Hybrid ERP Lean System Implementation Framework for Small and Medium Manufacturing Enterprises

by

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ABSTRACT

Enterprise Resource Planning (ERP) and Lean Manufacturing (LM) are the important entities to run the manufacturing systems. Although, many organizations use the ERP and Lean systems, but rarely a combination. ERP and Lean systems are perceived as opposing in nature i.e. push Vs pull respectively. The research aims at combining ERP and Lean into a hybrid system, by exploring contradictions and connection between the ERP and Lean for an effective implementation. Moreover, Small and medium enterprises (SMEs) need support in the implementation of both the systems as they lack resources and experience. Therefore, the research proposes a Hybrid ERP Lean Framework (HELF), which is built on the capabilities of both the ERP and Lean systems. The HELF has a distinct feature for ERP and Lean implementation in a hybrid fashion. To derive HELF, the research progresses through four phases. The first phase is the identification of SMEs' business requirements and ERP-Lean contributions to achieving the business requirements; these are derived using literature mapping and Alberta SMEs survey. The second phase aims at the ERP implementation in SMEs, wherein, the research proposes a methodology focusing on the selection of most suitable ERP modules and Critical Success Factors (CSFs) for successful ERP implementation. The third phase is Lean implementation, which presents a unique method to evaluate current Leanness and a guide to achieve the target Leanness at the shop-floor level. In the fourth phase, the developed tools and methods are integrated into an integrated Hybrid ERP Lean Framework (web-based) to guide SMEs with the Hybrid system implementation. The framework is validated through a case study at the Alberta Learning Factory at the University of Alberta. In addition, the HELF is designed to support industry 4.0 to improve the communication, data sharing and decision making in SMEs.

PREFACE

This thesis is the original work by Saraswati Jituri. Two journal papers and two conference papers related to this thesis have been submitted or published and are listed as below. As such, the thesis is organized in paper format by following the paper-based thesis guideline.

1. **Saraswati Jituri,** Brian Fleck, Rafiq Ahmad, "Lean OR ERP – A Decision Support System to Satisfy Business Objectives" *Procedia CIRP, 70, 422–427, 2018.*
2. **Saraswati Jituri,** Brian Fleck, Rafiq Ahmad "A methodology aiming to satisfy Key Performance Indicators for successful ERP implementation in SMEs." *International Journal of Innovation, Management and Technology*, *(ICCMA2017,* **BEST PAPER AWARD***) V09N2, 79-84, 2018.*
3. **Saraswati Jituri**, Brian Fleck, Demetirz Mourtzis, Rafiq Ahmad "A decision support system to define, evaluate, and guide the Lean assessment and implementation at the shop-floor level" *AMSE Journal of Computing and Information Science in Engineering.* (Under review)
4. **Saraswati Jituri,** Brian Fleck, Rafiq Ahmad "Hybrid ERP-Lean Implementation Framework for Small and Medium Enterprises" *International Journal of Production Research.* (Under review)
5. Rafiq Ahmad, Cole Masse, **Saraswati Jituri**, John Doucette, Pierre Mertiny "Alberta Learning for training reconfigurable assembly process value stream mapping" *Procedia Manufacturing 23, 237–242, 2018.*

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LIST OF ABBREVIATIONS

ERP	Enterprise Resource Planning
SME	Small and Medium Enterprises
LM	Lean Manufacturing
LI	Leanness Index
LR	Lean Rules
CSF	Critical Success Factor
KPI	Key Performance Indicator
LET	Leanness Evaluation Tool
LRF	Lean Rules Formulation
DETG	Define Evaluate Target Guide
HELF	Hybrid ERP Lean Framework
HELS	Hybrid ERP Lean System

Chapter 1 Introduction

This chapter introduces the thesis, describes the work done, and gives motivation for the research. It also defines the preliminary research questions and sets the objectives of the research project.

1.1. Background and Motivation

Manufacturing information system has been growing since the industrial revolution 2, which have brought in the robots, complex machines and automation. A platform to manage the manufacturing information system is Enterprise Resource Planning (ERP) system. The ERP system is in use in many manufacturing companies during across the globe. Similarly, Lean manufacturing an increasingly popular concept pioneered in Japan by Toyota Motor Corp and embraced by thousands of firms because of the organizational excellence the Lean brings. With traditional manufacturing resource planning (MRP), an application of the ERP systems, manufacturers base their production schedules on the sales forecasts. In contrast, Lean manufacturing connects production schedules to actual customer demand. Lean emphasizes getting the manufacturing process right and then continually improving it, while ERP the emphasis is on planning. Few manufacturing industries consider the two concepts can coexist in the same plant, others consider them as oil and water. The Lean has the aim of eliminating all wasted time, movement, and materials and the ERP track every activity and every piece of material on the plant floor. “Lean is action-oriented whereas ERP is data-dependent”. Nevertheless, ERP and Lean are the two important systems used by the manufacturing firms, hence exploring the connections and contradiction between these systems should be explored.

1.2. Enterprise Resource Planning (ERP) System

The pace of business is faster than ever before, which means employees across a company need immediate access to key data. Therefore, the organization needs an efficient information system, which is capable of providing the right information on time [1] thereby bringing rewards to organizations in the competitive world. In addition, the business world that is characterized by alliances, mergers, and acquisitions followed by cost cutting, downsizing, and outsourcing, data plays an essential role. Hence, the organizations have to align and integrate its business processes with the information system, which comprehensively handles data from all facets of the organization. The information system should provide an integrated view of all business processes happening in various facilities and locations of the organization [2]. In this regard, Enterprise and Resource Planning System (ERP) is a platform for information system solution for most of the organizations [3], [4]. The main goal of ERP is to process the data, integrate data from all areas of the organization, unify the processed data and present the data matching to the user understanding level [2], [5]. ERP Systems usually accomplish this through one single database [1] that employs multiple software modules. It integrates all departments and functions across a company in a single computer system that is able to serve all those different department's particular needs. An ERP system also automates business processes by placing them into a useful format that is standardized and common for the whole organization [6]. A simple definition of the ERP [7], [8] "Enterprise resource planning (ERP) is an integrated system, which is designed to automate and integrate business processes and operations together". The process is sequence of operations consisting of people, machine, material, and method for the design, manufacture, and delivery of a product or service. Whereas operation is an activity or activities performed on a product or service by a machine or person.

Tenhi & Helki 2015 [9] defines the ERP, as "ERP systems are modular software packages that integrate a firm's business functions around a common database and standardized processes that are configured to fit the needs of the user organizations." Most common and core modules of ERP systems are listed as follows [1]

- Finance management module
- Accounting management module
- Production management module
- Transportation management module
- Manufacturing management module
- Human resources management module
- Sales & distribution management module
- Customer relationship management module
- Supply chain management module
- Warehouse management module
- Add on Lean tool supporting module

Some of the advantages and disadvantages of ERP system are listed in Table 1.1.

Advantages	**Disadvantages**
Access to reliable information [1], [10]	System is expensive [3], [11]
Avoid data and operations redundancy [1]	The implementation process is time-consuming [3], [11]
Inventory reduction [6]	High risk factor [12]
On time delivery [6]	Complex system [1], [11], [13]
Reduction of Personnel [6]	High cost of ERP software [11]
Increased productivity [6]	High consultation charges for implementation [11]
Reduction in transportation and logistics cost [6]	Expensive business process reengineering [3]

Reduction in Procurement cost[6]	High failure rate of the projects [14]
Increase revenue and profit [6]	Conformity of the modules to business processes [1]
Improved business process [6]	Vendor dependence [1]
Improved responsiveness to the customer [3], [6]	
Improved communication [6]	
Integration between the functions [6], [11]	

Table 1.1 ERP system advantages and disadvantages

1.2.1. Evolution of ERP system

World War 2 and the industrial revolutions led the industrial growth. Especially manufacturing industries were excelling in the technologies. As the mass production was spurring in manufacturing industries, it was a difficult task to manage the inventories and plan the production. That is the period when material requirement planning (MRP) was developed [15]. The developed MRP systems functioned on the planning of the product or parts requirements according to the master production schedule. Although there was a vision to develop the information system application that integrates the processes information, due to lack of hardware and programming languages it was not possible [13]. Later advancement in material requirement planning was Manufacturing Resource Planning (MRP II) which optimized the manufacturing processes by synchronizing the materials with the production requirements [1], [11], [16], [17].

Enterprise Resource Planning (ERP) system was implemented during late in 1980's and early 1990's [1], [13], [18]. ERP systems have a technological foundation of MRP and

MPR II, providing enterprise wide inter-functional correlation and integration. The term ERP was coined by Gartner Group of Stamford Connecticut, USA [17]. Advancement in technology has further led to upgrading of the ERP called as "Extended ERP" which has "add on" [1] modules such as customer relationship management (CRM), supply chain management (SCM) and Advance planning and scheduling (APS). Taking advantage of internet facility ERP vendors moving to cloud systems platform called SaaS (Software as a Service) [19]. Most popular ERP software language used by ERP vendors are C#, JAVA, PHP, visual basics, JavaScript [13].

Literature shows that during the late 1990's Prognosticators forecasted 30-40% growth rate of ERP market and ERP market might reach $50 billion by 2002 [20]. ERP system bought a shift in the use of IT in the organizations in the 1990's. From 1999 to 2004 the ERP software market showed accelerated growth of $15 billion to $50 billion [11]. Add-on modules like customer relation management, supply chain management and integration of internet-enabled applications contributed in sustained ERP system market [1]. Allied Market Research Place have anticipated the ERP market growth at approximately $41.69 billion in sales by the year 2020 [21]. Therefore, literature on trends of ERP system shows that there is a chance of continues growth in ERP system. Even though ERP system is growing, the complexity associated with it also growing. Research in the direction of reducing the complexity in the ERP system and its implementation is in progress.

1.2.2. ERP system life cycle

The life cycle of ERP system starts with building the ERP software by the ERP vendors, then an industry make a decision to implement the ERP system, next the industry identify the ERP software package for the implementation, after that implement the ERP system, maintain and monitor the implemented ERP system, ending with the decline stage of ERP system [22]. The decline stage occurs when technologies advances and ERP software package do not match with the advancement. Figure 1.1, shows overview of the ERP system implementation process [11].

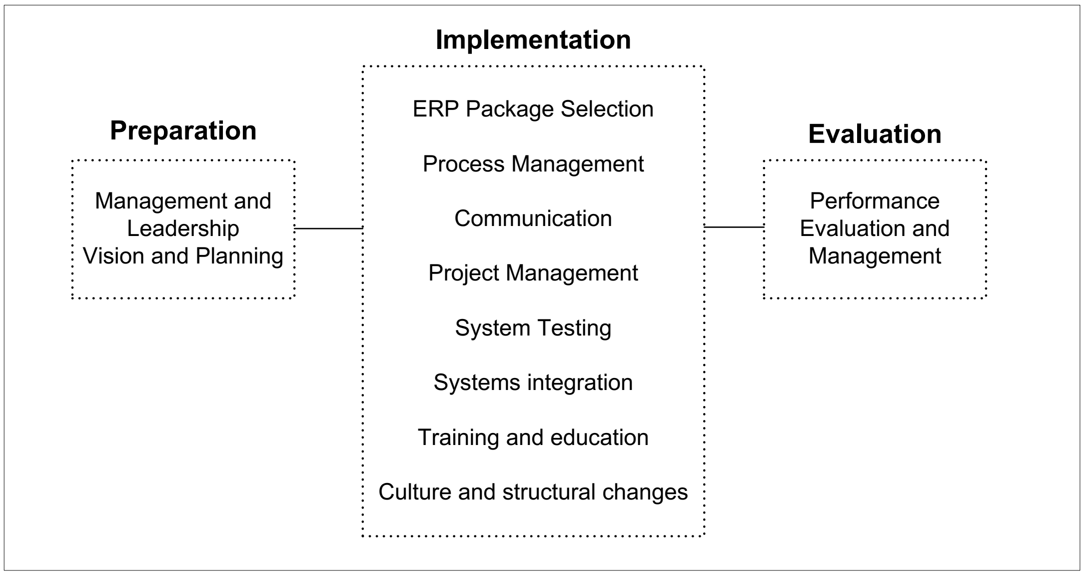

Figure 1.1 ERP system implementation overview

ERP system is advantageous because of decline in inventory, reduction in working capital, abundant useful information collection, increased productivity and many more post-implementation. On the other hand, it can turn into a nightmare because of the increased cost of installation, improper integration, and reengineering more than expected. An implementation in the information system category is defined as ‘‘the process that begins with the managerial decision to install a computer-based organizational information system and is complete when the system is operating as an integral part of the organization’s information system’’ [3]. ERP implementation is time consuming and costly process [23], thus successful implementation of the ERP system is necessary and essential. To have successful implementation and post-implementation benefits it requires the right management, right people, right software and right resources. Therefore, improper planning of the ERP system implementation before the implantation may become the major factor for the failure of ERP system in the organization [3], [23]. Important points to be considered before the ERP implementation are as follows [17].

- ✓ Assessing the need and choosing right the ERP system
- ✓ Matching business process with ERP system
- ✓ Understanding the organizational requirements
- ✓ Economic and strategic justification

Factors behind successful implementation of ERP system involves cautious, evolutionary, bureaucratic implementations backed by careful change management and cultural readiness [1], [6]. Implementation of ERP system should be aligned with a firm's competitive strategy [6]. ERP implementation cost includes the cost of the software, hardware, consulting and reengineering. This cost can be nearly 2 to 3% of companies revenue [17]. Literature research shows 50% failure rate and 60% to 90% implementation have no return on investment. According to Mohammad Reza et al [18] in 2010, ERP failure rate was 40 % to 50% and it is a risky process. Looking at these figures, ERP implementation is a difficult task for Small and Medium industries.

1.3. Lean Manufacturing or Lean Management

Lean manufacturing is a philosophy originated in Japan at Toyota back in the 1940s [24]–[26]. Taiichi Ohno and some of his coworkers developed the Lean tool and techniques over the period of 30-40 years [25], [27]. Dora et al [24] define the Lean as "A system that utilizes fewer inputs and creates the same outputs while contributing more value to customers". Another definition of Lean quoted by Mourtzis et al. [26], [28] "Lean Thinking has been defined and coded as a dynamic, knowledge-driven, continuous effort to eliminate waste, with the goal of creating value, in which, customers' satisfaction should always be the primary goal". Lean manufacturing focus on waste elimination and value addition in the manufacturing process [24]. Womack & Jones spread the knowledge about Lean manufacturing through their book Lean Thinking [29]. The term Lean was used for the first time in 1988, during the International Motor Vehicle Program, which aimed at understanding the differences in productivity between Japanese and Western industries. Womack et al in their another book "The Machine That Changed the World" then popularized the term Lean [30]. Elimination of non-value-added activities in Lean philosophy supports the business strategy of creating more with fewer resources. Lean manufacturing has become the choice of industries as Lean brings a competitive advantage to the business [24]. The source of Lean Manufacturing came from the Toyota Production System; it is based on the principle of eliminating all forms of wasted value within the enterprise [26].

Following are the key principles of Lean manufacturing as defined by Womack and Jones, which are widely accepted [29]. The five Lean principles are

1. Precisely specify the value by specific product – indicates to eliminate waste of unused features.
2. Identify value stream for each product - indicates to eliminate waste of non-required processes
3. Make value flow without interruptions - indicates to eliminate waste of waiting, motion and transportation
4. Let customer pull value from producers – indicates to eliminate waste of inventory
5. Pursue perfection- indicates to eliminate waste of correction

Lean manufacturing principally focuses on the reduction of the seven wastes, which are waiting, unwanted motion, unwanted transportation, excessive processing, over production, excessive inventory, and defects. Elimination of these wastes improves overall customer value. Waste reduction, just-in-time manufacturing, error proofing, kanban system, problem-solving, kaizen, heijunka, standardization, total productive maintenance and smart automation are some of well-known the tools of the Lean manufacturing [25], [27].

Lean manufacturing has been widely used to increase operational excellence and performance in manufacturing systems [31]. The goal of Lean manufacturing systems is to realize a balanced and smooth flow of production with the zero wastes. Intangible and tangible benefits of the Lean system are reduced inventory levels, high quality, reduced lead times, increased productivity, delivery, employee and customer satisfaction, equipment utilization, and reduced amounts of scrap and rework [24], [27], [31]. These benefits, in turn, lead to cost reduction improvement in efficiency and effectiveness.

Implementation of Lean manufacturing is a time-consuming process. Vast nature of the Lean calls for thorough knowledge and deep understanding. An organization implementing the Lean should undergo behavioral and cultural changes [30]. Prior research shows that Lean principles have reached only up to top management, meaning top management aware of benefits of Lean. However, Lean philosophy is failing to reach down the levels in the organization [25]. Implementation of Lean requires changes in business processes, which is a cost to the company if failed in the implementation. Lack of tools and techniques to measure the gains of post-Lean implementation has made the organization reluctant to the Lean implementation. Lean requires statistic and reliable data for effective problem solving. Studies by [31] point out that Lean system fails due to an insufficient number of observations (data collection), non-reliable data, non-availability of continues real-time data. Sometimes the Lean experts collect production data by manually, which are inaccurate. There is a support needed in terms of a well-defined information system for managing the data, required for Lean manufacturing [31].

1.4. Hybrid ERP and Lean (Push Vs Pull)

In the manufacturing sector, ERP tries to make complete utilization of the machine or capacity, prepares the schedules accordingly. Similarly, it does the demand forecasting based on the history of sales of the products. This scenario is called as a push system [32], [33]. ERP is pushing the order without the customer really placing an order as shown in Figure 1.2. However, the Lean promotes a pull system, meaning the schedules are prepared based on the customers' orders. Lean promotes the production of the products only when customers place an order. It does not try to utilize the capacity of machine or equipment, which is called as pull system as shown in Figure 1.3 [32], [33]. Therefore, the condition Push Vs Pull has appeared. This Push Vs Pull condition has led to the discussion that ERP and Lean are opposing each other [4]. Despite this situation of opposition, manufacturing industries need both the ERP and Lean system. ERP has its own valuable advantages and so is the Lean, which are critical to run a manufacturing firm.

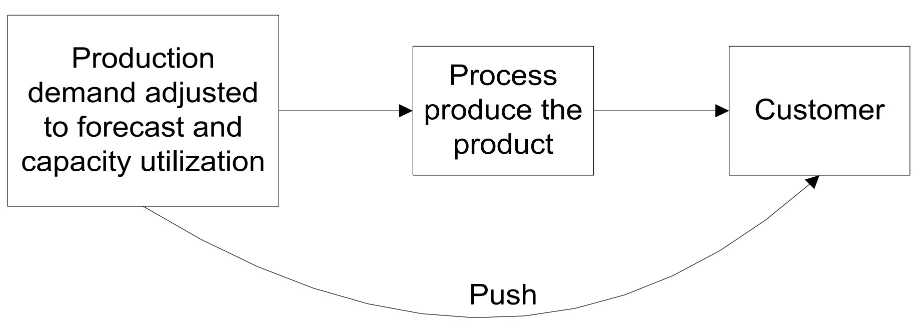

Figure 1.2 Push system

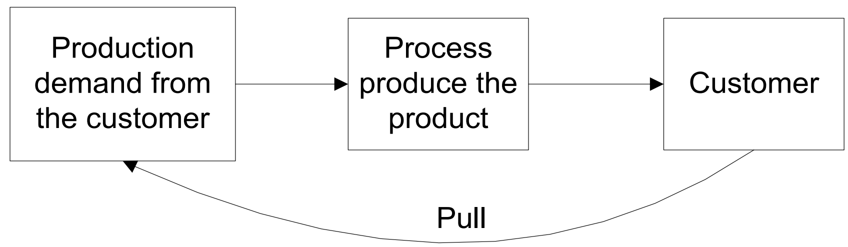

Figure 1.3 Pull system

The large manufacturing industries generally used the batch production techniques to process the orders. Since large manufacturing firms are the potential customers of the ERP vendors, the vendors designed ERP as per the business process of the large firms. The trend before 2010 was that ERP systems were being designed to suit the business processes of the large manufacturing industries [20], [34]. Nevertheless, the increased awareness of the Lean manufacturing concepts and its benefits have made manufacturing firms to change their way of doing the business from the push system, i.e. batch production, to the pull system [33]. Therefore, the changes are necessary for the ERP system to accommodate the Lean (pull system). The ERP vendors are now thinking in the direction of redesigning the perception of ERP system for the manufacturing firms [35]. The advancement in the information technology has led the ERP system to incorporate the pull system methods by modifying ERP system functionality [36]. Looking at the progress of the Lean system, information technology and industry 4.0, hybrid ERP Lean System can be a good start for advancement in modern manufacturing operations.

1.5. Challenges for Small and Medium Enterprises (SMEs)

Small and Medium Enterprise (SME) manufacturing industries run their business with the limited resources. Saving cost is a crucial task for them. In this situation, SMEs do not take risk of spending their valuable resources on ERP and Lean system implementation. Thus, SMEs are deprived of benefiting from organizational excellence brought by ERP and the Lean. SMEs lack influence with suppliers, their production schedules are unstable, and they require extensive training in order to implement the Lean system but often do not have the sufficient financial backup for this task [37]. An ERP implementation can range from $2 to $4 million for a small company to over $1 billion for the large firms [20]. SMEs organizational structure is less formalized, and employees are multi-tasking. In this situation, casting attention on implementing the system is a tough game, unlike large manufacturing enterprises. In addition, the financial impact of failing in implementation and not completely utilizing the implemented systems is generally fatal to an SME [38]. The failure of ERP system is affecting the SMEs then the large manufacturing sector, as large manufactures employ a systematic procedure to counteract the risk. SMEs fail to adopt the system as they lack “know how” about the implementation. There are not many studies on implementation-designed suiting to the SMEs business process. Therefore, SMEs need a systematic approach, which guides them in the implementation. The guidance should take care of all the disadvantages related to the ERP and the Lean system implementation.

1.6. Research objectives

The research objectives are derived from studying the ERP and Lean Manufacturing systems applications, trends, benefits and drawbacks with respect to the Small and Medium Enterprises (SMEs) with the scope restricted to Manufacturing. The main research objective is to:

"Develop a framework for small and medium enterprises, which assists in selection, implementation, and sustenance of ERP and Lean systems in a hybrid way, promoting the hybrid ERP Lean system leading to optimized utilization of resources and achieve the business objectives."

To develop the framework the **objectives (Os)** are subdivided into following actions.

O1. Identify Key Performance Indicators (KPIs) and Business Objectives which are important for SMEs and analyze contributions of Lean and ERP implementation in achieving the KPI/business-objective, through extensive literature mapping and survey.

O2. Develop a methodology to implement the ERP system results in reduce initial investment, lesson underutilization, minimize the risk of failure and promotes the Lean applications.

O3. Develop a novel Lean implementation tool to evaluate the status and guide the people working in shop-floor to implement Lean through the elimination of manufacturing wastes.

O4. Integration of the Lean and ERP systems implementation tools into a combined Hybrid ERP-Lean Framework, supported by a user interface, in order to provide a decision-support system and roadmap for the implementation.

The research have fulfilled the objective through the Hybris ERP Lean Framework, which is the contribution of the thesis. The Hybrid ERP Lean System has new approaches for ERP and Lean system implementation, which the existing systems does have. For example, the ERP modular approach, ERP Lean importance score, leanness targets and leanness evaluation tools are the novel work. ERP vendors can incorporate these features in their ERP software's.

1.7. Organization of the thesis

This thesis comprises of six chapters. Chapter 1 present a brief introduction to research motivation, ERP system, Lean manufacturing system, aspects of combining ERP and Lean system as a hybrid system, and frames the research objectives. Chapter 2 presents the article "Lean OR ERP – A Decision Support System to Satisfy Business Objectives" addressing the first research objective. Chapter 3 fulfils the second research objective through the article "A methodology aiming to satisfy Key Performance Indicators for successful ERP implementation in SMEs". Chapter 4 is an article "A decision support system to define, evaluate, and guide the Lean assessment and implementation at the shop-floor level" focusing on third research objective. Chapter 5 is article "Hybrid ERP-Lean Implementation Framework for Small and Medium Enterprises" which fulfils the fourth objective, achieving the aim of the thesis. Finally, Chapter 6 provides conclusions and summarizes the research contributions, limitations, and future-work directions. Figure 1.4 presents the layout of the thesis.

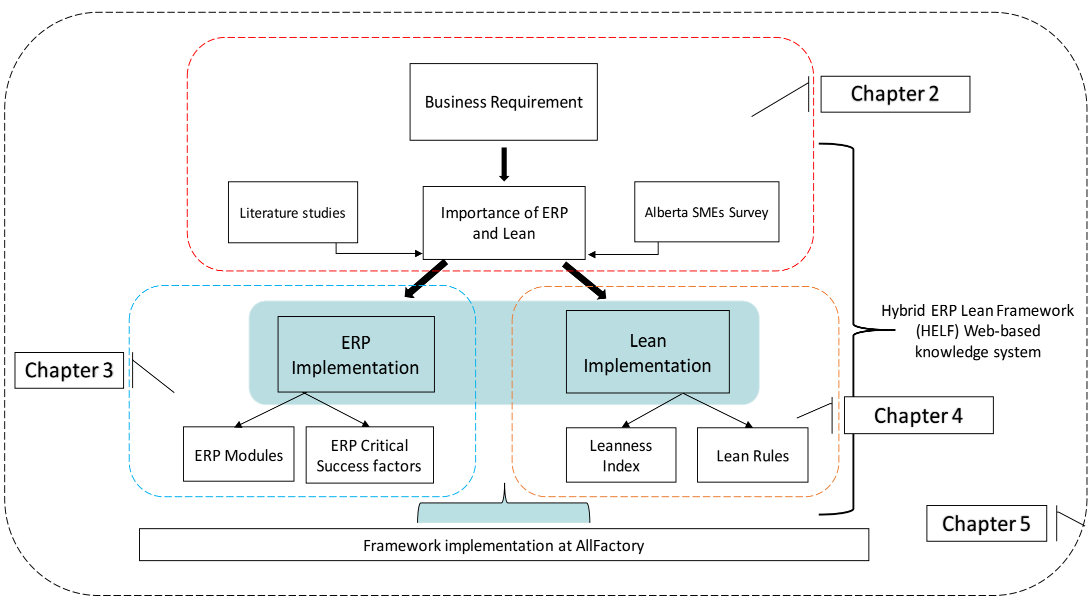

Figure 1.4 Structure of the thesis

Chapter 2 Lean OR ERP – A Decision Support System to Satisfy Business

2.1. Introduction

The advancement in production and manufacturing operations management has brought many choices for a manufacturing organization. Whether it is automation, information management, customer relations, or eBusiness, continuous improvement is necessary and expected. Enterprise resource planning (ERP) and Lean manufacturing are two popular important tools in the production and manufacturing fields [4], [39]. The ERPs caters to an integrated view of the business process [2] while Lean thinking should make the manufacturing processes effective and efficient [40].

2.1.1. Enterprise Resource Planning (ERP)

The faster business pace has created necessity to have the access to key data from the organizations knowledge depository (if exist). Constant information flow between business functions is essential for decision-making and performing tasks on time. Organizations, therefore need efficient information system, which is capable of providing the right information at the right time [1] which brings tremendous rewards to the organization in the competitive world. ERP is the right tool for this purpose.

A powerfully integrated ERP system enables interactions of marketing, sales, quality control, product processes, supply lines, stores and many other elements. It integrates all departments and functions across a company in a single computer system to serve all those different department's particular needs [6]. Some of the important benefits of the ERP system are access to the reliable information, avoid data processing redundancy, inventory reduction, on-time delivery, reduction of personnel, increased productivity, improved business process and improved responsiveness [1], [6].

ERP system implementation brings benefits however; implementation of the ERP is quite expensive. There are evidence of ERP implementation failure and the system is underutilized. Literature research shows that many ERP implementation projects do not reach the expected results which leads to failures. In some cases, the failure of ERP projects had led to bankruptcy [12], [23]. ERP implementation is a careful exercise because once the implementation takes place undoing is more expensive [12]. Adding to these drawbacks, cost addition, complexity, time and resource requirements during the ERP implementation, has alerted smaller enterprises[1]. Due to these disadvantages, SMEs are taking back step in adapting the ERP system [33].

Many organizations that adopted ERP system are disappointed in reaching the anticipated business goals. Failure of the ERP implementation may stem from the under-utilization of ERP system, especially in the post-implementation phase [41]. The usefulness is been strongly linked to usage of ERP system [42]. The reason for underutilization is that ERP only cannot achieve all the business objectives. The questions now arising are: whether an organization is making complete utilization of ERP system? Is it a right decision to spend resource only on ERP system when we know it is a costly process? Can organization invest partially in ERP system for improving their business process and partially in other improvement tools? The answers lie in: organizations need, Lean system in the place where ERP has a little contribution or the combination of ERP and Lean manufacturing should be promoted [32], [33], [43].

2.1.2. Lean Manufacturing (LM)

Lean manufacturing is derived from Toyota Production system; it focuses on waste elimination and value addition in the process. The Lean manufacturing system is defined as "A system that utilizes fewer inputs and creates the same outputs while contributing more value to the customers" [24]. Manufacturing firms are looking more and more towards the Lean manufacturing process to make their process efficient, productive and cost-effective [24], [31]. Lean assists in achieving operational excellence. As Lean philosophy is extensive, implementation of Lean manufacturing is a time-consuming process and it needs resources which is weak point of SMEs [26]. Due to these constrains SMEs has to think before investing their resources in implementing Lean manufacturing methods. Literature reveals that business objectives can be achieved in a faster pace when the Lean tools are backed by IT system like ERP [39], [44]. Therefore there is need for hybrid approach, which SMEs can make use to decide optimal resource to be invested in ERP and Lean manufacturing.

2.1.3. Lean or ERP?

Any organization brings systems in practice to accomplish specific business objectives. These objectives can be an improvement in quality, productivity, business process or any other business requirements. Literature shows that ERP can improve productivity, improve business process, reduce inventory, boost on-time delivery and improve inter-departmental communications [6]. Alike ERP, Lean manufacturing improves quality, improves productivity, reduces inventory, reduces waste, and optimizes space utilization [32]. Not all the improvements can be achieved by only ERP, and so is the Lean manufacturing. ERP can contribute to the process improvement in some areas of manufacturing. Similarly, in some areas only Lean manufacturing can afford the improvement while ERP cannot. There are business objectives like 'customer relation management' and 'integration between functions' where the ERP has great importance but not the Lean. Similarly, in some areas as 'quality improvement' and 'reduce waste' Lean system has a lot to contribute but not the ERP. This has led us to thinking which system (Lean/ERP) is better to implement?

When we look into research, Halgeri et al., [33] throw light on progress made in integrating Lean production methodologies with ERP system. They suggest the SMEs to revisit production controls methodologies and re- evaluate where they stand in relation to ERP use and Lean manufacturing implementation. Houti et al., [32] have compared ERP system and Lean manufacturing and considered them as two production methods in improving the production efficiency. Xian Li el al., [43] & Riezebos et al., [39] promoted ERP and Lean manufacturing as mutually inclusive, supplementary and balanced. Moreover the case studies in presented in [4], [5], [8], [44]–[46] encourage the combination of ERP and Lean. For the overall success, the industry needs both Lean system and ERP. However, the notion that "Lean and ERP are opposing to each other" [4], [44] is keeping SMEs away from using both the systems in combination. Manufacturing organizations practicing the Lean system, likely do not believe in the ERP system and organizations inclined to the ERP do not practice the Lean. With the scope restricted to manufacturing small and medium enterprises, in this paper, we are presenting a concept, based on hybrid ERP and Lean approach aiming to analyze the contribution of ERP and Lean in achieving business objective. This article addresses following research question.

"How ERP and Lean manufacturing system can contribute in achieving the business objective of SME?"

Next section covers the methodology to answer the research questions followed by the results, discussion, and conclusion.

2.2. Methodology

The understanding of ERP system and Lean manufacturing system shows that both the systems are helpful to achieve the business objective, even better is the hybrid approach [26], [33]. The risk associated with these systems are high, as SMEs cannot afford the failure. Therefore, they should make use of these systems carefully. Investing their resources only on ERP system or only on Lean manufacturing system is not suggested as they get only partial benefit. SMEs should understand what must be the level of ERP and Lean combination is good to achieve a specific business objective. The presented research study address this complication. Focusing on the kind of business objective SMEs would like to improve; the work proposed in the article suggests the contribution of ERP and Lean in terms of importance weightings in improving that particular objective.

Business objectives are the goals as the measurable targets, industry aim to attain. The objectives of manufacturing industries can also be delineated into key performance indicators (KPIs) using balance scorecard (BSc) [47] approach. Referring to manufacturing industries, more than thirty important business objectives and key performance indicators (KPI) are selected using the literature [1], [6], [20], [35], [44], [48]. The business-objectives/KPIs selected are listed in following table 2.1. These are the most common and important business-objectives/KPIs, which SMEs wish to enhance. Efforts have taken to cover the business objectives of all functions of manufacturing firm. The method used to obtain answer to the research question in the section 2.1.3 is by evaluating the importance weights of the business-objectives/KPIs in relation to ERP and Lean manufacturing. Detailed analysis of the importance weights gives an idea; either ERP is important, Lean manufacturing is important or the combination plays a major role for the business objective. The method selected to evaluate the importance weights is through systematic literature analysis of the research publication linked to the ERP, Lean and the objective/KPI.

Table 2.1 List of business objectives and KPIs

List of selected KPIs	
Inventory reduction	Productivity improvement
Supply chain Management	Total productive maintenance
Resource Management	Integration between systems
Increased flexibility	Improve delivery performance
Standardization of work process	Automating cross function
Order Management	Improved visual management
Customer Relationship Management	Improved business processes
Increased visibility of corporate data	Customer service improvement
Information/Data Management	5S
Reduce Waste	Rework cost reduction
Improve Lead time	Performance improvement
Improve supplier relations	Overall cost reduction
Improved decision making	Building business innovation
Increase of revenue and profit	Customer satisfaction
Supporting Business alliance	Sales growth
Cycle time reduction	Total quality management
Quality improvement	Increase market share

2.2.1. Hypothesis

Initially business-objectives/KPIs listed in Table 2.1 are segregated under the importance levels, very low, low, medium, high, and very high in relation to ERP and Lean. This clustering of KPIs is considered as a hypothesis as it is based on general knowledge on ERP system and Lean system, and the experience in the manufacturing field. Figure 2.1 represents the hypothesis. The hypothesis should be verified for the practicality. Verification presented in this article is by systematic literature research from scientific database in relation to ERP and Lean.

2.2.2. Literature analysis

A scientific database contributed in the field of ERP and Lean manufacturing was extracted from various publications like “Web of Science” and “Science direct’. The assumption is more the number of publication explaining the business objective in the field of ERP/Lean system, higher the contribution of that system. Similarly, more the count of business objectives in form of keywords presented in publication related to ERP/Lean system, higher the contribution of that system improving the objective. A Hammer software is used to carry out the systematic search from the scientific database [49], [50]. The software renders the overview on the state of a field of science using systematic mapping studies [8], [50]. It takes the input of selected publication list and gives the systematic bibliographic analysis on keywords, citations, and publication. In presented method to evaluate the importance weights, we are focusing on the number of publications and number of keyword occurrence, for a given objective/KPI. The analysis of resulted data helps to derive importance weightings of given objective/KPI with respect to ERP and Lean manufacturing.

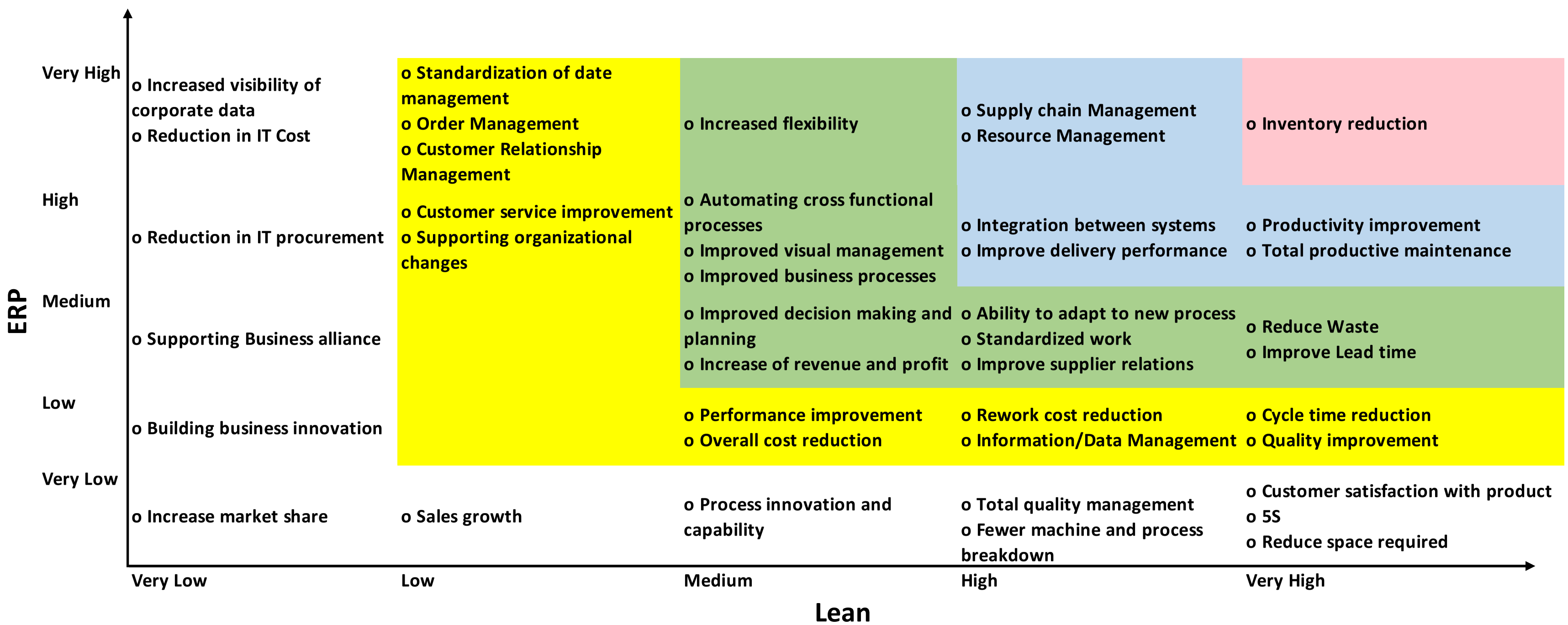

Figure 2.1 KPIs importance hypothesis

The publications for each KPI were searched in the 'web of science' using the following combination.

- Lean *AND* the business-objective/KPI
- Lean Manufacturing *AND* the business-objective/KPI
- ERP *AND* the business-objective/KPI
- Enterprise resource planning *AND* the business-objective/KPI
- Lean OR Lean Manufacturing *AND* the business-objective/KPI
- ERP OR Enterprise resource planning *AND* the business-objective/KPI

The resulted set of publications was fed to the software. It generated the systematic mapping of the number of publications and keyword occurrence. The detailed process to calculate the importance weight is discussed in next section.

2.2.3. Derivation of 'importance weight'

At this stage for each business objective/KPI, the data, number of publications and number of keyword occurrence is available with respect to ERP and Lean separately. Weighted average method is deployed to convert these numbers into weightings. Weights determine the relative importance of each quantity on the average and also helps in multi-criteria decision making [51]. A weight is computed by the frequency of occurrence in a dataset [51], [52]. In collected dataset, frequency is nothing but the number of publication and number of keyword occurrence. A weighted average of any value is given by standard equation (1).

$$Weighted\ Average = \frac{Value * Frequency}{\sum Frequencies} \qquad (1)$$

[Value = 1]

Value for each objective/KPI being '1', weights are determined by using equation (1) for each KPI. These calculations are done separately for ERP and Lean. Representations are

$\boldsymbol{P_E}$ = Frequency of publications related to ERP AND objective/KPI

$\boldsymbol{P_L}$ = Frequency of publications related to Lean AND objective/KPI

$\boldsymbol{O_E}$ = Frequency of keyword occurrence related to ERP AND objective/KPI

$\boldsymbol{O_L}$ = Frequency of keyword occurrence related to Lean AND objective/KPI

n = Total numbers of KPI

Weighted average of the objective/KPI for ERP system

$$\boldsymbol{w_{PE}} = \frac{\boldsymbol{P_E}}{\sum_{i=1}^{n} \boldsymbol{P_E}}, \quad \boldsymbol{w_{OE}} = \frac{\boldsymbol{O_E}}{\sum_{i=1}^{n} \boldsymbol{O_E}} \tag{3}$$

Weighted average of the objective/KPI for Lean system

$$\boldsymbol{w_{PL}} = \frac{\boldsymbol{P_L}}{\sum_{i=1}^{n} \boldsymbol{P_L}}, \quad \boldsymbol{w_{OL}} = \frac{\boldsymbol{O_L}}{\sum_{i=1}^{n} \boldsymbol{O_L}} \tag{5}$$

ERP weight of a specific objective/KPI

$$\boldsymbol{W_E} = \boldsymbol{w_{PE}} + \boldsymbol{w_{OE}} \tag{6}$$

Lean manufacturing weight for a specific objective/KPI

$$\boldsymbol{W_L} = \boldsymbol{w_{PL}} + \boldsymbol{w_{OL}} \tag{7}$$

The level of ERP contribution for a specific objective/KPI improvement.

$$\%\,\boldsymbol{W_E} = \frac{\boldsymbol{W_E}}{\boldsymbol{W_E} + \boldsymbol{W_L}} * \mathbf{100} \tag{8}$$

The level of Lean contribution for a specific objective/KPI improvement

$$\%\,\boldsymbol{W_L} = \frac{\boldsymbol{W_L}}{\boldsymbol{W_E} + \boldsymbol{W_L}} * \mathbf{100}$$

Table 2.2 KPI importance weightage calculation, results in relation to Lean, and ERP

KPI or Obejective	ERP & objective/KPI		Lean & objective/KPI		ERP No of papers weight w_PE	ERP-KPI Occurance weight w_OE	ERP weight Sum W_E	ERP weight %	Lean No of papers weight w_PL	Lean KPI Occurance weight w_OL	Lean weight Sum W_L	Lean weight %	Weightage distribution among 100%	
	No of Papers P_E	No of Occurance O_E	No of Papers P_L	No of Occurance O_L									ERP weightage W_E	Lean Weightage W_L
Inventory reduction	304	28	438	27	0.1083	0.0838	0.1922	64.0572	0.1951	0.0954	0.2905	96.8355	40%	60%
Supply chain Management	240	65	272	45	0.0855	0.1946	0.2801	93.3806	0.1212	0.1590	0.2802	93.3896	50%	50%
Resource Management	159	39	43	12	0.0567	0.1168	0.1734	57.8103	0.0192	0.0424	0.0616	20.5188	74%	26%
Increased flexibility	155	6	105	4	0.0552	0.0180	0.0732	24.4009	0.0468	0.0141	0.0609	20.3016	55%	45%
Standardization of work process or data	41	4	11	1	0.0146	0.0120	0.0266	8.8625	0.0049	0.0035	0.0084	2.8111	76%	24%
Order Management	6	2	0	0	0.0021	0.0060	0.0081	2.7088	0.0000	0.0000	0.0000	0.0000	100%	0%
Customer Relationship Management	72	26	17	5	0.0257	0.0778	0.1035	34.5012	0.0076	0.0177	0.0252	8.4134	80%	20%
Increased visibility of corporate data	8	1	7	1	0.0029	0.0030	0.0058	1.9483	0.0031	0.0035	0.0067	2.2172	47%	53%
Productivity improvement	262	8	93	57	0.0934	0.0240	0.1173	39.1078	0.0414	0.2014	0.2428	80.9463	33%	67%
Total productive maintenance	2	0	49	16	0.0007	0.0000	0.0007	0.2376	0.0218	0.0565	0.0784	26.1211	1%	99%
Integration between systems	49	24	29	5	0.0175	0.0719	0.0893	29.7730	0.0129	0.0177	0.0306	10.1951	74%	26%
Improve delivery performance	3	2	8	0	0.0011	0.0060	0.0071	2.3524	0.0036	0.0000	0.0036	1.1878	66%	34%
Automating cross functional processes	21	3	32	1	0.0075	0.0090	0.0165	5.4887	0.0143	0.0035	0.0178	5.9292	48%	52%
Improved visual management	10	1	10	6	0.0036	0.0030	0.0066	2.1859	0.0045	0.0212	0.0257	8.5519	20%	80%
Improved business processes	208	22	23	2	0.0741	0.0659	0.1400	46.6650	0.0102	0.0071	0.0173	5.7707	89%	11%
Customer service improvement	25	1	8	3	0.0089	0.0030	0.0119	3.9678	0.0036	0.0106	0.0142	4.7214	46%	54%
Reduce Waste	2	3	132	31	0.0007	0.0090	0.0097	3.2316	0.0588	0.1095	0.1683	56.1127	5%	95%
Improve Lead time	15	0	141	11	0.0053	0.0000	0.0053	1.7819	0.0628	0.0389	0.1017	33.8918	5%	95%
Improve supplier relations	4	1	10	2	0.0014	0.0030	0.0044	1.4732	0.0045	0.0071	0.0115	3.8405	28%	72%
Improved decision making and planning	194	18	48	0	0.0691	0.0539	0.1230	41.0099	0.0214	0.0000	0.0214	7.1269	85%	15%
Increase of revenue and profit	51	0	36	0	0.0182	0.0000	0.0182	6.0584	0.0160	0.0000	0.0160	5.3452	53%	47%
Supporting Business alliance	77	6	16	2	0.0274	0.0180	0.0454	15.1351	0.0071	0.0071	0.0142	4.7314	76%	24%
Cycle time reduction	3	1	48	16	0.0011	0.0030	0.0041	1.3544	0.0214	0.0565	0.0779	25.9726	5%	95%
Quality improvement	5	0	21	3	0.0018	0.0000	0.0018	0.5940	0.0094	0.0106	0.0200	6.6516	8%	92%
Rework cost reduction	0	0	9	0	0.0000	0.0000	0.0000	0.0000	0.0040	0.0000	0.0040	1.3363	0%	100%
Performance improvement	500	15	386	7	0.1782	0.0449	0.2231	74.3666	0.1719	0.0247	0.1967	65.5575	53%	47%
Overall cost reduction	26	3	79	0	0.0093	0.0090	0.0182	6.0826	0.0352	0.0000	0.0352	11.7298	34%	66%
Building business innovation	191	28	48	4	0.0681	0.0838	0.1519	50.6336	0.0214	0.0141	0.0355	11.8384	81%	19%
Customer satisfaction with product	20	4	14	0	0.0071	0.0120	0.0191	6.3679	0.0062	0.0000	0.0062	2.0787	75%	25%
Sales growth	9	0	5	0	0.0032	0.0000	0.0032	1.0691	0.0022	0.0000	0.0022	0.7424	59%	41%
Total quality management	6	2	18	8	0.0021	0.0060	0.0081	2.7088	0.0080	0.0283	0.0363	12.0955	18%	82%
Increase market share	7	0	6	0	0.0025	0.0000	0.0025	0.8316	0.0027	0.0000	0.0027	0.8909	48%	52%
Information/Data Management	96	21	9	1	0.0342	0.0629	0.0971	32.3622	0.0040	0.0035	0.0075	2.5142	93%	7%
5S	0	0	36	9	0.0000	0.0000	0.0000	0.0000	0.0160	0.0318	0.0478	15.9459	0%	100%
Operations Management	35	0	38	4	0.0125	0.0000	0.0125	4.1578	0.0169	0.0141	0.0311	10.3536	29%	71%

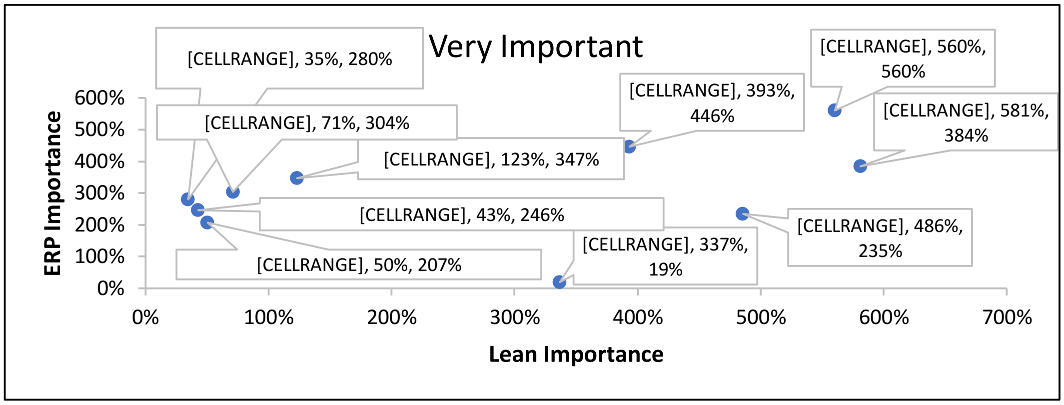

Figure 2.2 KPIs with high importance of either ERP or Lean manufacturing

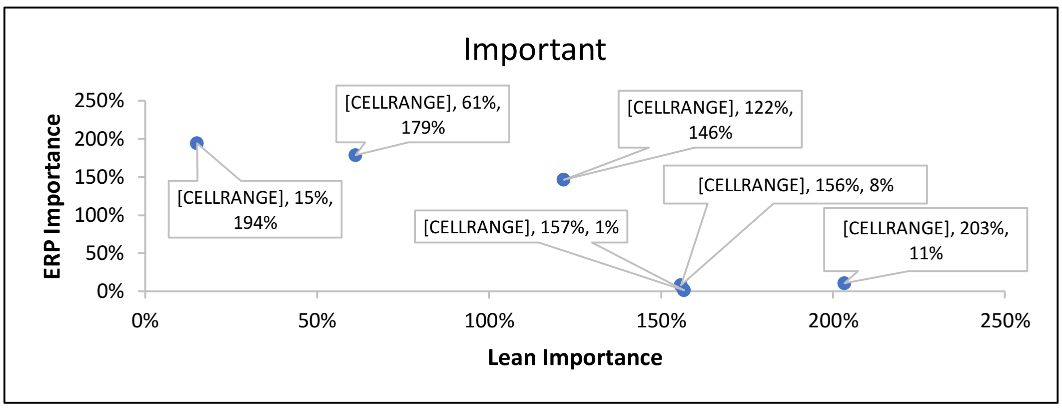

Figure 2.3 KPIs with avearage importance of either ERP or Lean manufacturing

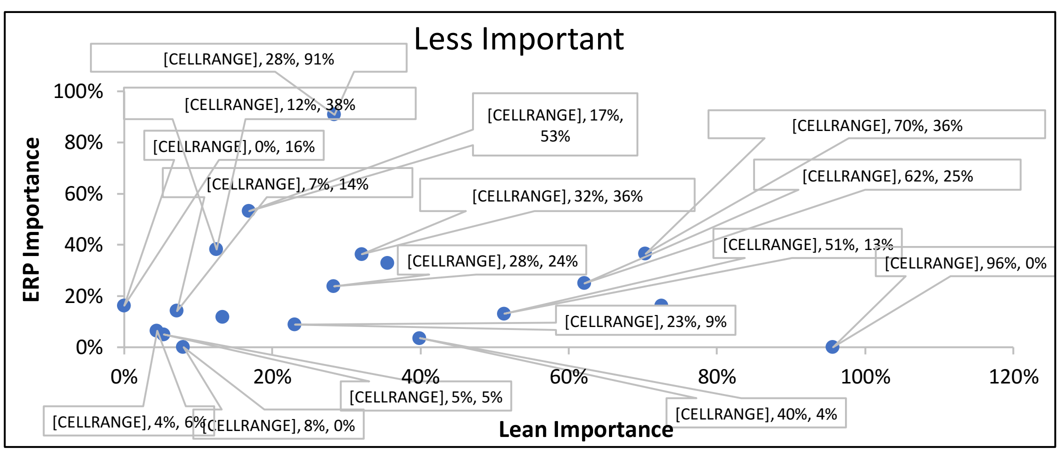

Figure 2.4 KPIs with less importance of either ERP or Lean manufacturing

2.3. Results and Discussion

From Table 2.2, it is clear that each objective/KPI has a weight for ERP and Lean system, which tells us the contribution level. The objective 'quality improvement' has relative importance weight of 92% for the Lean system and 8% for ERP system. This shows that if the business objective is 'quality improvement', then the firm should spend their 92% of resources on the Lean system and remaining 8% on ERP system approximately. If the firm's objective is to improve their 'data management system', from the Table 2, one can see that ERP system has a higher level of contribution that is 93% and the Lean has 7% of relative contribution. Moreover, there are cases wherein both ERP and Lean manufacturing system plays the important and equal role. An example of this kind of KPI is 'automated cross-functional processes'. It has 52% of relative Lean importance and 48% of relative ERP importance.

Focusing on absolute weights, business-objectives/KPIs having higher ERP absolute weight can be improved using the ERP system. Similarly, business-objectives/KPIs having higher absolute Lean weight can be improved by practicing Lean manufacturing system. If the absolute weight is low, then the chances of improving that objectives/KPI is less hence, probably it is a bad idea to have that respective system for that objectives/KPI. Considering this interpretation, the business-objectives/KPIs are divided into 'less important', 'important' and 'very important' based on absolute weights as shown in Figure 2.2, 2.3 and 2.4.

2.4. Conclusion

The article gives the overall idea about the business-objectives/KPIs, which can be improved using the ERP and Lean manufacturing practices. Using this information, enterprises can strategically distribute their resources on ERP and Lean system. The article also gives the information on the business objectives and KPIs that ERP can improve and that Lean can improve. The study is based only on the available literature on ERP and Lean system. The methodology also supports the hybrid ERP-Lean approach. To support the proposed work next part of the research will be conducting the survey to get the information on Lean and ERP to derive the importance weights there by find the contribution levels.

Chapter 3 A methodology to satisfy Key Performance Indicators for successful ERP implementation in Small and Medium Enterprises

3.1. Introduction

Enterprise Resource Planning (ERP) is growing business solution to keep pace with rapidly changing market demands and sustainable business growth. ERP system is the efficient information management system capable of providing the right information at right time [1] there by bringing tremendous rewards to the organization in the competitive world. However, ERP implementation is time-consuming and expensive [3], [11]. Small and medium enterprises (SMEs) are facing difficulties in ERP system implementation as there is lack of knowledge, expertise, and guidelines in this area [4], [33]. SMEs using Lean technology are not willing to use ERP system believing in the critique that Lean and ERP are opposite to each other [5], [33]. Dilemma and difficulty related to ERP implementation are keeping SMEs away from harnessing benefits of ERP system. Therefore, SMEs has to change their view on ERP system and hence article shows the ways, SMEs have to see ERP system. The basic idea is to see ERP system as modular and focus on the portion that satisfies their requirements instead of viewing it as a huge and complex system.

In the available literature on ERP system, the study has been carried out on a successful implementation of ERP and different methods have been proposed to reduce failure in implementation [3], [16], [22], [32]. Even though scarce publications provide ERP selection methods for selecting ERP package [53] but currently there is no modular level approach based on KPI.

3.1.1. Implementation of Enterprise Resource planning system in SMEs: Why it fails?

Benefits of ERP system such as reliable information access, inventory reduction, on time delivery, increased productivity, reduction in IT cost, transportation and logistics cost reduction, improved business process, improved responsiveness to customer, improved communication and integration between the functions [1], [6], [10], [23], [54] are the obvious reason for ERP implementation. In some cases, SMEs go for ERP only due to peer pressure without knowing what they actually want out of the system.

ERP system is advantageous however, if not properly managed it can be seen negatively, because of increased cost of installation, extended time plan, high manpower requirement, improper integration of software with business processes, re-engineering of processes more than expected and lack of top management support [3], [11], [14], [18]. In some cases, the failure of ERP project has led to bankruptcy [12], [23]. Adding to this, SMEs weakness such as [26] local management, short-term strategy, lack of expertise, non-functional organization, limited resources and lack of method and procedure; successful ERP implementation is questionable. Therefore improper implementation planning becomes a major factor for the failure of ERP system in the organization [20]. The proposed research methodology may reduce the failure rate of ERP implementation in SMEs. Methodology explores the best & suitable ERP modules, which serve the purpose of SMEs in ERP implementation.

3.1.2. Why is it necessary to identify Critical Success Factors?

Critical success factors are the guiding points, following and addressing them increases the probability of a successful ERP implementation [14], [18]. When we carried out the research by studying various publications on CSFs for ERP implementation, number

CSF count reached more than fifty!! [8], [10], [14], [18], [23], [55]. Each CSF is associated with cost, schedule, and level of achievement [23]. If SMEs focus on all the CSFs eventually, they fall into resource crisis. Hence, the research methodology focus of identification of CSFs, which are relevant to only selected ERP modules using cause and effect approach.

3.2. Methodology

The main purpose of this article is to provide a methodology for identification of relevant ERP modules and CSFs to satisfy identified KPIs for SME from the pool of ERP modules and CSFs. Following are the important steps of the proposed methodology:

- Identify the Key Performance Indicators (KPIs) from Business requirement
- Select relevant ERP modules
- Identify related Critical Success Factors (CSFs)

The proposed methodology as shown in Figure 3.1, support the selection of modules and CSFs for ERP implementation as explained below.

3.2.1. Identify KPIs from the Business Requirements

The ultimate goal of any organization is to improve business performance; hence, they look for different initiatives that will enhance their performance. This is the strategic level decision. Key Performance Indicator (KPI) is one of the dimensions to represent the business performance [6], [47].There are many ways [31] to arrive at KPIs and one of the ways is Balance scorecard (BSc) [47]. The method can be used to drill down strategic level business requirement into the KPIs [47]. When ERP is the choice of organization, which satisfies their business requirement first step is to select the KPI they want to improve.

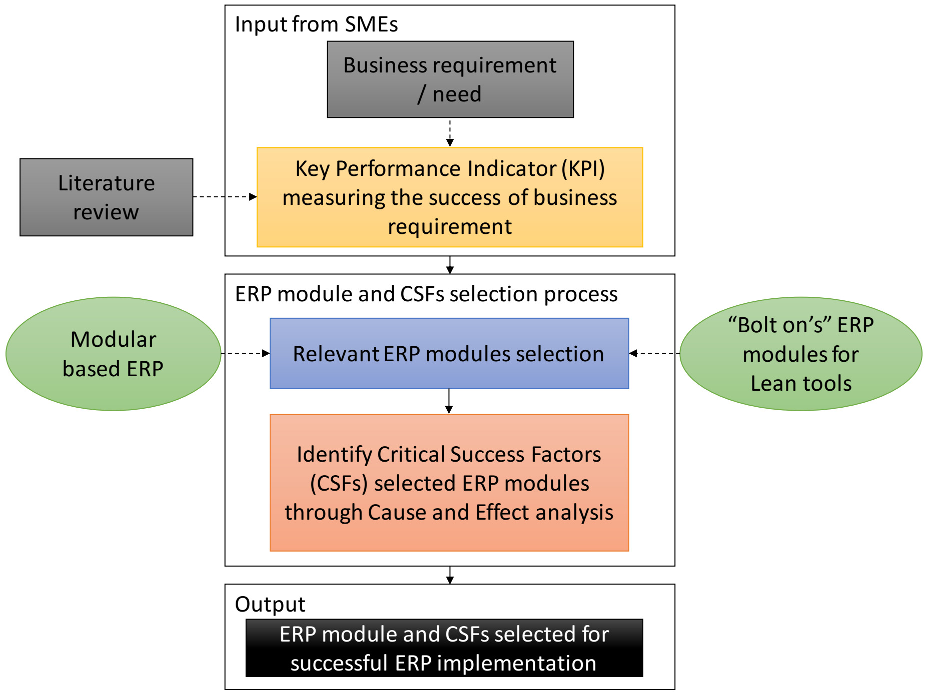

Figure 3.1 Schematic representation of methodology for ERP implementation in SMEs

For example, improve customer service may be the one of the business requirement. KPI for customer service improvement can be customer satisfaction level, on time delivery and reduction in complaints. Another example for a business requirement can be, to improve the productivity of the business process. For this requirement, KPI can be the reduction in work force and non-value added activity reduction. In a similar way for demonstration, we have selected four KPIs 'Inventory Reduction', 'Overall Cost Reduction', 'Information/Data Management' and 'Performance Improvement' from the top search in literature. These KPIs will be discussed more in section 3.3.

In general, other KPIs can be functional level data integration, supply chain management, lead-time reduction, quality improvement etc. Once SMEs have KPIs defined, next step is to select the relevant ERP modules.

3.2.2. Select relevant ERP modules

All standard ERP modules in ERP software package do not serve the purpose of an organization [56]. Either ERP vendors mislead SMEs to purchase the complete software package or SMEs drop the idea of having ERP system in their organizations due to the high price of the ERP software packages and cost associated with the implementation of the complete package [45]. This is the serious concern for SMEs and drawback created around ERP systems. Therefore, before jumping into a decision of purchasing entire package, SMEs has to analyze what are the modules that will improve the KPIs identified in step one. In the methodology, the process of identifying relevant ERP modules is systematic literature studies, expert advice, and feedbacks from the ERP vendors. They should find the answer to the question "Which ERP module leads to improvement of what kind of KPI?" For example, literature studies on inventory reduction [37], [55], [57]–[59] show that 'Inventory Management', 'Supply Chain Management', 'eKanban' and 'Customer Relation Management' are the key ERP modules for inventory reduction KPI. Therefore, "Relevant ERP modules for KPI inventory reduction are 'Inventory Management', 'Supply Chain Management', 'eKanban' and 'Customer Relation Management'. SMEs focused on cost reduction, which can be a business requirement, select inventory reduction KPI and select only relevant ERP modules (as discussed in the example). They do not need to waste their resources on purchasing the whole ERP package. Selected ERP modules can be standard modules or bolt-on modules [4] like value stream mapping, advance planning & scheduling and overall equipment efficiency management [4], [33], which supports Lean manufacturing activities.

3.2.3. Identify related CSF for selected ERP modules

After selection of ERP modules, SMEs has to find ways for successful implementation of these modules. As per discussion in section 3.1.2 of this article 'Why is it necessary to identify Critical Success Factors?' SMEs do not have resources to address all the CSF. As the result, SMEs overlook important CSF and hence fail in implementation or end up in not achieving the objectives [23]. Causes for the failure of ERP systems will become reasons for the success when these causes convert into CSF. Using this idea, the methodology proposes a fishbone cause and effect analysis tool to identify the CSFs [60]. Fish bone cause and effect analysis is the general tool, which can be applied for any kind of problem-solving. SMEs can use literature studies, brainstorming, expert advice, and ERP vendor suggestions to identify causes of failure for only selected ERP modules. From the examples demonstrated in this article in next section, one can see that any selected ERP module has a combination of generic and unique CSFs. For inventory reduction, generic CSF is 'top management support' and unique CSF is 'trust-based and synergistic alliances with supplier' identified through literature. To have more clarity, CSFs are classified under Strategic, Organizational, Operations, User and ERP software categories [23], [3].

The proposed methodology optimizes the resources SMEs have to spend on ERP implementation. Following this methodology, SMEs will successfully select relevant ERP modules and corresponding CSFs for ERP implementation but the process does not end here. SMEs should make sure that all selected CSFs addressed and they should follow a systematic ERP implementation process to gain the benefits. This will be done in future works of the proposed methodology. The proposed method is limited to modular based ERP systems only; therefore, SMEs using this methodology should look for such ERP software vendors.

3.3. Demonstration with examples

3.3.1. Selection of KPIs

To demonstrate the methodology selection of KPIs will be such that those are important to an organization and most of the SMEs would like to improve. To find those important KPIs, Hammar software is used to systematically map the selected publications [49], [61]. The generated reports consist of trends of KPIs occurrence in literature. By analyzing the trends top four KPIs inventory reduction, information/data management, overall cost reduction, and performance improvement have selected. From literature, it is clear that implementation of ERP system will definitely improve the selected KPIs. Let us assume that these KPIs have derived from the business requirements of SMEs, as they represent the top ranked KPIs in the literature.

3.3.2. ERP modules Selection

Each KPI has been studied individually to recognize the aspects of ERP modules that suites in improving the corresponding KPI and recommend those modules only. For Inventory reduction (KPI), the required aspects identified in the literature are:

- *Automated information flow between buyer and supplier* [55], [58]
- *Support demand leveling, JIT procurement and production leveling* [4], [57], [62].

ERP modules suitable to these aspects are Inventory Management [1], [45], Advance planning and scheduling [20], [55] eKanban and Customer Relation Management [1], [4], [55], [57]. If KPI requires Lean tools, ERP modules specially built for Lean (called as Add on or Bolt on) are the recommendations.

In case of KPI Information/Data Management, important features required are:

- *Shared data and visibility across all the areas of the company* [20]
- *Affords one to manage all departments from production to distribution and accounting in one integrated system* [63]
- *Abundant information availability including supplier, customers, and alliances* [20].

The basic ERP modules such as Production planning module, Finance module, HR module, Marketing module, Sales module, Purchase module [1], [63] are suitable modules. SMEs has to select these modules for Information/Data management in their organization.

For KPI Overall Cost Reduction required aspects are

- *Reduction of personnel, increased productivity, increase of 'on-time' deliveries, reduction in IT and procurement costs, reduction of business operating and administrative expenses* [6]
- *Lean initiatives envisage to achieve the highest quality at a lowest cost* [64].

Therefore recommended modules are more related Lean tools which are, 'Line Design and Balancing' module [32] 'Value Stream Mapping' module [33] along with basic ERP modules.

Similarly for KPI Performance improvement recommended modules are Basic ERP modules [1], Customer Relationship Management [1], [4], Value stream mapping module and Just In Time modules [33]. Important aspects of modules for these KPIs are

- *Improved customer services, flexibility, and integration of functions enhance performance* [37]
- *Lean tools for Elimination of waste leads to performance improvement* [25].

Now relevant ERP-modules have identified for selected KPIs, next step is the identification of CSFs.

3.3.3. CSF identification using Cause and Effect analysis

Using literature research with help of cause and effect analysis, main reasons for failure in implementation of ERP modules have recognized. In case of KPI inventory reduction, reasons for the increase in inventory are improper communication of organization with supplier and customers regarding requirements and delivery of parts or products, fear of losing data confidentiality by sharing data with suppliers and improper production planning [37], [55], [58], [59]. In addition to these reasons, lack of managers' support, ERP module training deficiencies and resistance due to organizations culture are general reasons for failure. If these cause the failure in implementation, SMEs have to consider these as CSFs and address them during implementation. Figure 3.2, 3.3, 3.4 & 3.5 shows the complete Cause and Effect analysis of the selected four KPIs. For Information/Data management KPI, important CSFs are user involvement, user friendliness of interface of the software, quality of information and ERP vendor service [3], [6], [10], [23]. CSFs for the KPI Overall cost reduction are systematic thinking, performance measurement, and selection Lean tools supporting ERP modules [65], [66]. For productivity improvement KPI, important CSFs are process and information based management, the vision of the future and business process reengineering [33], [65].

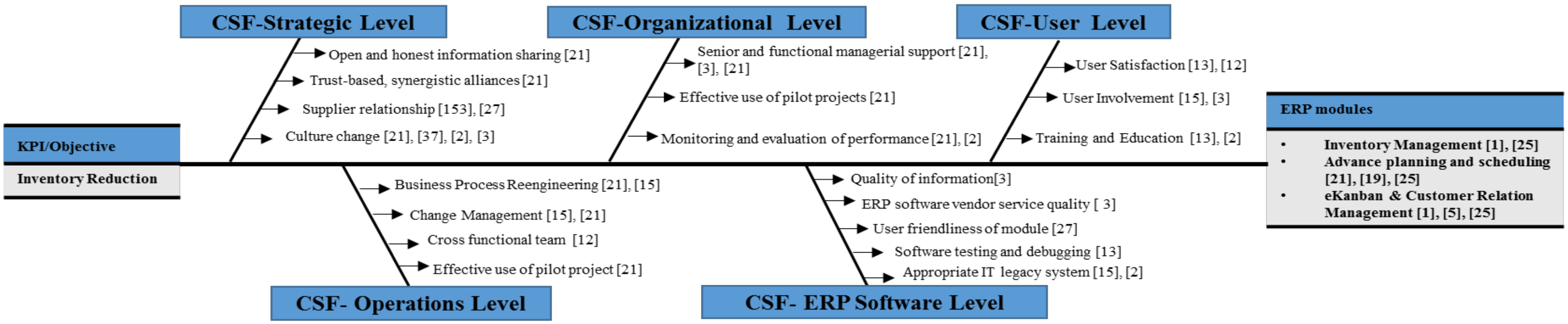

Figure 3.2 Cause and Effect Analysis for the KPI inventory reduction

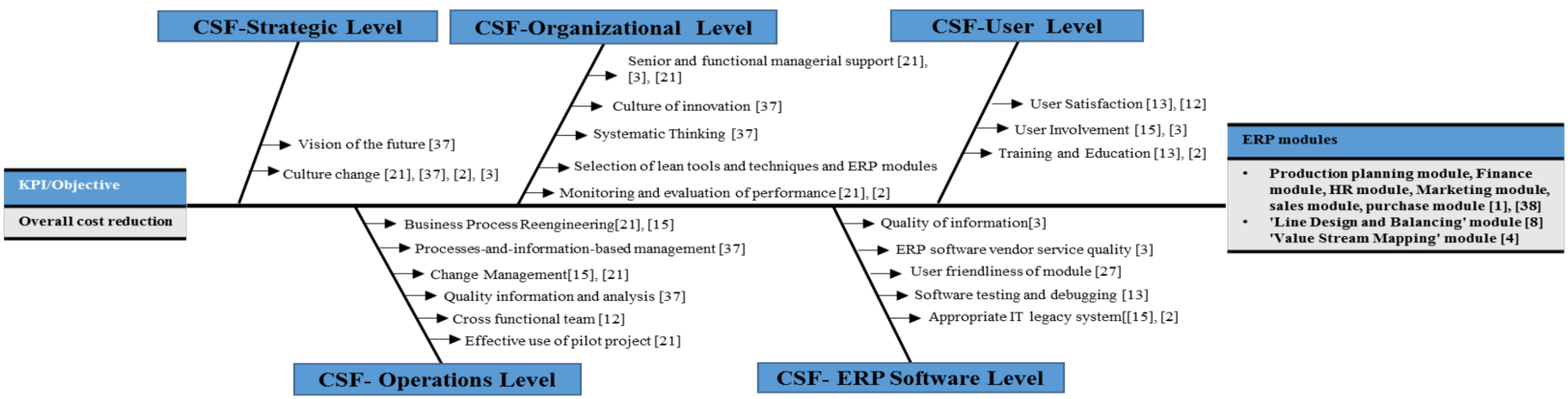

Figure 3.3 Cause and Effect Analysis for the KPI information/data management

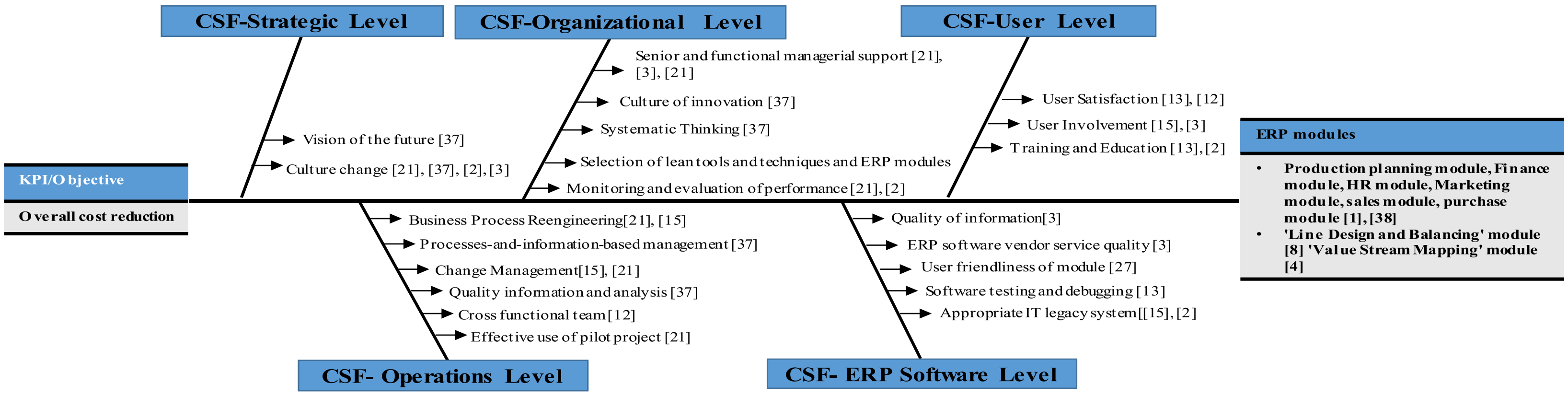

Figure 3.4 Cause and Effect Analysis for the KPI overall cost reduction

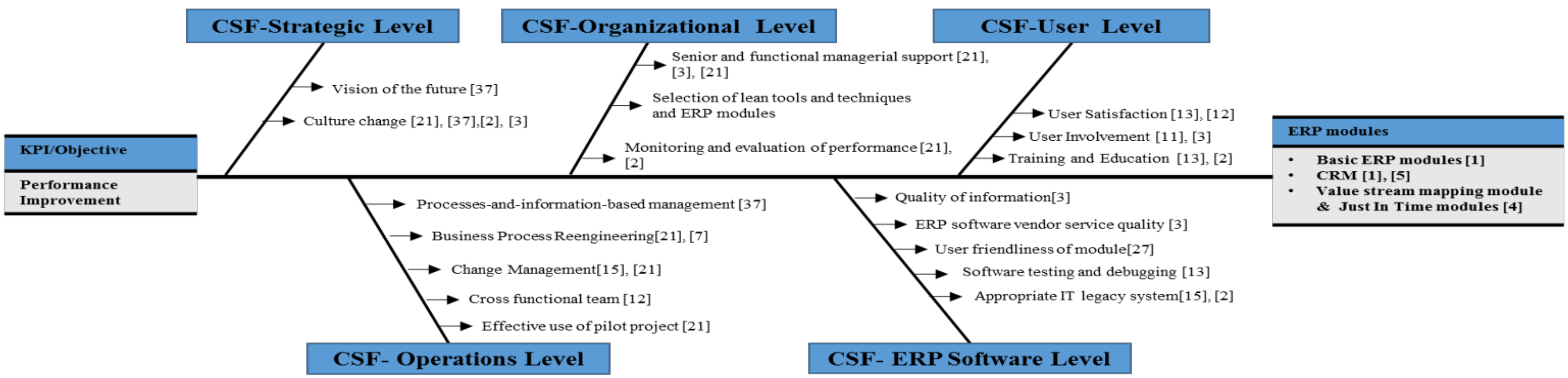

Figure 3.5 Cause and Effect Analysis for the KPI performance improvement

3.4. Conclusion

SMEs can make use of the proposed methodology to make the process of ERP implementation easier and profitable. The proposed approach optimizes the resources SMEs has to spend on ERP system through selection and purchase of just right ERP modules and addressing only key CSFs. This paper is limited to only four KPIs to identify the key ERP modules and corresponding CSF. However, KPIs, which SMEs would like to improve, are many and need extensive research. Therefore, future directions will consider those KPIs and develop them under the proposed methodology. Experimentation of practicality of proposed methodology in SMEs is another scope of future research.

Chapter 4 A decision support system to define, evaluate, and guide the Lean assessment and implementation at the shop-floor level

5.1. Introduction

Evolved from Toyota Production System Lean manufacturing has captured the attention of manufacturing industries from more than five decades. It has been proven as a significant tool for operational excellence in manufacturing firms [31], [67]. Lean manufacturing or Lean production, often simply "Lean", is a systematic method for the Lean waste minimization within a manufacturing system leading to an increase in the production efficiency and productivity [68]. It entails the philosophy of continually reducing waste in all manufacturing areas, giving cost benefits. Once the Lean manufacturing system is implemented, measuring its progress is essential. Otherwise, it becomes difficult to understand the performance and take appropriate actions for improvement.

Leanness is defined as “degree of the adoption and implementation of Lean philosophy in an organization” [69]. There are extensive tools/ways, to grasp an organization’s performances on following Lean practices. For example, results such as benefits from a six-sigma project, gains from the value stream mapping, increase in the through-put from setup time reduction, increase in the quality levels, change in the cultural behavior of employees and cost reductions give us perspective on the Lean performance. From the viewpoint of profit to organization, these results fit to the understanding of top management at the strategic level. Nevertheless, at the working level like shop-floor, the Lean manufacturing is a method for waste elimination. At the shop-floor level, one following the Lean manufacturing path is struggling to evaluate the progress made in improving their work area using the Lean principles. Focusing on key metrics at their work area, such as 5S levels, number of items on Kanban, number of kaizen events and leveled production shows results of the Lean implementation. But the question of how do you gauge "how Lean is current production?" [70], remains unanswered at the shop-floor level. How does one set an integrated Lean target, which gives a holistic view on Lean progress at the working level, has remained unexplored. In addition, even after more than 50 years of the Lean journey, the Lean philosophy and its principles remain in the books and are localized to the Lean expertise. It is vital that these Lean manufacturing practices should be scaled down to the understanding level of line managers and operators working at the shop-floor, especially for small and medium enterprises (SMEs).

The objective of the presented work is to create a closed loop decision support system for Lean assessment and Lean implementation helping employees working at the shop-floor in the manufacturing firm. Employees need to calculate their current state of Leanness at the shop-floor, compare the current state with the target Leanness and find Lean rules relevant to achieve their required Leanness target. The output Leanness as shown in Figure 4.1 is compared with target Leanness; resulted difference is monitored and guided through practicing the Lean rules. The entire methodology is framed into a graphical user interface (GUI), which is a Lean 4.0 approach [71]. It is an integrated application of Lean manufacturing and Industry 4.0, which is termed as Lean 4.0. The GUI is an effective way to have flexibility at the shop-floor. Using the web application the managers, supervisors, and operators can get accesses to the Leanness evaluation system at any time and at any place.

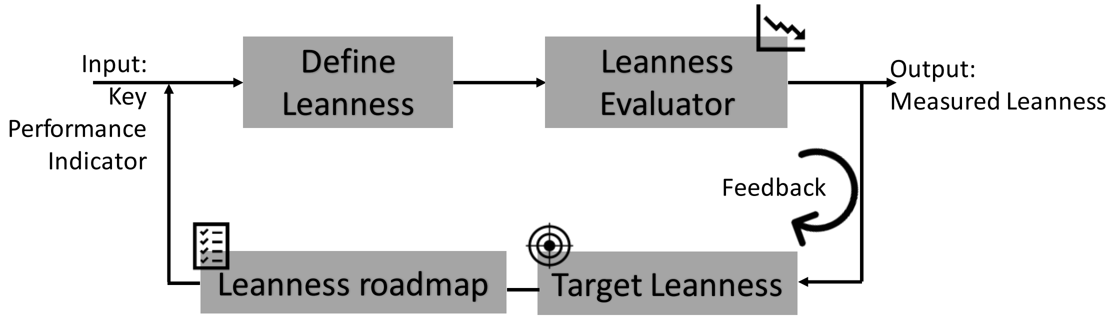

Figure 4.1 Required closed loop feedback system for Leanness assessment and implementation at the shop-floor

5.2. The literature review

5.2.1. Lean Manufacturing

Lean manufacturing is a philosophy originated at Toyota back in 1940s [24]–[26]. The team of James P. Womack coined the term "Lean", in their book "The machine that changed the world". Just-in-time manufacturing, error proofing, kanban system, poke-yoke, kaizen, heijunka, standardization, total productive maintenance and jidoka are some of the notable tools of Lean manufacturing [27]. It has become the choice of industries [37], [59] as Lean brings competitive advantage to the business [24]. Key intangible and tangible benefits of the Lean system are reduced inventory levels, high quality, reduced lead times, increased productivity, improvement in the on-time delivery, maximized employee & customer satisfaction, maximized equipment utilization, and reduced scrap/rework [4], [27], [31]. Successful implementation of Lean manufacturing requires the support, commitment and active participation of management and employees [72], [73].

Even though there are many systematic tools and methods available under the umbrella of Lean Philosophy, *the core of the Lean lies in value addition* [29]. Value to the customer is of great importance in today's business world due to increase in the competition. Thus, elimination of non-value-added activities and waste is crucial, which is the aim of the Lean philosophy. With respect to the manufacturing firms source of non-value adding activities and wastes are considerable at the shop-floor. Therefore, it is important to measure the Lean manufacturing progress at shop-floor level.

5.2.2. Lean practices in manufacturing industry

Most of the large manufacturing industries hire a Lean manufacturing consultant [74] or dedicate a full-time employee to facilitate the practice of Lean manufacturing. Lean consultant or the facilitator perform the activity of evaluating the Lean manufacturing performance; they also provide the guidance for improving Leanness. It takes years to implement the Lean principles, then evaluate the performance; therefore, the companies must be patient to realize the Lean manufacturing implementation results. Since dedicated people do the Lean system implementation, involvement of regular employees is low. Due to less involvement of the employees [75] in the implementing Lean tools and in evaluating Lean progress by themselves, the employees do not pay much attention towards practicing and implementing Lean methodologies.

Small and medium enterprises (SMEs) run their business with limited resources [26]. They cannot afford to either hire a Lean manufacturing consultant or to deploy a full-time employee to implement the Lean [76], [77], especially for a longer duration. They practice the Lean principles in a scattered manner, without any intention of evaluating the performance. Even though they try to measure the progress, it is a time-consuming and complex process.

A simple and quick Leanness-evaluation tool, which involves employees itself in evaluating the Lean progress, is the need for the shop-floor, especially for SMEs. Another limitation is lack of simple Lean manufacturing procedural guide to improve the Leanness. The guide should be an easy way forward for the Lean implementation and continuous improvement, which an operator at the shop-floor can understand. The way forward must guide the users on simple Lean tools, methods and practices that can be used to improve Leanness.

5.2.3. Tools and methods for evaluating the Leanness at the shop-floor level

The methods described in the literature have the Leanness measured in both quantitative and qualitative form. Elnadi et al. [78], has developed a qualitative model that assesses the Leanness of the enablers which are supplier relationships, management relations, workforce Leanness, process excellence and customer relationship. Another approach by Wahab et al. [79], focuses on seven dimensions for measuring Leanness, such as workforce, processes, suppliers, planning and scheduling, customer, visual information system and product development. Similarly, the qualitative Leanness assessment model by Tekez & Tasdeviren [80] emphasizes resource management, knowledge management, customer management and performance management. These methods evaluate the Leanness at the broader level based on the organization's Lean manufacturing culture and the demonstrated Lean practices [81]. They use questionnaires, checklists, Likert scales and elaborative assessment tools to evaluate Leanness. All these methods are theoretical in nature, have a broader scope, and takes long time to evaluate the Lean progress. The evaluation methods are suitable for top management to understand the Lean progress at organizational level. The Lean progress evaluator using these methods should be an expert in Lean manufacturing. The results of the assessments using these methods are not appropriate to understanding level of people working the shop-floor. Therefore, a method which represents an easy evaluation, implementation and way forward for operators at the shop-floor for SMEs is still missing.

A Lean assessment tool (LAT) by Omongbai and Salonitis [68], [82] assess the overall performance of Lean practices using discrete event simulation model (DES). It is a quantitative method. This method is suitable for the employees working at the shop-floor, where they can track the Leanness of their activities. However, it requires computer programming for designing the simulations of individual metric and map the improvement. Mourtzis et al., [25] have done further improvement in evaluating the Leanness by placing the KPI (key performance indicator) of the user at the center of evaluating Leanness. They have proposed evaluating the Leanness in the form of a Lean-index considering seven Lean wastes and technical parameters affecting KPI. The aim of their method is to extract Lean rules for improving the Leanness of a selected KPI. However, Lean-index evaluated does not give any interpretation about the Leanness. In addition, the significance of the Lean-index has not is given importance and the method does not aid in hierarchical Leanness evaluation. Nevertheless, there is a way forward in the form of Lean rules, but the shortcoming of the method is that, it seeks continuous collection of data and run multiple data analysis iterations to get optimized results.

The existing methods discussed in these sections are analogous to an open loop system where the 'way forward' to control and improve the evaluated Leanness is not established. These methods can be employed when there is a dedicated Lean team for performing the assessment. In addition, the assessment procedures are complex and slow paced. The methods and tools have penetrated well into companies' different functions. However, they are assessment tools at the organization level serving the middle and top managements requirements, which is a top-down approach. Operators, line managers, and supervisors at the shop-floor show interest in the Lean tools only when they themselves evaluate the outcomes of their efforts in making their work area Lean. Hence, there is a need for a bottom-up approach for evaluating the Leanness and progressive evaluation should lead to assessing the Leanness of the entire organization as demonstrated in the Figure 4.2. A quick, simple, and generalized, Lean assessment tool and implementation guide, which can be used by the employees at any functional level especially at the shop-floor, is unavailable. There is also no defined target for the Leanness, which industries keep as a goal.

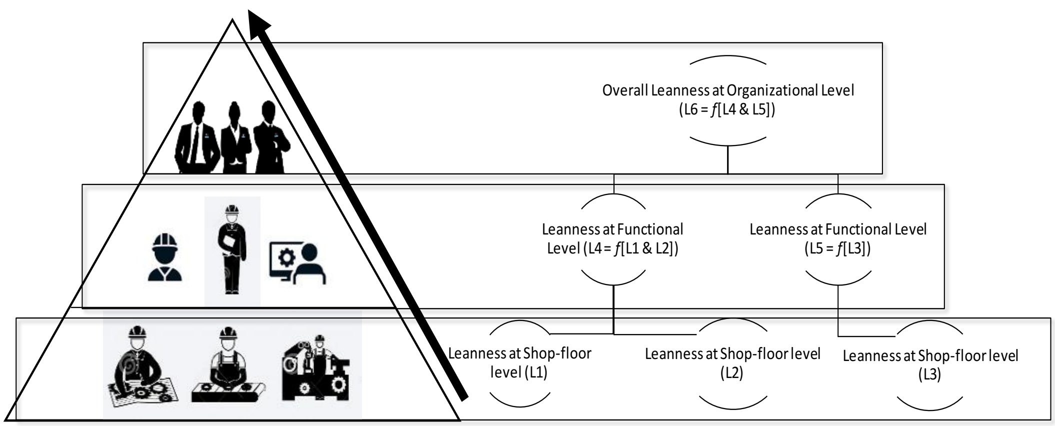

Figure 4.2 Bottom-up approach for Leanness evaluation (f➔ function of)

To summarize, manufacturing firms at the shop-floor level need:

- A way to ***define*** the integrated Leanness-measuring unit.
- A tool to ***evaluate*** Leanness of a production system.
- Attainable Leanness ***targets*** to achieve.
- A roadmap to ***guide*** Lean users to attain target Leanness.

The article presents Define, Evaluate, Target and Guide (DETG) support system, which addresses all the shortcoming discussed in the literature. The DETG methodology defines the Leanness Index as a unit to measure the Leanness. It presents a method named Leanness Evaluation Tool (LET) to evaluate the Leanness by keeping the user interest (KPIs) [25], [67] at the focus. It presents the ways to identify the target Leanness index for top business objectives and KPIs. Further to that, the methodology sets a roadmap to achieve the target through Lean Rules Formulation (LRF). The scope of this methodology is restricted to manufacturing enterprises and is oriented towards small and medium enterprise (SMEs).

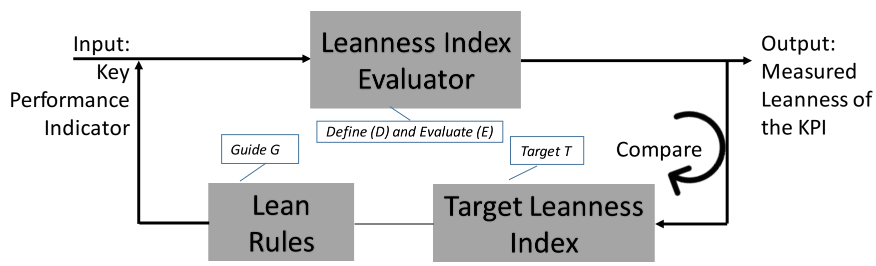

Figure 4.3 DETG Leanness assessment and implementation support system

5.3. Define, Evaluate, Target and Guide (DETG) system for the Leanness assessment and implementation at the shop-floor

The proposed methodology is divided into four modules, which are *define, evaluate, target* and *guide*. The define module explains the standard way of measuring the integrated Leanness. The evaluate module proposes the tool to calculate the Leanness, the target identification module presents ways adapted to identify the target Leanness index and the guide module presents a formulation of Lean rules.

5.3.1. Definition module – Leanness Index

Leanness is defined as [69] "degree of adoption and implementation of Lean philosophy in an organization". As discussed in section 1.2.1 '*core of the Lean lies in value addition'* [29], waste elimination is the purpose of the Lean philosophy. Lean manufacturing focuses on reduction of the seven wastes, named as waiting, unwanted motion, unnecessary transportation, excessive processing, over-production, excessive inventory, and defects [83]. The ultimate objective of all the Lean practices, tools and methods is waste elimination [84]. Table 4.1 shows relationship between Lean tools/methods and Lean manufacturing wastes. The evaluation of the wastes gives a probabilistic estimation of the Lean manufacturing performance as shown in Figure 4.4. If we gauge the progress made in eliminating waste, indirectly we are measuring the Leanness of a production system hence, measuring the Lean manufacturing progress.

Table 4.1 Lean tools/methods connection with Lean wastes

Lean Tools/Methods	**Target Lean waste elimination**
5S	Motion, Waiting [64]
Kanban	Inventory, Over production [40]
Leveled production/Heijunka	Waiting, Inventory and Transportation [29], [39]
Total Productive Maintenance	Waiting, defects [37]
Total Quality Management	Defects, Processing [40]
Value Stream Mapping	All seven wastes [85]
Just in Time	Inventory, Waiting [72]
Standardized Work	Defect, Processing, Motion [74]
Kaizen	All seven wastes [74]
Jidoka/Automation	Motion, Defect, Processing [84]
Single Minute Exchange of Die (SMED)	Inventory, Waiting [86]
Visual Management	Processing. Motion [84]

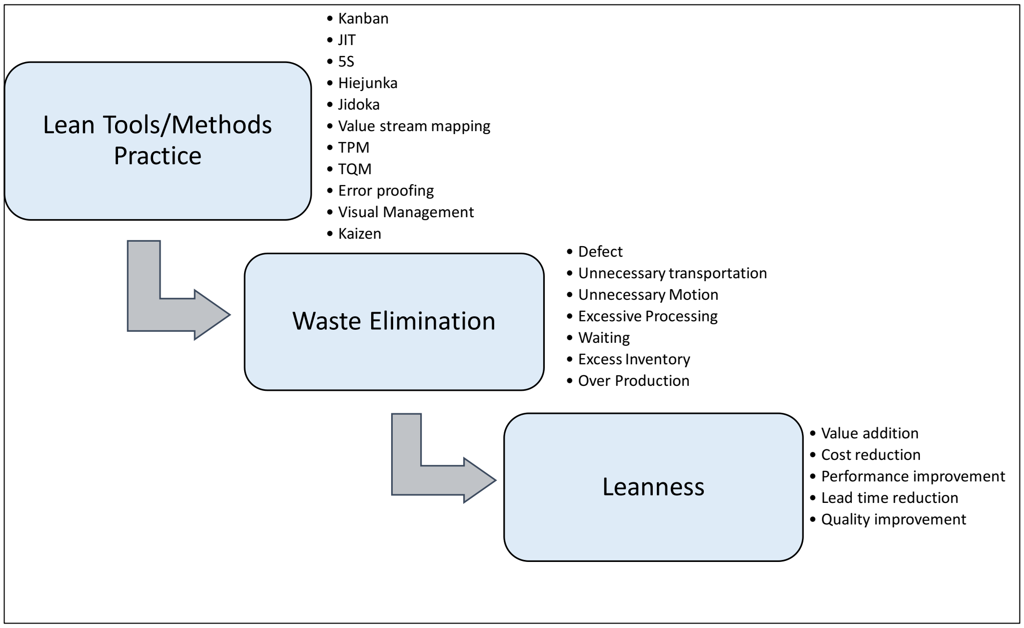

Figure 4.4 Relation between Leanness, Lean wastes and Lean tools

The production system as a whole needs waste elimination; this includes waste elimination in processes such as manufacturing, inspection, design, production administration, purchase, warehousing or in any sub-activity under these functions. The person performing a given job certainly knows the non-value added activities and wastes involved in that job. When he/she knows the wastes involved in their work, the progress made in eliminating those wastes makes potential impact. Therefore, it is necessary to gauge the progress, which indicates variations in the existing wastes. An index is a way to measure the variation. Index is the right tool when one wants to know the variation in the value but not the value itself. This is what employees working at the shop-floor need. Hence, variation in the Lean performance can be measured as the "Leanness index". The Leanness index is a standard measure that integrates the results of the Lean practices in eliminating the wastes into a scalar value [78]. It helps in determining the gap between the current state and the optimal Lean target [68] thus, it indicates the alignment of organizational behavior to Lean manufacturing philosophy.

High index value shows higher performance in becoming Lean, whereas the low index value indicates a need for improvement. This helps managers to make correct decisions and to improve the system [48]. In the proposed model, the self-assessment tool gives the holistic view of the manufacturing wastes in terms of Leanness index, which is a scalar value between 0 and 1. The Leanness index will be evaluated using the Leanness Evaluation Tool (LET) for selected KPI. Thus, the article presents the Leanness index as the unit for measuring the Leanness at the manufacturing shop-floor.

5.3.2. Evaluation module - Leanness Evaluation Tool

The Leanness Evaluation Tool (LET) functions on the assessment of the waste associated with the specific KPI, indicating the result as the Leanness index (LI). Figure 4.5 shows the flow of the derivation of LET. The evaluation of Leanness index by operators, line managers and supervisors at shop-floor is the one of the intents of proposed work. Thus, methodology starts with keeping the objective of the user at the center evaluation of the Leanness index.

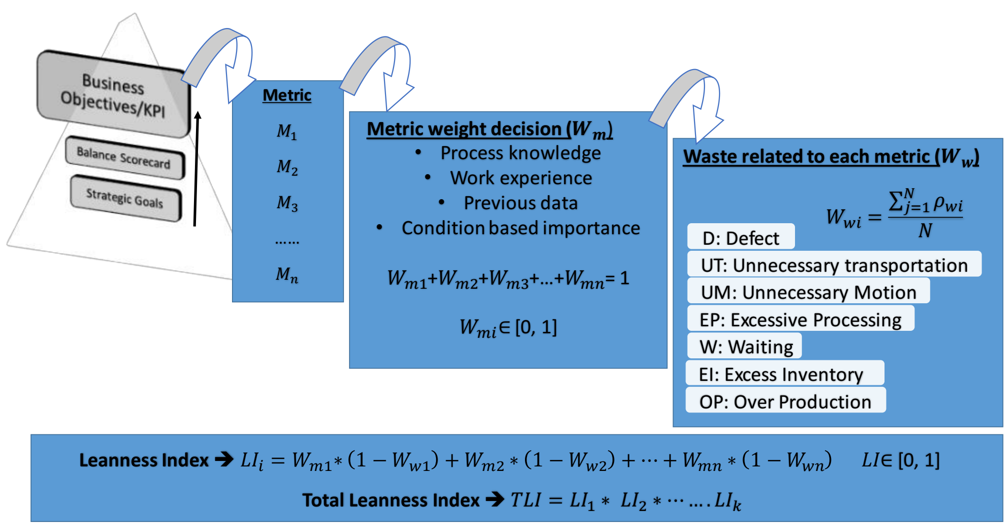

Figure 4.5 Methodology of Leanness Evaluation Tool (LET)

I. *Business objective/KPI:* Derived from an organization's strategic goals and balance scorecard [47], the user selects a KPI to improve using Lean philosophy [87], [88]. Thus, first step of the methodology is to select a business objective or a key performance indicator (KPI), which needs improvement. The KPI can be related to any processes improvement, product improvement or any activity in the shop-floor. For example, in the manufacturing environment, KPIs such as Productivity, Cost, Quality, Delivery 5S level, and many more can be improved by Lean manufacturing practices. Once the business objective/KPI for the improvement is selected, the next step is to identify the metrics affecting the selected business objective/KPI.

II. *Define the Metric:* The business objective/KPI is affected by certain factors, called metrics. For example, consider 'cost reduction' is a business objective. The critical factors which influence the cost are inventory, cost of poor quality, fixed cost and variable cost [59], [89]. Hence, inventory, cost of poor quality, fixed cost and variable cost are the metrics of the business objective/KPI - 'Cost reduction'. The process owner tracking the KPI is aware of the metrics affecting the KPI.

Let 'n' be the total number of metrics affecting the KPI. Each metric affects the KPI to different degree. User decides the degree of importance in terms of metric weight (W_m) for each metric using his/her previous experience, process knowledge and past available data. In addition, multi-criteria decision-making tools such as the Analytical Hierarchy Process (AHP) [90], Analytical Network Process (ANP) [91] and Decision matrix analysis [92] are also helpful in deriving the weights. Note that the requirement is value of weights assigned should fall on the scale of [0, 1] and sum of the weights of all metric should up add to 1.

M_1, M_2, M_3 ...... M_n are the metrics

W_{m1},W_{m2},$W_{m3}\ldots\ldots\ldots\ldots W_{mn}$ weights assigned to each metric

Sum of all weights is 1: W_{m1}+W_{m2}+W_{m3}...........+$W_{mn} = 1$

III. *Identify waste associated with each Metric:* There are seven prominent wastes related to Lean manufacturing. Those are defect (D), unnecessary transportation (UT), unnecessary motion (UM), excessive processing (EP), waiting (W), excess inventory (EI), and over production (OP) [93]. On studying each metric, the user can observe the wastes associated with that metric. The user must identify the wastes associated with each metric. Weight of the metric related to waste is calculated using following expression [25].

$$W_{wi} = \frac{\sum_{j=1}^{N} \rho_{wi}}{N}, \quad (1)$$

if waste is applicable value of $\rho = 1$, else 0.

N = 7 (seven Lean manufacturing wastes)

Let W_{w1}, W_{w2}, W_{w3}......... W_{wn} be the weights related to waste for *n* metrics.

IV. Calculate the Leanness Index: The Leanness index is calculated using the following expression.

$$Leaness\ Index\ (LI) = W_{m1} * (1 - W_{w1}) + \cdots + W_{mn} * (1 - W_{wn}) \quad (2)$$

The resulting Leanness index is a value between 0 and 1, with zero being the lowest Leanness and one being highest Leanness. Thus, LET evaluates the Lean progress in terms of Leanness Index. A practical understanding on the Leanness index will be demonstrated in the case study. The waste weighting W_{wi} calculated using expression (1) shows the degree of waste associated with the metric. Non-value adding activities of the metric are high when W_{wi} of the metric is 1; on the other hand, a process is very much Lean when W_{wi} is 0. Using these data user can even identify the dominant wastes in their work area. The total Leanness index of the organization considering all the 'k' KPI can be derived using following expression.

$$\text{Total Leanness index} = \prod_{i=1}^{k} LI_i \qquad (3)$$

Where 'k' is the total number of KPIs.

Total Leanness index shows the Leanness at the organizational level or at the functional level. Thus, top management can also keep track of Lean manufacturing progress at the organizational level demonstrating bottom-up approach. Figure 4.6 is the representation of LET.

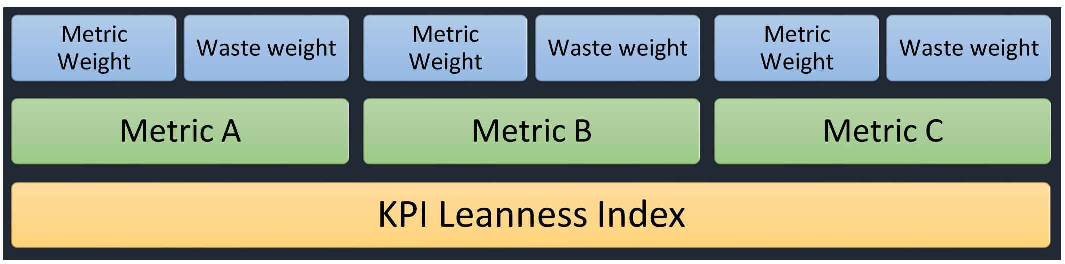

Figure 4.6 LET representation

5.3.3. Target Leanness index identification module

5.3.3.1. Literature mapping method

The authors previous work [94] "Lean or ERP – A Decision Support System to Satisfy Business Objectives" presents the relative contribution of ERP and Lean system to facilitate the realization of business objectives in manufacturing. It has derived the importance weightings of Lean system for specific business objectives/KPIs of production and manufacturing firms using the literature studies. An ontology-based systematic mapping of the literature was performed, and the weighted average method was used to derive the Lean importance weights, specific to the KPIs. These importance weights convey the meaning that, it is not required to have an ideal target Leanness index of '1.0' (100 %). It can be less than unity since only the Lean cannot contribute to improving the specific KPI. Table 4.2 shows a list of KPI/business objectives and their respective Lean importance weights [94]. The importance weights generated using literature mapping can be treated as the target Leanness index.

Table 4.2 Target Leanness index derived using literature

KPI or Obejective	Weightage distribution among 100%	
	ERP weightage W_E	Lean Weightage W_L
Inventory reduction	40%	60%
Supply chain Management	50%	50%
Resource Management	74%	26%
Increased flexibility	55%	45%
Standardization of work process or data	76%	24%
Order Management	100%	0%
Customer Relationship Management	80%	20%
Increased visibility of corporate data	47%	53%
Productivity improvement	33%	67%
Total productive maintenance	1%	99%
Integration between systems	74%	26%
Improve delivery performance	66%	34%
Automating cross functional processes	48%	52%
Improved visual management	20%	80%
Improved business processes	89%	11%
Customer service improvement	46%	54%
Reduce Waste	5%	95%
Improve Lead time	5%	95%

Improve supplier relations	28%	72%
Improved decision making and planning	85%	15%
Increase in revenue and profit	53%	47%
Supporting Business alliance	76%	24%
Cycle time reduction	5%	95%
Quality improvement	8%	92%
Rework cost reduction	0%	100%
Performance improvement	53%	47%
Overall cost reduction	34%	66%
Building business innovation	81%	19%
Customer satisfaction with product	75%	25%
Sales growth	59%	41%
Total quality management	18%	82%
Increase market share	48%	52%
Information/Data Management	93%	7%
5S	0%	100%
Operations Management	29%	71%

5.3.3.2. Industrial survey method

The study of Alberta industries with respect to Lean manufacturing is important to investigate the needs of the small and medium manufacturing industries. A survey was conducted to determine whether the industries practice Lean manufacturing in their production system, to know type of the Lean practices industries are practicing and to know the business objectives/KPIs they are achieving by following Lean principles. Online questioners and personal interviews with the industrial experts were the two means used to conduct the survey. Table 4.3 shows the Lean manufacturing survey questions asked to manufacturing industries in Alberta and the results of survey. We received responses from 28 enterprises out of 30 small and medium industries contacted for the survey. We have determined that for the sample size of 28, with 18 % of confidence interval the results of the survey have 95 % of confidence [95].

Table 4.3 The survey questions and responses

SN	Survey questions	Results
1	Lean manufacturing is an important strategy utilized by manufacturers attempting to compete for sales and profits in the global markets. Do you agree with this?	93% of the industries agreed
2	Please select the Key Performance Indicators (Business objectives/goals) important to your organization and rate the importance level.	Inventory Reduction, Information management, Overall cost reduction, Performance improvement, Reduce waste, Quality improvement, Productivity improvement, Customer service improvement, Improve business process
3	Are you practicing Lean manufacturing tools in daily operations?	89 % said YES
4	Rate from zero to four the contribution of the Lean manufacturing system in improving the KPIs listed.	Responses are analyzed to derive importance weights. Table 4.4 shows the results.

Table 4.4 Lean importance as target Leanness index from the survey

KPI	Importance weight (target Leanness index)
Inventory Reduction	0.85
Information management	0.00
Overall cost reduction	0.52
Performance improvement	0.56
Reduce waste	0.91

Quality improvement	0.98
Productivity improvement	1.00
Customer service improvement	0.31
Improve business process	0.39

Similar to the literature method, the responses of the survey are analyzed to derive the target Leanness index using weighted average method. The Lean importance weight alias the Leanness index as given in the Table 4.4 shows that, for the respective KPI, credibility of the Lean manufacturing. The KPIs inventory reduction, reduce wastes and productivity has higher importance. This means there is high probability that these KPIs can be improved by practicing the Lean system. On the other hand, KPIs like customer service improvement and information management, has lower importance weight, meaning probability of improving that KPI by practicing the Lean system is low [94]. These importance weights derived from the survey can be considered as the target Leanness index.

The Lean importance weight obtained from the literature and the survey can be a reference to compare with the evaluated Leanness index. Figure 4.7 gives insight into a target Leanness index and actual Leanness index (calculated using LET) comparison for the specific KPIs. The KPIs ahead of the their respective target Leanness index are termed as leading KPIs. Similarly, the KPIs behind the target Leanness index are termed as lagging KPIs. An interpretation looking at the Figure 4.7 is that the leading KPIs can be given less importance by diverting the resources spent on the leading KPIs to the lagging KPIs. In this way Leanness index also helps in optimizing the resources spent on KPI improvement in the Lean environment.

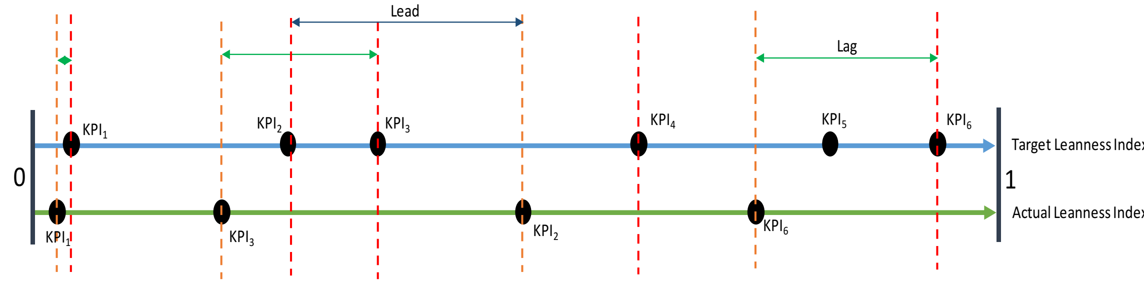

Figure 4.7 Interpretation of KPIs' Leanness index

5.3.4. Guidance module - Lean Rules Formulation (LRF)

Rules are the set of statements that has to be followed while performing an activity [67]. Lean philosophy explains the theory of Lean but Lean rules explain the actions to be taken to achieve the Leanness [25]. Lean rules are the guiding principles to achieve the Leanness. Mourtzis et al.[67] defines Lean rules as "Lean rules are, a set of explicit rules based on the Lean theory, principles and practices (Lean tools), concerning the entire product/service lifecycle, aiming at waste elimination, profit amplification, and stakeholders' satisfaction" [67]. Lean rules are simple Lean practices which user can easily practice while performing their job, thus making progress in Lean manufacturing performance. In this article, we have introduced simple Lean practices in terms of Lean rules, which have proven to be beneficial for making an organization Lean. Like closed-loop feedback system, Lean rules guide the users to control and improve the Leanness index. Figure 4.8 shows the relation between the Leanness index and Lean rules. Lean rules can also considered as continuous improvement tools for improving Leanness.

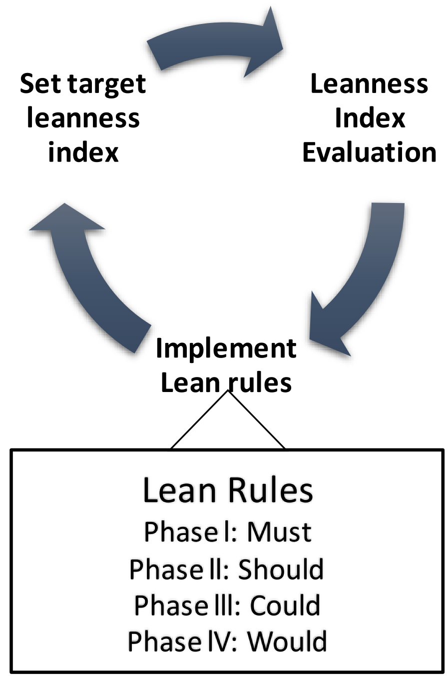

Figure 4.8 Closed-loop Leanness index continuous improvement

This article furnishes the Lean rules for the prominent nine KPIs related to manufacturing sector helping especially small and medium industries. The way to formulate the Lean rules is explained, which users can utilize to derive the Lean rules for their area of interest.

(i) Style of Lean rules formalization [67], [96]

- Lean rules must be comprehensive and compact.
- Lean rules must be firm, to the point, clear and free from unnecessary words.
- Lean rules should be short and easily understood.
- Lean rules should convey same meaning to different person reading it.
- Lean rules should be free of vague or ambiguous concepts.

(ii) Level of importance of rules identified is based on MoSCoW rule [96].

A. Rules labeled as ‘Must’, are critical, have high importance and must be practiced promptly. These rules are easy to practice and require very less or no resources. These are the simple Lean improvement activities in everyday process.
B. Rules labeled as ‘Should’ are of medium importance, might require some resources and time to practice. Sometimes you may also need guidance from expertise to practice these rules.
C. Rules labeled as ‘Could’ are desirable but not necessary. These rules can be incorporated gradually, if time and resources permit. These rules have medium-low importance. In some cases, these are strategic decisions, which organization has to take for practicing these rules. The rules under this category require the resources and long time to practice.
D. Rules labeled as ‘Would’ represent the recommendation. These have lowest importance. The organizations who are already following Lean practices from long period and wants to make their processes further Leaner can make use of these Lean practices. The rules categorized under this label requires large amount of resource in terms of money, time and workforce.

(iii) Techniques for rules identification are:

- Literature review
- Lean expert advice
- Inputs from the survey and interview with industry experts

5.4. Case study to demonstrate the DERG system

The Laboratory of Manufacturing, Design and Automation (LIMDA) at the University of Alberta has a learning factory setup, which offers the factory environment for students learning. The learning factory named as AllFactory (Alberta Learning Factory) [97] shown in Figure 4.9 consists of assembly stations for assembling a LEGO 3D printer. The proposed methodology to define, evaluate and guide the Leanness progress at manufacturing firms has been experimented at AllFactory. The objective for LEGO 3D printer assembly process was to increase the productivity of assembly operations and to minimize the non-value added activities. Thus, as per the requirement of the Leanness evaluation tool (LET), the first step business objective/KPI, was to improve the overall productivity of production operations and reduce waste. For each business objective/KPI, the Leanness index was calculated using LET to gauge the as-is Leanness index. Then the target Leanness index was set, the Lean rules were implemented and further practiced. Later the cycle was repeated to study the improvement in the Leanness.

Figure 4.9 AllFactory at LIMDA lab, University of Alberta

5.4.1. Leanness of productivity as a KPI

5.4.1.1. Using Leanness Evaluation Tool

Step1 - *Select the business objective/KPI*: Productivity improvement is the business objective. It is also a KPI by itself.

Step2 - *Define the Metric*: The metrics affecting the productivity are assembly processes, workforce, and product design [98], [99]. The supervisor of AllFactory selected the metrics based on the assembly process observations, process knowledge and experience in manufacturing. Depending on the business requirements, the first priority was the metric 'productivity of workforce', metric 'productivity of processes' was the second priority and the third priority was metric 'product design and engineering'. Therefore, following were the decided metric weights,

Workforce $- \; W_{m1} = 0.7$,

$Process - W_{m2} = 0.2$,

$Product\ design - W_{m3} = 0.1$

Step3 - *Identify waste associated with each metric*: After studying each metric, the wastes observed are listed as follows.

Table 4.5 Applicable wastes

Productivity of processes $(\boldsymbol{m1})$	Productivity of workforce $(\boldsymbol{m2})$	Product design and engineering $(\boldsymbol{m3})$
Defect Unnecessary transportation	Defect Unnecessary Motion Waiting	Defect Excessive Processing

Waste related weights are calculated using the expression $W_{wi} = \frac{\sum_{j=1}^{N} \rho_{wi}}{N}$ as follows

$W_{w1} = \frac{2}{7} = 0.27$, $W_{w2} = \frac{3}{7} = 0.43$, and $W_{w2} = \frac{2}{7} = 0.27$

<u>*Step4*</u> - *Calculate the Leanness Index*: Using the Leanness index expression

$$LI = W_{m1} * (1 - W_{w1}) + \cdots + W_{mn} * (1 - W_{wn})$$

Therefore, Leanness index = 0.3 x (1- 0.27) + 0.5 x (1- 0.43) + 0.2 x (1-0.27) = 0.65

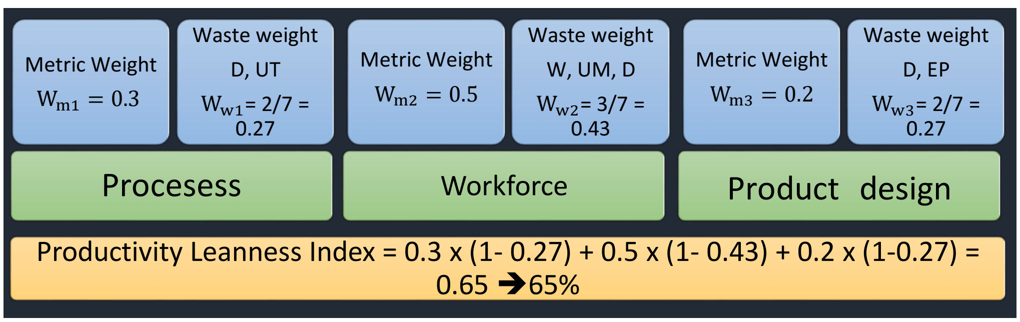

Figure 4.10 Leanness Index evaluation for KPI Productivity

5.4.1.2. Lean Rules Formulation

Lean rules designed [98], [99], [100] using the proposed Lean rules formulation for the KPI - Productivity are given in Figure 4.11. AllFactory implemented these Lean rules for improving the KPI productivity. The supervisor of assembly operations eliminated the bottleneck by balancing the assembly line using the leveled production Lean tool, worked on skill improvement of operators to reduce the defects and simplified the complex part assembly by working with the design team. The wastes eliminated were the defects generated by operator and waiting of operators under ‘workforce’ metric. Under the ‘process’ metric there was not much improvement, therefore wastes remained the same. Excessive processing was eliminated by simplifying the design of the LEGO 3D printer. Figure 4.12 represents post-Lean rule implementation scenario.

The Leanness index after the implementation of Lean rules was 0.82, which means there was 26% improvement in the Leanness. Comparing, the actual Leanness index with the target Leanness index (importance weight, Table 4.4) derived from the survey, the KPI productivity is still lagging. Following Lean rules continuously, the target Leanness can be achieved.

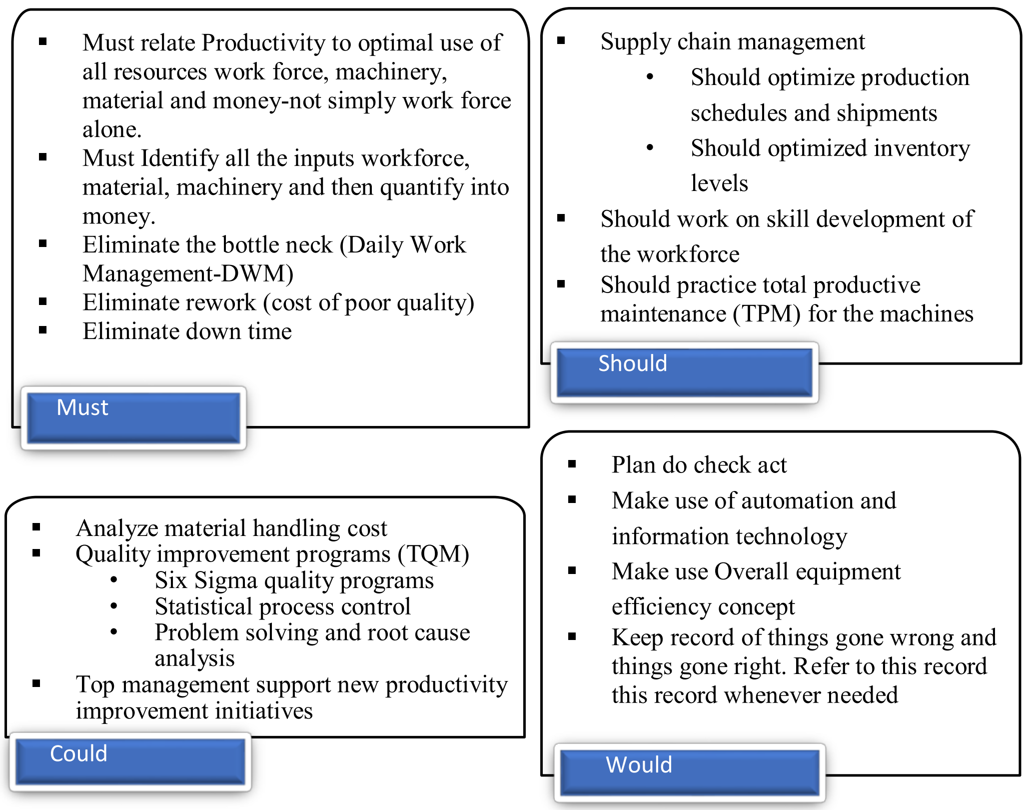

Figure 4.11 Lean rules for KPI Productivity

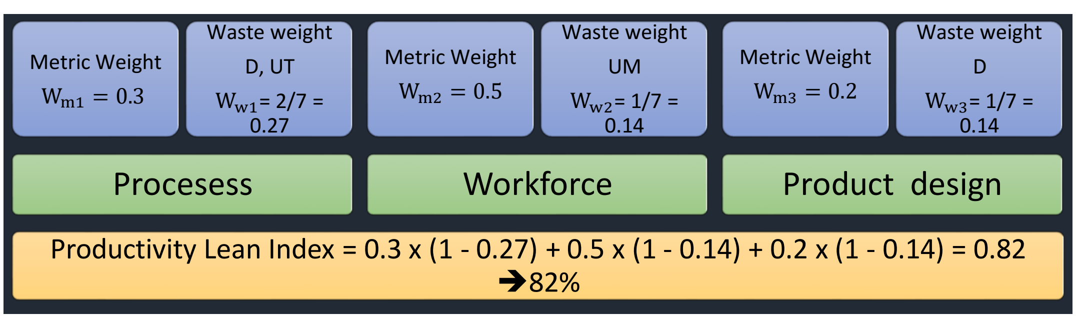

Figure 4.12 : Leanness index assessment for KPI Productivity after implementing Lean Rules

5.4.2. Leanness for the business objective Reduce-Waste

The same steps were followed to calculate the Leanness index for the business objective 'Reduce-waste' shown in the Figure 4.13. Quality, lead-time and cost were the crucial metrics affecting the value to the customers. The supervisor assigned the metric weights and identified the wastes linked to each metric. The resulted Leanness index was 0.55 (Figure 4.13). The Lean rules designed [85], [89], [101], [102] for elimination of non-value added activities as shown in the Figure 4.14, were practiced. The study group conducted the value stream mapping activity, 5S activity, standard work practice and trained operators on seven types of Lean manufacturing wastes. After the implementation of Lean rules and following the Lean practices shown in, the Leanness index was recalculated as shown in Figure 4.15. The post-Lean rules implementation Leanness index improved to 0.77 from 0.55, thus, there was 40 % improvement in the Leanness in terms of elimination of non-value adding activities. The target Leanness index from the survey for the business objective reduce-waste was 0.91. Therefore, the reduce-waste indicator was still lagging from the target Leanness index that shows need for improvement.

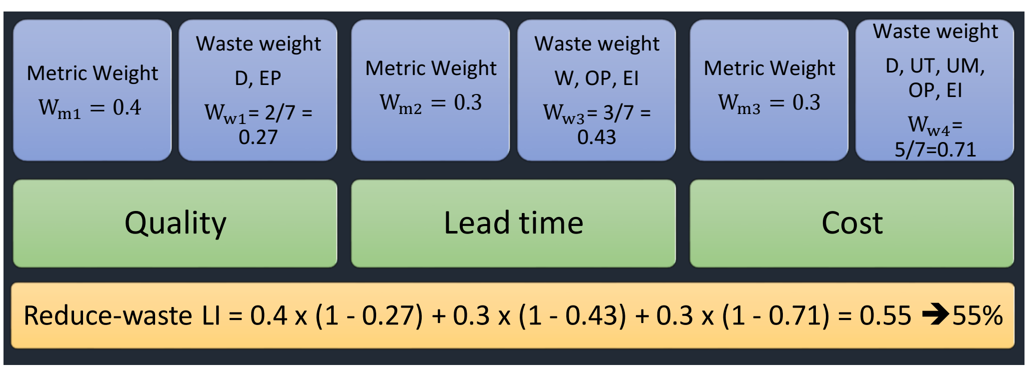

Figure 4.13 Leanness index assessment for KPI Waste Reduction

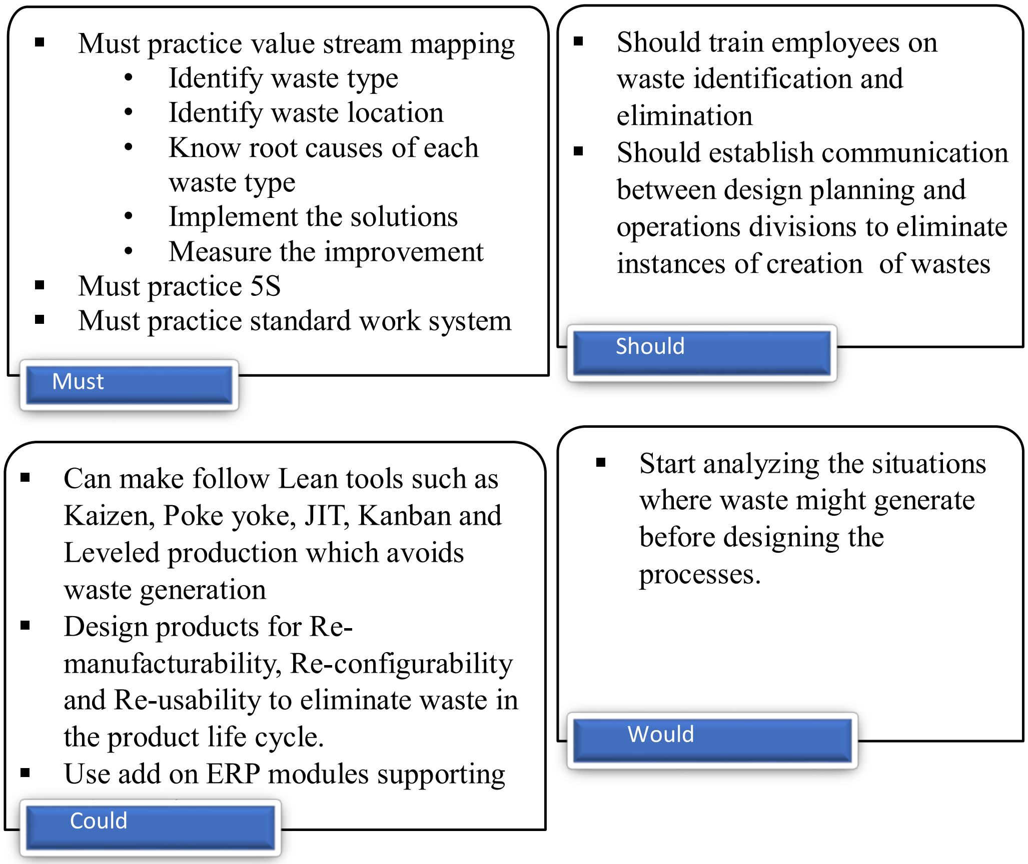

Figure 4.14 Lean rules for reducing the wastes

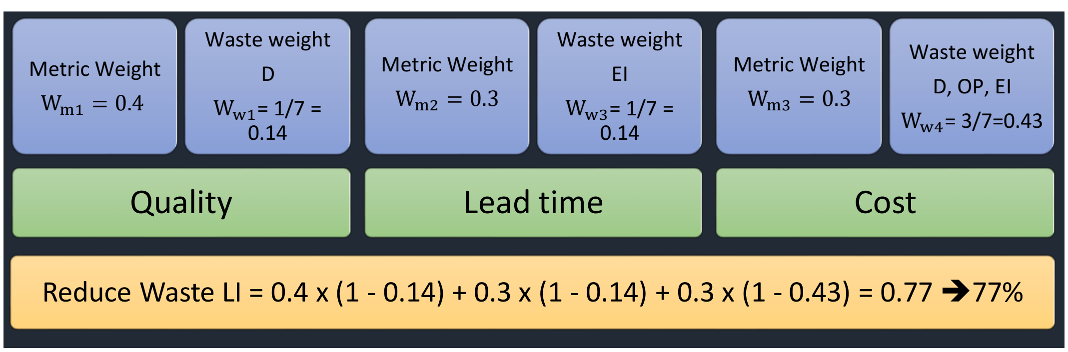

Figure 4.15 Leanness index assessment for KPI Waste Reduction after implementing Lean rules

5.4.3. Analysis of the results

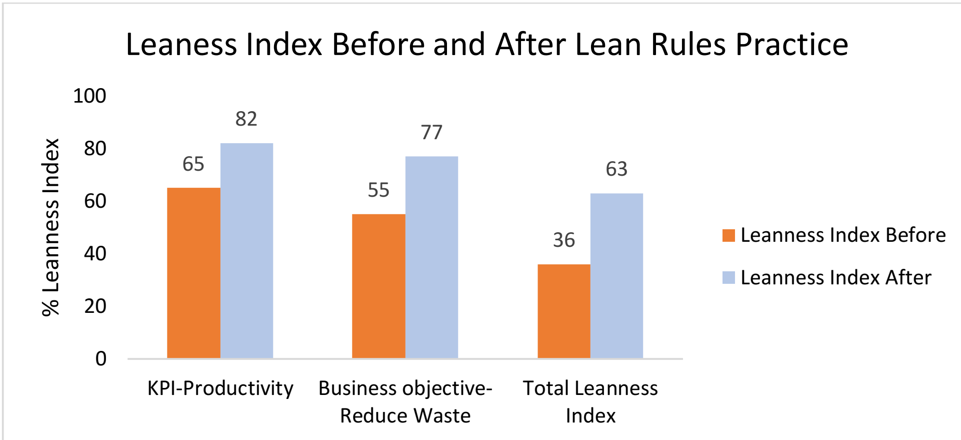

Figure 4.16 Results showing improvement in Leanness index

Evaluation of the Leanness index and its improvement using the Lean rules is a cyclic process. AllFactory begins with practicing the 'Must' rules. Upon following of the Must rules, AllFactory moved on to 'Should' rules and later to 'Could' and 'Would'. The methodology resulted in reduction of eight man-hours per product and reduction in lead-time from 210 minutes to 137 minutes. Thus, the methodology proved to be a very good tool for improving the Leanness. The Leanness index at the factory level was also evaluated. Total Leanness index of the Allfactory, before and after the Lean rules implementation, were respectively 0.36 and 0.63 as shown in results Figure 4.16. There was 75% improvement. The calculations are shown below.

Using the expression for total Leanness index $TLI = \prod_{i=1}^{k} LI_i$

Before: TLI = Productivity LI x Waste Reduction LI ➔ 0.65 x 0.55 = 0.36

After: TLI = 0.82 x 0.77 = 0.63

Thus, there is 75 % of improvement in total Leanness.

5.5. Web-based application for the proposed system

To make the proposed tool easily accessible to users, a graphical interface has been developed to evaluate Leanness index using LET and to guide the users on Lean rules. This makes the Leanness evaluation and guidance easy and quick. It is a contribution towards the Lean 4.0 which is part of the fourth industry revolution i.e. Industry 4.0 [71], [103]. Users will just input the metrics and associated wastes. The system will automatically calculate the Leanness index. Industries can make use of this tool any time and at any place. A library of business objectives, metrics related to business objectives and the Lean rules to improve the Leanness of the business objectives is also available in the web-based interface. Figure 4.17 & 4.18 shows the developed graphical user interface - GUI for Leanness index evaluation for the KPI productivity.

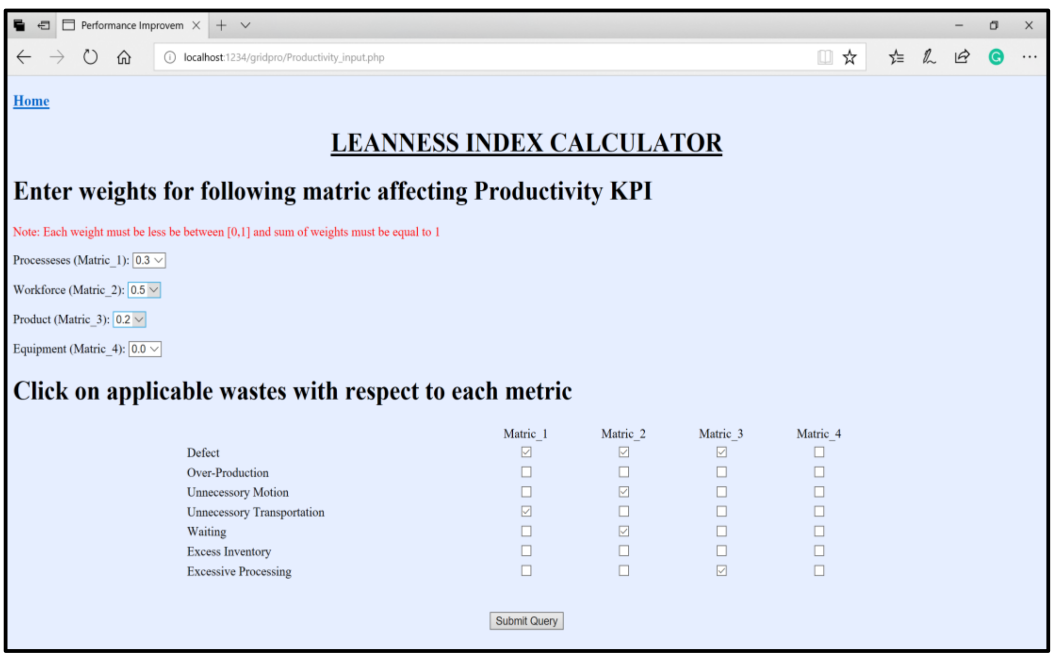

Figure 4.17 Web-based user interface for Leanness index evaluation

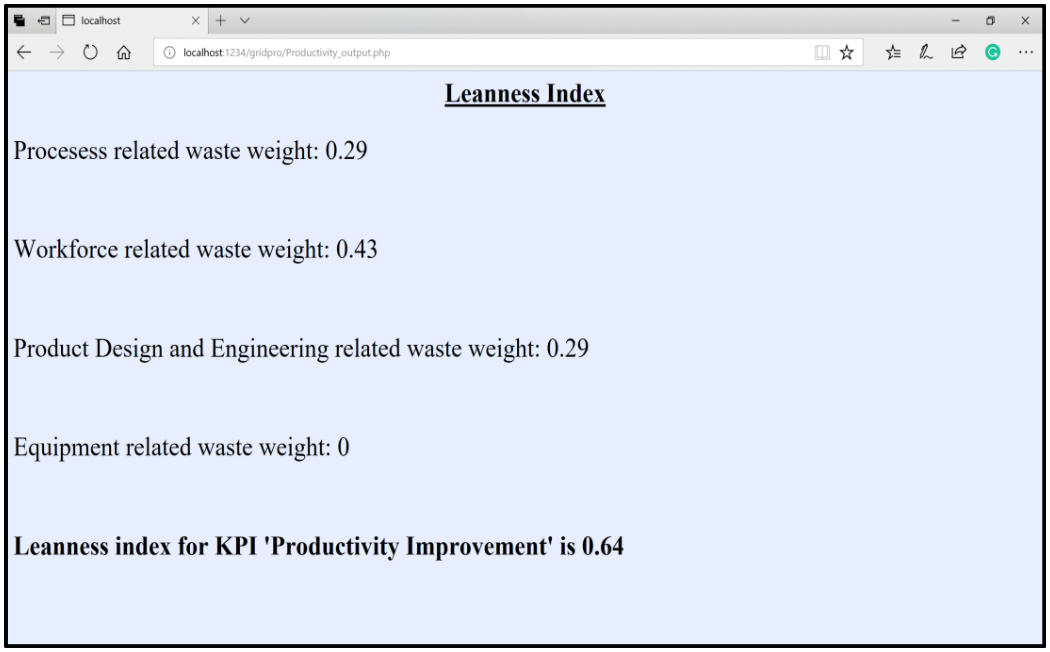

Figure 4.18 Web-based user interface for Leanness index evaluation

5.6. Discussion and Conclusion

The article has proposed the Define-Evaluate-Target-Guide decision support system to assess the Lean manufacturing progress to implement Lean practices. The Leanness index (LI), the Leanness Evaluation Tool (LET) and the Lean Rules Formulation (LRF) are integrated into a closed loop system for continuous improvement of the Leanness. The methodology is simple, user-friendly and takes less time compared to complex Leanness assessment methods in assessing the Lean manufacturing progress thereby serving the purpose of people working at the shop-floor. The total Leanness index also indicates the Leanness at the organizational and functional levels, which serves the purpose of top management. This article also presented the target Leanness index for the KPIs and business objectives relevant to the Alberta manufacturing field using the literature mapping and the survey. Small and medium manufacturing industries can make use of the identified target-Leanness-index data for improving Leanness at their firm. For continues improvement of the Leanness index, the article has provided Lean rules specific to key performance indicators and business objectives. This library of Lean rules is a valuable resource for improving the KPIs of manufacturing industries thereby implementing Lean in their production system. A case study validates the methodology and demonstrates the usefulness of the method. The methodology contributes to answering the question "*how Lean is our production?*" through the Leanness index value. The questions '*what is the existing level of progress?'* & '*how much the improvement is needed?'* have been answered by evaluating the as-is Leanness index and by setting to-be Leanness index targets in the case study. The relative value of the waste-weight W_{wi} answers the question '*where is the improvement essential?'* Lean rules have addressed *'how the improvements can be achieved?'* A knowledge-based web system designed to calculate the Leanness of a specific KPI addresses Industry 4.0/Lean 4.0 requirements. Enterprises can make use of this web tool to quickly evaluate the Leanness.

The methodology does not contribute in quantifying actual gains resulting from the progress made in Lean manufacturing; however, it meets the necessity of managers, supervisors and operators at the shop-floor in implementing and sustaining the Lean practices. Future work using this methodology is to develop the strong Lean rules base, covering the broad range of business objectives/KPIs. In addition, more studies are needed to test and confirm the usefulness of the proposed methods in the other sector of industries.

Chapter 5 Hybrid ERP-Lean Implementation Framework for Small and Medium Enterprise

5.1. Introduction

Enterprise Resource Planning (ERP) and Lean Manufacturing (LM) are two essential systems in manufacturing firms for performing business processes and operations effectively [1, 2]. The advancement in technology and rising importance of customer centricity in the manufacturing sector needs an upgrade in the conventional practices. Manufacturing organizations should be flexible to adapt the changes needed in the modern business environment. The ERP provides an integrated view of the business process and it is the platform to run the integrated business process [2], while Lean manufacturing drives customer centric approach [40]. If these two systems run together then the benefits organizations can achieve are remarkable [54]. The ideas, methods and suggestions by [2, 5–14] supports the importance of hybrid ERP Lean approach. A hybrid approach towards the integration and implementation of ERP and Lean systems to support Small and Medium Enterprises (SMEs) in improving their Key Performance Indicators (KPIs) is a primary goal of the proposed framework.

The World Bank Group approved 2.8 billion in support of the SMEs in 2016 [105], to foster economic growth. This gives us a sense of importance of the SMEs in the economic growth. SMEs struggle to survive in business as they run their activities with limited resources. They often lack expertise, knowledge and experience [26] in both ERP and Lean systems implementation. SMEs usually cannot risk investing in ERPs and Lean system, which require a significant. A risk associated with the implementation of these systems is keeping the SMEs away from harnessing the benefits them. Empirical evidence shows that, SMEs have greater degree of uncertainty in embracing the benefits of either ERP system or Lean system, which is not the case with a large manufacturing industries [4]. Therefore, SMEs need strategic decision-making support system, which assists the SMEs in making a choice on ERP-Lean and guides in systematic implementation with a minimal risk.

5.1.1. Enterprise Resource Planning (ERP) system

Ever growing global competition, changing market requirement, shorter product life cycle, verities in customer demands, complex multisite business practices, and product complexity have left organization with enormous amount of data [1]. The pace of the business is constantly increasing; hence, employees across a company need immediate access to the process data. Coping with today's faster business pace, ERP systems provide access to the key process data of an organization. ERP integrate business processes across the functions, plants facilities and locations of an organization. ERP system is defined as "a software architecture that facilitates information flow between all business functions and manages business activities" [22]. The ERP system has modular applications; most common ERP modules are human resources, finance, purchasing, sales & distribution, material management and Material Requirement Planning (MRP). These are basic modules aligned to the organizations' functions. Some of the benefits of the ERP system are data processing redundancy, reduction of personnel, access to the reliable information, on-time delivery, inventory reduction, improved business processes, increased productivity, and improved responsiveness to the customers [17, 19, 20].

The lifecycle of an ERP system consists of phases: software selection and purchase, implementation, system maintenance and decline/upgrade. The cost of purchasing the ERP software, realigning of business processes around the software, and the software maintenance are high. ERP projects are over budgeted [16], take more than scheduled project duration and do not return on the investment on time [22, 23]. Implementation and sustenance of the ERP system is an expensive process. The ERP system is also underutilized, as the ERP vendors sell the ERP software in a standard software package. Thus, underutilization occurs when all the ERP modules in the standard software packages do not align with the company requirements [106]. Some of the organizations who have adopted ERP systems are dissatisfied in reaching the anticipated business goals [107]. Looking at the facts SMEs are becoming cautious while implementing the ERP system. Even though fewer SMEs implement ERP systems, partial utilization [56] of an ERP system is disproportionate with the resources spent and investment made. Thus, underutilization and capital investment are barriers, which fewer SMEs are willing to surpass; therefore, they often seek looking into other solutions, such as Lean manufacturing to improve their performance.

5.1.2. Lean Manufacturing (LM) System

Originating from the Toyota Production system, Lean Manufacturing focuses on value addition via waste elimination in the production/manufacturing processes. LM is defined as, "a system that utilizes fewer inputs and creates the equivalent outputs while contributing more value to the customers" [24]. With the LM an organization can make their production process cost-effective, efficient and productive [27, 28]. LM paves the way for operational excellence in a modern manufacturing environment. SMEs can take advantage of the Lean system to improve business processes. Common Lean manufacturing tolls are just-in-time, value stream mapping, pull system, 5S, Kanban, visual management and continuous improvement [29–31].

Like ERP systems, implementation of LM need resources, time and commitment. Despite, LM does not requires huge investment to practice Lean basic tools; the implementation of the LM, however, requires thorough knowledge, factual data of the manufacturing processes and experience in implementation. The large manufacturing industries are aware of the benefits of LM and they have implemented the Lean principles, as they have the advantage of access to resources, experience and factory data. However, Lean philosophy is failing to reach down the levels in the organizations, mainly to the SMEs [25]. Cortes et al. [31], points out that the Lean system fails due to an insufficient number of observations (data collection), non-reliable data, and non-availability of the real-time data. Powel et al. [4], suggests that ERP system is the catalyst for Lean manufacturing implementation, as it provide a wealth of real-time factory data. Hence, an integrated system based on the combined Lean and ERP is the right answer to production effectiveness especially when it comes to SMEs.

5.1.3. Why do SMEs need an integrated ERP and Lean system?

Many organizations practice ERP or Lean systems with an aim to accomplish specific business objectives. These objectives can be to streamline business process, to improve the quality, or to improve productivity. An ERP can improve business processes, enhance productivity, boost on-time delivery, reduce inventory, and improve inter-departmental data flow and processing [6]. Similarly, Lean manufacturing improves productivity, improves quality, reduces waste, reduces inventory, and optimizes production processes [32]. Therefore, the sum of the outcomes of an ERP and Lean overlap. However, not all objectives are satisfied by only the ERP, and so only by the

Lean. As presented schematically in Figure 5.1, some business objectives or KPIs falls in the ERP and Lean overlapping zone, while some fall in the only ERP or Lean zones. The figure also indicates some objectives/KPIs falling outside the ERP and Lean zone, which means strategies other than ERP and Lean implementation are required to meet all objectives. Looking at such a distribution, a SME will be able to recognize where their business requirements are falling and can subsequently find the right tools to optimize their process. Therefore, the research aims at developing a decision support system, which assists SMEs to identify, which system they need for their particular business objective/KPI. Even though SMEs decide to implement either ERP or Lean, there is lack of support and guidance on the implementation part, which suits the manufacturing SME profile. Thus, another objective of the research is to present a novel framework, which supports both the ERP and the Lean implementation process.

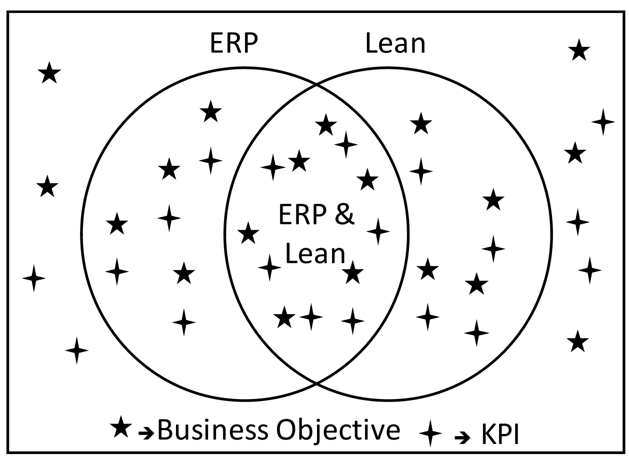

Figure 5.1 Representing overlap between ERP and Lean outcomes

Further to address the problem at-hand, Table 5.1 presents an elaborated literature review of approaches to combine ERP and Lean systems. Powel et al. [2, 6, 7], proposed to incorporate the Lean functionalities with the ERP system. Jha et al. [5, 33], explored the Lean six-sigma approach in implementing ERP systems. Halgeri et al. [33], suggested the add on ERP modules supporting the Lean tools at the shop-floor. Riezebos et al., Houti et al., and Halgeri et al. [1, 8, 13], clarified the difference between the ERP and the Lean as push/pull and established connection between the ERP and the Lean. Kong and Daud [62], analyzed the impacts of ERP system support in making organization Lean. Sanders et al. [36], suggested ideas for combining ERP and Lean in the context of industry 4.0. Alaskari et al. [8], identified the critical success factors common between ERP and Lean for the successful implementation of Lean and ERP. Iris and Cebeci [45] established a correlation between ERP modules and Lean tools. The literature shows a pattern wherein a systematic hybrid ERP Lean approach can be derived. Using this motivation, this article derives a framework to combine ERP and Lean, named “Hybrid ERP Lean Framework” (HELF) for the small and medium manufacturing enterprises.

5.1.4. Proposed Hybrid ERP Lean Framework

The designed hybrid ERP Lean framework (HELF) supports ERP and Lean implementation in combination for SMEs. The execution of the framework starts with identifying the KPIs/business objectives, which can be improved with the implementation of an ERP and/or Lean system. Then the ERP and Lean contributions to achieve the selected objectives are identified by deriving the importance score. Comparing the importance score, a user can select an appropriate implementation scenario out of three scenarios designed. The implementation scenarios are ERP implementation, Lean implementation and hybrid ERP Lean implementation. For each of the scenarios, an optimal method for implementation has been developed. After selecting a suitable implementation scenario, user can implement the system under the scenario by following the suggested method. Figure 5.2 shows the plan for the design of the Hybrid ERP Lean Framework. The research methodology to design this framework consists of systematic literature mapping, survey of the SMEs in Alberta, and development of methods for the ERP, Lean and Hybrid ERP Lean implementation.

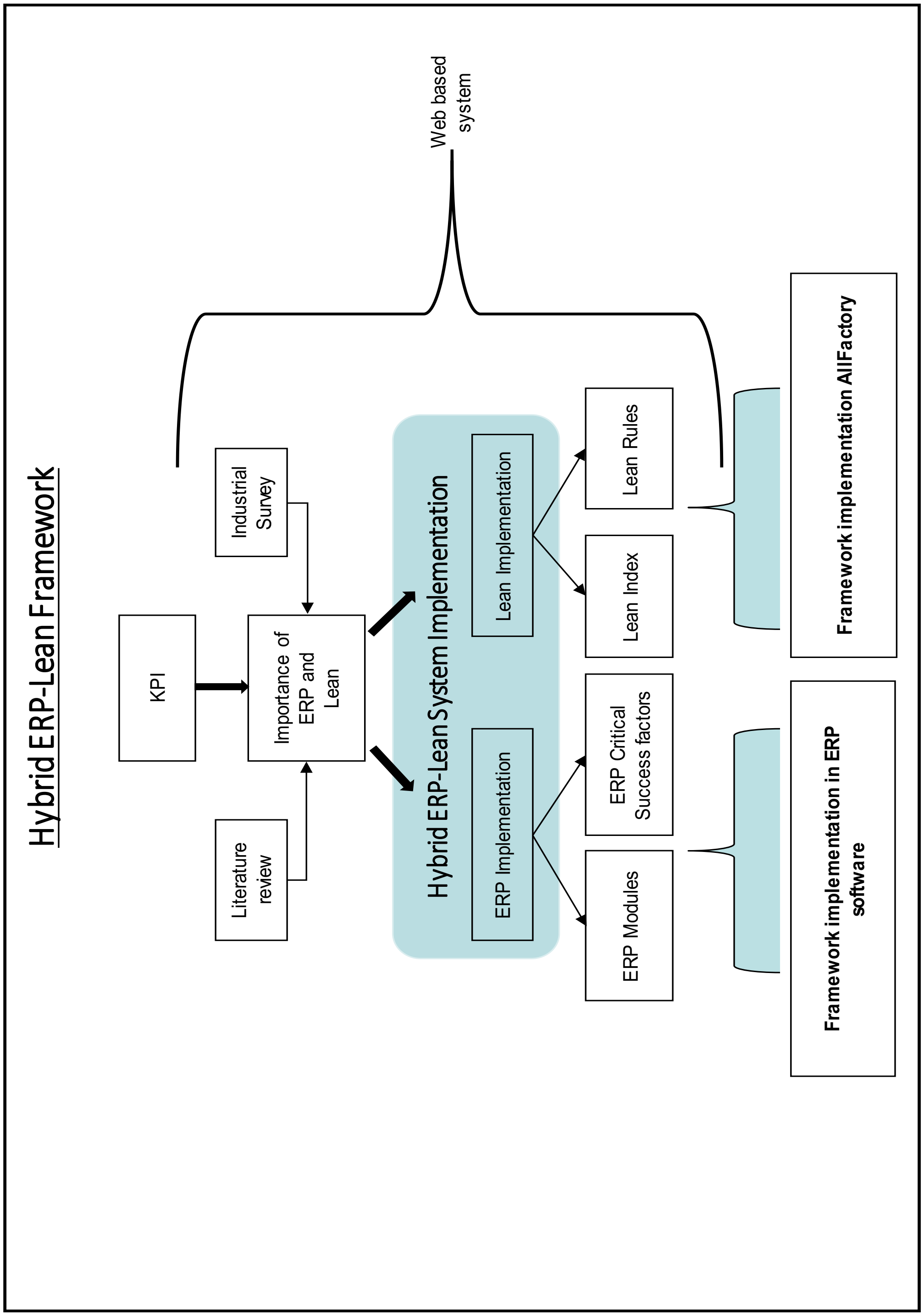

Figure 5.2 Outline for developing the Hybrid ERP Lean Framework

SL	Reference	Intended work	Promote Hybrid ERP Lean approach	ERP Module Selection	ERP implem entation	Lean index	Lean imple menta tion
1	Jha et al. [54]	Optimization of success parameters of ERP implementation by getting Lean.	✓	x	✓	x	x
2	Iris et al. [45]	Establish correlation between ERP modules utilization and Lean production	✓	✓	x	x	✓
3	Alaskari et al. [8]	Identify Critical Success factors for implementing ERP and Lean System	✓	x	✓	x	✓
4	Kong et al. [62]	Impacts of ERP system in leveraging the Lean practices on shop-floor and recommendation for continuous improvement	✓	x	✓	x	x
5	Halgeri et al. [33]	How ERP and Lean Methodologies can coexist in SMEs	✓	✓	x	x	x
6	Sanders et al. [36]	Analysis the incompletely perceived link between Industry 4.0 and Lean manufacturing and investigates whether Industry 4.0 can implement Lean.	✓	✓	x	x	x
7	Powell et al. [44]	Review the literature that focuses on compatibility of MRP and JIT	✓	✓	✓	x	x

8	Houti et al. [32]	Aims at clarifying the meaning of Push and Pull as in ERP and Lean	✓	✓	x	x	x
9	Powell et al. [4]	Asses the functionality offered by ERP system to support pull production using multiple case study approach	✓	x	✓	x	x
10	Riezebos et al. [4]	Review of IT in achieving the principle of Lean production	✓	✓	x	x	x
11	Mourtzis et al. [88]	Automatic Lean rules identification via monitoring of Lean index	x	x	x	✓	✓
12	Kaushik et al. [110]	Presented need of the hybrid framework for ERP implementation in the Lean manufacturing context	✓	x	x	x	x
13	Powell et al. [5]	Analyzed typical Lean and ERP implementation processes	✓	✓	✓	x	x
14	Li et al. [43]	Discussed mutual promoted effects of ERP and Lean and explains Dual implementation of Lean and ERP	✓	x	✓	x	✓
15	Moutaz Haddara [53]	Proposed ERP selection approach	x	✓	x	x	x
16	Jituri et al. [94]	Derived importance weights of ERP and Lean for improving specific KPIs	✓	x	x	x	x
17	Jituri et al. [106]	Proposed a systematic process to identify the ERP modules required for the organization	✓	✓	x	x	x
18	The proposed HELF [111], [112]	Proposed Hybrid ERP Lean Framework for implementation of ERP, Lean and Hybrid system	✓	✓	✓	✓	✓

Table 5.1 Literature studies on Hybrid ERP Lean Approach

5.2. HYBRID ERP LEAN FRAMEWORK (HELF)

The HELF consists of three layers, which are data collection, implementation and validation, as shown in Figure 5.3. The data collection layer is comprised of literature and survey methods that identify the KPIs/Business objectives relevant to the SMEs, and the ERP & Lean contribution levels termed as importance score (S). The implementation layer has three scenario's, which are methods to implement the ERP system, the Lean system and combination of ERP and Lean termed hybrid system. The case study and the web-application developed are gathered under the validation layer, which demonstrate the usefulness of HELF.

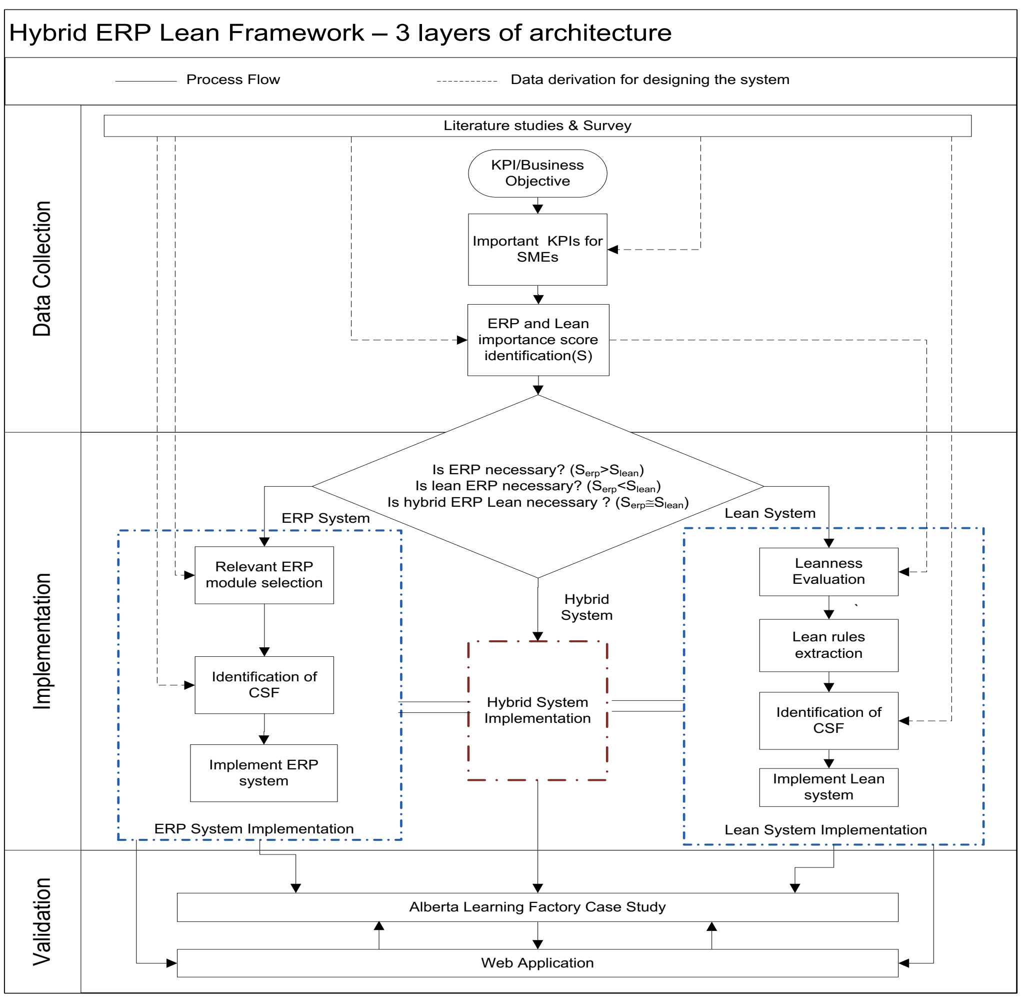

Figure 5.3 Hybrid ERP Lean Framework

5.2.1. Data Collection Layer

5.2.1.1. Survey of SMEs in Alberta

A study on the manufacturing SMEs in Alberta is performed through the survey to examine the SMEs perspectives and current practices related to the ERP, Lean and the Hybrid approach. The survey is also used to validate the KPIs and importance scores derived under literature mapping method [94]. The survey is conducted by sending a set of online questioners and by the personal interviews with the manufacturing SMEs and industrial experts in Alberta. There are 14 questions asked related to ERP and Lean system practices as listed in Table 5.2. Even though there are more than 1000 SMEs in Alberta [113], for statistics, a population size of 1000 is considered. Out of 30 surveys and interviews in total, 28 responses are fit to use. The sample size of 28 responses provide 95% of confidence level with confidence interval of 18 %.

Table 5.2 Listed of questions asked in the survey

SL No	Survey Questions
1	Lean manufacturing and Enterprise Resource Planning (ERP) systems are two most important strategies utilized by manufacturers attempting to compete for sales and profits in the global markets. Do you agree with this?
2	Have you realized that combined practice of Lean manufacturing and enterprise resource planning posing problems to each other's smooth functionality?
3	At the operations management level, you are agreeing with which of the following case.
4	Please select the Key Performance Indicators (Business objectives/goals) important to your organization and rate the importance level.
5	Are you using Enterprise Resource planning system software for managing the business process?

6	Considering your experience and knowledge, please appreciate the possibility to use the following ERP modules in improvement of KPIs listed below.
7	Are you practicing Lean manufacturing tools in daily operations?
8	Considering your experience and knowledge, please appreciate the possibility to use the following Lean Manufacturing related Add-on ERP modules in improvement of KPIs listed.
9	Rate from zero to four contributions of the ERP system in improving the KPIs listed below.
10	Rate from zero to four contributions of the Lean manufacturing system in improving the KPIs listed below.
11	At which level(s) of the organization, the ERP system usage has been established in your organization.
12	Select the factors, which affects the implementation of ERP system.
13	Select the factors, which affects the of Lean system practices implementation.
14	According to your experience which one of the following is the major contributor for improving the KPIs listed below.

Responses for the survey question number 1, 2 and 3 shows that, the Hybrid system is acceptable and required by the SMEs. Results show 89% of the SMEs agreed to the point, both ERP and Lean system are important for their organization as shown in Figure 5.4. As shown in Figure 5.5, 75% of SMEs responded ERP and Lean are not opposed to each other and they can be implemented in a supporting manner. Out of 28 respondents, 71 % supported ERP and Lean in combination and 25 % supported using ERP and Lean independently, as shown in Figure 5.6. Clearly, the results of the survey support the need for the Hybrid ERP Lean approach.

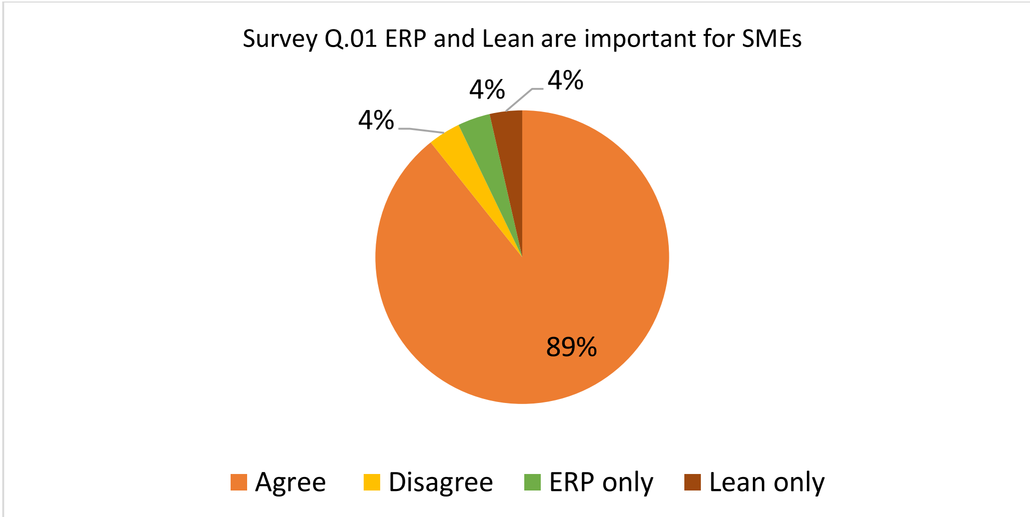

Figure 5.4 ERP and Lean importance, the survey result

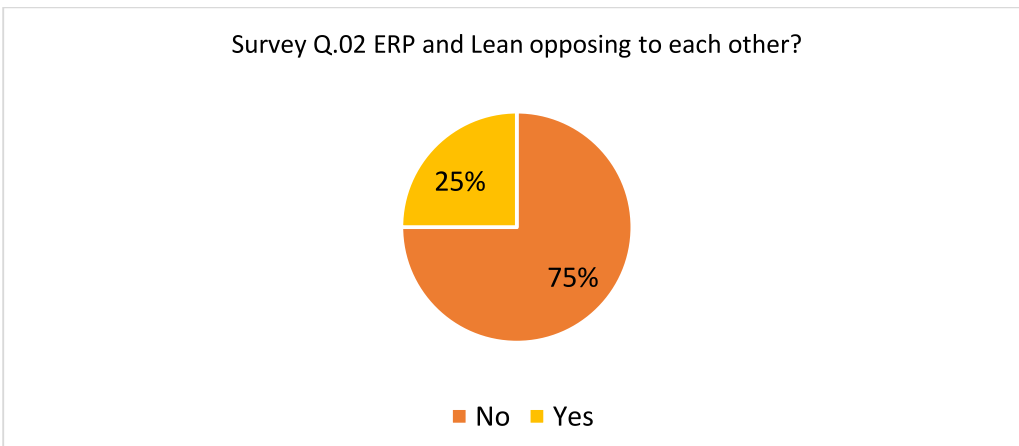

Figure 5.5 ERP and Lean opposition, the survey result

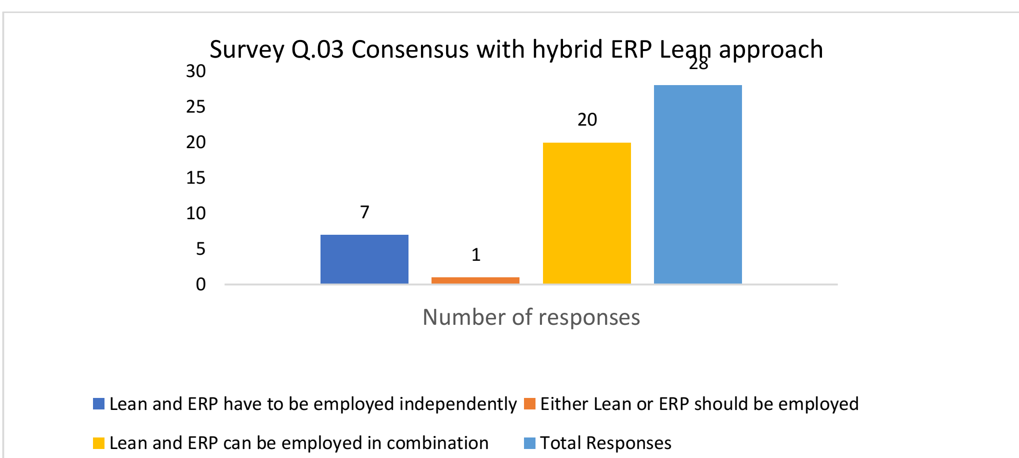

Figure 5.6 Support for the hybrid approach, the survey result

5.2.1.2. KPIs/Business-Objectives

Compared to large enterprises, SMEs have limited resources in terms of capital, time and workforce; it is necessary to recognize the KPIs/business-objectives that can be improved by either an ERP system or Lean system or both [2, 24]. Selecting the required KPI/business-objective is an optimized way for getting benefits for the investments made on ERP and Lean system [106]. The purpose of selecting the KPI/business-objective is to have a focused approach in achieving the objectives via ERP and Lean implementation. Thus, SMEs need to identify the KPIs/business-objectives based on their business requirements. A set of 30 KPIs/business-objectives published previously [94] indicating the KPIs/business-objective, which can improved by implementing ERP and Lean systems, identified using the literature mapping method. The top nine KPIs/business-objectives out of the 30 KPIs/business-objective are validated using the survey. More than 75% of SMEs identified the nine selected KPIs/BO as important KPIs for their organization, as shown in Figure 5.7. Thus, the KPIs/business-objectives, which are the SMEs priority have been identified.

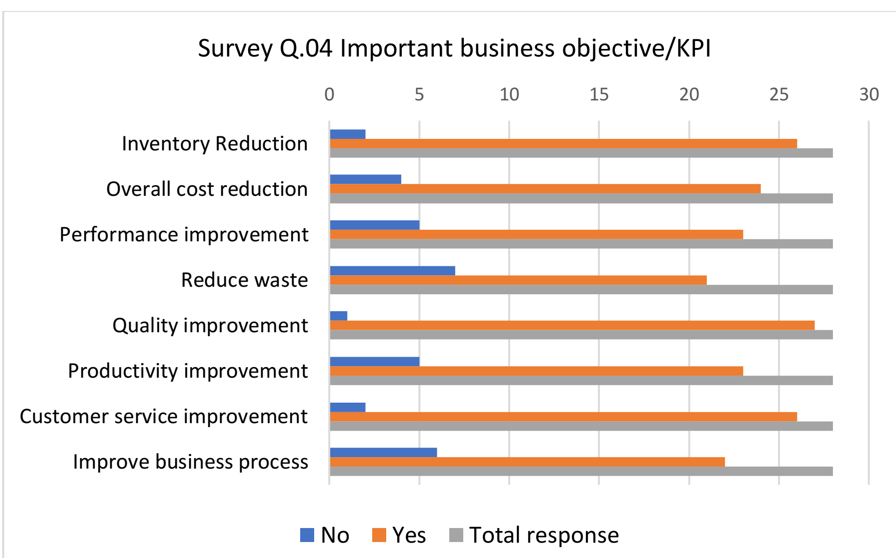

Figure 5.7 Top 9 KPIs of Alberta SMEs identified through the Survey

5.2.1.3. Derive importance score (S)

Once the KPIs/business-objectives are recognized, it is important to know which system contributes in improving the specific KPI. Is it the ERP or Lean? Alternatively, Hybrid ERP Lean system? An importance score represents probable contribution of the ERP and the Lean to improve the KPI. To recognize the contributions quantitatively, importance scores are derived with respect to each of the KPI/business-objective. As discussed previously [94], the literature are mapped based on the combination of keywords such as 'Lean' *AND* 'KPI' or 'ERP' *AND* 'KPI'. This method used ontology based bibliographic mapping software to process the resulting data while a weighted average method was used to derive the scores. The approach to compute the importance score is reproduced for the readers as follows.

$\boldsymbol{P_E}$ = Frequency of publications related to ERP AND objective/KPI

$\boldsymbol{P_L}$ = Frequency of publications related to Lean AND objective/KPI

$\boldsymbol{O_E}$ = Frequency of keyword occurrence related to ERP AND objective/KPI

$\boldsymbol{O_L}$ = Frequency of keyword occurrence related to Lean AND objective/KPI

n = Total numbers of KPI

Weighted average of the objective/KPI for ERP system

$$\boldsymbol{w_{PE}} = \frac{\boldsymbol{P_E}}{\sum_{i=1}^{n} \boldsymbol{P_E}} \quad (1)$$

$$\boldsymbol{w_{OE}} = \frac{\boldsymbol{O_E}}{\sum_{i=1}^{n} \boldsymbol{O_E}} \quad (2)$$

Weighted average of the objective/KPI for Lean system

$$\boldsymbol{w_{PL}} = \frac{\boldsymbol{P_L}}{\sum_{i=1}^{n} \boldsymbol{P_L}} \quad (3)$$

$$\boldsymbol{w_{OL}} = \frac{\boldsymbol{O_L}}{\sum_{i=1}^{n} \boldsymbol{O_L}} \tag{4}$$

ERP weight of a specific objective/KPI

$$\boldsymbol{W_E} = \boldsymbol{w_{PE}} + \boldsymbol{w_{OE}} \tag{5}$$

Lean manufacturing weight for a specific objective/KPI

$$\boldsymbol{W_L} = \boldsymbol{w_{PL}} + \boldsymbol{w_{OL}} \tag{6}$$

The level of ERP contribution for a specific objective/KPI improvement

$$\% \boldsymbol{W_E} = \frac{\boldsymbol{W_E}}{\boldsymbol{W_E} + \boldsymbol{W_L}} * \mathbf{100} \tag{7}$$

The level of Lean contribution for a specific objective/KPI improvement

$$\% \boldsymbol{W_L} = \frac{\boldsymbol{W_L}}{\boldsymbol{W_E} + \boldsymbol{W_L}} * \mathbf{100} \tag{8}$$

The importance scores obtained from the literature mapping [94] are cross verified from the survey for selected nine KPIs/business-objectives. Results of the survey for the question 9 and 10 (Table 5.2) helps in validating the importance scores of the ERP and Lean. The comparison of importance scores obtained from the literature mapping method [94] with that of the survey is shown in Figures 5.8 and 5.9. The importance score from the survey for the business objectives information management, overall cost reduction and customer services (Figure 5.8) are higher than that of the literature mapping. Therefore, in practice ERP has significance for improving these KPIs/ Business-Objectives. In case of the Lean (Figure 5.9), the KPIs/Business-objectives reduce waste and quality improvement have higher Lean importance score from survey than the literature mapping, suggesting the Lean has greater contribution improving these KPIs. Remaining other KPIs/business-objectives' survey importance score match with that of the literature.

The importance score is also measure of utilization of ERP system [45]. If a company gives 100% importance to ERP, however importance score is 70%, then 30% of the resources spent on the ERP system is a waste. This indicates the underutilization [10, 41], hence question of usefulness is addressed through the importance scores [42]. The Figure 5.10 also shows level of importance of ERP and Lean for the nine KPIs/Business objectives from the survey. As you can see from Figure 10, KPIs/Business objectives such as inventory reduction, cost reduction and business process improvement need a contribution from both the ERP and from the Lean system. The other business objectives/KPIs, such as reduce waste and quality improvement, need a contribution from the Lean system.

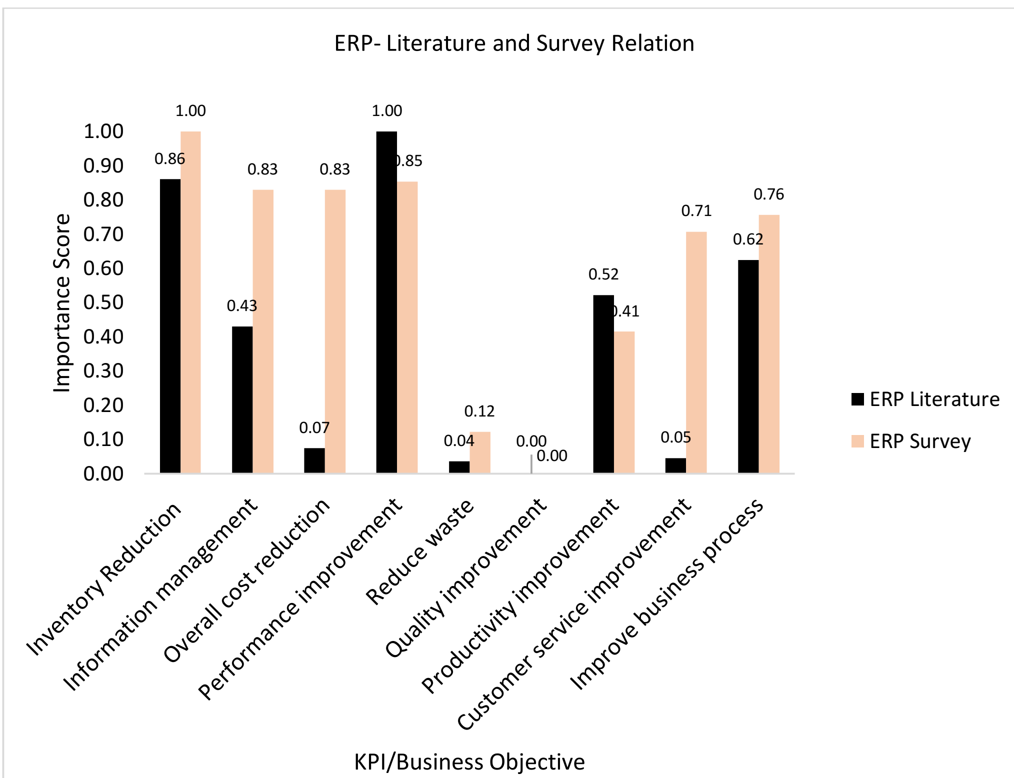

Figure 5.8 Comparison of ERP importance scores obtained from the literature mapping and the Survey

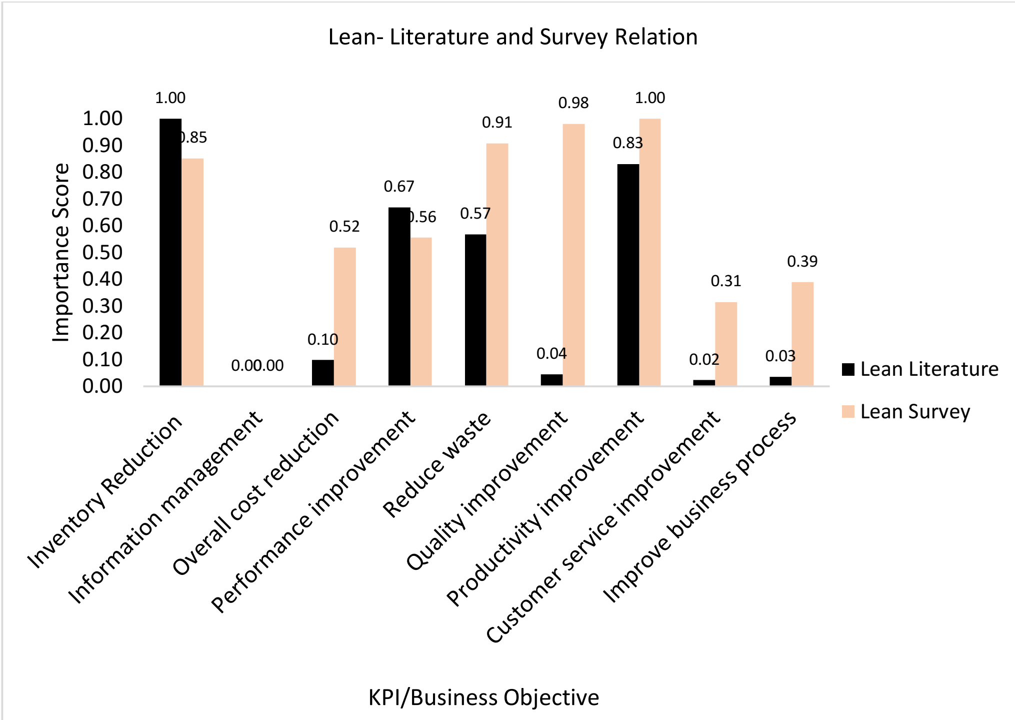

Figure 5.9 Comparison of the Lean importance scores obtained from the literature mapping and the Survey

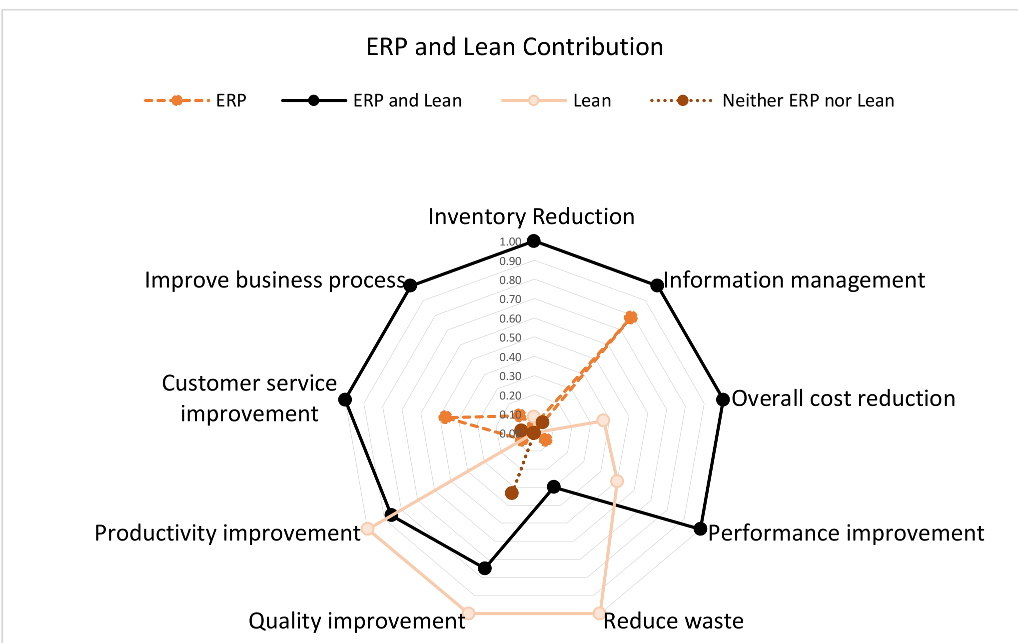

Figure 5.10 Proof the assumption on satisfying KPI/Business Objectives using both ERP and Lean System

After the SMEs know the ERP and Lean importance scores for the selected KPI, the next step is to select the system to be implemented using following conditions.

If S_{ERP}> S_{Lean} then they should implement the ERP system

If S_{Lean}> S_{ERP} then they should implement Lean system

If $S_{ERP} \cong S_{Lean}$ then they should implement Hybrid ERP Lean System.

5.2.2. Implementation Layer

5.2.2.1. ERP implementation

Once the SMEs see that an ERP has comparatively higher importance score (S_{ERP}>S_{Lean}) as per the HELF, they should implement an ERP system. The method for implementing an ERP system the involves selection of relevant ERP modules and relevant Critical Success Factors (CSF) [106]. Since SMEs often have limitation on investing resources, they may afford to purchase entire ERP software package. Therefore, the implementation method promotes a modular approach, that is selects only those modules, which satisfies their business objectives [106]. As shown in Figure 5.11, the proposed HELF promotes a modular approach, meaning purchase only relevant ERP modules package [26, 38], which are aligned to the business processes, functions and requirements. The cost related to buying, implementing and maintaining the ERP modules, which are not aligned with the selected KPI/business-objective can be eliminated using this approach. The alignment can also be with respect to the Lean manufacturing practices. In addition to selecting basic ERP modules such as human resource, accounting & finance, material management, purchase and distribution the HELF promotes selection of Add-On or Bolt-On ERP modules [2, 13, 43], which support the Lean manufacturing practices. The Add-On or Bolt-On can be eKanban, electronic work methods, finite scheduling (accommodates push/pull), support for JIT, value stream analysis, and line design & sequencing.

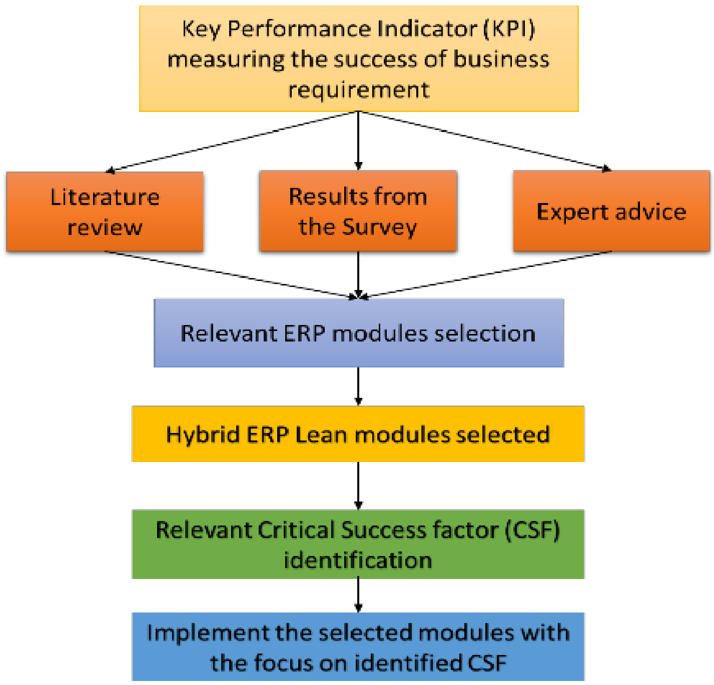

Figure 5.11 ERP implementation approach

For the SMEs, implementation of the ERP modules is a critical process. The implementation takes investment in terms of money, work force and time. Cases are being found where scope creep of the implementation projects is common [23]. Once the ERP system is implemented, undoing is very difficult. Cases of bankruptcy due to improper implementation also exist [22, 23]. Therefore, SMEs should be cautious in implementation of selected modules. Critical Success Factors (CSFs) are the guiding principles whose presence increases the probability of successful implementation. The Ishikawa (fish bone) cause-and-effect method is followed to select the ERP modules and CSF as shown in Figure 5.12. The CSFs are identified for the different levels using the literature studies. The levels are the strategic level, the organization level, the operations level and the user level and ERP software level. Causes of failure will be reasons for the success if the causes are addressed [106]. Thus, the effect is the KPI improvement; to improve the KPI the ERP modules should be selected in such a way that, the selected modules drive the KPI improvement. To increase the probability of success of ERP implementation, CSFs for each selected KPI/business-objective have been identified. The framework optimizes the resources spent on CSF by providing relevant success factors for the selected KPIs and ERP modules. In this fashion, relevant ERP modules, add-on Lean supporting ERP modules and CSF are identified using the literature review and the survey for selected top KPIs. Table 5.3 shows results of the literature studies on identification of the ERP modules and the Critical Success Factors. Table 5.4 shows the results of the question 6 and 8 of the survey, which indicates relevant ERP modules. Figure 5.13 shows the list of the CSF derived from the survey via question number 12 and 13. The CSF recommended by the SMEs are presented from highest priority to lowest priority in the chart as in Figure 5.13.

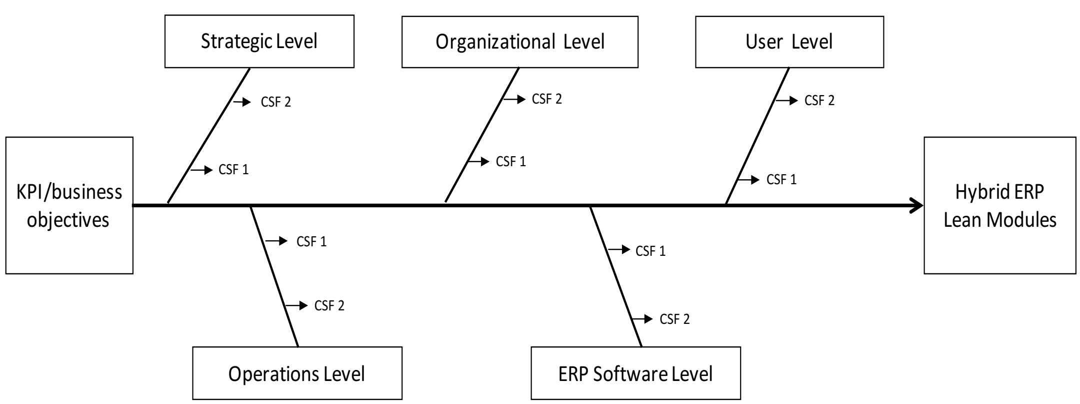

Figure 5.12 Ishikawa Cause an Effect Approach

Table 5.3 ERP modules and critical success factors identified through the literature mapping

KPI	Main Reference	Requirements for improving the KPI	Hybrid Lean-ERP Module	CSF-Strategic Level	CSF-Organizational Level	CSF-Operation Level	CSF-User Level	CSF-Information Technology system Level
Productivity improvement	[115] – [117]	• Manage back end processes [115] • Automates the routine, frequently-repeated manual tasks that waste staff time and result in errors and re-work [116] • Make employees job easier [116] • Employees are productive because of more accurate, easy to access data [117] • Reduction in errors and on time availability of reliable information [115]	• Human resource, finance • sales and distribution, • supply chain management, • order management, • production planning • Advance planning and scheduling [115]–[117]	• Select ERP systems which has embedded best business practices [117] • Culture change [3], [11], [18], [65] • Open and honest information sharing between industry and supplier[55]	• Streamline business process with ERP system [115] • Senior and functional managerial support [3], [18], [55] • Selection of Lean tools and techniques • Monitoring and evaluation of performance post of implementation project [11], [18]	• Business Process Reengineering [8], [10] • Change Management [14], [18] • Cross functional team [6], [7]	• Easy to use [117] • Easy to learn and train [117] • User Satisfaction [6], [23] • User Involvement [3], [10] • Training and Education [11], [23]	• Easier to integrate with existed system [117] • Capacity to automate communication and integrate information between functions [116] • ERP software vendor service quality [3], [66] • Deliver information in the context of the process for which user is responsible [117]
Improve business process	[114], [116], [118], [119]	• Simplify and streamline highly specialized business processes in manufacturing and distribution enterprises.[116] • Process improvement initiatives require the application of both knowledge management techniques and analysis tools to assist users in decision-making. [119] • Require a vast amount of process performance data in order to support a valuable analysis with highest precision and accuracy. [119]	• CRM [114], [120] • Marketing and Sales [118] • Finance and Accounting [118] • Human resource [118] • Supply chain management [118] • Visual management • Value stream mapping	• Understanding of the business requirement [114] • Clarity of objectives by for the implementation [120] • Culture change [3], [11], [18], [65]	• Project management skills [114] • Strong and committed leadership [119] • Balanced and empowered implementation [120] • Monitoring and evaluation of performance post of implementation project [11], [18]	• Involve persons working close to the process [114] • Communication & cooperation between the involved departments of the enterprise [120] • Change Management [14], [18] • Cross functional team [6], [7]	• Open and honest communication [120] • User Satisfaction [6], [23] • User Involvement [3], [10] • Training and Education [11], [23]	• Smooth integration of modules [120] • Business process fit [120] • ERP software vendor service quality [3], [66] • Software testing and debugging [23] • Appropriate IT legacy system [11], [14] • User friendliness of module [56]
Customer Service improvement	[121] – [123]	• CRM systems establish and maintain bonds with customers [121] • Responding to customers' needs, retaining customers, market research, sales promotion and cost reduction[121] • Higher degree of supply-side electronic integration makes firms achieve cost savings, cross-selling, customization, and improved customer satisfaction in customer service [123]	• CRM • Order management, • Supplier relation management • Marketing, sales and delivery • Advance planning and scheduling	• Strategic goal to improve customer service [124] • Drive to move from traditional system to more customized customer oriented systems [4] • Culture change [3], [11], [18], [65]	• Coordination betweem departments • Balanced and empowered implementation [120] • Monitoring and evaluation of performance post of implementation project [11], [18]	• Business Process Reengineering [8], [10] • Change Management [14], [18] • Cross functional team [6], [7] • Effective use of pilot project [55]	• User Satisfaction [6], [23] • User Involvement [3], [10] • Training and Education [11], [23]	• Quality of information [3] • ERP software vendor service quality [3], [66] • Software testing and debugging [23] • Appropriate IT legacy system [11], [14]

		• Poor performance by not meeting delivery deadline due to inadequate coordination between the departments [122] • Access to every piece of relevant customer order data from quote to shipment is the key increase customer service efficiency[121]	• Manufacturing resource planning • Logistic management		• Drive for customer focus [121]			• User friendliness of module [56]
Reduce Waste	[33], [35], [125]	• Waste related information in support of waste-reduction decisions. [125] • Access to accurate, consistent and timely waste cost information is possible [125] • ERP system is combined with an add-on waste specific capturing system [125] • Trends and analysis of data to see increase and decrease in waste generation to take quick action [125] • ERP software can automatically notify a product manager for a change order or a need for approval, and know the priority of the tasks. [35]	• Material Flow Cost Accounting [125] • Just in Time, • VSM • Demand smoothing • Engineering change management • eKanban	• Policy maker's Strong commitment and support to waste reduction [62], [126] • Supplier relationship [20], [37], [127] • Culture change [3], [11], [18], [65]	• Leadership to drive waste reduction process • Process-centered management • Benchmarking • Senior and functional managerial support [3], [18], [55] • Monitoring and evaluation of performance post of implementation project [11], [18]	• Quality of decision-making process through the availability of integrated data. • Business Process Reengineering [8], [10] • Change Management [14], [18] • Information based process management [65] • Cross functional team [6], [7]	• Sustained training on waste identification and elimination [125] • User Satisfaction [6], [23] • User Involvement [3], [10] • Training and Education [11], [23]	• Add on waste management module integration with regular ERP • Quality of information [3] • ERP software vendor service quality [3], [66] • Software testing and debugging [23] • Appropriate IT legacy system [11], [14] • User friendliness of module [56]
Quality improvement	[128], [129]	• Quality management and documentation of the quality and content of goods produced is essential [128] • ERP systems help improve quality by providing a record of how products are built vs. how they were designed [129] • ERP systems provide manufacturers identify problems with incoming parts and materials. [128] • Real-time data and records on defects generated and trends of defective parts • Electronic check sheets that validate quality and process control in real time [129] • Achieve and retain quality certifications with best-in-class functions providing auditors with instant access to evidence of compliance [129] • Accessibility to contact suppliers spontaneously to address corrective actions within the Problem Control module [128]	• Quality management • Customer relation Management, • Supplier relation management, • Inventory inspections • Reject & scrap tracking and analysis • Supplier performance rating system • Certificates of conformance • Receiving inspections [129]	• Vision and Plan statement for quality • Commitment to quality [128] • Supplier relationship [20], [37], [127] • Culture change [3], [11], [18], [65]	• Supplier quality management • Customer Focus [129] • Senior and functional managerial support [3], [18], [55] • Monitoring and evaluation of performance post of implementation project [11], [18]	• Continuous improvement, Planning for quality [129] • Business Process Reengineering [8], [10] • Change Management [14], [18] • Processes-and-information-based management [65] • Cross functional team [6], [7]	• Employee Empowerment [128] • User Satisfaction [6], [23] • User Involvement [3], [10] • Training and Education [11], [23]	• Integration of Add on module related to quality with regular ERP [128] • Quality of information [3] • ERP software vendor • service quality [3], [66] • Software testing and debugging [23] • Appropriate IT legacy system [11], [14] • User friendliness of module [56]

Table 5.4 List of the relevant ERP modules and CSFs obtained from the survey

Hybrid ERP Lean ERP modules from the survey		
KPI/business-objective	**ERP Modules**	**ERP Modules supporting the Lean**
Inventory Reduction	Material management module	VSM module
	Advance planning and Scheduling	eKanban module
	Supplier relation management module	JIT support module
	Inventory management module	Line Sequencing modules
	Material requirement planning module	
	Production planning module	
	Supply chain management module	
	Purchase module	
Information Management	Sales and distribution module	Electronic standardized Work
	Finance Module	VSM module
	Human resource module	
	Production planning module	
	Supplier relation management module	
	Purchase module	
	Customer relation management module	
	Material management module	
	Advance planning and Scheduling	
	Marketing module	
Overall cost reduction	Sales and distribution module	eKanban module
	Material management module	Demand smoothing module
	Supplier relation management module	VSM module
	Human resource module	
	Production planning module	
	Customer relation management module	
	Advance planning and Scheduling	
	Inventory management module	
Performance improvement	Supplier relation management module	Electronic standardized Work
	Quality management module	JIT support module
	Customer relation management module	
	Advance planning and Scheduling	
	Human resource module	
	Sales and distribution module	
	Finance Module	
	Material management module	
	Production planning module	
Reduce Waste	Inventory management module	eKanban module
	Material management module	JIT support module
	Production planning module	VSM module
	Quality management module	
	Material requirement planning module	
Quality improvement	Quality management module	Electronic standardized Work
	Supplier relation management module	
	Customer relation management module	

Productivity Improvement	Advance planning and Scheduling	Electronic standardized Work
	Material management module	eKanban module
	Production planning module	
	Human resource module	
	Sales and distribution module	
	Quality management module	
Customer service improvement	Customer relation management module	JIT support module
	Supplier relation management module	Demand smoothing module
	Marketing module	
	Supply chain management module	
	Advance planning and Scheduling	
Improve Business Process	Finance Module	Visual Management modules
	Customer relation management module	
	Supplier relation management module	
	Material management module	
	Production planning module	
	Supply chain management module	
	Human resource module	
	Sales and distribution module	

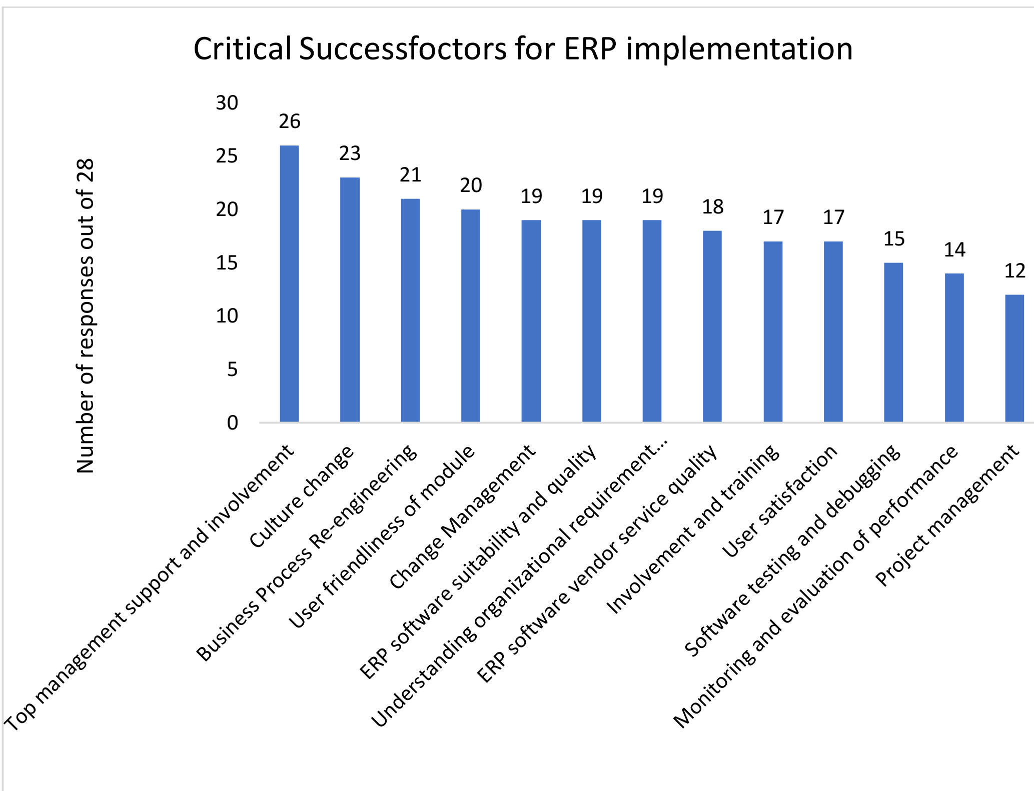

Figure 5.13 CSFs for ERP implementation from the survey

5.2.2.2. Lean implementation

If the condition $S_{Lean}> S_{ERP}$ then SMEs should implement the Lean management system. The method for Lean manufacturing implementation is followed from the work of Mourtzis et al [25]. The detailed method is published in “Lean rules extraction methodology for Lean PSS design via key performance indicators monitoring” [25] and schematically presented in Figure 5.14. Lean index evaluation promotes the evaluation of the Leanness considering the Lean wastes present at the shop-floor. It evaluates the status of the Leanness with respect to selected KPIs then recommends practicing the Lean principles derived as set of Lean rules. The Lean rules are simple Lean practices, which lead to the improvement of the Leanness [67]. The respective Lean rules should be implemented to improve the Leanness. Evaluation of the Lean index and practicing the Lean rules is a cyclic process that gradually leads to the Lean implementation. In addition, the CSFs to implement the Lean system successfully are obtained through the survey. Figure 5.15 presents the top CSF for the Lean implementation as identified by the SMEs. The highest priority is given to the CSF, ‘top management support’ then to the ‘culture change’ and so on as show in Figure 5.15.

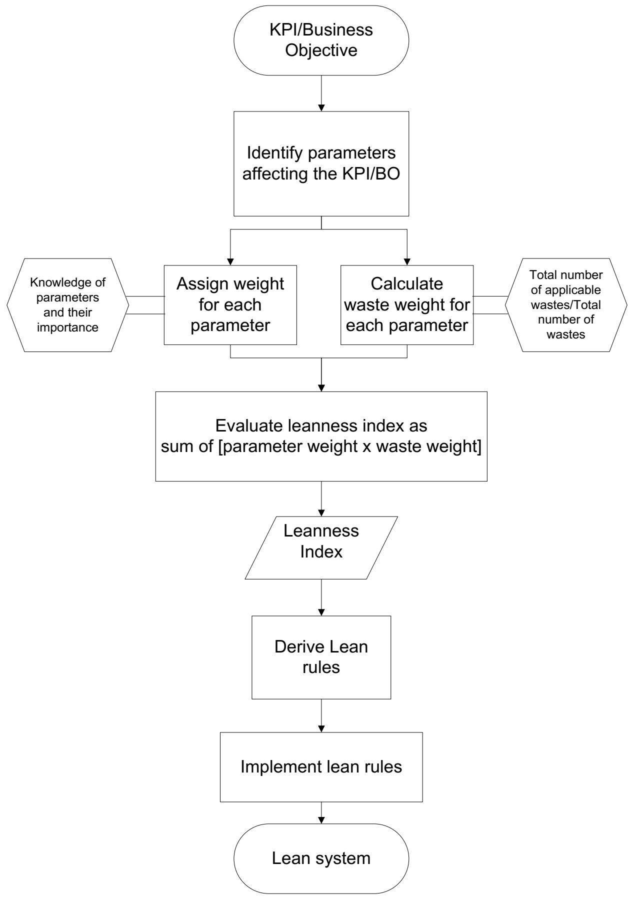

Figure 5.14 Lean manufacturing system implementation method

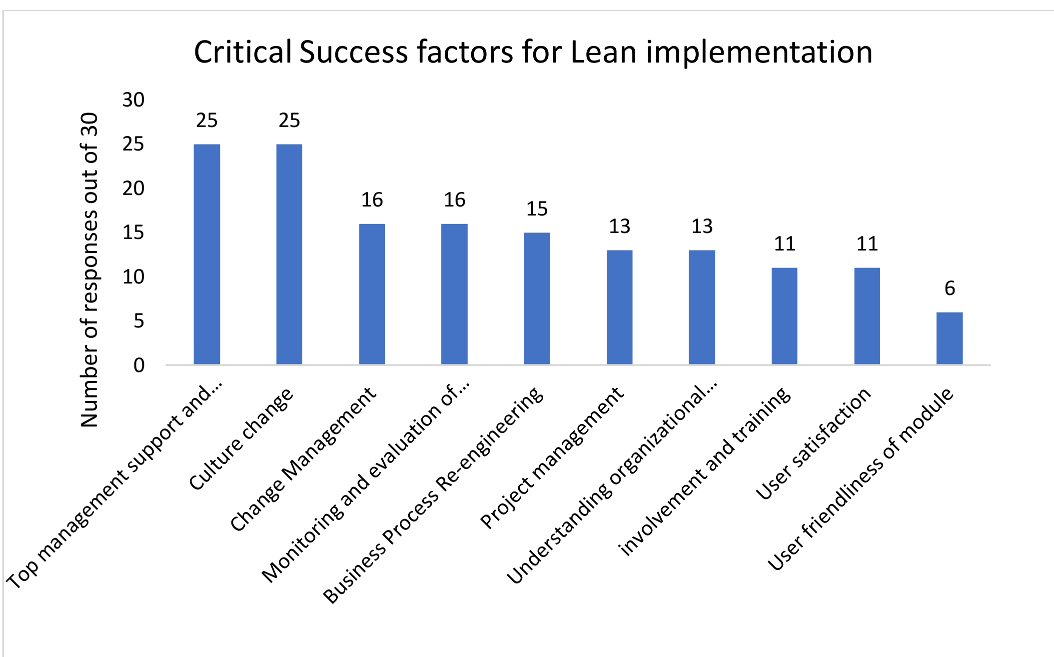

Figure 5.15 CSF for the Lean implementation from the survey

5.2.2.3. Hybrid ERP Lean system

If the condition $S_{ERP} \cong S_{Lean}$ applies, then SMEs should implement both the ERP and the Lean system as discussed in the section 2.2.1 and 2.2.2. Even when the importance score of ERP and Lean are not equal, for example $S_{erp} = 65\% \; and \; S_{Lean} = 35\%$, SMEs can opt to implement the Hybrid ERP Lean system. The Hybrid ERP Lean system is recommended, as the SMEs can get the advantage of synergic *1+1=3* effects with hybrid systems. They can use importance score to as an estimate for resources spent on ERP system and Lean system.

5.2.3. Validation layer - The HELF web-based application (Case study)

The Hybrid ERP Lean Framework is developed into a web-based application GUI. SMEs can make use of this web application to implement Hybrid ERP Lean system. Using the application, the user can select the KPIs they want to improve. Once the KPI is selected, the application pops-up the ERP and Lean importance scores accordingly. For the ERP implementation, the application recommends the ERP modules, Add-on Lean supporting ERP modules and critical success factors. Further, for the Lean implementation the application takes the parameter and the Lean waste as inputs, and then evaluates the Lean index of the selected KPI. Following, it suggests predesigned Lean rules to improve the Leanness. Thus, the application supports the Lean system implementation. Figure 5.16 shows the interface of the developed Hybrid ERP Lean Framework web-application.

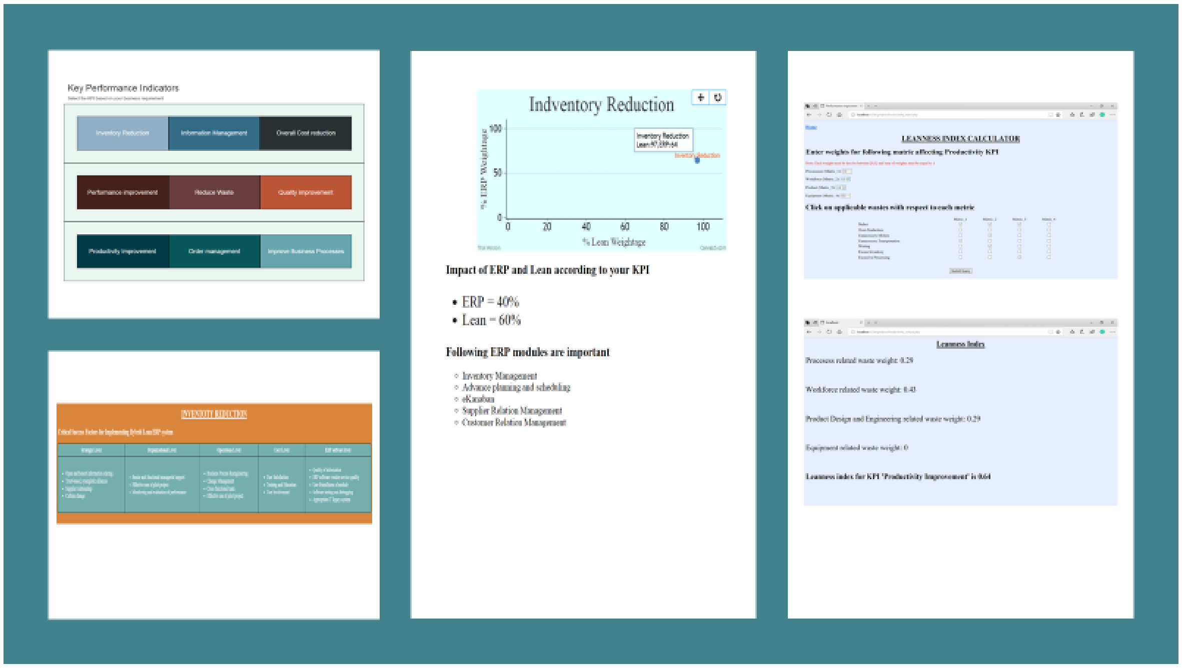

Figure 5.16 HELF web-based application GUI

The HELF framework is validated in the Alberta Learning Factory (AllFactory) created at LIMDA Lab (University of Alberta) from a case study. The AllFactory [97] has a setup of assembly stations to assemble mechanical products to facilitate students learning. The aim of the AllFactory is to streamline the assembly operations of an in-house designed LEGO 3D printer over the 7 assembly stations. The major constraint for the production are lack of productivity of the operators and high lead-time. Therefore, the KPIs/business-objectives selected for the improvement using the HELF are to improve the *productivity* and *reduce waste*. Using HELF, the importance scores for the *productivity* derived from literature mapping are 0.52 for the ERP and 0.82 for the Lean (Figure 5.8 & Figure 5.9). Since the condition $S_{Lean} > S_{ERP}$ applies the Lean system is used to improve the KPI *productivity*. For the business objective *reduce waste*, the ERP importance score is 0.04 and the Lean importance score is 0.57. The condition $S_{Lean} > S_{ERP}$ is true for this case as well. Therefore, the Lean system is implemented to reduce the waste, thereby improving the lead-time. For the detailed case-study, readers are advised to refer to the AllFactory assembly case study [97]. For the KPI productivity, the value of the ERP importance score is comparatively higher (i.e.0.52), hence, condition $S_{erp} \cong S_{Lean}$ is also valid. Therefore, the user at the AllFactory decided to go with hybrid system implementation, where ERP and Lean combination is vital for productivity improvement. An AzarBod shop-floor management ERP software is integrated into the AllFactory environment. The AzarBod has Lean supporting Add-on ERP modules, which support performing the manufacturing activities at the shop-floor, specifically focuses on the productivity. Thus, hybrid system is deployed at Allfactory.

In future, to promote Industry 4.0 and Lean 4.0 the web-application will be developed as a systematic software application to support the SMEs. The application will have broad database of KPIs, importance scores and systematic guidelines to implement the hybrid system.

5.3. Conclusion

The article presented the designed Hybrid ERP Lean Framework supporting the combination of the ERP and Lean system. The framework has provided flexibility to implement either ERP system or Lean system or combination of both the systems, which is the requirement of small and medium manufacturing enterprises. Results of the survey shows that ERP and Lean system are mutually inclusive. SMEs can make use of the proposed framework to achieve business objective of their interest, which is the unique part of the methodology. In addition, selection of only relevant ERP modules considerably reduces the underutilization of an ERP system. The research methodology, which includes the literature mapping and survey, have provided knowledge data for Hybrid ERP Lean system implementation for SMEs. The data consist of top KPIs for manufacturing firms, which can be improved by implementing Hybrid ERP Lean system. The knowledge data are also comprises of importance scores of ERP and Lean for top KPIs, which gives a clarity to SMEs on selecting the systems. In addition, the identified CSFs helps SMEs successfully implement the 'Hybrid ERP Lean System'. The HELF web-based application addressed the industry 4.0 requirements. Thus, HELF is the systematic approach for implementing and practicing the hybrid ERP Lean system. The future work of the framework will be to expand on more manufacturing KPIs. The scope of the framework will also be expanded to other industrial sectors and large industries.

Chapter 6 Conclusion

6.1. General conclusion

Hybrid ERP Lean System is a promising approach for small and medium enterprises to improve their business requirements. We have successfully designed a flexible HELF, which is the main contribution of the research. The framework supports the combination of ERP and Lean system, addressing ERP and Lean are not opposing each with some exceptions. The research also explains the perception of Alberta SMEs on ERP and Lean system. SMEs can make use of both ERP and Lean systems to improve their manufacturing system. Through the literature mapping and the survey of Alberta SMEs, top KPIs/business-objectives, ERP & Lean importance scores of the KPIs, and critical success factors for the implementation are recognized. Knowing the KPIs/Business objectives helps SMEs to select the ERP modules and the Lean tools to improve the KPI. The importance score of ERP and Lean for the KPI gives an information on the systems (ERP, Lean or both) should be used and the probable resource distributions on the ERP and the Lean for enhancement of the selected KPI. Using the literature, thirty KPIs/business-objectives relevant to manufacturing SMEs are identified and nine KPIs/business-objectives out of the thirty are validated through the survey. This indicates the selected KPIs are essential for the SMEs. Similarly, the ERP-Lean importance scores are also validated by the survey for the nine KPIs showing agreement from the manufacturing industries in Alberta. The research also determines the critical success factors (CSFs) which are guiding principles for the systems implementation, which reduces the risk of failure in the implementation. Set of CSFs are identified using the literature mapping and the same is validated by the survey for top nine KPIs. Until this point, the groundwork of the research has generated significant knowledge for efficient utilization of ERP and Lean system, customized to SMEs in manufacturing. Use of this data minimizes the efforts the SMEs has to put in the implementation.

The methods developed to implement ERP, Lean and Hybrid ERP Lean Systems are tailored to fit the SMEs manufacturing environment. The Hybrid ERP Lean Framework is a platform, which guides the SMEs in systematic implementation of the system of their choice. The framework optimizes the resources SMEs has to spend on purchasing and implementing ERP software using the developed modular approach i.e. selecting and implementing relevant ERP modules. It directs SMEs in implementing the Lean system, which is focused on the shop-floor people and processes. The designed Leanness evaluation tool and Lean rules address the specific drawbacks of the SMEs such as lack of Lean expertise, the involvement of shop-floor employees and know-how. Thus, HELF supports in achieving the business objectives such as reduce inventory, productivity, improve on-time delivery, improve performance, improve production, improve quality, improve efficiency, and improved information management at SMEs.

The case study at the Alberta Learning Factory at the University of Alberta demonstrates the usefulness of the framework. The developed HELF web application provides an accessibility to the HELF model anywhere at any time using a computer graphical user interface (GUI). The web-based application also demonstrates the application of industry 4.0. To conclude the outcomes of the research are favorable to the SMEs who are facing challenges in implementing ERP and Lean systems. In addition, the results of the research present a new way of approaching the modern manufacturing systems. The research has highlighted a fresh industrial engineering feature for the manufacturing world.

6.2. Research contributions

The contributions of this research can be summarized as follows:

- Lean OR ERP – A Decision Support System to Satisfy Business Objectives.
  - ✓ Identified KPIs/business objectives, which can be improved by implementing ERP and Lean system.
  - ✓ Numerically quantified ERP and Lean contribution levels for the KPI improvement.
- A methodology aiming to satisfy Key Performance Indicators for successful ERP implementation in SMEs.
- A decision support system to define, evaluate, and guide the Lean assessment and implementation at the shop-floor level.
- Hybrid ERP-Lean Implementation Framework for Small and Medium Enterprises.

6.3. Research limitations

This research is subject to the following limitations:

- The importance scores are derived by processing the data using hammar software. The accuracy of the software performance is not tested at the moment.
- The results validated by the survey are limited to 28 responses from SMEs in Alberta. Higher sample size with the elaborated global scope will enhance the accuracy of our conclusions.
- The HELF system is validated in AllFactory, which is a Learning Factory for training students. Therefore, a practical industrial case study will be more advantageous.

- The HELF web application is developed using basic skills in HTML and PHP basic programming languages just to demonstrate the future HELF application.

6.4. Future research

- The scope of the research is limited to manufacturing SMEs. Future work of the research will be extended to other sectors of enterprises such as chemical, oil and gas and service industries and large manufacturing companies.
- A HELF App will be a developed to support work-force at the shop-floor with the real-time implementation of Lean and ERP systems.
- A real-time visual dashboard will be developed to track, visualize and forecast, the current and future state of the important KPIs at the shop-floor, based on the data from Hybrid ERP-Lean system.

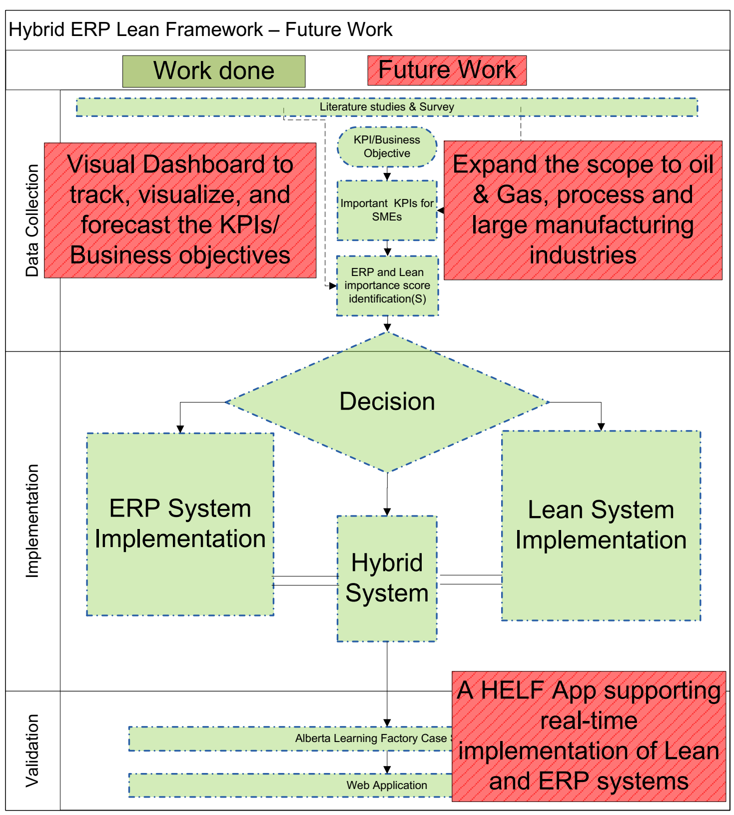

Figure 6.1 Future Work map

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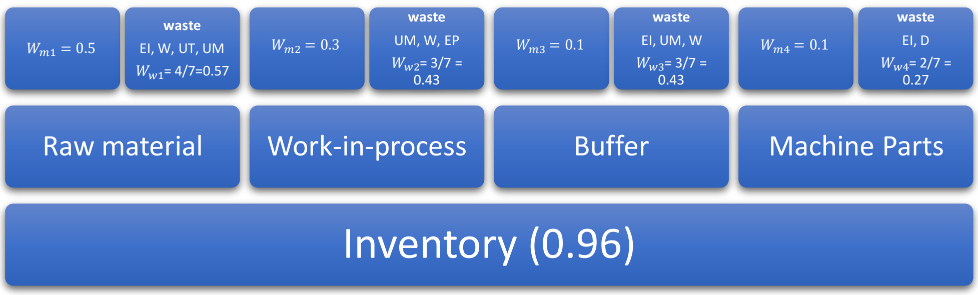
Appendices

1. Lean rules

The Lean rules are designed for nine KPIs/business –objectives, out of which the Lean rules for only two KPIs/business –objectives are discussed in chapter 4. The Lean rules for rest of the KPIs are as follows.

1.1.Inventory reduction: Reference [37], [40], [89], [130], [131]



Must	**Should**
• Must use Kanban system • Batch must be as small as possible • Must follow **F**irst **I**n **F**irst **O**ut **(FIFO)** rule • Must practice following Lean rules with external agencies i. Establish feedback system with supplier ii. Establish a strong communication i.e. contact your suppliers frequently iii. Give feedback on quality and delivery performance to the suppliers iv. Establish long term relationship with suppliers • Must use ABC analysis: i. A: High dollar usage; Order only when imminently needed	• Should change scheduling frequency according to specific demand pattern • Should use Runner, Repeater and Stranger strategy in levelled production • Should focus on Product life cycle management as discussed in *[seifert 2016]* • Should analyze Continuous inventory reduction practices (Max 2011) i. Cycle counting ii. Safety stock management iii. Economic order quantity management

ii. B: Intermediate dollar usage; Reorder point in a continuously monitored approach iii. C: Low dollar usage; Two bin system is adapted for these items	
Could • Can centralize the inventory control (e.g. use ERP tools) • Can increase Customer involvement i. Close and frequent contact with customer ii. Take feedback from customer • Can Reduce supplier lead time through supplier commitment and interest	**Would** • Extend JIT to your suppliers i. Direct involve suppliers in new product development ii. Implement supplier certification program iii. Categorize suppliers according to their performance/need iv. Standardized information flow system v. Standardized product and process language

- **FIFO**: FIFO warehouse system is an inventory management system in which the first or oldest stock is used first and the stock or inventory that has most recently been produced or received is only used or shipped out until all inventory in the warehouse or store before it has been used or shipped out. This ensures that the oldest stock is been used first and reduces the costs of obsolete inventory. It is also considered the ideal stock rotation system.
- **ABC classification**: ABC analysis is the most widely used technique in inventory management to categorize a large number of inventory items into three predefined and ordered categories: category A contains the very important items, category B includes the moderately important items and category C contains the relatively unimportant items.
- **Runner, repeater, and stranger**: Runners are products or services – or families of products or services – that are made in sufficient volumes to economically justify having facilities and resources dedicated solely to making them. The facilities and resources are been used for no other activity. In case of Repeaters a product or service – or a family of products or services – that is been made often, but does not have enough volume to justify dedicating facilities and resources exclusively to just them.

Strangers are products or services that are been done rarely, sporadically, or in low volumes.

- **Cycle counting**: Periodic inventory system audit-practice in which different portions of an inventory are counted or physically checked on a continuous schedule. Each portion is counted at a definite, preset frequency to ensure counting of each item at least once in an accounting period (usually a year). Fast-moving or more expensive items are counted more often than slower moving or less expensive ones, and certain items are counted every day. Also called cycle inventory.
- **Economic order quantity**: Under this policy, the inventory status is continuously monitored. Whenever the inventory level falls to a predetermined level called as reorder point (ROP), a replenishment order of fixed quantity called economic order quantity (EOQ) is placed.

1.2.Performance improvement: Reference [64], [89], [132]

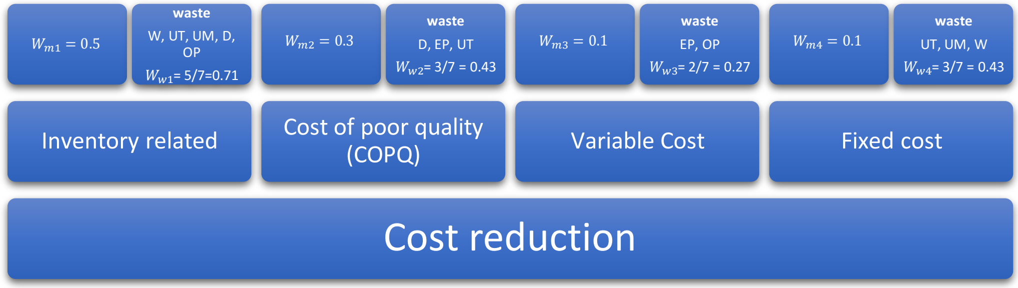
*safety: d➔ accidents and incidents, w➔ waiting to clear safety related issues

Must	**Should**
• Must practice 5S • Must carry out Value stream mapping • Must develop the habit of: Standardize-Do-Check-Act ➔ Plan-Do-Check-Act ➔ Repeat	• Should practice Cross functional team management • Should perform Continues improvement i. Kaizen ii. Product and process innovation • Should practice Total productive maintenance i. Jishu Hozen activity ii. Scheduled maintenance (Preventive, Reliable, need based maintenance)

Could	Would
• Can initiate Human resource management i) Self-directed team ii) Formal skill training iii) Cross training program iv) Job rotation	• Recommended to have Visual Management

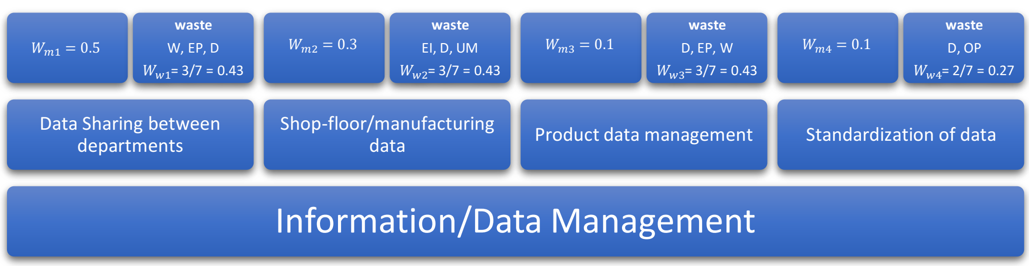
- **Cross functional team**: CFT are permanent or temporary groups aimed at reducing conflicts in goals, language and processes that require cross-functional integration. These groups facilitate the interaction of members of distinct functions while performing temporary tasks, such as the development of new products or in permanent departments that aim to integrate operational processes.
- **5S**: 5S is a philosophy for systematically achieving overall organization cLeanliness and standardization at workplace that is motivating and pleasing to all the employees in the organization. 5S is a philosophy for reshaping the workplace and providing foundation for significant improvements at workplace. 5S changes the approach of the employees toward their work, workplaces and improves communication among various business functions and departments. (1S-Sort, 2S-Set in order, 3S-Shine, 4S-Standardize, 5S-Sustain)
- **Kaizen**: It can be defined as change for improvement in the shop floor area.
- **Jishu hozen**: It is a daily maintenance activity on machine or tool performed by operator using that machine. It involves daily cLeaning, inspection, lubrication, tightening.
    - Level1: Operator performs CLIT (CLeaning, Lubrication, inspection, Tightening) if finds any abnormality tie red tag to notify the abnormality and indicate maintenance assistance
    - Level2: Operator performs CLIT (CLeaning, Lubrication, inspection, Tightening) if finds any minor abnormality, operator itself make correction and tie white tag. If abnormality is major operator tie, red tag and call for maintenance assistance.
    - Level3: Operator performs CLIT (CLeaning, Lubrication, inspection, Tightening) if finds any minor or major abnormality, operator itself trained to rectify the problem. Therefore, operator resolves the issue and tie white tag.

1.3.Cost reduction: Reference [59], [89], [131]



<u>Must</u> • Must define value from prospective of the customer • Must determine cost value stream • Must deploy inventory control methods to eliminate inventory waste	**<u>Should</u>** • Should eliminate the bottleneck • Should reduce rework (cost of poor quality) • Should reduce downtime • Should reduce setup time
<u>Could</u> • Can analyze material handling cost • Optimize the number of processes • Optimize the time spent in each process • Optimize scheduling	**<u>Would</u>** • Apply Plan do check act (PDCA) • Assign target to down the hierarchy level up to operators

1.4.Information/ data management



*D➔ wrong information, EI➔extra unwanted information, UM➔flow of information, EP➔unclear information (representation) W➔speed of information flow and access OP➔ lot of information

Must	**Should**
• Must implement data management system • Must establish procedure to identify, storage, protect, retrieve, retention and disposal of records. • Must ensure that records are legible, identifiable and traceable • Must let data speak • Data must be available for use, sharing and modification. • Must form date security policies	• Should establish procedures for internal communication and exchanges of information between various levels and functions. • Should use data for determining trends, reviewing performance of key areas of control, planning for policy development, improvement activities, training and development of human resources. • Should use the visual data representation tools such as dashboards which assists in easy understanding of data
Could	**Would**
• Can develop procedures for external communication (outside the company) and exchanges of information in order to receive, document & responds. • Can have a procedure to decide whether to communicate the significant aspects and documents its decisions.	• Would have Open access of the updated and reliable data to all division for further and continuous improvement in managing, planning and evaluating quality i) Inter-department ii) Intra-department (inside the company) iii) External (outside the company)

1.5.Customer service improvement: References [101], [133], [134]

*W➔ waiting for execution of customer focused initiatives, for new product, for getting issues resolved UT➔ levels of decision making process D➔ wrong policies or things gone wrong, UM➔stages through which customer has to go through to get specific issue resolved , EP→repeated details on form, providing non required services

Must	**Should**
• Must integrate the customer requirements/needs to improve the product and processes. • Must maintain the expected level of service to the customer. • Must built quality to satisfy the customers. • Must improve the feedback system. Seek feedbacks. Ways for feedback are online reviews and customer satisfaction surveys	• Should focus on developing long lasting relation with customer. • Should develop effective ways of communication. • Should measure and improve customer satisfaction at downstream such as customer interaction functions like service, repair, and maintenance.
Could	**Would**
• Can alter strategies to focus on the customer satisfaction. • Can have 'customer satisfaction improvement' programs to train the employees who deal with customers more closely on interpersonal skills, technical aspects of job and problem solving.	• Recommended to practice customer satisfaction improvements with suppliers and product delivery companies.

1.6.Improve business process: Reference [135]–[137]

Must	**Should**
• Must identify Areas for Improvement (AFIs). Review how those processes affects	• To make the entire process effective and efficient, one

your organization and customers. Perform Value stream Mapping. ✓ Identify the value-added and non-value-added activities. ✓ Eliminate non-value-added activities. Setup the target and improvement activities • Plan for Continuous improvement. Must monitor and measure the process improvements. (e.g. DMAIC, Six Sigma, 5 Why technique) • Must empower workers • Must involve the person who is responsible for the improvement process • Must analyze effect on related processes during improvement a given process • Must support collaboration across roles and organizational boundaries and inform all stakeholders about the change	should add new processes wherever required. • Should eliminate inefficient and outdated processes. • Should make sure the right people are involved • Should apply 5S technique for workplace organization. • Should standardize the improvements
<u>Could</u> • Stay flexible to change the process • Timely ask questions such as i. What happens if you introduce new products or introduce changes to existing products? ii. What changes needed if you gain new customers or new Sales Avenue? iii. Think about the scenario, when your products get subject to new/changing regulatory requirements. iv. What happens when the corporate strategy changes, work force changes and reorganization take place?	**<u>Would</u>** • Recommended to think outside IT system (ERP) solutions for business process improvement • Integrate and coordinate human activities with system/machine activities. E.g. Human-Machine Collaboration. • Enforce compliance with customer requirements and regulatory statutes.(ISO standards) • Improve workspace for safe operations. Apply Occupational Health and Safety codes and standards.

1.7.Quality improvement: Reference [131]

Must

- Must practice legacy of
  - Do not accept the defect
  - Do not create the defect
  - Do not ship the defect
- Must follow standard work instruction
- Must monitor quality performance every day.
- Must implement Total Quality Management
  - Tools : House of Quality
- Must Benchmark quality processes.

Should

- Should stop the process whenever defect is seen and resolve it before moving to next process
- Should empower the operators to stop the line whenever defect occurs
- Should train operators in problem solving tools
- Should follow the world class manufacturing principles
  - People involvement
  - Standardization
  - Built in quality
    - Defect don't leave plant
    - Defect don't leave shop
    - Defect don't leave team
    - Defect don't leave station
    - Defect not created
  - Short lead time
  - Continues improvement

Could

- Can make use of Lean tool
  (1) Statistical process control
  (2) Problem solving and root cause analysis
  (3) 5 Why tool

Would

- Design for quality

2. Survey Details

Background calculations of ERP and Lean importance score referring to section 4.3.3.2 of Chapter 4 and section 5.1.2.3 of the Chapter 5.

ERP Response (26)

	No Contribution-0	Little Contribution-1	Medium Contribution-2	Slightly High Contribution-3	High Contribution-4
Inventory Reduction	0	0	2	11	13
Information management	0	1	6	7	12
Overall cost reduction	0	2	3	10	11
Performance improvement	0	1	4	10	11
Reduce waste	2	9	7	2	6
Quality improvement	1	11	8	3	3
Productivity improvement	0	4	10	7	5

Customer service improvement	0	1	8	8	9
Improve business process	0	1	7	8	10

ERP Importance score derivation from the survey response (Figure 5.8)

KPI	No Contribution	Multiplied 0	Little Contribution	Multiplied 1	Medium Contribution	Multiplied 2	Slightly High Contribution	Multiplied 3	High Contribution	Multiplied 4	Weight Sum	Importance Score
Inventory Reduction	0	0	0	0	2	4	11	33	13	52	89	1.00
Information management	0	0	1	1	6	12	7	21	12	48	82	0.83
Overall cost reduction	0	0	2	2	3	6	10	30	11	44	82	0.83
Performance improvement	0	0	1	1	4	8	10	30	11	44	83	0.85
Reduce waste	2	0	9	9	7	14	2	6	6	24	53	0.12
Quality improvement	1	0	11	11	8	16	3	9	3	12	48	0.00
Productivity improvement	0	0	4	4	10	20	7	21	5	20	65	0.41

Customer service improvement	0	0	1	1	8	16	8	24	9	36	77	0.71
Improve business process	0	0	1	1	7	14	8	24	10	40	79	0.76

Lean Response (26)					
KPIs/Business objectives	No Contribution	Little Contribution	Medium Contribution	Slightly High Contribution	High Contribution
Inventory Reduction	0	0	0	14	11
Information management	3	10	6	2	3
Overall cost reduction	0	4	7	6	8
Performance improvement	0	2	5	10	7
Reduce waste	0	0	1	9	15
Quality improvement	0	0	0	7	18
Productivity improvement	0	0	1	4	20

Customer service improvement	0	5	11	6	3
Improve business process	0	5	9	6	5

Lean Importance score derivation from the survey response (Figure 5.9)

KPI	No Contribution	Multiplied 0	Little Contribution	Multiplied 1	Medium Contribution	Multiplied 2	Slightly High Contribution	Multiplied 3	High Contribution	Multiplied 4	Weight Sum	Importance Score
Inventory Reduction	0	0	0	0	0	0	14	42	11	44	86	0.85
Information management	3	0	10	10	6	12	2	6	3	12	40	0.00
Overall cost reduction	0	0	4	4	7	14	6	18	8	32	68	0.52
Performance improvement	0	0	2	2	5	10	10	30	7	28	70	0.56
Reduce waste	0	0	0	0	1	2	9	27	15	60	89	0.91
Quality improvement	0	0	0	0	0	0	7	21	18	72	93	0.98
Productivity improvement	0	0	0	0	1	2	4	12	20	80	94	1.00
Customer service improvement	0	0	5	5	11	22	6	18	3	12	57	0.31
Improve business process	0	0	5	5	9	18	6	18	5	20	61	0.39

Background calculations for deriving ERP and Lean importance referring to section 5.2.1.3, Figure 5.9.

Number of Responses out of 28				
	ERP	ERP and Lean	Lean	Neither ERP nor Lean
Inventory Reduction	1	24	2	0
Information management	11	14	0	1
Overall cost reduction	0	19	7	0
Performance improvement	2	15	8	1
Reduce waste	0	6	20	0
Quality improvement	0	9	12	4
Productivity improvement	1	12	14	0
Customer service improvement	8	16	1	2
Improve business process	4	19	2	2

Scaling of responses to the scale of 0 to 1				
	ERP	ERP and Lean	Lean	Neither ERP nor Lean
Inventory Reduction	0.04	1.00	0.08	0.00
Information management	0.79	1.00	0.00	0.07
Overall cost reduction	0.00	1.00	0.37	0.00
Performance improvement	0.07	1.00	0.50	0.00
Reduce waste	0.00	0.30	1.00	0.00
Quality improvement	0.00	0.75	1.00	0.33
Productivity improvement	0.07	0.86	1.00	0.00
Customer service improvement	0.47	1.00	0.00	0.07
Improve business process	0.12	1.00	0.00	0.00