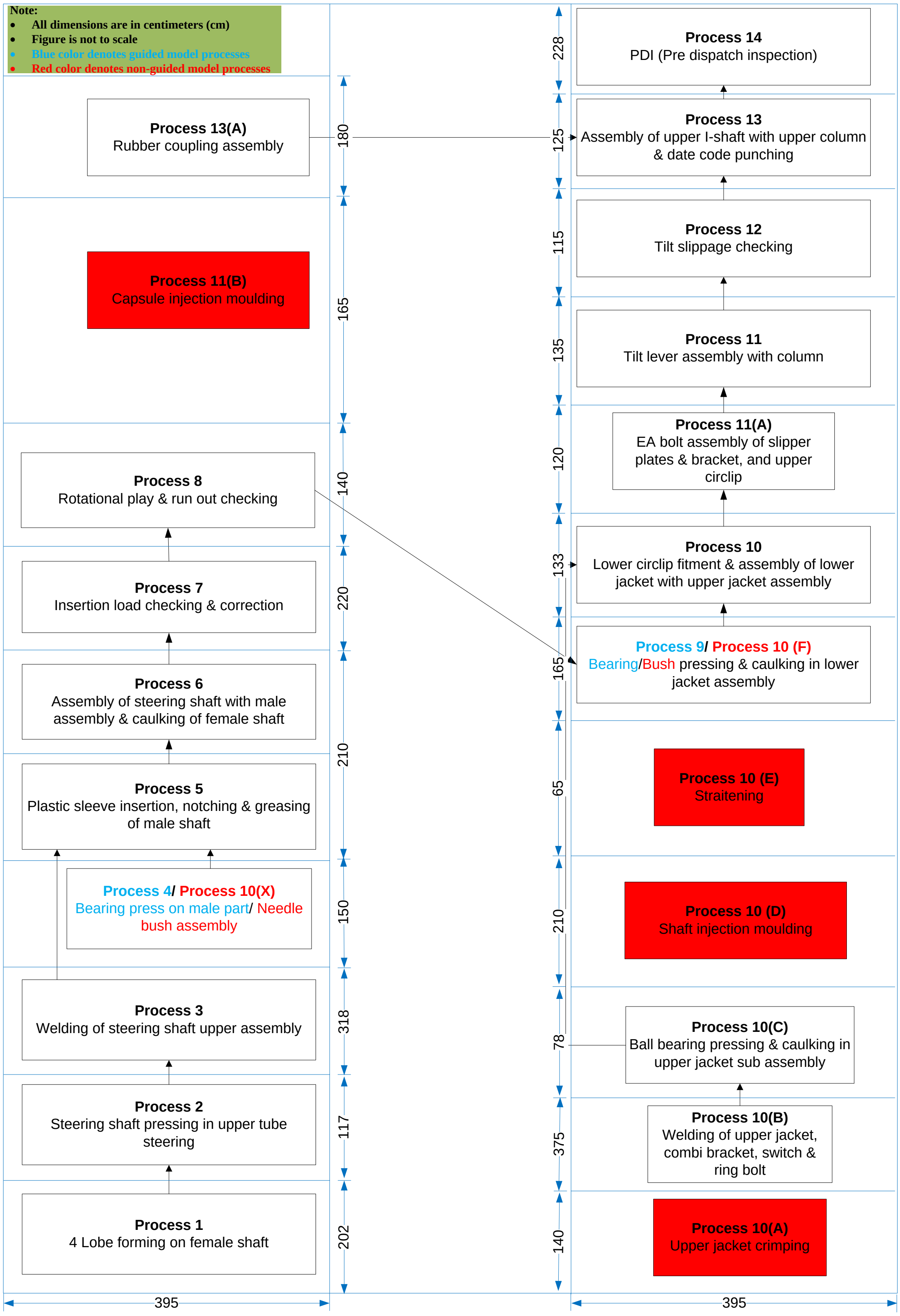


Figure 6.18: Proposed machine positions and material flow for W-501 guided model

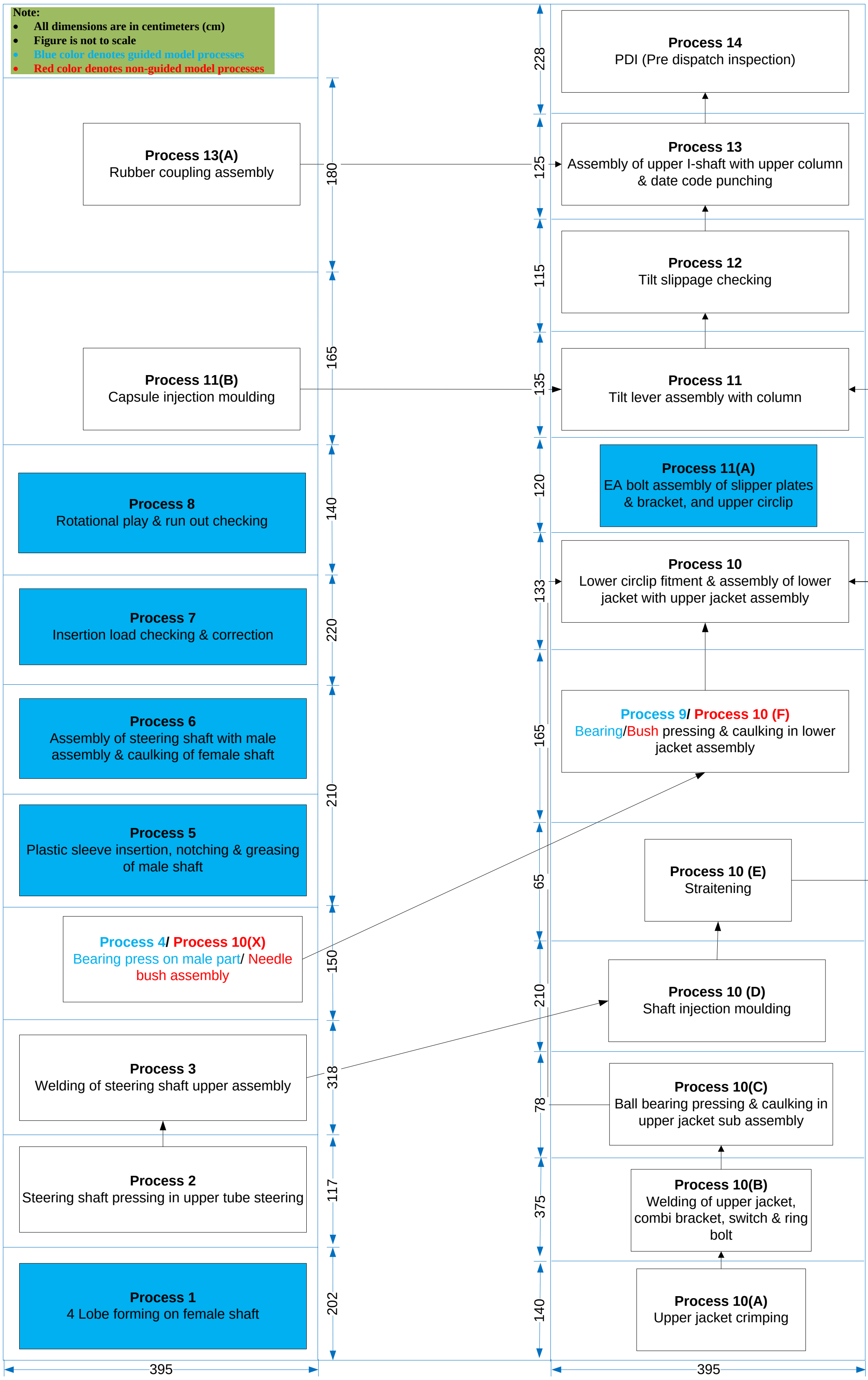


Figure 6.19: Proposed machine positions and material flow for W-501 non-guided model

Table 6.4: List of proposed improvements in the future state map for leanness improvement

Type of improvement	Proposed improvement initiatives	Interrelationship with lean
Local or process level (Short term)	Identify the pre-dispatch inspection (PDI) as pacemaker process.	Value stream principle
	Load leveling should be done at pacemaker process.	Heijunka
	Eliminate "press the Enter key' process after each bar code reading in PDI process	Motion waste
	The finished product trolley should be redesigned to reduce the operator movement and fatigue due to the frequent bending while placing the finished product on the trolley	Motion waste
	Place the marker near the writing area at process 13 (work cell 5)	Motion waste
	The marker should be shifted near fixture area and right-hand side of the operator in process 13(A)	Motion waste
	Operator code writing should be eliminated in process 13(A) due to single piece flow	Flow principle
	Bush presence checking in process 13(A) should be shifted to universal joint (UJ) assembly line	Motion waste
	Child part bin should be placed nearer to the operator in process 11	Motion waste
	The inclined stand should be provided for spanner in process 11	Flow principle
	Provide stand for lever cam assembly in process 11	5S and motion waste
	Provide *loctite* near assembly point in process 11	Motion waste
	Shift the marker near marking point in process 11	Motion waste
	Decrease number of threads on mandrel to reduce the assemble and dis-assemble time of process 10	Motion waste
	Provide a stand for *circlip* press for W-501 non-guided model in process 10	Motion waste
Global or line level (long-term)	*Kanban* card should be implemented to assure internal pull systems and to reduce the large WIP inventory	Pull principle
	Machines should be arranged in such a way that there is a minimum cross movement (left to right or right to left) within the line	Transportation waste, Flow principle
	Machines should be placed nearer as per the use of the particular machine in specific model	Transportation waste
	Total productive maintenance (TPM) should be implemented to avoid frequent machine breakdowns	Waiting waste
	Total quality management (TQM) should be implemented to reduce the rejections	Defect waste

Table 6.5: Summary of different wastes

Type of waste	Process	Root cause	Possible solution	Improvement plan
Defect	7, 10, 11(B), & 13	Rejection specific	TQM implementation	Long-term
WIP inventory	At every process	Lack of internal pull system	*Kanban* card implementation	Long-term
Waiting	1, 5, 8, 10(B), 11A), & 11	Machine breakdown and material unavailability	TPM implementation	Long-term
Motion	10, 11, 13, 13(A), & 14	Poor workstation design	Continuous *kaizen* implementation	Short-term
Transportation	1-9 & 11(A)	Poor line layout	Line layout redesign	Long-term

6.2.7 Implement Continuous *Kaizen*

Following series of *kaizen* activities are carried out to improve leanness as per the proposed initiatives given in tables 6.4 and 6.5.

- ***Kaizen* at process 14**

The process 14 is pre dispatch inspection (PDI) and this is the last process of the steering column assembly line. Further, this process has high cycle time of 78 seconds. Thus, process 14 is the pacemaker process and decides the heartbeat of the assembly line. The fishbone diagram of motion waste (Figure 6.15) and table 6.5 clearly show that the high cycle time is due to unnecessary movement of the operator. To critically analyze the situation, the cross-functional team did the 3M analysis of process 14 as presented in table 6.6. The team found two major activities (activities 8 and 17) that need improvements.

The team decided to implement the *kaizen* for the improvements of these two activities. First, the team found that the activity of ‘press enter key’ just after scanning the sticker code is not required and can be eliminated by changing the software. The team discussed this issue with the information technology (IT) department; and the activity was eliminated by improving the software. Now, the cursor automatically moves to the next row after scanning the sticker. This elimination of unnecessary hand movement decreased the activity duration from six seconds to four seconds and reduced the operator fatigue. Second, there was an unnecessary movement of operator due to poor trolley design. The operator had to bend to put the final assembly on the trolley. This means extra time and operator fatigue. The cross-functional team suggested improvement in the existing trolley design. The new trolley reduced the operator movement and decreased the activity duration from nine seconds to three seconds. Thus, the cycle time of process 14 is reduced from 78 seconds to 70 seconds.

Table 6.6: 3M analysis of process 14

S. No.	Process 14	Time (sec)	Observation	Action plan
1	Uplift lower jacket and apply cotton	3		
2	Confirmation of torque on bolt	4		
3	Down lower jacket & check lever movement	6		
4	Pick-up marker, mark on part	6		
5	Gauge checking and marking	3		
6	Apply cover on part	3		
7	Put marker and press push button to unclamp	5		
8	Scan sticker code & press enter key on the keyboard	6	Unnecessary hand movement for pressing the enter key	Eliminate the unnecessary hand movement by improving the software
9	Pick-up part from fixture and put on next fixture	4		
10	Rotation torque checking	4		
11	Thread checking using Go gauge	3		
12	Thread checking using No-Go gauge	2		
13	Serration checking using Go gauge	3		
14	Serration checking using No-Go gauge	2		
15	Flush pin checking using gauge	4		
16	Apply cover on thread	3		
17	Pick-up part, put on trolley and trolley adjustment after every 6 parts	9	Poor trolley design	New trolley design
18	Come back for next cycle	3		
19	Shift loaded trolley (after 24 parts) and bring empty trolley for next loading	5		

- ***Kaizen* at work cell 5**

The work cell 5 has two processes: process 12 and process 13. To comprehend the activities of work cell 5, the cross-functional team carried out 3M analysis as presented in table 6.7. It shows that activities 2, 3 and 11 should be improved. The team found that the process 11 operator can carry out two activities of the process 12 (load the part and start cycle). This reduces the cycle time of work cell 5 by four seconds. The process 13 is used to assemble upper I-shaft and upper steering column and to punch the date code on the part. The team found that the activity (11) of 'write lever force on sticker and paste" requires comparatively more time.

Table 6.7: 3M analysis of work cell 5

S. No.	Work cell 5	Time (sec)	Observation	Action plan
1	Unload the part	4		
2	Load the part	2	Can be accomplished by previous operator	Assign this activity to process 11 operator
3	Start cycle	2	Can be accomplished by previous operator	Assign this activity to process 11 operator
4	Put part on fixture	4		
5	Pick-up coupling and check gauge	6		
6	Insert coupling in shaft & clamp	4		
7	Pick-up bolt & washer and fit in part	5		
8	Apply torque	7		
9	Paste part number sticker	6		
10	Start cycle	2		
11	Write lever force on sticker and paste	10	Marker pick-up stand is away from the writing point	Place the marker near to the writing area
12	Pick-up polythene & rubber and apply on part	8		
13	Pick-up marker and do marking	8		
14	Unload, and load part on next bin	6		
15	Press push button	2		
16	Pick-up next part for next cycle	4		

The marker used to write on the sticker is far away from the writing area in the existing working condition. The marker is placed nearer to the writing area (sticker) as shown in figure 6.20. This *kaizen* reduced the hand movement from 240 mm to 80 mm and saved 2 seconds per part. For the work cell 5, total cycle time reduces from 80 seconds to 74 seconds.

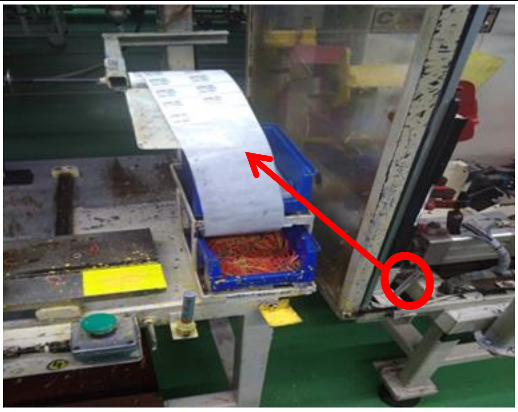
***Kaizen* Sheet**			
Purpose	Motion reduction	**Location**	Process 13
Before		**After**	
			
Description	Marker pick-up point is 240 mm away from sticker	Marker placed near to the sticker	
Results	• Hand movement reduced from 240 mm to 80 mm • Time saving of 2 seconds/part. • Operator fatigue reduced.		

Figure 6.20: *Kaizen* sheet for reduction of motion waste by replacing marker at process 13 in work cell 5

- ***Kaizen* at process 13(A)**

The process 13(A) is rubber coupling assembly. In this process, the team decided to conduct the ECRS study instead of 3M analysis. The team observed that the process 13(A) has number of activities which can be eliminated or combined or reduced or shifted as presented in table 6.8. The process 13(A) is also divided into elemental work (activities) to find out the activities, which should be improved. Two activities (17 and 18 in table 6.8) were identified as critical activities.

After identification of critical activities, the team decided to implement the *kaizen*. Three *kaizen* activities are carried out for the improvement of process 13(A). First, the marker pick-up position was on the opposite side of the picking hand and away from the sub-assembly (part). This sub-activity can be reduced by relocating the marker on the right hand side and nearer to the sub-assembly as shown in figure 6.21. This relocation of marker position reduces the operator fatigue and cycle time by 0.6 seconds per part.

Table 6.8: ECRS study of process 13(A)

S. No.	Elemental work	Time taken	Can be eliminated	Can be combined	Can be reduced	Can be shifted to next/prev. process
1	Pick-up two bolts and put on the fixture	2	×	×	×	×
2	Pick-up upper I-shaft, apply grease and put on the fixture	4	×	×	×	×
3	Pick-up spacer and fix on the fixture	2	×	×	×	×
4	Pick-up and apply rubber coupling	3	×	×	×	×
5	Pick-up stopper plate and fix on the fixture	3	×	×	×	×
6	Pick-up two nuts and apply ring gauge	5	×	×	×	×
7	Apply torque	5	×	×	×	×
8	Confirm torque by spanner	4	×	×	×	×
9	Unload part and put two bolts on the fixture	5	×	×	×	×
10	Pick-up washer and put on the part	3	×	×	×	×
11	Load the part on fixture	4	×	×	×	×
12	Pick-up and apply spacer	3	×	×	×	×
13	Pick-up UJ assembly and put on the part	3	×	×	×	×
14	Pick-up nut and apply torque	5	×	×	×	×
15	Pick-up nut and apply torque at other side	5	×	×	×	×
16	Confirm torque by spanner	4	×	×	×	×
17	Unload part, mark on part and write operator code	5	√	×	√	×
18	Check bush presence	3	×	×	×	√
19	Unload part and put on next stand	4	×	×	×	×

Kaizen Sheet			
Purpose	Motion reduction	**Location**	Process 13 (A)
Before		**After**	
			
Description	Marker pick-up position on opposite side of picking hand and away from sub-assembly	Marker relocated on right hand side and near to sub-assembly	
Results	• Operator fatigue reduced. • Time saving of 0.6 sec/part		

Figure 6.21: *Kaizen* sheet for reduction of motion waste by relocating marker at process 13(A)

Second, the operator code is required due to WIP inventory of sub-assemblies. This sub-activity is eliminated by implementing the single piece flow. This *kaizen* further reduced the activity duration by 0.4 seconds per part as shown in figure 6.22.

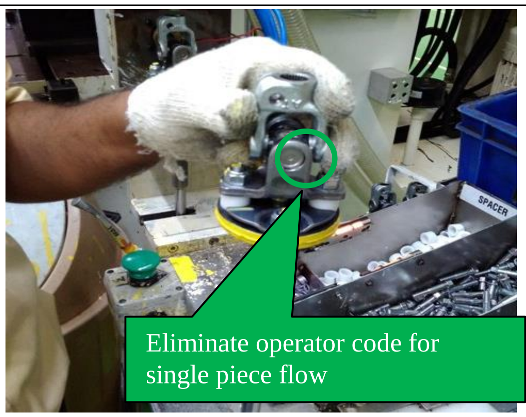
Kaizen Sheet			
Purpose	Motion reduction	**Location**	Process 13 (A)
Before		**After**	
			
Description	Operator code marking on part due to batch production	Operator code writing eliminated by single part flow	
Results	• Extra activity eliminated • Saving of marker consumption • Time saving of 0.4 sec/part		

Figure 6.22: *Kaizen* sheet for reduction of motion waste by eliminating operator code at process 13(A)

Third, the activity of 'check bush presence' required three seconds to complete. This activity is shifted to previous workstation of universal joint (UJ) assembly line as shown in figure 6.23. The UJ assembly line is used to assemble upper UJ using different child parts. This line also has low cycle time as compared to steering column assembly line. Thus, the activity of 'check bush presence' can be carried out in UJ assembly line. The team shifted this activity to previous line resulting in the reduction of cycle time of process 13(A) by three seconds per part.

<table>
<tr><td colspan="4">Kaizen Sheet</td></tr>
<tr><td>Purpose</td><td>Motion reduction</td><td>Location</td><td>Process 13 (A)</td></tr>
<tr><td colspan="2">Before</td><td colspan="2">After</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Description</td><td>Bush presence checking of upper UJ</td><td colspan="2">Bush presence checking process shifted to UJ assembly line</td></tr>
<tr><td>Results</td><td colspan="3">• Time saving of 3 sec/part by shifting process</td></tr>
</table>

Figure 6.23: *Kaizen* sheet for reduction of motion waste by shifting bush presence checking to previous line

- ***Kaizen* at process 11**

The process 11 is 'tilt lever assembly with column'. The cross-functional team conducted the 3M analysis for the process 11. The 3M analysis indicated that there are numerous activities, which have the motion waste (table 6.9). After 3M analysis, the team decided to conduct the *kaizens* for the process 11. First, total six types of small child parts are used to assemble the tilt lever assembly with column as shown in figure 6.24. The child part bins were away from the operator due to which operator had to move a long distance to pick-up these child parts. The child part bins were relocated near to the operator. This *kaizen* reduced the operator fatigue and saved five seconds per part.

Table 6.9: 3M analysis of process 11

S. No.	Process 11	Time (sec)	Observation	Action plan
1	Pick-up mounting bracket and put on the fixture	4		
2	Pick-up sub-assembly and fix it on fixture	7		
3	Pick-up washer and apply *loctite*	4	• Pick-up time more as child parts are away from the operator • Spanner position inconvenient	• Put child part bin nearer to the operator • Inclined stand provided for spanner
4	Pick-up nylon nut, apply torque by spanner and release	9		
5	Pick-up cam B and fix it on part	4		
6	Pick-up lever cam assembly	4	No designated place for mounting bracket & lever	Provide stand for lever cam assembly
7	Pick-up plain washer, needle bearing and fix on part	9		
8	Apply *loctite* and pick-up nut	7	*Loctite* location is away from the assembly point	Place the *loctite* near to the assembly point
9	Apply torque and check lever movement	7		
10	Check rotational play	6		
11	Check lever force	7		
12	Pick-up marker and write force value	4	Marker pick-up is distance long	Re-locate the marker near to marking point
13	Unlock fixture	2		
14	Unload part and put in the bin	5		

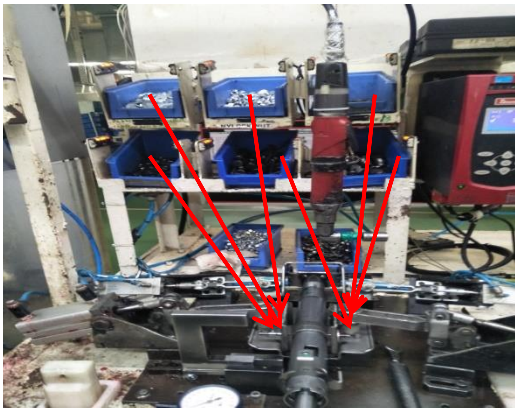
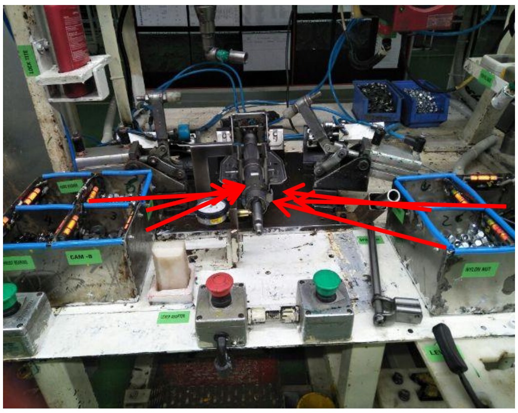
<table>
<tr><th colspan="4">*Kaizen* Sheet</th></tr>
<tr><td>**Purpose**</td><td>Motion reduction</td><td>**Location**</td><td>Process 11</td></tr>
<tr><td colspan="2">**Before**</td><td colspan="2">**After**</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>**Description**</td><td>Child part bins away from operator and assembly area</td><td colspan="2">Child part bins relocated near to operator and assembly area.</td></tr>
<tr><td>**Results**</td><td colspan="3">• Operator fatigue reduced.
• Time saving of 5 sec/part</td></tr>
</table>

Figure 6.24: *Kaizen* sheet for reduction of motion waste by relocating child part bins at process 11

Second, in the current situation, the spanner is lying on the table; therefore difficult to pick-up and requires extra time to orient. The team conducted a *kaizen* and provided the inclined stand near the assembly area for easy pick-up of spanner and less hand movement as shown in figure 6.25. This *kaizen* saved the activity time of 0.5 second per part.

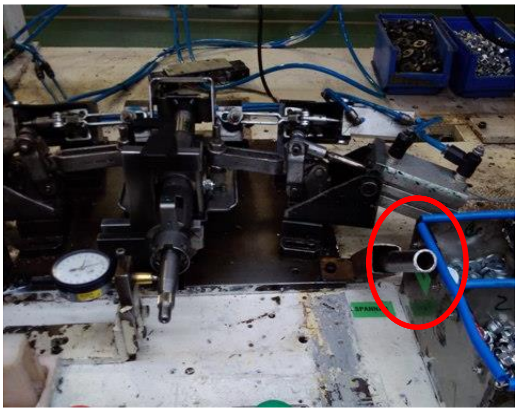
<table>
<tr><th colspan="4">Kaizen Sheet</th></tr>
<tr><td>Purpose</td><td>Motion reduction</td><td>Location</td><td>Process 11</td></tr>
<tr><td colspan="2">Before</td><td colspan="2">After</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Description</td><td>Spanner laying on table, difficult to pick-up & takes extra time</td><td colspan="2">Inclined stand provided near to assembly area for easy pick-up of spanner and less hand movement</td></tr>
<tr><td>Results</td><td colspan="3">• Easy pick-up.
• Spanner distance reduced from 180mm to 150mm
• Time saving of 0.5 sec/part</td></tr>
</table>

Figure 6.25: *Kaizen* sheet for reduction of motion waste by providing inclined stand for spanner at process 11

Third, in the current situation, no designated place is provided for bracket and cam-lever sub-assembly and laying on the table. This cluttering of brackets and cam-lever sub-assemblies create difficulties for the operator to pick-up the parts and operator requires extra time for the sorting. The team conducted a *kaizen* activity and provided a separate stand for the bracket and cam-lever sub-assemblies as shown in figure 6.26. This *kaizen* saved the activity time of 1.5 seconds per part. Fourth, the *loctite* position is far away from its point of use or assembly area. The team conducted a *kaizen* activity and provided the *loctite* stand at the point of use as shown in figure 6.27. This *kaizen* saved the activity time of 0.5 seconds and reduced the hand movement from 260 mm to 210 mm.

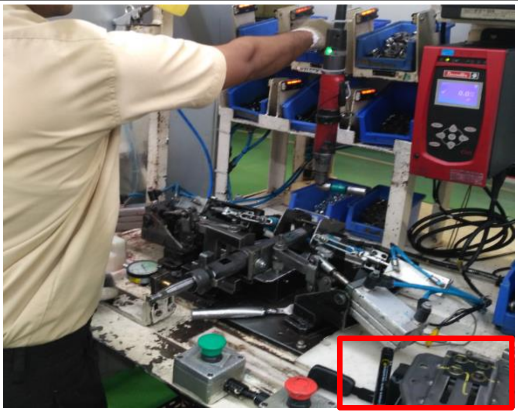
<table>
<tr><th colspan="4">Kaizen Sheet</th></tr>
<tr><td>Purpose</td><td>Motion reduction</td><td>Location</td><td>Process 11</td></tr>
<tr><td colspan="2">Before</td><td colspan="2">After</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Description</td><td>No designated place for bracket and cam-lever sub-assemblies.</td><td colspan="2">Separate stand is provided for bracket and cam-lever sub-assemblies.</td></tr>
<tr><td>Results</td><td colspan="3">Easy pick-up
Hand movement reduced
Time saving of 1.5 sec/part</td></tr>
</table>

Figure 6.26: *Kaizen* sheet for reduction of motion waste by providing separate stand for bracket and cam-lever sub-assemblies at process 11

<table>
<tr><th colspan="4">Kaizen Sheet</th></tr>
<tr><td>Purpose</td><td>Motion reduction</td><td>Location</td><td>Process 11</td></tr>
<tr><td colspan="2">Before</td><td colspan="2">After</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Description</td><td>Loctite position is far away from its point of use or assembly area.</td><td colspan="2">Provided a loctite stand nearer to its point of use.</td></tr>
<tr><td>Results</td><td colspan="3">Operator fatigue reduced.
Hand movement reduced from 260 mm to 210 mm
Time saving of 0.5 sec/part</td></tr>
</table>

Figure 6.27: *Kaizen* sheet for reduction of motion waste by providing *loctite* stand at point of use at process 11

Fifth, in the current situation, the marker is far away from the assembly area. The team conducted a *kaizen* activity and placed the marker nearer to the marking point (assembly area) as shown in figure 6.28. This *kaizen* further reduced the activity time by 0.5 second and reduced the hand movement from 370 mm to 280 mm.

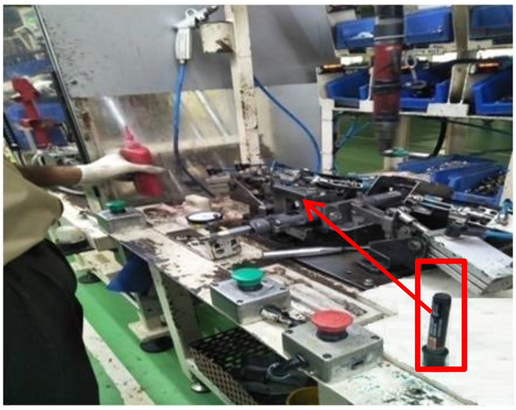
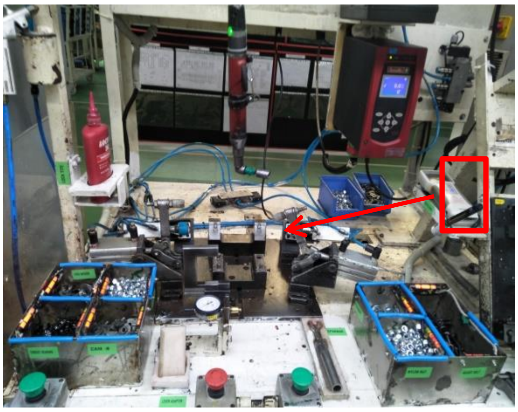
***Kaizen* Sheet**			
Purpose	Motion reduction	**Location**	Process 11
Before		**After**	
			
Description	Marker placed away from point of use	Marker placed at the point of use	
Results	• Operator fatigue reduced. • Hand movement reduced from 370 mm to 280 mm. • Time saving of 0.5 sec/part		

Figure 6.28: *Kaizen* sheet for reduction of motion waste by placing marker at point of use at process 11

Total 8 seconds are saved by conducting the *kaizens* at the process 11. However, to avoid the waiting waste, the operator working on process 11 is given two additional activities (load the part and start cycle) of process 12. Due to these additional activities, the cycle time of process 11 is increased by four seconds.

- ***Kaizen* at process 10**

Process 10 is 'jacket & shaft pressing'. The team decided to conduct the 3M analysis to critically analyze the activities of process 10 (table 6.10). The 3M analysis indicates that two activities (3 and 10 in table 6.10) have motion waste.

Table 6.10: 3M analysis of process 10

S. No.	Activity	Time (sec)	Observation	Action plan
1	Pick-up part from oil box with *circlip* assembly	3		
2	Insert in outer jacket assembly.	3		
3	Pick-up mandrel and assemble in part	6	Mandrel assembly time is high due to 12 no of threads	Reduce no of threads on mandrel
4	Load part in fixture and clamp	5		
5	Start cycle	2		
6	Pick-up retainer and assemble in outer jacket	5		
7	Pick-up part, fit *circlip* and mark on it	8		
8	Put part in oil box	4		
9	Unload part, de-clamp and put on fixture	6		
10	Disassemble mandrel	5	Mandrel disassembly time is high due to 12 no of threads	Reduce no of threads on mandrel
11	Pick-up *circlip* and assemble in part	5		
12	Pick-up marker, mark for *circlip* presence	3		
13	Check shaft movement	7		
14	Write load value on part and put on the next fixture	6		
15	Check slot dimension using Go-No Go Gauge	6		
16	Come back to pick-up part for cycle next cycle	3		

The team found that mandrel assembly and disassembly time is high due to a large number of threads on the mandrel. The team conducted a *kaizen* activity and reduced the number of threads by decreasing the length of the mandrel as shown in figure 6.29. This *kaizen* saved the activity time of three seconds and reduced the hand movement due to decreased number of threads from 12 to six, which also results in lesser operator fatigue.

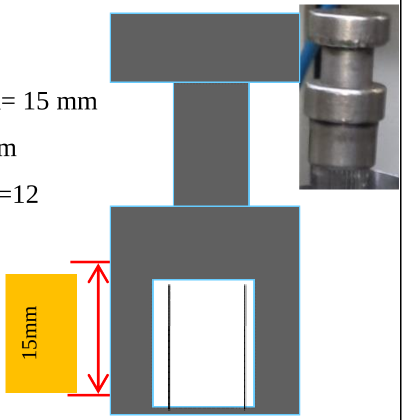
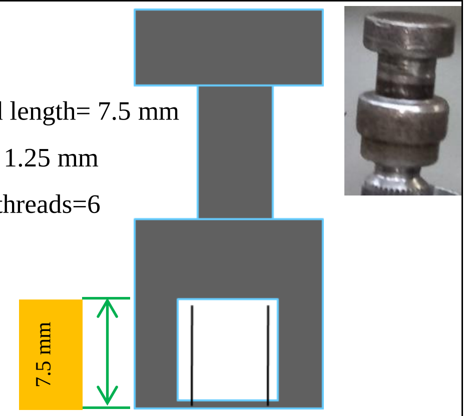
<table>
<tr><td colspan="4">Kaizen Sheet</td></tr>
<tr><td>Purpose</td><td>Motion reduction</td><td>Location</td><td>Process 10</td></tr>
<tr><td colspan="2">Before</td><td colspan="2">After</td></tr>
<tr><td colspan="2">Thread length= 15 mm
Pitch= 1.25mm
No of threads=12

</td><td colspan="2">Thread length= 7.5 mm
Pitch= 1.25 mm
No of threads=6

</td></tr>
<tr><td>Description</td><td>Mandrel assembly and disassembly time high due to large number of threads on mandrel</td><td colspan="2">Number of threads on mandrel reduced from 12 to 6</td></tr>
<tr><td>Results</td><td colspan="3">Operator fatigue reduced.
Hand movement reduced
Time saving of 3 sec/part</td></tr>
</table>

Figure 6.29: *Kaizen* sheet for reduction of motion waste by decreasing number of threads on the mandrel at process 10

6.3 RESULTS AND DISCUSSION

The case study has demonstrated that considerable improvements are achieved through the leanness assessment using integrated VSM in a complex assembly line environment. The elimination of various types of wastes improved leanness and facilitated the organization to enhance the performance of shop floor without additional resources. The continuous *kaizen* reduced the operator fatigue by decreasing the various types of human movements. The elimination of motion wastes expedites the organization to improve the leanness level of shop floor without additional investment. Some of the specific improvement are:

6.3.1 Reduction of Cycle Time

The main objective of meeting the high customer demand of 388 assemblies per day has been achieved by the implementation of integrated VSM in steering column assembly line. The reduction of cycle time is accomplished due to the elimination of motion, transportation, and waiting wastes. The total cycle time is reduced from 746 seconds to 699 seconds and 636 seconds to 601 seconds for W-501 guided and non-guided models respectively. Now, the cycle time of all processes/work cells is matching with the takt time as shown in figures 6.30 and 6.31. Seth, Seth, and Dhariwal (2017) also found the reduction in cycle time and obtained the improvements at both local and global levels through VSM.

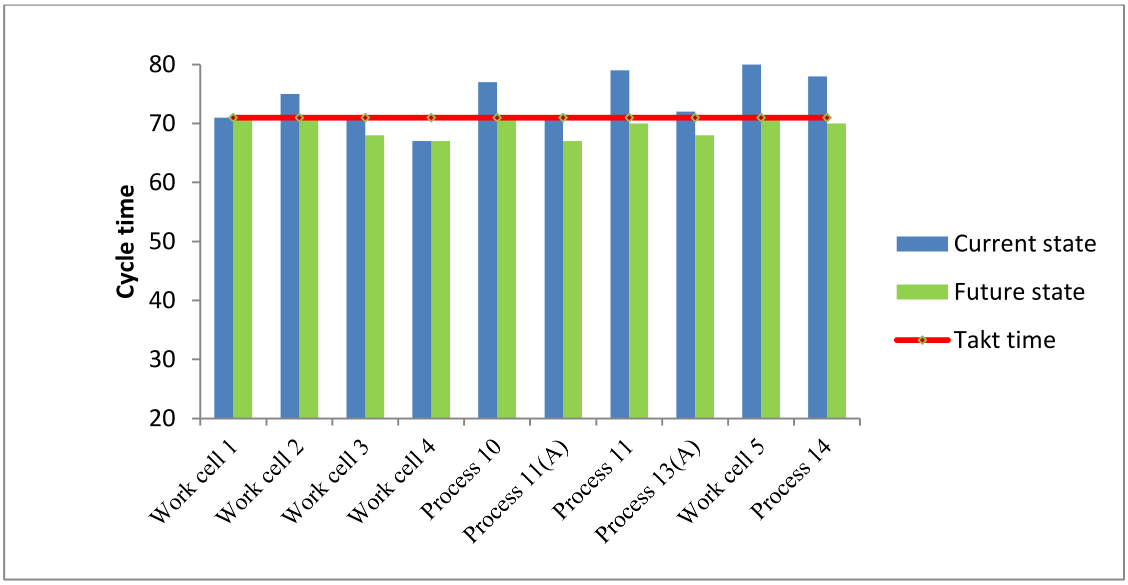


Figure 6.30: Current and future state cycle times for W-501 guided model

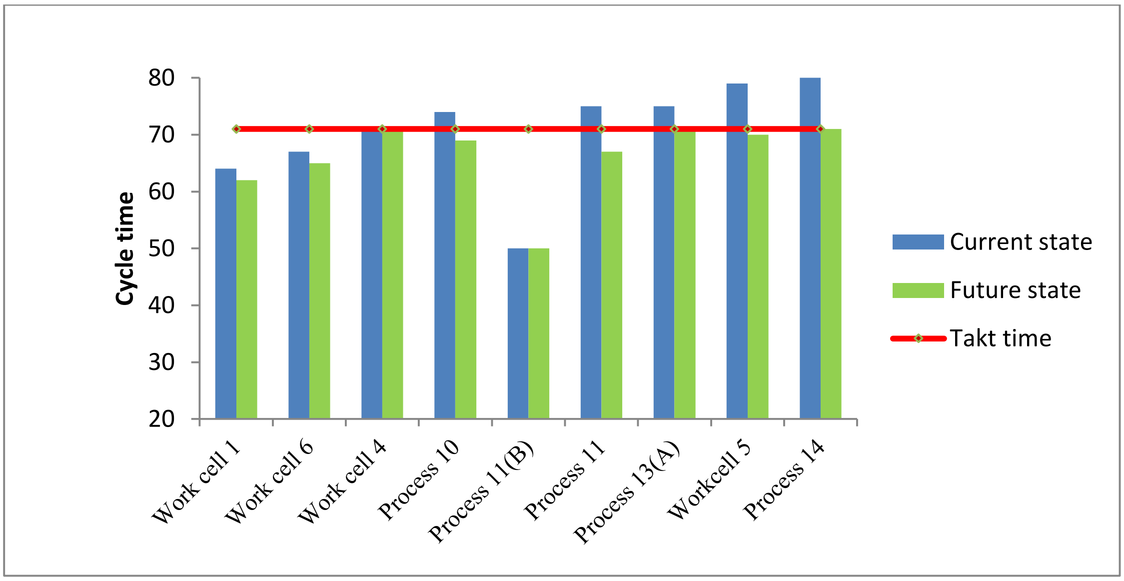


Figure 6.31: Current and future state cycle times for W-501 non-guided model

6.3.2 Reduction in Distance Traveled

The proposed line layout improved the material and information flows across the assembly line and decreased the distance traveled by the material and operators. For guided model, the distance travelled by the material from process 1 to process 14 has been reduced from 3148 centimeters (cm) to 3033 cm, whereas, the distance travelled by operators is reduced from 4980 cm to 4260 cm as presented in table 6.11. Correspondingly, for the non-guided model, the distance traveled by the material is reduced from 3351 cm to 3071 cm, whereas the distance traveled by the operators is decreased from 4370 cm to 3685 cm as presented in table 6.12.

Table 6.11: Distance traveled in existing and proposed layouts for W-501 guided model

Processes	Distance traveled by material in the current layout (cm)	Distance traveled by material in the proposed layout (cm)	Distance traveled by the operator in the current layout (cm)	Distance traveled by the operator in the proposed layout (cm)
Process 1	202	202	1390	1390
Process 2	117	117		
Process 3	318	318		
Process 4	180	150	680	350
Process 5 & Process 6	210	210		
Process 7	220	220	680	680
Process 8	180	140		
Process 9	165	180		
Process 10	140	140	70	30
Process 10 (B)	375	375	900	900
Process 10 (C)	78	78		
Process 11	135	135	30	30
Process 11 (A)	180	120	270	120
Process 12	115	115	440	240
Process 13	125	125		
Process 13 (A)	180	180	320	320
Process 14	228	228	200	200
Total	**3148**	**3033**	**4980**	**4260**

Table 6.12: Distance traveled in existing and proposed layouts for W-501 non-guided model

Process	Distance traveled by material in the current layout (cm)	Distance traveled by material in the proposed layout (cm)	Distance traveled by the operator in the current layout (cm)	Distance traveled by the operator in the proposed layout (cm)
Process 2	117	117	1000	800
Process 3	318	318		
Process 10 (X)	390	350		
Process 10 (A)	140	140	1200	1200
Process 10 (B)	375	375		
Process 10(C)	78	78		
Process 10 (D)	520	210	670	600
Process 10 (E)	190	180		
Process 10 (F)	120	80		
Process 10	140	260	70	30
Process 11	135	135	150	30
Process 11 (B)	180	180	320	320
Process 12	115	115	440	185
Process 13	125	125		
Process 13 (A)	180	180	320	320
Process 14	228	228	200	200
Total	**3351**	**3071**	**4370**	**3685**

The distance traveled by the operators is reduced more as compared to the material for both the models, which also results in reduced operator fatigue. Anand and Kodali (2009b) also stated that the reduction in distance traveled by the operator reduces the fatigue, which have a positive effect on the labour productivity. Moreover, the proposed line layout imparts the smooth workflow and shuns the zigzag movements of material and operators, which reduces the transportation waste and cycle time of the various processes in the assembly line.

6.3.3 Reduction of WIP Inventory

The high WIP inventory in the current VSM results cluttering, extra cost and extra efforts at the workstations. To overcome this, Álvarez *et al.* (2009) advised the use of *kanban* system and assembly line redesign to respond to the need of stock reduction. The high WIP leads to the mixing of small child parts at some workstations, which requires segregation leading to the increased cycle time. In the current state, the WIP inventories for guided and non-guided models are 7.56 days and 5.88 days respectively. The cross-functional team suggested to implement the *kanban* card for the reduction of WIP inventory. In the first phase, it is decided to maintain the average WIP inventory level of two hours which resulted in the reduction of total WIP inventory from 7.56 days to 2.69 days for the guided model. For non-guided model, the (WIP) inventory level is reduced from 5.88 days to 2.43 days as shown in figure 6.32. Singh and Singh (2013) also reduced the WIP inventory from 1720 units to 370 units in an auto-component manufacturing unit using *kanban*.

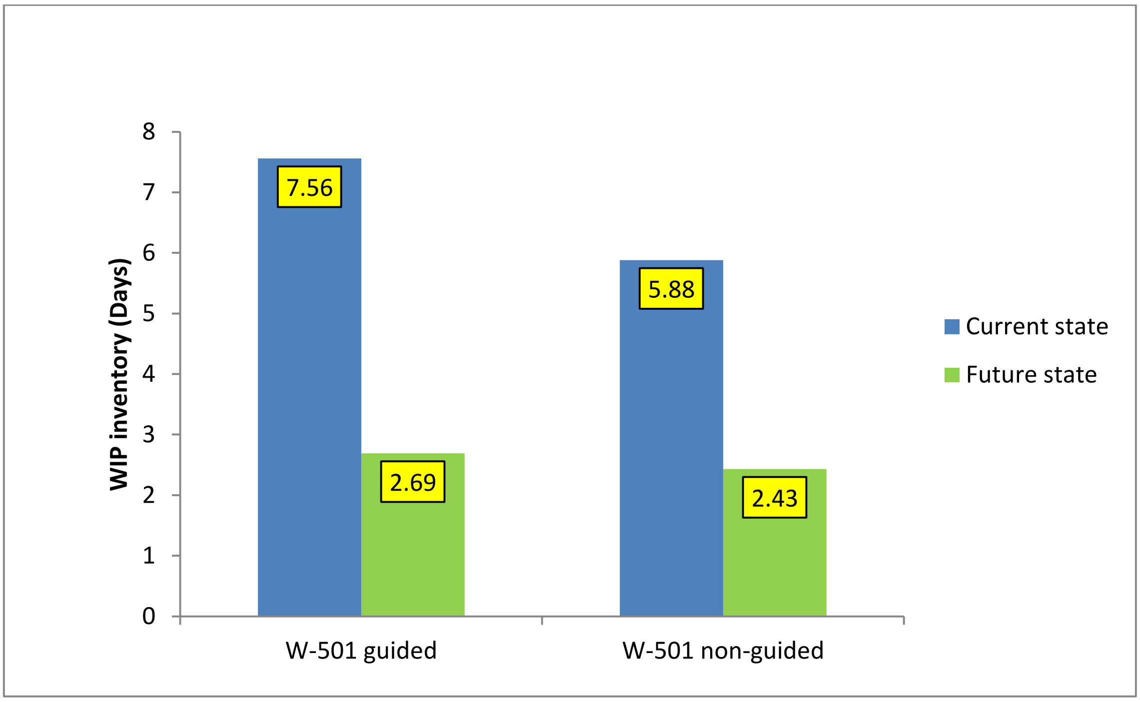


Figure 6.32: WIP inventory results at steering column assembly line

6.3.4 Improvement of Productivity and Line Efficiency

The *kaizen* increased the production from 45 products per hour to 51 products per hour. The improvement in productivity facilatated the achievement of customer demand of 388 assemblies per day. The production per labour hour (PPLH) is increased from 4.5 to 5.1 and from 5 to 5.67 for the guided and non-guided models respectively (Figure 6.33). Correspondingly, the line efficiency is also enhanced from 92.63% to 97.75% and 88.19%

to 93.27% for the guided and non-guided models respectively (Figure 6.34). Bhamu *et al.* (2013) also achieved improvement in cycle time and production rate by eliminating lean waste in an automotive organization.

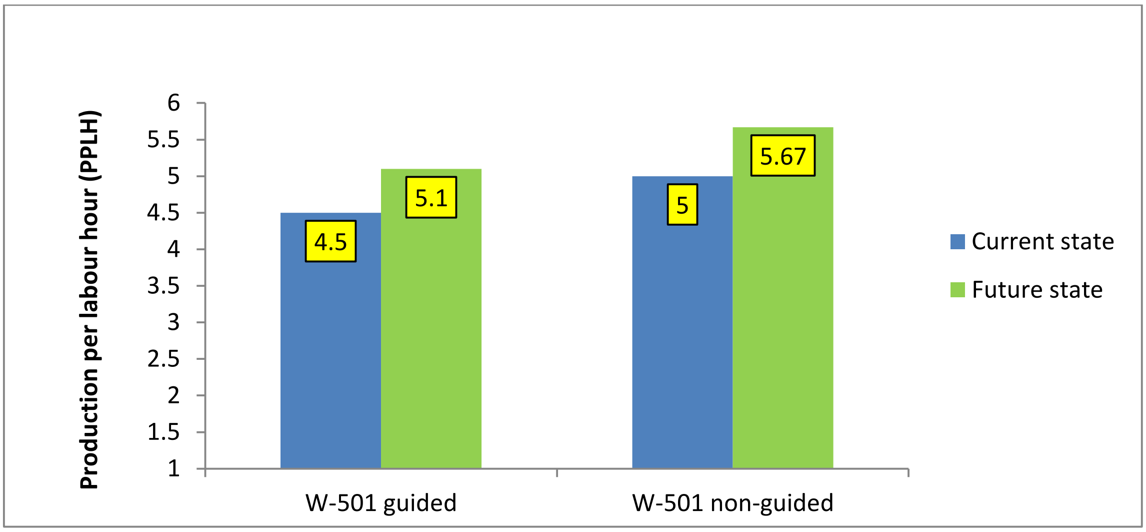


Figure 6.33: Production per labour hour of steering column assembly line

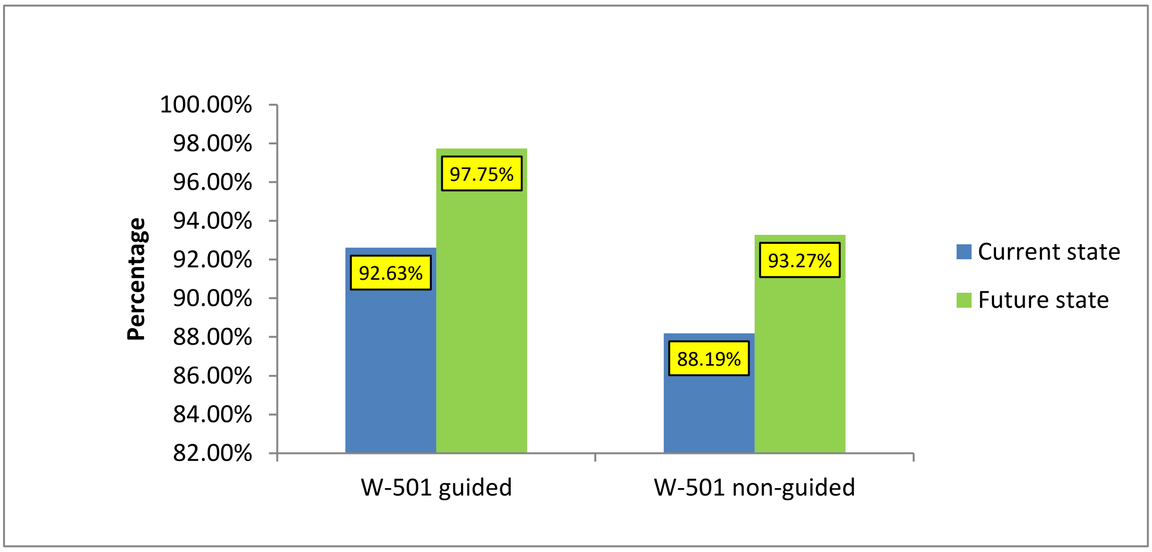


Figure 6.34: Line efficiency of steering column assembly line

The following challenges, faced during this study, are worth mentioning for future researchers and practitioners:

- Difficulties in measuring process data due to a large number of small child parts (i.e. different type of washers, nuts, bolts, bearings, *etc.*).
- Difficulties in data collection due to low-skilled and less experienced operators.

6.4 KEY RECOMMENDATIONS

- Develop virtual cells on the line/shop floor by using the concept of multi machine activities (MMA) for the simplifications of complex production environment.
- Use micro concepts of ECRS/3M to analyse the processes for the improvements.
- Involve shop floor employees for the improvement activities.
- Use visual aids at the shop floor to demonstrate the usefulness of the proposed actions. In particular, recorded actions related to movements are very helpful for change management.

6.5 CONCLUSIONS

This chapter presents an integrated VSM for a complex environment using the concept of multi-machine activity with a single operator as a unit or work cell to represent the complex material/information flow. The integrated VSM is applied on an assembly line in an automotive component manufacturing organization where the similarity between the products assembled on the line is 59%. The integrated VSM shows different processes and work cells, various wastes, non-value added activities, cycle time, uptime, and the material and information flows for both products on the same map, which is expected to help practitioners to use VSM for the leanness assessment and improvement. The high customer demand of 388 assemblies per day for a complex product assembly line is achieved without adding machinery or labour. Chapter also shows how multi-hierarchical cross-functional teams can diagnose the root causes of the problems by drawing and analysing Ishikawa diagrams. Micro analysis methods of 3M and ECRS helped to unravel the problematic activities. The total cycle time is reduced from 746 seconds to 699 seconds for the guided model and 636 seconds to 601 seconds for the non-guided model. The reduction of cycle time is accomplished due to the elimination of different types of wastes (motion, transportation, waiting, *etc.*) by implementing the 'continuous *kaizen*' and establishing the flow principles through layout redesign. WIP inventory is reduced from 7.56 days to 2.69 days for the guided model. For non-guided model, the WIP inventory level is reduced from 5.88 days to 2.43 days. Further, the line efficiency is enhanced from 92.63% to 97.75% and from 88.19% to 93.27% for the guided and non-guided models respectively. Moreover, the proposed line layout imparts the smooth workflow and shuns the zigzag movement of material and operators, which reduces the transportation waste and cycle time of the various processes in the assembly line. The production per labor hour is increased from 4.5 to 5.1 and from 5 to 5.67 for the guided and non-guided models respectively. Integrated VSM proves to be a versatile process improvement approach, which facilitates the reduction of wastes and non-value-added activities and can be meaningfully applied for leanness improvements of complex assembly lines.

The study also proposes a new delineation of *kaizen* philosophy – continuous *kaizen* – which means continuous improvements at the global or whole value chain level instead of just ‘change for better’ at local or single workstation level. The various tools & techniques of the *kaizen* philosophy have been reviewed to provide salient points of each tool & technique. The continuous *kaizen* has improved the leanness of the assembly line by reducing or eliminating the motion waste to improve the productivity, line balancing and line efficiency.

It is expected that the proposed integrated VSM for a complex assembly line environment can be replicated by the practitioners to leverage the numerous advantages of VSM. The future research may be conducted using the developed integrated VSM approach in other complex production environments such as high mix low volume (HMLV) production, merging flows due to large number of bills of materials. Future studies should also include financial measures to provide the lean benefits in terms of value-added and non-value-added costs.

CHAPTER 7

CONCLUSIONS AND FUTURE SCOPE OF THE WORK

During last few decades, industry has realized the importance of lean manufacturing for waste reduction and continuous improvement to be globally competitive. A leanness assessment of organizational performance is a pre-requisite for continuous improvement. The existing literature shows that there is less research on leanness assessment as compared to lean implementation. There are many reported failures of lean manufacturing implementation because of many factors like lack of clear understanding of main attributes of leanness and its assessment, lack of methods for leanness assessment, lack of implementation of lean soft practices, *etc*.

The study identifies the following research issues:

- Lack of integration of manufacturing process lean indicators with assessment of other functions of an organization like human resource, finance, administration, supplier management, new product development, and customer management. This may be one of the reasons for the lean implementation failures.
- Unstructured implementation of lean practices leads to anarchy and failures. There is hardly any structural model of lean practices, particularly soft lean practices, for clustering and prioritizing of lean practices.
- Literature has large number of value stream mapping papers but the number of papers on VSM application in complex production environments are few. The existing VSM papers on complex environments do not show full VSM, though various wastes, non-value added activities, cycle time, uptime, takt time, and the material and information flows are generally shown.

- The existing few papers have either developed VSM for one variant or drawn different VSMs for different variants or superimposed VSMs of different variants to develop cells to simplify material flow between cells without considering the load levelling of cells. This mystifies the identification of waste leading to poor leanness assessment and dents the continuous improvements in future.

Chapter 2 presents a systematic literature review of peer-reviewed articles on leanness assessment to know about various types of themes, approaches and functional areas to assess the leanness level of an organization. 86 articles are identified for the systematic literature review of leanness assessment (1998-2018). The descriptive analysis of these papers shows that the research on leanness assessment is mainly empirical using qualitative judgment. The number of publications on leanness assessment has increased from an average of 0.8 articles per year in the first phase (1998-2004) to an average of eight articles per year in the third phase (2012-2018). The six thematic areas used for leanness assessment are: lean manufacturing, lean organization, lean supply chain, lean product development, lean management, and lean supplier. In first phase (1998-2004), the focus of leanness assessment was narrow to assess the manufacturing process. In third phase (2012-2018), the scope became wider and included the whole organization along with its supply chain. The study identifies three basic leanness assessment approaches: tool & technique based assessment, outcome based assessment, and waste elimination based assessment. However, in practice, a combination of these practices is used. Earlier, researchers used tools and techniques based assessment whereas at present the focus is on the outcome based assessment. However, it is recommended that a combination of the three approaches is a pragmatic approach for the lean assessment. First, outcome based approach should be used to assess the current level of leanness. Next, appropriate tools & techniques should be identified and prioritized for the effective lean implementation. In the next step, lean wastes should be identified and eliminated throughout the organization. Finally, outcome based assessment should be done again to measure the improvements and continuous improvement, which is a key concept of lean philosophy. The focus of leanness assessment shifted from assessing only manufacturing process and financial areas by using quantitative performance measures to the use of non-financial and qualitative performance measures related to manufacturing process, human resource, administration, new product development, suppliers, and customers. This study also depicts that the leanness assessment should be carried out in all functional areas of an organization for better results. The scope of leanness assessment in an organization has become wider from manufacturing process to whole organization.

Leanness assessment research is predominately through empirical studies devoid of concepts. During last decade, the increase in the rate of growth of tool & technique based assessment approach and decrease in the rate of growth of outcome based assessment approach articles also show the lack of proper conceptual frameworks/models for leanness assessment. There is a need to develop conceptual frameworks/models for leanness assessment. The practical knowledge gained through the empirical research should be used to develop the theory (conceptual models) for the leanness assessment.

Chapter 3 develops a framework for the leanness assessment of an organization in an integrated way. The organization is divided into seven functional areas, functional areas are divided into 26 performance dimensions and 119 KPIs have been identified to measure these performance dimensions. The study identifies eight criteria on the basis of literature review and discussion with industry professionals, for the selection of KPIs. These criteria ensure that the KPIs are aligned to the goal of leanness assessment, for strategic and operational assessment covering the socio-technical as well as financial & non-financial aspects of the whole organization for the continuous leanness improvement. KPIs are developed on the basis of selection criteria and frequency analysis of existing literature. Each KPI is related to either one or more of the eight lean wastes or/and five lean principles. The developed KPIs are categorized as qualitative or quantitative, strategic or operational, social or technical, financial or non-financial, leading or lagging, static or dynamic. The proposed framework is a generic framework for the manufacturing sector. The developed framework is dynamic in nature. So, it is essential to review the existing KPIs periodically as a part of the target and goal setting. The manager should do the required changes in KPIs as assessment goals change over the period of time. Obsolete KPIs should be deleted and new appropriate KPIs should be introduced. It is expected that the developed framework will help the managers to justify the implementation of lean manufacturing in their organizations.

It is expected that the proposed integrated performance measurement framework, depicting the proper structure and linkages with lean principle/waste, will be a good reference for the accurate and effective leanness assessment at different organizational levels irrespective of the industry type. Most of the research papers have considered traditional performance dimensions like quality, cost, delivery, time, rate of return, inventory, *etc.* The performance dimensions like employee empowerment, skill, decision making, communication, health and safety, *etc.* derived from organizational core values, are not in common use.

Chapter 4 presents leanness assessment of an Indian automotive component manufacturing organization at different levels by using the proposed IPM framework and fuzzy methodology. The results show that the case organization is not using all KPIs in the same proportion in different functional areas. However, it is found that the organization covers a large number of performance dimensions at the middle level. The various performance dimensions from different functional areas are prioritized based on their importance obtained from fuzzy ANP methodology. The study shows that the performance dimension of serviceability received the highest importance rating. This is followed by performance dimensions of supplier quality. The lowest ranking is given to the communication dimension.

It is found that the case organization uses only 61 KPIs. The used KPIs cover all the functional areas of the organization but the level of coverage varies in different areas. The range of used KPIs varies from 10% to 70%. The overall leanness score of the case organization is 60%. Finance, administration and supplier management functional areas need to be improved to enhance the overall organizational lean performance as the leanness score in these functional areas is less than or equal to 50%.

The customer management functional area achieved the best leanness score of 90.83%. It shows that the commitment of the case organization towards its core value of ‘service to the customer’ is strong. The leanness level of the case organization in different functional areas is highly variable (ranges from 45% to 91%), which provides the possibility of improvements in the overall organization lean score.

Chapter 5 presents 20 hard lean practices and 12 soft lean practices from the literature. The hierarchical models of hard and soft lean practices are developed by using ISM and IRP approaches. Employee ownership, a soft lean practice, is assessed and improved using the case study. Both the models provide almost similar results; however, IRP models are more detailed than the ISM models. Chapter 5 delineates that hard and soft lean practices are two major paradigms for the successful lean implementation. The ISM based model finds that the hard lean practices can be categorised as organization centric, system/technology centric, value chain centric, and motivators. The organization should first focus on motivational practices, than value chain practices, than the system and technology related practices, and finally organization wide practices. Similarly, the organization should first focus on rewards and recognitions (motivators), than practices which are important for its core competencies, than internal enablers, and finally external enablers. *Takt* time and VSM have high dominance or driving power as compared to other hard lean practices in both the approaches. It shows that the lean implementation should start with mapping of organizations' value streams after finding the takt time to fulfil the customer demand.

The developed hierarchical structures of hard and soft lean practices facilitate sequential implementation of lean manufacturing. It is expected that the structuring of hard and soft lean practices into hierarchies will enable the organization to concentrate on the limited resources as per the priority provided by the developed models. It can be concluded that for an effective and efficient implementation of lean practices, an organization should prioritize the lean practices for sequential implementation. The structural models also assist the top management to assign proper roles to employees/departments for the effective lean implementation. The assessment results support the organization with a realistic framework to deal with many challenges, especially the challenge of resource allocation during lean implementation. The developed IRP models help practitioners to prioritize lean practices with respect to their performance targets.

Chapter 5 also presents a case study of an Indian automotive component manufacturing organization to assess and improve the employee ownership. The case study shows the improvements in employee ownership based on simple managerial interventions. Simple managerial intervention led to the improvements in employee accountability, commitment & involvement, satisfaction, and morale. It is expected that this study will be beneficial to HR personnel to improve the sense of ownership in the employees.

Chapter 6 presents an integrated VSM for a complex environment using the concept of multi-machine activity with a single operator as a unit or work cell to represent the complex material/information flow. The integrated VSM is applied on an assembly line in an automotive component manufacturing organization where the similarity between the products assembled on the line is 59%. The integrated VSM shows different processes and work cells, various wastes, non-value added activities, cycle time, uptime, and the material and information flows for both products on the same map, which is expected to help practitioners to use VSM for the leanness assessment and improvement. The high customer demand of 388 assemblies per day for a complex product assembly line is achieved without adding machinery or labour. Chapter 6 also shows how multi-hierarchical cross-functional teams can diagnose the root causes of the problems by drawing and analysing Ishikawa diagrams. Micro analysis methods of 3M and ECRS helped to unravel the problematic activities. Following improvements are achieved at the case organization by implementing the 'continuous *kaizen*' and establishing the flow principles through layout redesign:

- Reduced cycle time
- Reduced WIP inventory
- Enhanced line efficiency
- Reduced movements of material and operators
- Improved production per labor hour
- Reduced operator fatigue, and
- Improved production rate

The study also proposes a new delineation of *kaizen* philosophy – continuous *kaizen* – which means continuous improvements at the global or whole value chain level instead of just 'change for better' at local or single workstation level. The various tools & techniques of the *kaizen* philosophy have been reviewed to provide salient points of each tool & technique. The continuous *kaizen* has improved the leanness of the assembly line by reducing or eliminating the motion waste by improving productivity, line balancing and line efficiency. It is expected that the proposed integrated VSM for the complex assembly line environment can be replicated by the practitioners to leverage the numerous advantages of VSM.

Although the study uses a single case study to validate the proposed framework but the proposed framework is a generalized conceptual framework for the whole manufacturing sector based on the existing literature.

MANAGERIAL RECOMMENDATIONS

The proposed framework is a conceptual framework. So, author recommended the following points for company specific adoption:

- The proposed framework is a generic framework for whole manufacturing sector. Therefore, it is prerequisite to develop a check list to identify the proposed KPIs used in the company and also add KPIs which are important for the industry. The motto is continuous improvement, including the continuous improvement of KPI list.
- The management should provide an assessment facilitator who has the required skills and knowledge to collect, examine, and interpret the data. The facilitator should be competent to coordinates with employees and managers alike at all hierarchical level throughout all functional areas of the organization.
- The managers should measure the KPIs against the predefined targets.
- The managers should use the proposed framework for continuous improvement rather than for assessment only.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

The limitation of the study is that the study uses a single case study methodology for the validation and implementation of framework or models. More case studies or survey based studies are needed to generalize the outcomes. Exploratory multiple-case studies or exploratory longitudinal analysis for benchmarking the leanness assessment levels can be taken up in future.

The future researchers can conduct empirical tests using the following propositions:

Proposition 1: The KPIs are used in similar proportions to measure the leanness level of all functional areas.

Proposition 2: Both, quantitative and qualitative KPIs are used for the leanness assessment.

Proposition 3: The leanness level is assessed for all the performance dimensions throughout the organization.

Proposition 4: The level of lean implementation is identical in all functional areas of a manufacturing organization.

The study can be extended to other industries and parts of the world. The study uses ISM and IRP approaches, which are reliant on the expert judgments and this may have induced some bias. Future work can also be done to statistically test the proposed ISM models using structural equation modelling (SEM). Other techniques such as fuzzy can be integrated to improve the power of ISM. The results of the study can be compared with other existing studies to check the robustness of developed models. Sensitivity analyses can be carried out to check the robustness of the proposed models.

The future research may be conducted using the developed integrated VSM approach in other complex production environments having merging flows due to large number of bills of materials or high mix low volume (HMLV) production. Future studies should also include financial measures to provide the lean benefits in terms of value-added and non-value-added costs.

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APPENDIX – A

Leanness Assessment KPIs' Checklist

Department: Manufacturing Engineering

Please tick (√) the appropriate answer for each KPI as **Yes,** (if you are using this KPI); **No,** (if you are not using this KPI); **Would,** (if you are not using this KPI, but you would like to use it).

S. No.	KPI	Yes	No	Would
1.	Defect rate			
2.	Percentage cost of poor quality			
3.	Overall equipment effectiveness index			
4.	Manufacturing lead time			
5.	Manufacturing cycle time			
6.	Throughput rate			
7.	Inventory turns			
8.	Scrap ratio			
9.	Percentage of work in process (WIP) inventory			
10.	Processing cost per unit			
11.	Percentage of maintenance cost			
12.	Percentage of raw material cost			
13.	Percentage of labor cost			
14.	Percentage of inventory cost			
15.	Percentage of in-house material movement cost			
16.	Percentage of raw material inventory			
17.	Percentage of finished goods inventory			
18.	First pass yield (FTY)			
19.	Machine down time			
20.	Set up rate			
21.	Utilization efficiency			
22.	Worker efficiency			
23.	Space productivity			
24.	On-time delivery			
25.	Lot size reduction			
26.	Transportation or motion			
27.	Changeover time			
28.	Allocation efficiency			
29.	Poka-yoke			
30.	Pull process			
31.	Number of non-value added activities			
32.	Process capability index			
33.	Flexibility			

Leanness Assessment KPIs' Checklist

Department: New Product Development

Please tick (√) the appropriate answer for each KPI as **Yes,** (if you are using this KPI); **No,** (if you are not using this KPI); **Would,** (if you are not using this KPI, but you would like to use it).

S. No.	KPI	Yes	No	Would
1.	Rework rate or change requests			
2.	Quality specifications			
3.	Percentage of development cost			
4.	Time to market			
5.	Product design cycle time			
6.	Product design lead time			
7.	New market development or growth			
8.	Expected market share			
9.	Percentage of marketing cost			
10.	Customer satisfaction			
11.	Part standardization			
12.	Percentage of sales from new products			
13.	Number of new product launched in last 5 years			
14.	Number of non-value added activities			
15.	Return on investment			
16.	On-time delivery			
17.	Resource utilization			
18.	Number of patents filed			
19.	Number of design changes to specification			
20.	Life cycle design/assessment			
21.	Number of bottlenecks			
22.	Innovativeness rating			
23.	Strategic competence			
24.	Effectiveness of risk management process			
25.	Design manhours			
26.	Timeliness			
27.	Number of processes reduced			
28.	Employee training and satisfaction			
29.	Percentage of profit from new product			
30.	Involvement of suppliers in product development			
31.	Product customization			
32.	Product performance			
33.	Knowledge management			
34.	Quality function deployment (QFD)			
35.	Benchmarking			
36.	Life cycle costing			
37.	Actual project cost to budgeted cost			

Leanness Assessment KPIs' Checklist

Department: Human Resource Management

Please tick (√) the appropriate answer for each KPI as **Yes,** (if you are using this KPI); **No,** (if you are not using this KPI); **Would,** (if you are not using this KPI, but you would like to use it).

S. No.	KPI	Yes	No	Would
1.	Absenteeism rate			
2.	Health and safety of employees			
3.	Number of accidents/ incidents per year			
4.	Training hours per employee per year			
5.	Percentage of skilled or multifunctional workforce			
6.	Labor turnover			
7.	No of suggestions implemented per worker per month			
8.	Employment security			
9.	Number of remuneration policies or incentive schemes			
10.	Employee satisfaction			
11.	Average cost of training per year			
12.	Use of multifunctional task forces/teams			
13.	Respect for people			
14.	Work-related flexibility			
15.	Average labor wage rate			

Leanness Assessment KPIs' Checklist

Department: Finance

Please tick (√) the appropriate answer for each KPI as **Yes,** (if you are using this KPI); **No,** (if you are not using this KPI); **Would,** (if you are not using this KPI, but you would like to use it).

S. No.	KPI	Yes	No	Would
1.	Net profit margin			
2.	Total cost of capital employed/ total sales			
3.	Sales volume or turnover			
4.	Revenue generated			
5.	Return on assets (ROA)			
6.	Return on investment (ROI)			
7.	Return on sales (ROS)			
8.	Current ratio			
9.	Rate of return on capital employed			
10.	Procurement cost/ total sales			

Leanness Assessment KPIs' Checklist

Department: Administration

Please tick (√) the appropriate answer for each KPI as **Yes,** (if you are using this KPI); **No,** (if you are not using this KPI); **Would,** (if you are not using this KPI, but you would like to use it).

S. No.	KPI	Yes	No	Would
1.	Communication/information loss			
2.	Percentage of administrative costs			
3.	Reduction of paper work in office areas			
4.	Synchronized scheduling			
5.	Business relationship with partners			
6.	Commitment of top management			
7.	Competitive policy			
8.	Strategic planning			
9.	Quality control			
10.	Visual control of the shop floor			

Leanness Assessment KPIs' Checklist

Department: Customer Management

Please tick (√) the appropriate answer for each KPI as **Yes,** (if you are using this KPI); **No,** (if you are not using this KPI); **Would,** (if you are not using this KPI, but you would like to use it).

S. No.	KPI	Yes	No	Would
1.	Customer satisfaction			
2.	Customer retention rate			
3.	Annual customer complaints			
4.	Responsiveness			
5.	Customer involvement			
6.	On-time delivery			
7.	Service quality			

Leanness Assessment KPIs' Checklist

Department: Supplier Management

Please tick (√) the appropriate answer for each KPI as **Yes,** (if you are using this KPI); **No,** (if you are not using this KPI); **Would,** (if you are not using this KPI, but you would like to use it).

S. No.	KPI	Yes	No	Would
1.	Relationship with suppliers			
2.	Contract length with important suppliers			
3.	Percentage of certified suppliers			
4.	Percentage of total cost of supplier evaluation			
5.	Percentage of distant supplier eliminated			
6.	Supplier involvement in design			
7.	Incoming parts/materials defect rate			

APPENDIX – B

List of Publication

Journal Papers

- Sangwa, N.R. and Sangwan, K.S., 2018. Development of an integrated performance measurement framework for lean organizations. *Journal of Manufacturing Technology Management*, *29*(1), pp.41-84.
- Sangwa, N.R. and Sangwan, K.S., 2018. Leanness assessment of organizational performance: a systematic literature review. *Journal of Manufacturing Technology Management*, *29*(5), pp.768-788.
- Sangwa, N.R. and Sangwan, K.S., Leanness assessment of a complex assembly line using integrated value stream mapping: a case study. *Production planning & control*, Under Review, Manuscript ID: TPPC-2018-0278.
- Sangwan, K.S. and Sangwa, N.R., Fuzzy methodology Based Hierarchical Leanness Assessment of an Indian Automotive Organization. *Benchmarking: An International Journal*, Under Review, Manuscript ID: BIJ-08-2018-0258.
- Sangwan, K.S. and Sangwa, N.R., Identification and Prioritisation of Lean Practices: A Case Study. *Journal of Modelling in Management*, Under Review, Manuscript ID: JM2-12-2018-0222.
- Sangwa, N.R. and Sangwan, K.S., Continuous Kaizen Implementation to Improve Leanness: An Indian Automotive Component Assembly Line Case Study. Working Paper.
- Sangwa, N.R. and Sangwan, K.S., Improvement of Employee Ownership at an Indian Automotive Component Manufacturer: A Case Study. Working Paper

Conference Paper

- Sangwa, N.R., Choudhary, K. and Sangwan, K.S., 2015, January. Performance Evaluation Framework for Lean Manufacturing-A Review. In proc. Of National Conference on Sustainable Manufacturing, (NCSM-2015), MNIT Jaipur, 2-3 January, 2015.

APPENDIX – C

Biography

About the candidate (Mr. Narpat Ram Sangwa)

Mr Narpat Ram Sangwa received his BE in Mechanical Engineering from the Govt. Engineering College, Ajmer (Rajasthan), India and M Tech in Manufacturing System Engineering from the Malaviya National Institute of Technology, Jaipur (Rajasthan), India. Currently, he is pursuing his PhD as a Research Scholar in the Department of Mechanical Engineering, BITS, Pilani and has over 2.5 years teaching experience at under graduate and post-graduate levels. His areas of interest are lean manufacturing, TQM, and sustainable manufacturing. Mr. Sangwa is a member of Decision Sciences Institute (DSI), USA and associate member of The Institution of Engineers (India).

About the supervisor (Prof. Kuldip Singh Sangwan)

Dr. Kuldip Singh Sangwan is a Professor of Mechanical Engineering at Birla Institute of Technology and Science, Pilani, Rajasthan. He is an active researcher in the field of sustainable manufacturing, cyber physical production systems, industry 4.0, reverse logistics, lean manufacturing, life cycle engineering, and application of AI in manufacturing system design. He has guided eight PhDs and six PhDs are in progress. Prof. Sangwan has published more than 100 papers in international journals of repute like IJPR, PPC, IJOPM, JCLEPRO, Annals of OR, IJLCA, JMTM, etc. He has an active collaboration with TU Braunschweig, Germany since last 10 years. He has established Joint Indo-German Experience Lab and Sustainable Manufacturing & Life Cycle Engineering Lab at BITS Pilani, Pilani Campus. Currently, he is the Chief of Placement and Workshop Unit.