Development of Lean Maturity Model for Operational Level Planning

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ABSTRACT

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Mohammad Ali Maasouman

The purpose of this thesis is to develop a visual, data-driven operational lean maturity model (LMM). The model intends to assess the level of lean maturity and the lean effectiveness in different axes of production cells (PCs).

Lean is a transformation journey, in which, change management and organizational culture are critical elements of successful implementation. Diverse maturity and assessment models have been developed to evaluate and lead the organizational transformation toward leanness. The main goal of lean is to create more value for the customers by removing wastes. Despite the important role of PCs in creating value, the transformation principles in the operational level have not been considered as deserved. Moreover, the research on lean assessments has used either inputs (tools and processes) or outputs (performance) to evaluate leanness. However, to evaluate the effectiveness of lean practices, both groups of indicators should be measured separately but analyzed together.

Considering the mentioned gaps, the findings of a thorough literature review on lean principles, tools, metrics and assessment models were synthesized to develop LMM for PCs through four stages: defining maturity levels; defining lean axes; suggesting main control items and performance measures; and suggesting enablers. A case study is carried out for gathering data of analysis and explanatory study of results. The qualitative and quantitative data on lean capability and performance results of two PCs was collected through direct observation and audit. To quantify the qualitative indicators of leanness, a scoring system is used based on the major and minor non-conformances. Minimum of fuzzy membership value is selected to calculate the overall performance of each lean axis. Then, the results of leanness are compared with the performance of PCs to find the gaps between requirements of leanness and results of their practices, and to fill that gap by focusing on the areas of strength and those needing improvement.

Results of the case study show that the developed model can be successfully used to measure both leanness and lean effectiveness through assessment of lean-performance. The model can be applied by practitioners as a framework to design and develop a company-specific LMM.

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This thesis is dedicated to:

My beloved wife for her support throughout my time at graduate school, I appreciate her patience during some of the more stressful times, as well as her time to take care of my dearest Sepanta.

My beloved parents for their never fading support and love, and my younger brother, who takes care of my father with his health issues when I was far away from home during graduate study.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBRIVIATIONS

AHP	Analytic hierarchy process
EDI	Electronic data interchange
FMEA	Failure Mode and Effects Analysis
FIFO	First In, First Out
JIT	Just In Time
KPI	Key Performance Indicator
LMM	Lean Maturity Model
MTBF	Mean time between failures
MTTR	Mean Time To Repair
OEE	Overall equipment effectiveness
PDCA	Plan, Do, Check, Act
TPS	Toyota Production System
TQM	Total Quality Management
TPM	Total Productive Maintenance
VA	Value added
VSM	Value stream mapping
WIP	Work in process

CHAPTER 1: INTRODUCTION

1.1 Introduction

Over the last three decades, there has been a growing focus in both manufacturing and service organizations on implementation and development of improvement techniques to reduce costs and increase benefits. Cost reduction strategies have become one of the main objectives of many companies in order to remain in the global competition market and to increase profits. As a result of this approach, several management techniques such as Six Sigma, Total Quality Management (TQM), Total Productive Maintenance (TPM), lean Manufacturing and Business Process Management have been created and have become more popular in the recent years. Most of organizations have applied a combination of different management tools, methods and procedures in order to reduce non-value added activities, to eliminate variations in the processes, to solve their problems and to improve the quality of their products and services.

Lean manufacturing based on the Toyota Production System (TPS) is a set of principles, tools and Methods that form a management philosophy in the organization in which value is defined from the customer's perspective as anything that customer is willing to pay for (Womack, et al., 1991). The main focus of lean, according to this paradigm is to provide a systematic way of identification and elimination of waste, to reduce cost, and to empower employees (Ohno, 1988).

Many organizations have improved their market leadership, profitability and productivity through application of lean principles and techniques. Based on a survey conducted by Process Excellence Network (PEX) on over 874 process professionals in 2013 (see Figure 1), lean, Six Sigma and Business Process Management remain the most widely methodologies of process improvement (Davis, 2013). Lean manufacturing is now a part of management philosophy in different sectors from automotive and aerospace industries to IT and Healthcare services.

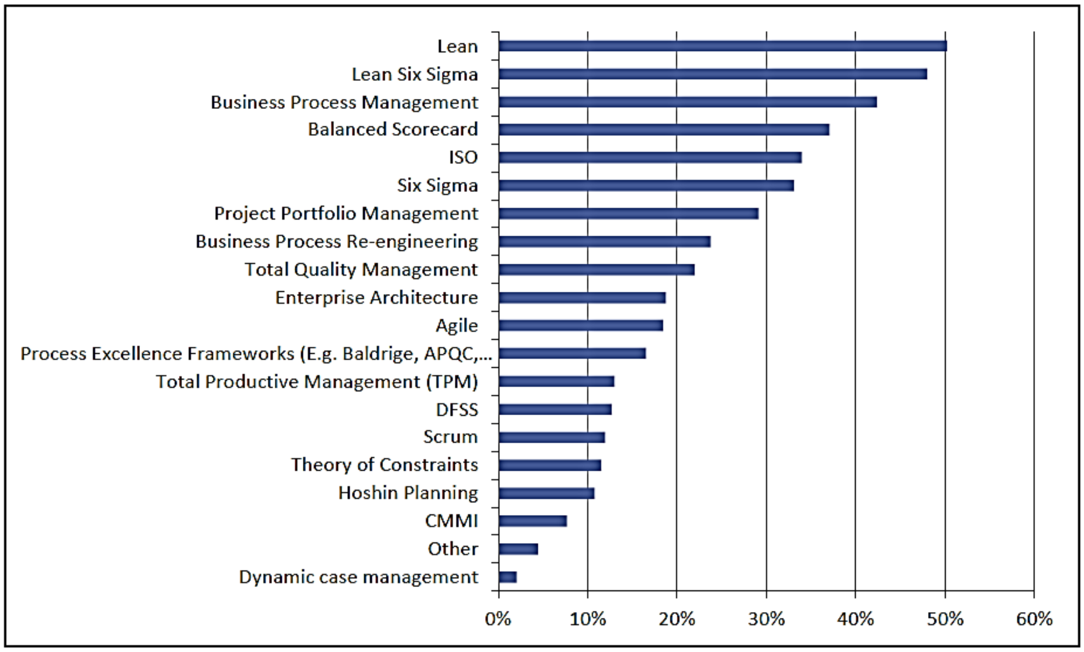


Figure 1 : Most widely methodologies of process improvement (Davis, 2013)

1.2 Statement of Research Problem

Lean is a management philosophy and a transformation journey, in which, time, evolution and organizational culture are critical elements of implementation. Diverse maturity models and assessment tools have been developed to guide lean practitioners through the process of lean evolution (LAI-MIT, 2001). Most of the maturity models provide a general direction and a company-wide roadmap to improve organizational performance in the level of enterprise. Developing a roadmap in the enterprise level, linked to organization's objectives and strategies, is crucial to transform the organization to a sustainable leanness status. This is the reason of huge investments on developing and applying generic and specific models of lean transformation.

Although many companies have tried to implement lean to reduce cost and increase productivity, most of them have been unsuccessful in creating a set of goals and a clear roadmap in the level of operations so that employees on the frontline can follow a step by step, daily plan of refinement, problem solving and continuous improvement. As stated by Michael E. Porter (1988), Organizational processes are divided into two main groups: primary activities and support activities (Figure 2). From a value-adding standpoint, the operations create the majority portion of the value through value chain in both production and service. Lean Manufacturing focuses on elimination of non-value-added activities (Womack, et al., 1991) and the improvement of value-added processes through continuous improvement. In addition, sustainable results are the consequence of behavioural changes, which will not happen instantaneous (Capgemini Consulting, 2010). According to the results of a global survey conducted by Capgemini Consulting (2010), the most key issue preventing the progression to lean sustainability has been identified as "Resistance to change".

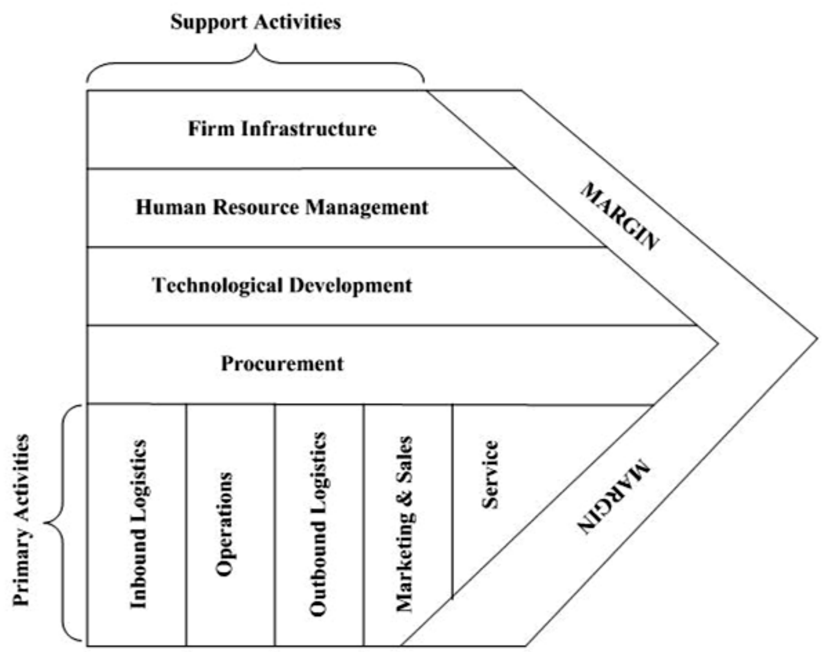


Figure 2: Porter value chain (Porter, 1998)

Despite the importance role of production cells in creating value, the transformation principles to respond to the change requirements in the operational level have not been considered as deserved. Maturity models identified in the literature do not provide a practical measurement system for assessment of lean implementation in order to meet the explicit objectives at the shop-floor level. Using the Toyota Production System model known as Toyota House (Figure 3) as a basic model of lean implementation, when lean has been discussed in the operational level, the focus has been turned to application of lean tools and techniques such as 5S, Kaizen, TPM, and Standardization.

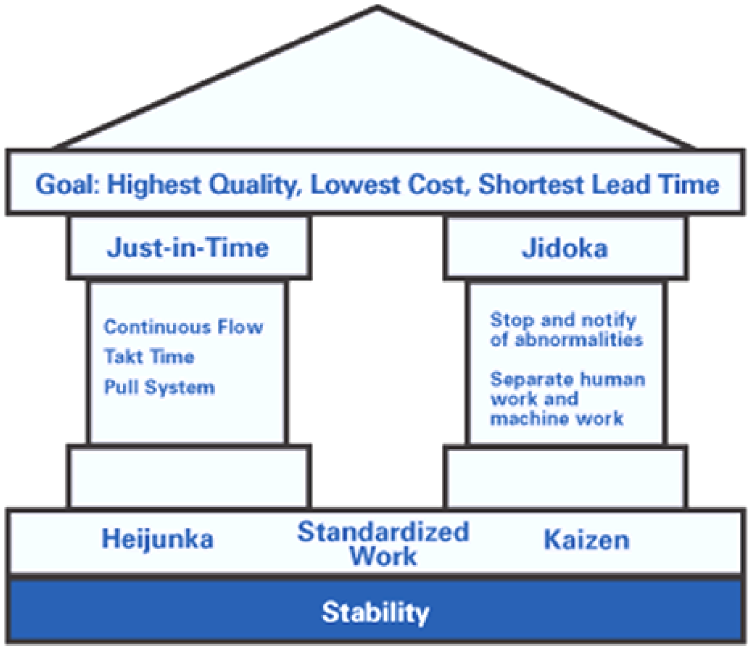


Figure 3 : Toyota Production System "House" (LEI, 2008)

Considering the relationship between maturity models and assessment systems, a gap exists in the literature about the lean manufacturing assessment tools similar to what was stated about maturity models. While some studies have given a lot of attention to assessment of organization's leanness (Amin & Karim, 2012; Chauhan & Singh, 2012; LAI-MIT, 2001; Pakdil & Moustafa Leonard, 2014), some others have concentrated on performance measurement as a result of lean initiatives (Anvari, et al., 2012; Seyedhosseini, et al., 2011; Tupa, 2013). However, each study has either focused on the lean tools and techniques or lean performance measures in the level of enterprise. Existing lean assessment models did not consider the leanness measures in the Production cells, nor did they examine the relationship between the daily activities related to lean implementation in the production cells and production cell's performance.

Furthermore, most of the proposed models on developing and evaluating lean have been conducted from an assessment viewpoint, as would be conducted by the lean practitioner or the third parties. These assessment models are comprehensive, but can be incompetent due to their either generality or unrelated elements to the certain organization's characteristics. They are mostly used for the assessment of lean implementation based on general requirements and provide general guidelines. In each organization, it is necessary to develop a self-assessment model in order to assess and lead the lean efforts.

1.3 Research Objectives

A comprehensive, dynamic, multi-dimensional lean Maturity Model (LMM) is developed in this study to assess the leanness and lean effectiveness in seven axes of production cells, namely: People, Working Conditions, Facilities, Production Processes, Quality, JIT and Leadership. The performance criteria are categorized into the axes of the model. The lean assessment criteria are also developed in each axis and in four levels of lean maturity which are: Understanding, Implementation, Improvement and Sustainability. The data of leanness and performance of a case study then compared together to evaluate the effectiveness of lean practices.

By developing a customized LMM for production cells, this study intended to fill the gap mentioned earlier about the lack of tailored maturity models at operational level. The proposed model can be applied by practitioners as a framework to design and develop a company-specific LMM. Concluding that there is no one-best-way recipe for lean implementation (Netland, 2013), this study is not intended to provide a detailed prescription for production cells to develop and assess lean implementation; rather it proposes a framework to assess lean maturity based on grounded lean principles. It also suggests a dynamic process to adopt designed framework according to firm's strategies and company's priorities.

Also, by measuring the performance of production cells from different perspectives and then comparing them with the results of lean assessment in each dimension, as suggested in this study, the model can be used to evaluate the effectiveness of lean initiatives. The visual format of lean LMM can be applied to find the gaps between requirements of leanness and results of their practices, and to fill that gap by focusing on the areas of strength and those needing improvement.

The model can be used as an assessment tool to evaluate the leanness of production cells from different perspectives. Furthermore, it can also be used to assess the effectiveness of lean efforts on organizational performance. Thus, it creates insight into the relationship between lean indicators and production's performance measures. It can also be used as a guideline for selecting the appropriate tools of process improvement and for benchmarking the weaknesses and strengths of each production cell from the different perspectives.

1.4 Research Questions

Considering the mentioned important void within the body of knowledge and practical initiatives, by providing a conceptual model of lean maturity in operational level, this research seeks to address the following fundamental questions:

RQ1: How can an organization measure the overall leanness and lean maturity level of a production cell? Which quantitative and qualitative metrics should be used?

RQ2: How can an organization measure the overall performance of a production cell?

RQ3: How can an organization evaluate effectiveness of its lean practices in production cells? How can a multi-dimensional maturity model support an organization to assess its overall lean performance?

1.5 Research Overview

This study examines the existing literature on lean concept in general, as well as on lean maturity models and lean assessment tools in particular. To do so, firstly, an extensive literature review on lean principles, tools, and objectives is conducted; and the fundamental principles of lean manufacturing and corresponding tools, methodologies and techniques (as they relate to the shop-floor activities) are identified, analyzed, classified and described. Then, a conceptual model is developed for assessment of lean maturity in production cells. The best practice of lean maturity and lean assessment models are investigated and the principles and the design concepts behind them are analyzed. As a result of data gathering and analysis on maturity models and according to transformation rules and general design principles of maturity models, axes and levels of maturity as they relate to the shop floor activities are suggested. Next, a methodology to define organization's leanness and performance objectives is proposed. As a result, a simple visual maturity model is proposed as a communication tool to show the leanness status and the weaknesses and the strengths of lean initiative. The model proposed a link between the leanness and the performance of production cells in order to evaluate both lean efficiency and lean effectiveness. Then, to test the applicability of model, data of for both leanness and performance measures is collected within a case study. Using a proposed simple fuzzy logic concept, the performance results associated with each dimension of lean are summarized into a single benchmarking number and determined leanness level is compared to performance result of production cell. Finally, the study is concluded by presenting the main limitations of the proposed framework and action needed for its customization, as well as potential future research in this area.

1.6 Definition of Terms

Cell: "The location of processing steps for a product immediately adjacent to each other so that parts, documents, etc., can be processed in very nearly continuous flow, either one at a time or in small batch sizes that are maintained through the complete sequence of processing steps" (LEI, 2008)

Downtime: Loss of production efficiency because of planned or unplanned stoppage (LEI, 2008)

Effectiveness: Capability of meeting exact customer requirements

Efficiency: "Meeting exact customer requirements with the minimum amount of resources" (LEI, 2008)

Gemba: The Japanese term for "actual place," often used for the shop-floor or any place where value-creating work actually occurs (LEI, 2008).

Heijunka: Or load-levelling box is a tool used to help levelling both the mix and volume of production (Rother & Shook, 2003)

Jidoka: Providing machines and operators the ability in detecting when an abnormal condition has occurred, and instantly stopping work (LEI, 2008)

Just In Time: "A system for producing and delivery of the right items at the right time in the right amounts" (Womack & Jones, 1996)

Kaizen: Incremental improvement to a process or a product within a manufacturing context (Rother & Shook, 2003)

Kanban: A request signal to produce or withdraw upstream materials in a production process (Rother & Shook, 2003)

Lean manufacturing: An approach to production based on the philosophy of eliminating all waste from operations. In lean manufacturing, production only occurs when there is a demand from a downstream process (Rother & Shook, 2003)

Lean principles: The fundamental lean practicing concept on which transforming and sustaining lean is based. The principles guide organizational initiatives into leanness.

Lead time: The time elapsed between the order of a product or service to the time of delivery (Jones & Womack, 2003)

Level of leanness: The level of implementation lean manufacturing principles and practices in order to achieve organizational objectives through continuous improvement activities (Soriano-Meier & Forrester, 2002)

Mistake proofing (Poka Yoke): Providing the capability of alerting or preventing passing or producing of non-conformity products or services in the process by avoiding or alerting mistakes in the work

Non value-added work: Work done by a supplier that for whom customer is not willing to pay (Rother & Shook, 2003)

Pull: One of the basic principles of lean manufacturing system. Producing only the type and the quantity of product which are asked by internal following process based on the customer order

Supermarket: "The location where a predetermined standard inventory is kept to supply downstream processes" (LEI, 2008)

True North: "An organization's strategic and philosophical vision or purpose" (LEI, 2008)

Takt time: Derived from the German word Taktzeit which means beat. Takt in lean lexicon is a reference number which set the production pace of industrial manufacturing lines based on the rate of the customer demand (Rother & Harris, 2001)

Visual Management: Application of visual signals, charts and graphs instead of numbers, texts and written instructions in order to clarify and facilitate communication between all levels of organization

Waste Reduction: There are three types of waste, with the Japanese terms Muda, Mura, and Muri

- ***Muda*** indicate the diverse wastes occurring in production and quality processes in the shop-floor activities. Waste in the context of lean means any activity that uses resources but not creating any value for the customer. Seven basic types of waste include: Overproduction, Overprocessing, Waiting, Inventory, Defects, Transportation, and Motion (Ohno, 1988).

- ***Mura*** refers to "unevenness in operations. For example, a gyrating schedule not caused by end-consumer's demand but rather by the production system, or an uneven work pace in an operation causing operators to hurry and then wait" (LEI, 2008)

- ***Muri*** refers to "Overburdening equipment or operators by requiring them to run at a higher or harder pace with more force and effort for a longer period of time than equipment designs and appropriate workforce management allow" (LEI, 2008)

XPS: A company specific production system which is the same as Toyota Production system (TPS) in basis and principles

CHAPTER 2: LITERATURE REVIEW

2.1 The Theoretical Framework

In order to answer the research questions, lean manufacturing in its institutional and academic context is investigated in this section by collecting the information and data on the following subjects:

- A review of the lean history
- A review of the lean manufacturing principles, tools and objectives
- A review of the content and the design principles of maturity models
- A review of the lean maturity/assessment models

Then, an inductive approach is used to develop a conceptual model and a framework for leanness assessment in the operational level. The proposed methodology for assessing lean implementation is built based on the data and the fact collected from the most applicable and addressed model of maturity and leanness. Since the study focuses on implementation of lean in the operational level with consideration of lean requirements at the strategic level, the models have been chosen to analyze the both perspectives. In addition, based on the nine years of the author's experience in Renault Production System, this model has been considered as a part of the research in operational level.

2.2 Review of Lean History

Considering the difficulties caused by the economic crisis after the Second World War, Japan emerged defeated and had to fight difficulties such as high cost of raw material and low internal demand (Chiarini, 2013). In order to struggle with the crisis, Japanese companies started to develop some strategies and techniques to improve the quality of products and decrease the cost of production. In 1947, Dr. Deming came to know and developed a respect from the Japanese after engagement to advise on sampling techniques for a major census and once again, after when he received an invitation from The Union of Japanese Scientists and Engineers (JUSE) in March of 1950 to return to

Japan and to teach the application of statistics to quality improvement as a part of Japan program to improve quality (Robert B. Austenfeld, 2001).

Drucker suggested managers in the West pay close attention and study the Japanese industry as an important competitor as well as an industry teacher (Drucker, 1971). He discussed some important Japanese management characteristics such as decision by consensus, willingness to change, continuous training and continuous improvement as the key elements of Japanese success. After the oil crisis of 1974 and by the end of the 1970s, Japan was the nation to follow for its industrial and economic structure (Chiarini, 2013).

2.2.1 TPS and Lean

Of all attentions to Japanese management system, the Toyota Production Way drew widest consideration (Chiarini, 2013) as a result of Toyota dramatic spurt in the sales and its 6th place in the ranking by sales table of market share in 1970 (Watanabe, 2007). In 1978, Ohno published "Toyota Production System" in Japanese and credited FPS and American supermarkets behind his just-in-time thinking (Shah & Ward, 2007). He suggested a sale-based scheduling system instead of schedule-based forecast. In 1988, Ohno's book was published in English. In 1989 Shingo and Dillon (1989) described the principles and mechanics of Toyota Production System such as Just In time, elimination of wastes, SMED and Kanban in detail. Toyota's way of shop floor management was later called lean by John Krafcik in 1988 (Womack, et al., 1991).

Turning industry's attention to the Japanese way of management and specifically Toyota Production System entered to a new phase after publishing Womack *et al*.'s book, *The Machine That Changed the World;* the book in which the word "lean Production" was used to explain the production system created by the founder of Toyota, Sakichi Toyoda and Toyota engineer Taiichi Ohno (Womack, et al., 1991). Womack *et al* (1991) investigated Japanese production system on behalf of International Motor Vehicle Program. Stone (2012) termed these two periods as "Discovery" and "Dissemination" phases of lean, which started in 1970 and finished in 1996.

At the end of "Dissemination" phase, when most of the companies had spent enough time to apply lean tools and techniques and had not achieved the same benefits as Toyota, more attention turned to lean principles and Toyota culture underlying lean rather than simply imitation of applying lean tools and methods. Based on the series of research started by Spear and Bowen (1999), followed widely by other researchers, more attention has been turned to rules and principles of lean, the nature of working they called "DNA of TPS". The book "*lean thinking"* by Womack and Jones which was published in 1994 was another response to the question in mind of organizations looking for the results of their lean Practices. Stone (2012) also determined another three phases of lean literature as "Implementation", "Enterprise" and "Performance" phases. Stone's systematic literature review shows a growing attention on different perspectives of lean philosophy from 1997 to 2009.

The concept of lean has been evaluated and expanded significantly beyond its origins in the automotive industry (Hines, et al., 2004). Today, lean has being applied in all sectors of manufacturing, banking, healthcare, retail, IT, government and even non-profit organizations. It is employed by small, medium and large enterprises as a popular change and transformation framework (Taggart & Kienhöfer, 2013). Its application also has expanded from door to door manufacturing to whole supply chain.

2.2.2 XPS

While many companies have attempted to implement Toyota Production System or lean manufacturing as the best practice of manufacturing system, after development of system over time, or even in some cases, during the introduction of system to the facilities, they realized that imitating the TPS model is not a perfect prescription for their companies.

First, the internal and external regulations, organization's priorities, organizational culture, nature of industry, organizational environment, economical factors and company's processes made some TPS's tools and principles more effective in some organization, while not important or even applicable in others. Different manufacturing systems have specific characteristics which distinguish their way toward excellence.

Second, in most cases, access to the TPS knowledge was limited to the observed elements which were tools and visual procedures. As a result, companies started to create and implement a company specific model as own best-way of continuous improvement programmes (XPS) (Netland, 2013). Mercedes-Benz Production System, Hyundai Production System, Renault Production System and Chrysler Operating System are some samples of these approaches. The movement has not been limited to the automotive companies, once the concept of lean was developed by other industries; they started to initiate their own best way as well. Honeywell operating system (HOS), Nestlé continuous improvement programme, Siemens Production System, Bombardier Achieving Excellence System (AES) and Boeing lean+ are some examples of efforts made in the other industries.

A general model of lean consists of the tools and concepts applied by the firm in the form of a graphical model or a sort of procedures and instructions which guide employees to use those tools and methods. However, regardless of design and visual form of model, it represents a piece of TPS puzzle. The approach of focusing on the tools and techniques and the approach which grew naturally in Toyota over decades are so often counter-cultural that they have made successful implementation of lean a major challenge.

2.3 Lean in Strategy Level, Lean in Functional Level

Creating a lean culture in the organization always requires behavioural changes in all organizational level. There is an explicit need for leveraging supportive tools and trainings to apply change. On one hand, being lean is often part of the core business strategy and should be considered in any important and strategic decision made by the company. On the other hand, equipping employees with appropriate techniques and methods and empowering them to use a suitable set of those techniques for any difficulties or improvement events can make an indicative impact on an organization's performance.

The practical and academic research which have been tried to drive lean to a more efficient and effective concept can be divided into two main categories. First, lean concept from a strategic standpoint which focuses more on philosophical perspective of lean as a management philosophy and a way of thinking (Womack & Jones, 1996; Spear & Bowen, 1999). Second, lean concept as an improvement technique in operational level which focuses more on practical perspective of lean as a set of management techniques and tools for improvement (Shah & Ward, 2003).

Hines *et al* (2004) maintained that lean exists at two levels: Strategic and operational (figure 4). In their study on the evolution of lean, they concluded that the difference between lean thinking at the level of strategy and lean production at the level of operation is an important element in understanding lean in order to implement the right techniques and strategies and to create value from the customer perspective.

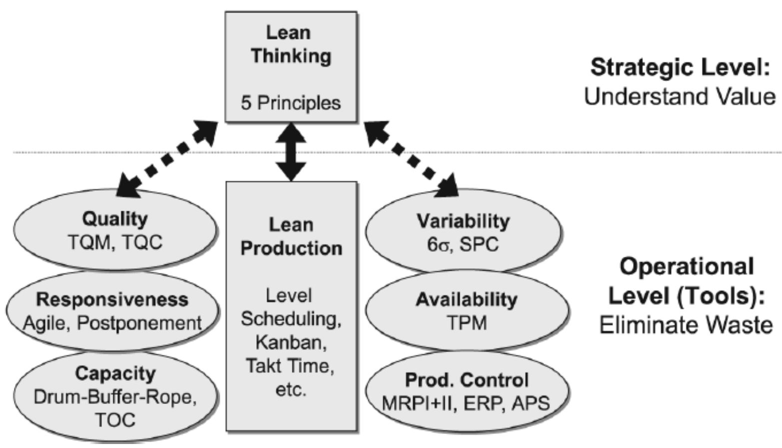


Figure 4: Two level of lean Management (Hines, et al., 2004)

Hines *et al* (2004) suggested the use of lean production as a set of lean tools such as Kanban and Takt time for implementation of lean at the shop-floor level and application of lean thinking based on the Womack and Jones's proposition of lean principles for implementation of lean at the strategic value chain dimension. Womack and Jones (2003) pointed out that a lean way of thinking helps companies to "specify and line up value, to create actions in the best sequence, to conduct these activities without interruption whenever someone requests them, and to perform them more and more effectively". They suggested companies to follow the five principles of lean thinking include: *Value*, *Value Stream*, *Flow*, *Pull* and *Perfection*. However, by considering the five principles of lean thinking as the core management philosophy of Japanese firms, we could not separate them from application of lean at operational level. What is known as a principle should be applied through all elements of a system in all levels. For example, *pursue perfection* is a generally accepted convention through all levels of organization in both operational and non-operational sections.

As depicted in Table 1, Pettersen (2009) added two perspectives of philosophical and practical orientation based on the Shah and Ward study (Shah & Ward, 2007) to the two level of strategic and operation as mentioned above. Pettersen (2009) characterized the lean in four different ways: *Performative*, O*stensive*, *Discrete* and *Continues*.

Table 1: Four Approach of lean production (Pettersen, 2009)

	Discrete (Operational)	Continuous (Strategic)
Ostensive (Philosophical)	Leanness	Lean thinking
Performative (Practical)	Toolbox lean	Becoming lean

However, this classification fails to consider the importance of lean principles and lean thinking in the implementation of lean at all the stages from strategy to practices. In other words, there is not such a concept as a separate lean thinking approach or a lean toolbox. Kosandal and Ferris (2004) also suggested two level of transformation: strategic level for achievement of enterprise benefits and tactical level for localized improvements.

Regardless of the type of strategy plan and deployment system an enterprise use, lean in the strategy level needs to be considered and its interdependencies and interactions with other strategy's elements should be addressed. Considering lean as a management philosophy, its effects on other company's strategies is beyond question. As a simple example, using the lean concepts such as takt time or one-piece flow can directly influence organization's strategy on technology selection. Impact of using supermarket and Kanban system on company's infrastructures is another example of this. In practice, an enterprise-level lean strategy can be a key component of corporate strategy plan.

2.4 Lean Principles, Tools and Metrics

A wide range of management concepts have been introduced and analyzed due to the broad volume of lean literature and vast lean practices (Wang & Huzzard, 2006). Design and implementation of LMM required identifying and gathering comprehensive information from the literature about principles and practices related to lean manufacturing, and thereafter applying those when developing the model. To achieve an overall perspective, in this section, the literature has been studied from three main perspectives: lean principles, lean tools and lean metrics.

2.4.1 Lean Principles

According to Stephan Covey's definition, Principles are indispensable facts and common laws which are timeless, incontestable and self-evident (Covey, 1999). Principals are derived from a company's strategy and are used as the guidelines to operate in accordance with the overall strategy (Netland, 2013). Successful implementation of lean depends ultimately on its underlying principles. Lean principles in terms of lean thinking first were considered by Womack and Jones (1996) in the book *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. In their book, they suggested organizations to follow five lean principles as a framework of implementing lean. Womack and Jones' five principles are (Womack & Jones, 1996):

- *Value: identify the value from customers perspective*
- *Value Stream: Identify "specific activities required to design, order, and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer"*
- *Flow: "Progressive achievement of tasks along the value stream so that a product proceeds from design to launch, order to delivery and raw materials into the hands of the customer with no stoppages, scrap or backflows"*
- *Pull: Only make what is pulled by the customer signal of need*
- *Perfection: By continually removing successive waste from value stream*

In a guide developed at the Massachusetts Institute of Technology (MIT) under the auspices of the lean Aerospace Initiative (LAI), six core strategic concepts of the lean paradigm have been proposed as the overarching strategic concepts of lean. Four principles of lean introduced by Womack and Jones are summarized in tow principles of value and value stream and flow and pull by MIT team. They also suggested four other principles as: *Waste minimization and continuous improvement*, *near perfect product quality* (almost the same as perfection in Womack and Jones), *Horizontal Organizational Focus* and R*elationships Based on Mutual Trust and Commitment* (Mize, et al., 2000).

Based on the series of research started by Spear and Bowen (1999), more attention has been turned to rules and principles, the nature of working the so-called "DNA of TPS". They discussed four underlying principles of lean in the terms of TPS rules. The first rule discussed the way people work at Toyota. The high level of detailed work standards in all aspect of organization's processes in Toyota is the result of their first underlying principle. The second rule discussed the way customers, employees and suppliers interact with each other in Toyota. Simple and direct pathway of product or services and scientific and common method of improvement and problem solving under the guidance of a sensei are the third and fourth principles of Toyota based on the observations of Spear and Bowen in Toyota manufacturing sites (Spear & Bowen, 1999).

Liker (2004) in his book *The Toyota Way: fourteen Management Principles from the World's Greatest Manufacturer* provided a synopsis of the *fourteen* principles as the foundation of Toyota Way. These fourteen principles are organized in four categories: long-term philosophy, the right results from right process, adding value to the organization by developing people, and creating a learning organization by continuously solving root problems (Liker, 2004).

Among all the models of lean implementation/assessment, the principles have been considered most in the Shingo model. The model has been built based on the operational excellence principles and represents the guiding principles and the related supporting concepts in the graphical form of Shingo house in four categories: cultural enablers, continuous process improvement, enterprise alignment and results (Miller, 2012). The model is intended to assess the culture of operational excellence in an organisation by questioning the principle-based behaviour of its leaders, managers and associates.

Many other researchers have also attempted to classify lean manufacturing principles. For example, Pettersen (2009) listed lean principles in terms of most frequently mentioned characteristics of lean based on a literature review. Shah and Ward (2003) used sixteen key references and listed twenty-one lean practices which include both principles and techniques. Some of shah and ward's lean practices can be considered as lean objectives or tools. For example maintenance optimization, planning and scheduling strategies, preventive maintenance, process capability measurements, quality management programs, quick changeover techniques, safety improvement programs and total quality management. Netland (2013) ranked main principles of lean based on the study of thirty company-specific production systems. His list include the general management principles such as "Clear Communication" and "Innovation" which is not necessarily related to lean initiative, as well as lean specific principles and techniques like "Heijunka" and "Jidoka".

In Table 2, the lean principles are summarized based on the common definitions of subject in the key references. Since the distinction between lean tools, principles and metrics is very important when designing a LMM, only principles are categorized in Table 2. Lean tools and metrics have been studied in separate sections.

Table 2: Lean principles

Lean Principles	Source/s
Defining value precisely from the perspective of end customer. *Customer value and value stream* *Create value for the customer*	(Womack & Jones, 1996) (Mize, et al., 2000) Shingo Model
Identifying the entire value stream for each product or product family *Focus on Value Stream*	(Womack & Jones, 1996) Shingo Model
Establish Flow *Create continuous process flow to bring problems to the surface* *Bottleneck removal (Production Smoothing)* *JIT/Continuous Flow Production* *Simple and direct production pathway*	(Womack & Jones, 1996) Shingo Model (Liker, 2004) principle 2 (Mize, et al., 2000) (Shah & Ward, 2003) (Spear & Bowen, 1999)
Provide what the customer want only when the customer want It *Use "Pull" systems to avoid overproduction* *Pull System/Kanban*	(Womack & Jones, 1996) (Liker, 2004) principle 3 (Mize, et al., 2000) (Shah & Ward, 2003) Shingo Model
Pursue Perfection *Waste Minimization and Continuous Improvement* *Near Perfect Product Quality* *Continuous Improvement Programs* *Improvement at the lowest level and under a teacher's guidance*	(Womack & Jones, 1996) Shingo Model (Mize, et al., 2000) (Shah & Ward, 2003) (Spear & Bowen, 1999)
Base your management decisions on a long-term philosophy, even at the expense of short-term Financial Goals. *Strategic Alignment*	(Liker, 2004) principle 1 (Capgemini Consulting, 2010)
Level out the workload (Heijunka)	(Liker, 2004) principle 4
Build a culture of stopping to fix problems, to get quality right the first time *Assure quality at the source*	(Liker, 2004) principle 5 Shingo Model
Standardized tasks are the foundation for continuous improvement and employee empowerment *All work shall be highly specified as to content, sequence, timing and outcome* *Standardize processes*	(Liker, 2004) principle 6 (Spear & Bowen, 1999) Shingo Model
Use visual control so no problems are hidden	(Liker, 2004) principle 7
Use only reliable, thoroughly tested technology that serves your people and processes	(Liker, 2004) principle 8
Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others *Manager should coach, not fix* *Lead with humility*	(Liker, 2004) principle 9 (Spear, 2004) (Miller, 2012)

Table 2: Lean principles - continued.

lean Principles	Source/s
Develop exceptional people and teams who follow your company's philosophy *Cross-functional work force* *Self-directed work teams*	(Liker, 2004) principle 10 (Shah & Ward, 2003)
Respect your extended network of partners and suppliers by challenging them and helping them improve *Respect every individual*	(Liker, 2004) principle 11 Shingo Model
Go and see yourself to thoroughly understand the situation (Genchi Genbutsu) *Direct observation*	(Liker, 2004) principle 12 (Spear, 2004) Shingo Model
Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly	(Liker, 2004) principle 13
Become a learning organization through relentless reflection (Hansei) and continuous improvement (kaizen)	(Liker, 2004) principle 14
Horizontal organizational focus	(Mize, et al., 2000)
Relationships based on mutual trust and commitment	(Mize, et al., 2000)
Cellular Manufacturing *Cellular design*	(Shah & Ward, 2003) Shingo Model
Competitive Benchmarking	(Shah & Ward, 2003)
Focused factory production *Focus on process*	(Shah & Ward, 2003) Shingo Model
Direct and unambiguous customer-supplier relation	(Spear & Bowen, 1999)
Embrace scientific thinking	Shingo Model
Think systematically	Shingo Model
Create constancy of purpose	Shingo Model

2.4.2 Lean Tools

There is a wide range of lean techniques and methods which can be used to improve the organizational effectiveness and efficiency. The number and diversity of the management tools attributed to the lean production have been increased with the spread of this concept in industry. Ohno (1988) introduced the main TPS concepts and techniques in the book "*Toyota Production System: Beyond Large-Scale Production*". Toyota Production System model, known as TPS House, represents a set of main tools and techniques under the two pillars in a demonstrative model (Figure 3). The two pillars are just-in-time and automation (Jidoka) and the tools/principles are as follow:

- Heijunka
- Standardized work
- Kaizen
- Continuous flow
- Takt time
- Pull system
- Stop and notify of abnormalities
- Separate human work and machine work

Ohno (1988) presented many of the other main TPS techniques such as quick setup, Preventative maintenance, five-why, and visual control in his book. Shingo's book about TPS, *A Study of Toyota Production System from an Industrial Engineering viewpoint* consists of a functional description of continuous improvement tools, such as: Poka Yoke, Statistical Process Control, SMED, Kanban, fool-proofing, inspection processes, visual controls, Five-Whys, Andon and standardized work (Shingo & Dillon, 1989). Shingo and Dillon (1989) described the application of TPS tools to support the basic principles of Toyota Production System.

Womack *et al* (1991) also referred to some important lean practices, such as JIT, quick changeover, Kaizen, production leveling, Kanbans, problem-solving, Five Why's, mistake-proofing and supplier integration in the book "*The Machine That Changed The World*". In a comprehensive literature review conducted by Pettersen (2009) on 37 articles, as well as a number of books, he extracted the most frequently tools and principles of lean and called them "lean characteristics".

Many other researchers have attempted to introduce improvement tools and methods in terms of lean manufacturing which included the main lean tools and methods, as mentioned earlier, plus other more general management techniques. A wide range of research also have been conducted to analyze, compare and combine lean manufacturing practices and other management techniques such as Six Sigma (e.g. Souraj Salah, 2010; Snee, 2010; Corbett, 2011; K. Jeyaraman, 2010), agile (e.g. Marie-Joëlle Browaeys, 2012; Goran D. Putnik, 2012; Mattias Hallgren, 2009), ISO9000 (e.g. S. Karthi, 2011;

Chiarini, 2011) and Green (e.g. Susana Duarte, 2013; Helena Carvalho, 2011) A list of the widely acknowledged tools and techniques based on the reviewed literature is provided in Table 3, which can be used further in the development of LMM.

Choosing the right tools for successful implementation of lean manufacturing system is essential. To achieve sustainable results, lean tools and techniques should support and reinforce each other according to a pre-designed framework. To address these challenges, many organizations have developed a systematic visual model of tools and techniques similar to that of Toyota. For example, Renault-Nissan Company developed a structure as Renault Production System (an example of XPSs discussed in Review of lean History). The model, known as RPS Rocket (see Figure 5), represents the selected set of interdependent tools and techniques and their positions with regard to prerequisites and priorities. One of the main characteristics of RPS rocket is that its tools and techniques are applied synergistically with a close interface and predetermined order. This integrated holistic fashion provides a clear vision about the way company is approaching the objective of daily excellence.

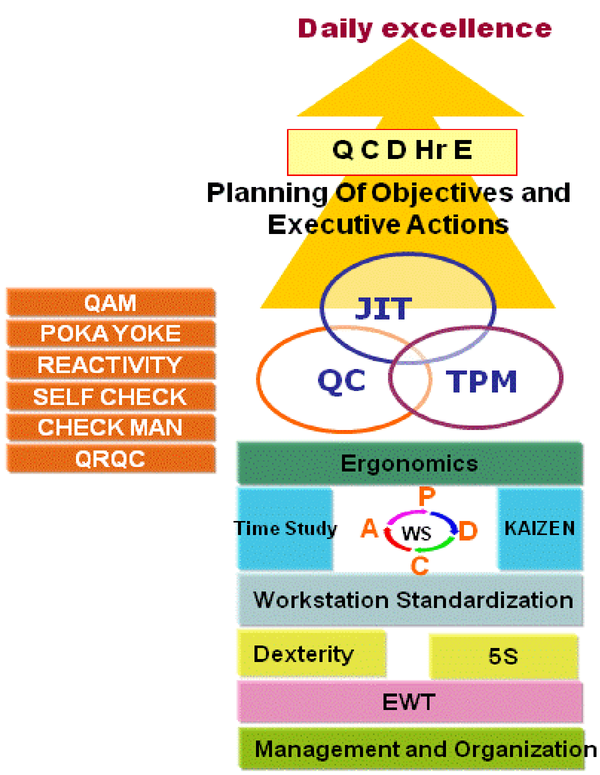


Figure 5: Renault Production System model (SPR, 2004)

Table 3 : lean tools and techniques (LEI, 2008; Shah & Ward, 2007; Liker, 2004; Netland, 2013; Pettersen, 2009; Vinodh & Chintha, 2011; SPR, 2004; Miller, 2012; Taggart & Kienhöfer, 2013)

General	*PDCA* *Kaizen* *Goal alignment/Policy deployment/Hushin kanri* *Benchmarking*
Total Quality Management	*Root cause analysis (5Whys)* *Statistical Process Control (SPC)* *Basic quality tools (Pareto chart, cause and effect diagram, decision making matrix, etc)* *Problem solving methodology(A3, DMAIC, QC Story)* *Gemba (Genchi Genbustu)* *Poka Yoke* *Reactivity* *Self control* *Check man workstation* *Voice of Customer* *FMEA*
Process Improvement	*Setup time reduction (SMED)* *Standardized work (SOPs, routing, travel paths)* *Value Stream Mapping (VSM)* *Kaizen/ Continuous improvement* *Stability study (Cpk, Cp)* *Flexibility*
Work force	*Employee involvement* *Ergonomics analysis* *Cross functional teams* *Suggestion system* *On-the-job training (on-line)* *Basic skill training (off-line)* *Multi-skill personnel*
Visual management and Workplace organization	*process control boards* *Andon system* *QCD board* *5S* *Point of use storage* *Inventory reduction*
Production planning and Material flow	*Kanban/Pull system* *Production leveling/Heijunka* ***EDI (Electronic data interchange)*** *Just-In-Time* *Takt Time* *FIFO* *Cellular manufacturing* *Time/work study* *Cross-Docking*
Infrastructures	*Elementary Working Teams* *Total Productive Maintenance (TPM)* *Supplier involvement/development* *Customer involvement* *Jidoka/Autonomation*

Reviewing the lean manufacturing literature demonstrate that there is no common and sharp boundary in definition and classification of lean principles and techniques. For example, Netland (2013) and liker (2004) maintained standardised work as a principle whereas it has been considered by Ugochukwu *et al* (2013) as a improvement tool. In such cases, it is important to delineate the boundries of lean principles and lean tools. As it has been mentioned before, principles are timeless, incontestable and long-term consistent rules. Thus, they hardly change due to the daily problems in mid-term. On the contrary, the lean tools are selected based on the problem or improvment programs. They may be applicable in some areas while innapropriate for some other intentions. Standardization as a principle, for example, refer to an approach in which all organizaional activitiies are highly specified as to the inputs, the process content, time and sequence and the outputs (Spear & Bowen, 1999). Whereas, standardization, as a tool, is assiciated with some standard formats, such as: Process Operation Sheet (POS), Flowchart and Process Map which are used for different purposes.

2.4.3 Lean - Performance Metrics

The goal of implementing improvement tools and methods is to increase productivity of current processes. Lean practices have strong positive effects on organizational performance (Agus & Hajinoor, 2012). Lean metrics helps organizations to evaluate effectiveness and efficiency of lean initiatives during transformation into the lean enterprise. Chiarini (2013) maintained that lean indicators help better control of process improvement and achievement of results. It increase awareness of lean and importance of continuous improvement throughout all levels, and improve analysis skills at shop-floor level.

At the enterprise level, lean metrics are related to the key performance indicators, such as: customer satisfaction, ROI and market share; whereas at the shop floor level, they include progression of lean program and implementation of lean elements: such as 5s score, number of suggestions, and results of ergonomic assessment, as well as intermediate indicators such as average downtime, set up time and work in progress. Organizations that ignore strategic aspect of lean and concentrate on point optimization of “island metrics” failed to drive the lean initiatives to achievement of the organizational objectives (Hines, et al., 2004).

According to Womack (1991), in order to assess the leanness of an organization, three groups of lean activities must be examined: business goals, processes and human resource. However, Allen *et al* (2001) classified lean metrics into four groups: productivity, quality, cost and safety. Krichbaum (2007) divided manufacturing performance measurements into five categories: safety, people, quality, responsiveness and financial performance. Al-Aomar (2011) suggested three groups of lean measures to evaluate the leanness of production system: productivity, cycle time and work-in-process inventory. Tupa (2013) divided the lean performance key indicators into the three main groups: time-related, cost-related and quality-related key performance indicators. Chiarini (2013) has divided lean metrics into three groups based on their purposes: improving cell/process performance, improving processes and the product/service value stream as well as improving strategic goals

Seyedhosseini *et al* (2011) proposed five perspectives for defining lean measurement criteria based on the Balance Scorecard concept. They used four prospective of BSC in addition to the measures related to suppliers as an indicative element of lean implementation (Seyedhosseini, et al., 2011). They also recommended a set of different objectives and criteria for each perspective, as depicted in Table 4. Similar to this approach, Bhasin (2008) suggested five following perspectives adapting Balance Scorecard approaches to dynamic multi-dimensional performance:

- Financial
- Customer/market measures
- Process
- People
- Future

The future dimension puts emphasis on the ability of organizations in setting the targets based on the new needs and organizational future prospects by considering competitors and customers.

On the other hand, some researchers have investigated the financial effects of lean programs (e.g. Fullerton & McWattersb, 2001; Jayaram, et al. 2008; Boyd, et al. 2006). Many publications discuss the “lean Accounting” as a solution to the problem of large, complex and wasteful traditional accounting systems (e.g. Maskell, et al. 2011; Stenzel, 2008). Chiarini (2013) also discussed the activity-based costing (ABC) as a simplified analysis of the benefits obtained from continuous improvement activities and lean accounting as an evolution of ABC. The impact of lean implementation on organizational financial performance is determined by various intermediate performance objectives, such as: delivery, cycle times, and manpower productivity (Fullerton, et al., 2003). Thus, most focuses were carried out on the mediators, such as: inventory leanness and its effects on financial performance.

Table 4: lean criteria for each lean objective (Seyedhosseini, et al., 2011)

Perspective	Objective	Criteria/measures
Financial	Profitability & satisfied shareholders	ROI% (Goran Olve et al., 2000)
		Profits/employee (Goran Olve et al., 2000)
		Market share (Niven, 2002)
	Productivity	COPQ (Cost Of Poor Quality) ratio (Besterfield et al., 2003; Oakland, 1995)
		Capital utilization percent in creating value (Ohno, 1988)
		Inventory turnover ratio (Niven, 2002; Sanchez & Perez, 2001)
Customer	More satisfied customers	After sale services (Womack et al., 1990)
		Percentage of resale (Yurdakul, 2002)
		Number of customers complaints (Niven, 2002; Yurdakul, 2002)
		Return rates (Niven, 2002)
	Flexible & robust product design	Concurrent engineering application (Womack et al., 1990; Womack, 2006)
		Matrix structure application in product design (Womack et al., 1990)
		Redesigning period after entering the product to the market-M
		Employees productivity for product design-man hour (Womack et al., 1990)
	Just-in-time delivery	Right products delivery (Ohno, 1988; Womack & Jones, 2003; Womack et al., 1990)
		Right quantity delivery (Ohno, 1988; Womack & Jones, 2003; Womack et al., 1990)
		On time delivery (Ohno, 1988; Womack & Jones, 2003; Womack et al., 1990)
		Percentage of interaction through EDI between customers, sales center and production planning department (Womack et al., 1990)
	More quality & lower price	Customers involvement in product value design and quality (Panizzolo, 1998)
		Percentage of interaction through EDI between after sale services center and factory (Womack et al., 1990)
		Price descending growth percentage
Processes	Flexible & adequate processes	Lot sizes (Besterfield et al., 2003; Ohno, 1988)
		Setup time (according to demands) (Ohno, 1988; Yurdakul, 2002)
		Percentage of standard, common and unique parts (products varieties to demands) (Yurdakul, 2002)
	Capable & reliable processes	Average inventory level (Yurdakul, 2002; Bhagwat & Sharma, 2007)
		C_P and C_{PK} of the processes (Besterfield et al., 2003; Jafari, 2003; Oakland, 1995)
		Application of mistakes proof parts and fixtures for production (Raayat Sanati, 2004)
	Available processes	Overall Equipment Effectiveness (OEE) (Alsyouf, 2006; Marchwinski, 2006; Raayat Sanati, 2004)
		The differences between actual start and completion dates and scheduled start and completion dates (Raayat Sanati, 2004; Yurdakul, 2002)
	Value creator processes	Percentage of waste elimination (Karlsson & Ahlstrom, 1996)
		Continuous reduction of lead time in the company (door to door)
		Production according to take time (Marchwinski, 2006)
		Continuous reduction of cycle time (Panizzolo, 1998)
	Creating perfect link between processes	Percentage of products that produced in cellular manufacturing method (Raayat Sanati, 2004)
		Percentage of the annual requirement value that is scheduled through a pull system (degree of pull) (Karlsson & Ahlstrom, 1996)
		Application of long and short time production smoothing percentage (Raayat Sanati, 2004)
Employees	Increasing lean culture and motivation	Number of suggestions per employee in a year (Kaplan & Norton, 2000)
		Percentage of implemented suggestion (Kaplan & Norton, 2000)
		Innovative performance appraisal and performance related pay system (Panizzolo, 1998)
		Flexibility in decrease and increasing the number of workers according to demands fluctuation (Shojinka implementation percentage) (Raayat Sanati, 2004)
	Empowerment	Worker identify defective parts and stop the line (Karlsson & Ahlstrom, 1996)
		Expansion of autonomy and responsibility (Panizzolo, 1998)
		Number of functional areas that are the responsibility of the teams (Sanchez & Perez, 2001)
	Expert employees	Worker training rate (Panizzolo, 1998)
		Multifunctional workers rate (Sanchez & Perez, 2001)
		Job rotation rate (Raayat Sanati, 2004)
Suppliers	Just-in-time delivery	Percentage of parts delivered just-in-time (right parts, right quantity, right time) by the suppliers (Sanchez & Perez, 2001)
		Average number of suppliers in the most important parts (Sanchez & Perez, 2001)
		Average length contract with the most important suppliers (Sanchez & Perez, 2001)
	Increasing suppliers performance level and their lean culture	Lean production tools applied by suppliers (Raayat Sanati, 2004)
		Percentage of documents interchanged with suppliers through EDI or intranets (Sanchez & Perez, 2001)
		Percentage of documents interchanged with suppliers through EDI or intranets (Sanchez & Perez, 2001)

In order to assess the effectiveness of lean implementation, evaluation of both financial and non-financial indicators is essential. Clarification of these indicators can help to develop a comprehensive LMM. For this purpose, the measures depicted in Table 5 have been extracted from study of literature. They are thereafter categorized into subsets of financial and non-financial measurements based on the four perspectives of Balance Scorecards. The operational measurements are divided into more detailed subsets.

Table 5 : lean metrics (Chauhan & Singh, 2012; Amin & Karim, 2012; Tupa, 2013; Pakdil & Moustafa Leonard, 2014; Miller, 2012; Chiarini, 2013; Taggart & Kienhöfer, 2013; Bhasin, 2008)

Financial	*Cost of goods sold*	*Cost per unit*
	EBIT (Earnings Before Interest and Tax)	
	Revenue	
	ROI	
	Sales per employee	
	Inventory turnover	*Inventory turnover rate*
	WIP value	*Total work in progress/Sales*
	Cash flow	
Customer/Market	*Customer complaints/Customer satisfaction/*	
	Customer returns	
	Market share	
Learning and Growth	*Absenteeism rate*	
	Number of [implemented] suggestions per employee	
	Training absenteeism rate	
	Multifunctional worker index	
	Hierarchy index	*Total number of job classifications/Total employees*
		Total indirect employees/total direct employees
	Labour turnover rate	
	Employee satisfactions rating	*Based on survey*
Quality	*First passed yield/ Rework*	*Rework cost/sales*
	Scrap	*(DPU/PPM)* *Scrap cost/sales*
	Defect-free delivery	
	Reliability	*Cp, Cpk*
	Cost of poor quality	
	Cost of inspection	*e.g. Number of quality control people*

Table 5: lean metrics (Chauhan & Singh, 2012; Amin & Karim, 2012; Tupa, 2013; Pakdil & Moustafa Leonard, 2014; Miller, 2012; Chiarini, 2013; Taggart & Kienhöfer, 2013; Bhasin, 2008) - continued.

Cost	*Overall equipment efficiency (OEE)*	
	Value added processing time (%)	
	Warranty cost	*Total cost of warranty/Sales*
	Transportation cost	*Cost of transportation/Total sales*
	Capacity Utilization	*Idle capacity/total capacity*
	Work In Process turnover (days)	
	Finished goods inventory	
	Raw material inventory	
	Labour productivity	*Labour hours per unit*
	Manufacturing space required	
	Product transportation length	
Safety	*Injuries index*	
	Ergonomics metrics	
	Safety risk factor	
	Days worked without a lost time accident	
Delivery/ Reliability	*Lead time*	*Average lead time per unit*
	Changeover/set up time	*Average set-up time per unite*
	On-time delivery	
	Right quantity delivery	
	Processing time	*Order processing time/Total orders*
	Material handling time	
	Down time	*Total down time/Total machine time*
	Cycle time	
	Waiting time for sharing tools	
	Waiting time for materials	
	Product stock outs	*No. of stock out/No. Of orders*
	Reorder rate	

Obviously, most of the metrics are not limited solely to the lean and operational excellence efforts, the other company's management dimensions effect results of some measures (such as ROI, cost of inspection and job classifications). Reviewing the literature shows a lack of boundaries between lean metrics and performance measures. Considering the effects of multiple factors on each key performance indicators on one hand and the correlation of different factors on the other hand, make finding the direct impact of individual improvement initiatives on key performance indicators one of the most difficult parts of management practices.

2.5 Lean Maturity and Assessment Models

Recent literature shows an increasing practical and academic interest in maturity models (Becker, et al., 2010). Maturity models have been formed on theory of evolution and change and have been defined as the sequences of stages that articulate an anticipated path of maturity (Gottschalk, 2009). Using a maturity model to define directions, prioritising improvement opportunities, and guide cultural changes is a helpful way of managing the major transformation changes (Nesensohn, et al., 2014).

Application of a maturity model is necessary to lead the project towards right direction, whether a company want to implement lean or to shift its established lean concept to a higher level. In a lean methodology that Capgemini (2005) uses, two level of maturity have been defined: "Taking control" and "Creating Excellence" (Figure 6). In the first level, "Generation I", it is suggested that organization should create a *basic* capability as a start point of progression (transformation phase) that will continue to create desired results and lean culture in second level, "Generation II"(sustainability phase).

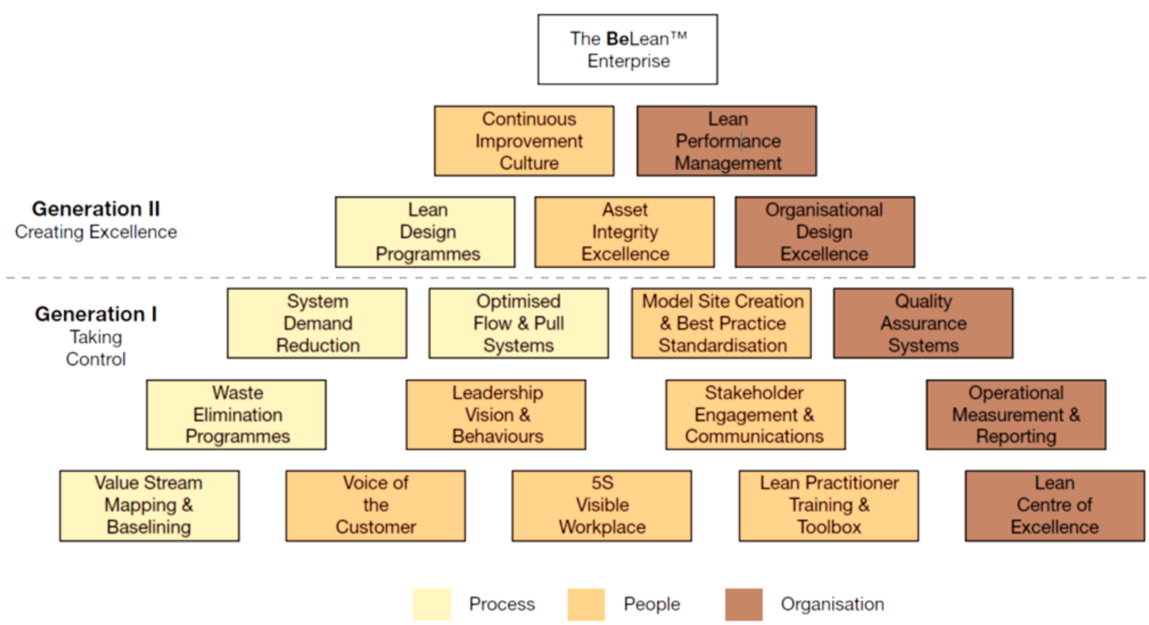


Figure 6: Two generation of lean implementation (Capgemini, 2005)

Lean manufacturing is a gradual process of deep-rooted change in the organizational culture and its people. Therefore, a maturity model and an assessment model to follow a step by step evolution of lean culture are crucial for achieving a sustainable lean status. The approaches were used to measure the leanness of organizations can be divided into two main groups (Behrouzi & Wong, 2013): measuring the level of implementing the lean principles and techniques qualitatively and measuring quantitative results of lean implementation based on the performance outputs.

2.5.1 Qualitative Assessment

Various qualitative assessment tools for the evaluation and development of lean concept have been developed in recent years.

In the operational level, for example, the "Renault Production System (RPS)" was developed by Renault Company based on the Nissan Production way. To increase customer satisfaction, four strategic targets have been set in RPS (SPR, 2004):

- Achievement of desired quality
- Reduction of overall production costs
- Right time and right quantity production
- Personal accountability and mutual respect

RPS rules, procedures and techniques are applied to increase industrial performance in four main manufacturing functions namely Product and Process design, Inbound Supplying, Outbound Logistics and Manufacturing (SPR, 2004). However, the primary focus of RPS is in the elementary working teams at the production workstations. The visual model of RPS (Figure 5) shows the set of tools and procedures that Renault used in its production system. A daily excellence roadmap is also developed in RPS which provides the way in which the RPS is deployed and assessed. The RPS roadmap also provides the coherence between all the improvement initiatives and their direction toward RPS strategy (Figure 7). The roadmap is supported by a assessment system which includes the general checklists related to requirements of system at each level of excellence in the eight pillars of the system. In each pillar, system is measured based on the "desired level of generalization", "management" and "desired results" (SPR, 2004).

Generalization indicates the degree of applying the SPR method on a daily basis. Management focuses on the desired skills, the control level and the required management practices. Finally, desired results concentrate on the associated level of performance in each step.

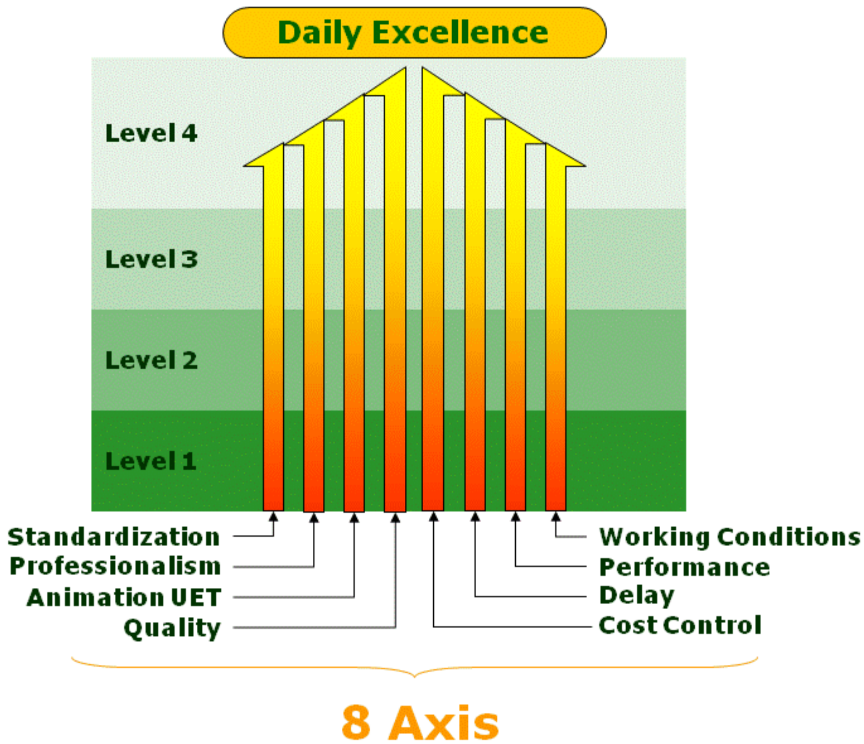


Figure 7: RPS Roadmap (SPR, 2004)

In enterprise level, the MIT assessment tool or lean enterprise self-assessment tool is one of the most comprehensive systems which was developed by the "Lean Aerospace Initiative" at the Massachusetts Institute of Technology. The lean Aerospace Initiative (LAI) has been formed from major element of U.S air force and Massachusetts Institute of Technology (MIT) to conduct research in the transformations at the large complex socio-technical enterprises (Nightingale, 2009). As a result, a framework for lean transformation was developed which includes key principles, transformation roadmap and assessment model. In comparison with the principles extracted from various lean studies as depicted in Table 2, Nightingale (2009) focused more on holistic view of lean principles related to stakeholders, lean transformation and leadership. Enterprise Transformation Roadmap has been designed to propose the holistic process of lean implementation. It consists three main cycles of activities for lean transformation: Strategic cycle, Planning cycle, and Execution cycle (Figure 8).

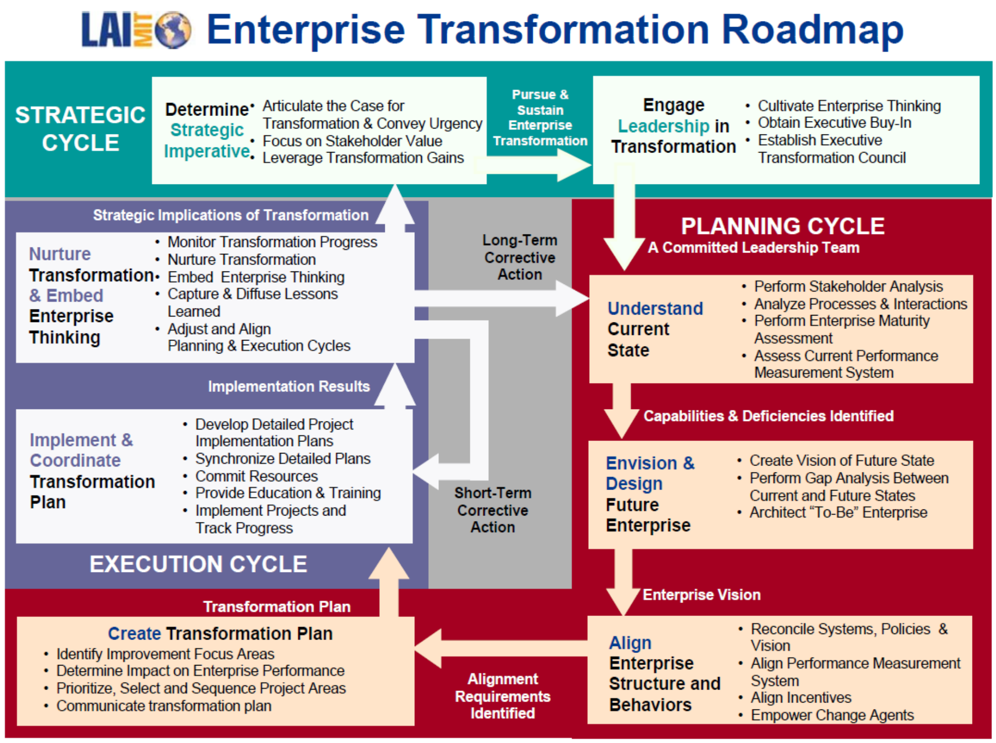


Figure 8: lean Enterprise model developed by LAI (Nightingale & Srinivasan, 2011)

To complete the model, LAI proposed a lean evaluation framework, lean Enterprise Self Assessment Tool (LESAT). LESAT is a powerful guideline which helps organization to assess their readiness for transformation as well as their level of maturity. LAI determined following five level of capability maturity in supply chain management: Traditional, Adopter, Performer, Reformer and Transformer (Bozdogan, 2004). Main characteristics of each level has described as follow (LESAT, 2001):

> ***Level 1***: *"Some awareness of this practice; sporadic improvement activities may be underway in a few areas".*

> ***Level 2***: *"General awareness; informal approach deployed in a few areas with varying degrees of effectiveness and sustainment".*

> ***Level 3***: *"A systematic approach/methodology deployed in varying stages across most areas; facilitated with metrics; good sustainment".*

> ***Level 4***: *"On-going refinement and continuous improvement across the enterprise; improvement gains are sustained".*
>
> ***Level 5***: *"Exceptional, well-defined, innovative approach is fully deployed across the extended enterprise (across internal and external value streams); recognized as best practice".*

Among all the developed models of lean management, LAI provided one the most comprehensive models described the primary activities and major tasks as well as supportive enablers and tools. According to Hallam's analysis (2003) of information obtained from thirty-one enterprises in the US and UK aerospace industry that were utilizing the LAI lean Enterprise Self-Assessment Tool (LESAT), going through the assessment process is a valuable way of understanding the current state of lean. It increase communication and common vocabulary around subject and clarify the current and next level of lean maturity. Although LAI's framework is one of the most comprehensive models of lean transition, like many other recent lean models, it concentrates on internal and external relations and strategic issues from the enterprise perspective. Implementation path (LEM) is clear with the support of LESAT and principles' guide, but practitioners need help with the details of implementations.

The Shingo Prize, as another widely used lean assessment models was created in 1988 at the Jon M. Huntsman School of Business at Utah State University. Shingo model maintains systematic lean assessment by considering the organization culture as a key driver of lean implementation. The Shingo Model highlighted that improvement will not be achieved only when tools and techniques ('know how') are used. Although the tools and techniques are the building foundations of lean transformation, for deeper and sustainable lean transformation, understanding and integrating the underlying Principles ('know why') is necessary. To support the assessment model, a visual model of operational excellence had been introduced by Shingo Academy. The Shingo house consists of four dimensions: "Cultural enablers", "Continuous Process Improvement", "Enterprise Alignment" and "Result" (Miller, 2012).

Shingo assessment model evaluates organizational performance in terms of organizational behaviours and the operational excellence results. The behaviours are assessed through first three dimensions in three organizational hierarchy levels: senior leaders in general, managers and associates in operations and support sections. The results are assessed based on five categories: quality, cost/productivity, delivery, customer satisfaction and safety/environment/morals (Miller, 2012). The model also categorized the business systems into five core sections covered by all dimensions: product/service development, customer relations, operations, supplying processes, management, and administrative support systems (Figure 9).

Shingo operational excellence model is supported by a transformation process based on cultural changes. Transformation methodology is based on the relationship between tools, results, system and principles (Figure 10). In Shingo model too much attention has been spent on the principles as fundamental element of organization culture and key drivers of business excellence. The principles' guidelines and supporting concepts focus on developing of principle-based behaviours. While Shingo model can be used as a comprehensive guideline of cultural change in all level of organization a complementary model of lean assessment based on the tangible evidences and formulated criteria is needed in each firm.

The maturity levels identified by study of lean maturity models are summarized in Table 6. The conceptual definitions of maturity phases are analyzed from different perspectives during the development of LMM in order to design an appropriate model of leanness for production cells in this study.

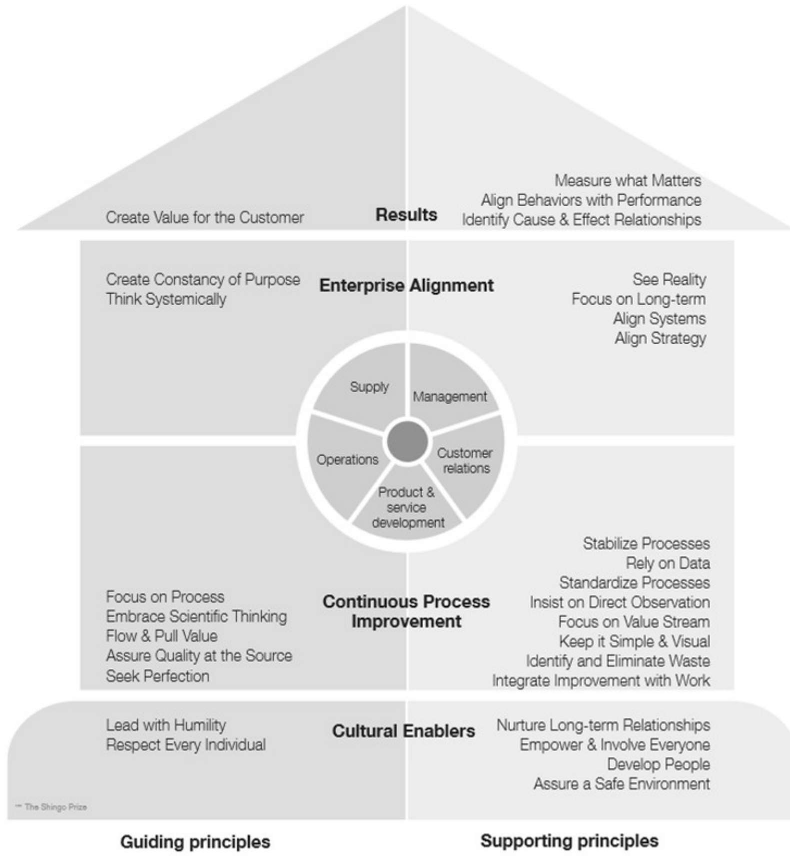


Figure 9: Shingo principles of operational excellence (Miller, 2012)

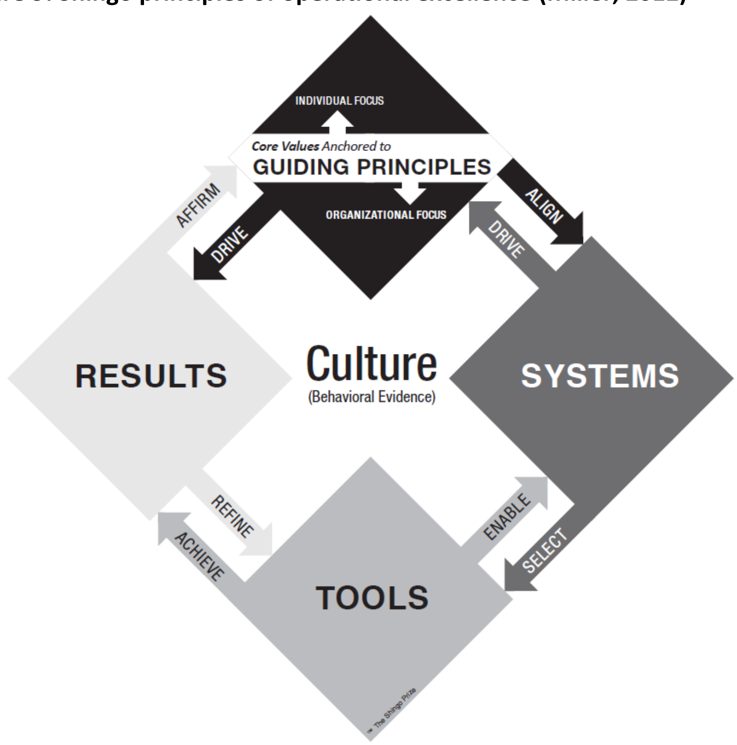


Figure 10 : Shingo Transformational Process (Miller, 2012)

Table 6: Summary of lean Maturity Levels

Model	Maturity Levels				
	1	2	3	4	5
Capgemini (2005)	Transformation phase	Sustainability phase			
Jorgensen *et al*(2007)	Sporadic production optimization	Basic lean understanding and implementation	Strategic lean intervention	Proactive lean culture	lean in extended manufacturing enterprise
SPR (2004)	Experimentation	Deployment	Consolidation	Continuity	
LAI-MIT (2001)	Some awareness of this practice; sporadic improvement activities may be underway in a few areas.	General awareness; informal approach deployed in a few areas with varying degrees of effectiveness and sustainment.	A systematic approach/methodol ogy deployed in varying stages across most areas; facilitated with metrics; good sustainment.	On-going refinement and continuous improvement across the enterprise; improvement gains are sustained.	Exceptional, well-defined, innovative approach is fully deployed across the extended enterprise (across internal and external value streams); recognized as best practice.
Peter Hines (2013) lean Business Model	**Reactive:** - Reactive approach - Little/no involvement - Ad hoc learning	**Formal:** - Formal structure - Only specialist - Team learning	**Deployed:** - Goal orientated - Selected teams - Value stream learning	**Autonomous:** - Driven deployment - Majority involvement - X-process learning	**Way of life:** - Autonomous habit - Full empowerment - External learning

2.5.2 Quantitative Assessment

The second groups of assessments use performance outputs as the result of lean implementation to assess the leanness. Wan and Chen (2009), for instance, proposed data envelopment analysis (DEA)-leanness as a single index of leanness level. They used a Slacks Based Model (SBM) for development of a lean measurement system and determination of the potential improvement direction. Some other researchers applied fuzzy logic concepts to assess leanness of organization. For example, Vinodh and Vimal (2012) used multiple measures based on lean enablers, lean criteria and lean attributes to develop a conceptual model of leanness assessment. They used 30 criteria based leanness and applied fuzzy leanness index to overcome the vagueness and impreciseness of scoring methods in evaluating the leanness of organization. In another study, Vinodh and Chintha (2011) carried out a case study in an Indian electronic manufacturer to test the applicability of multi-grade fuzzy approach on assessment of lean. Zanjirchi *et al.* (2010) also used fuzzy logic to measure the leanness degree of manufacturing companies. They developed a methodology based on the linguistic variables and fuzzy numbers to measure the organization's leanness. Singh *et al.* (Singh, et al., 2010) proposed an assessment method according to the judgment of leanness measurement team to evaluate the leanness through measurement of lean parameters such as supplier and customers' issues, investment priorities and waste elimination. They suggested fuzzy set theory to eliminate the individual's perception bias. In another model, Behrouzi and Wong (2013) used an integrated stochastic-fuzzy modeling approach to evaluate leanness of supply chain. They used expert's judgment to extract the 28 lean supply chain performance measures from an initial list and to score them using data gathered from a survey. Anvari *et al* (Anvari, et al., 2012) provided an innovative approach based on the fuzzy membership function to measure the impacts of lean attributes on organizational performance.

Some research use both quantitative and qualitative measures for a comprehensive evaluation of lean implementation. Amin and Karim (2012) proposed simultaneous application of value stream mapping (VSM), performance metrics and maturity level to measure the manufacturing performance in root cause analysis and lean strategy selection. In another study, Pakdil and Leonard (2014) developed Leanness Assessment Tool (LAT) for comprehensive evaluation of overall leanness based on the quantitative objectives and qualitative individual's perceptions.

2.6 Critical Analysis of Literature

Based on reviewing the literature, the studies and research on lean assessment models have divided into two main categories.

On one hand, several attempts had been made to codify and shape the lean practices into a synchronized set of tools and techniques specifically in the operational level. These efforts included the description of tools and methods, and in the best cases, focus on integration and synchronization of tools and methods and their relations to the organizational objectives. These studies failed to consider transformation principles and infrastructural requirements of lean as a management philosophy.

On the other hand, numerous studies have attempted to explain lean as a holistic approach in the enterprise level. The principles and infrastructural requirements in the strategic level have been mostly referred in these studies. Some perspectives such as strategies and performance management, organizational knowledge, organizational transformation, policies, leadership and external environment have been considered in these cases. These studies generally failed to provide a link between the lean concepts in holistic view and the daily practices of lean in the operational level. In fact, they don't provide a systematic approach to apply lean values and principles in production cells.

From another point of view, two types of assessment measures have been used in development of the practical and academic lean assessment models. On one hand, some studies focus on the evaluation of lean practices and techniques by assessment of inputs and processes. In these studies some data collection techniques such as direct observation, audit and survey instruments are suggested to record the evidence of lean tools and techniques implementation. In these cases, the extent to which lean is implemented is measured against presence of evidence on application of lean tools and principles. Although, supportive guidelines and descriptions are generally suggested for clarifying of assessment criteria, bias of human judgment affects the result of evaluations in these models. Moreover, the focuses of these studies are in lean tools and techniques than results. Consequently, they failed to monitor the effectiveness of lean practise. On the other hand, some researchers suggested measuring the leanness by assessment of outputs. In these studies, overall organizational performance, derived from key performance indicators, are used as the indication of leanness. Although these studies provide a good indication of lean effectiveness, they do not provide adequate visibilities on possible shortcomings and gaps in the implementation of system. Even some studies in which both qualitative and quantitative measure have been used; leanness and performance metrics have been aggregated into a unique indicator. Consequently, they failed to provide possibility of analyzing the lean effectiveness.

Both types of assessment models mentioned above also failed to provide a visual presentation of leanness and performance results in a single format and a simple way understandable by all levels of organization, specifically shop-floor and managerial levels. The research on quantitative assessment of lean generally proposed a final score as an integrated indication of lean performance measures. A single number can be used for benchmarking purpose, but it does not provide any insight into different aspects of lean implementation and strengths and areas of improvements in each dimension.

Based on the mentioned gaps in current lean assessment approaches, in this study, a visual multidimensional lean maturity model in shop floor level is proposed. Providing a condition in the level of shop-floor to assess and lead the implementation of lean is as important as the lean program in the level of enterprise. It should be at the center of attention in all the steps of lean implementation from introduction and training through practicing and applying of tools and principles. Behavioral changes will be achieved during the training, executing, coaching and monitoring steps and through the constructive communication between leaders, lean practitioners and executive teams.

While leanness indicators represent the extent to which lean principles and practices are applied correctly in each dimension of a production cells, related performance results demonstrate the effect of that practices in achievement of production cells' targets, and as a consequence, achievement of organizational objectives. The leanness indicators represent the correct execution of lean practices according to a customized way defined by organization. Thus, they are not appropriate subjects of benchmarking between different companies. Whereas, performance measures are common used indicators and can be benchmarked by best practices in each industry. Lean maturity model suggested in this study provide the possibility of self-benchmarking the best lean practices between the production cells of an organization and also suggest external benchmarking of performance targets between different companies in an industry.

CHAPTER 3: METHODOLOGY

The main purpose of this study is to develop a lean maturity model adapted to the specifications of the production cells in order to assess the leanness and performance of operational level lean initiatives from different perspectives. Thus the focus is on explanatory and descriptive analysis where the objective is to investigate a phenomenon in detail and to explain the relationships and predict outcomes (Yin, 2003). The units of analysis are production cells of a manufacturing company. Lean main control items and performance metrics are the elements of the analysis. A conceptual model is developed based on the review of literature. The suggested model provides the basis for deciding on the type of data to be gathered. Then, a case study approach is used to collect the data. The phenomenon is investigated within its real-life context (Yin, 2003) thorough analysis of both quantitative and qualitative data collected from two production cells of a manufacturing company. Then, data is analyzed inductively. Inductive research use a particular set of facts or ideas to form a general principle (Cambridge Advance Learner Dictionary, Third Edition) and develop a theory based on findings. Further analysis of data enhances the developed theoretical framework by interpreting the leanness and performance results and developing the overall measurements.

3.1 Overview of Research Procedure

Chapter one provides the statement of problem, purpose of the research, research questions and a general overview of the research. The literature review in chapter two presents a review of lean history. In order to answer the research questions, then, an exploratory study on lean manufacturing tools and principles, lean roadmaps, leanness criteria and assessment models was conducted. The research was not limited to academic articles, the reports and documents published and presented as the XPS models in practical cases were also considered. In first section of literature review, the focus is more on identification of lean principles, techniques and objectives in production cells. In the second section, information and fact collected from three most applicable models of maturity and leanness: Enterprise Transformation Roadmap developed by LAI MIT, Shingo Model and Renault Production System.

This chapter discusses the research methodology employed for this study along with the data collection procedure and data analysis methods. The chapter begins by establishing the overall approach and focus of the research. Then, the main stages of developing LMM are defined. The data collection plan and the way both quantitative and qualitative indicators are collected in a case study is then described. Finally, analysis of results is followed by discussion and explanation of research validity and reliability.

Based on the review of literature and experience of author, a conceptual framework is developed in chapter four, which provides a structure of LMM in the level of operation and particularly in production cells. The applicability of model then will be tested through an empirical study and analysis of leanness and performance results in chapter five and six. Finally, the contributions of research, its limitations and delimitations along with the recommendations are presented in chapter seven. Figure 11 shows the general framework of the research methodology.

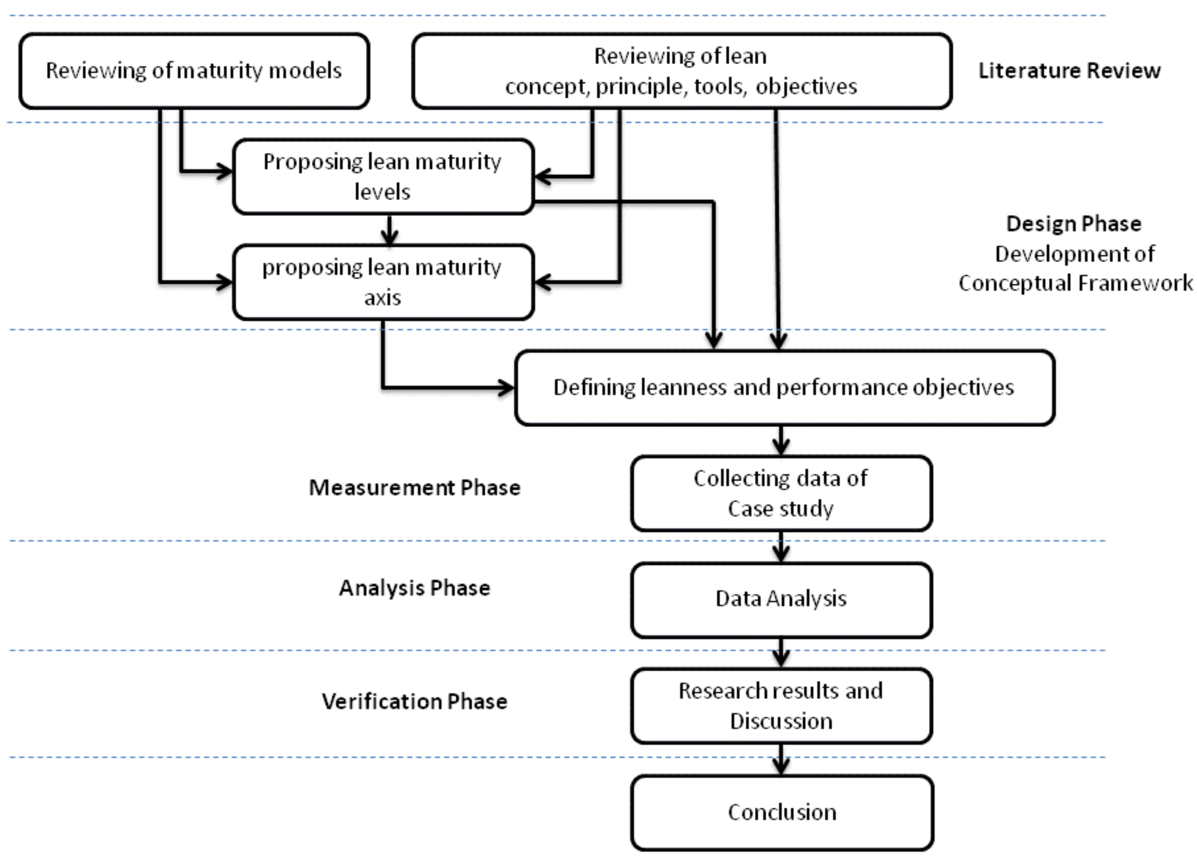


Figure 11: Framework of the research approach

3.2 Design Phase

When describing ideas and concepts, development of a shared language should be the first step in dissemination (Stone, 2012). In research about lean, a wide range of management methods and techniques are investigated. On one hand, general definition of lean makes the review of literature difficult, because a wide range of terms which have been referred as a part of lean system. On the other hand, it makes the research less effective due to an important part of literature which may not be considered by neglecting some special terms as the key words. For example, to implement a lean model, most of companies use a customized production system (referred as XPS). In XPS, according to the specifications and brands of each company, some specific model has been created. By neglecting the term "production system" in search, an important part of lean history will be disregarded. The same problem will happen if we do not consider other terms such as: "Company Production Way" or "Company Way" (X Way), "Operational Excellence" and "World Class Manufacturing". To avoid ambiguity in this research about what we mean exactly by leanness in operational Level, first, the most related terms are defined in "Definition of Terms" section of the Chapter one. The findings of initial research were also filtered by looking more closely in their contents and their relations to the study's objectives. Second, with reference to the results of study in the second chapter, a lean implementation framework adapted to production cells is developed in chapter four. The framework creates a consensus on the boundaries and scope of lean in production cells in this research.

The main steps applied in this research to develop the maturity model of lean are given below:

Step 1-1: Maturity levels: based on the study of existing qualitative and quantitative lean assessment models and customization of maturity concept for operational level, the maturity levels of lean implementation are proposed in the first section of chapter four. Organizational transformation principles, evolution concept of lean implementation and perquisite requirements of lean tools and techniques are considered during development of maturity levels. As a result, following four levels of maturity are suggested:

- Level 1: Understanding
- Level 2: Implementation
- Level 3: Improvement
- Level 4: sustainability

The characteristics of each level and expected level of implementation and result are described in detail in Chapter four.

Step 1-2: Maturity axes: in second step, lean axes are defined based on the requirements of lean implementation in production cells. Balanced development of lean concept in all axes during implementation of lean in shop-floor is very important. Consequently, it is necessary to evaluate the progression of lean program in each pillar to ensure that progression is made in a balanced condition. Based on the explanatory analysis of information obtained from review of lean concept in the literature, following seven axes are defined in the second step of conceptual model development. The axes are specifically defined for implementation of lean in production cells in manufacturing environment. They can be adapted to other industries based on the same logic as used in Chapter four.

- Axis 1: People
- Axis 2: Facilities
- Axis 3: Working Condition
- Axis 4: Production Processes
- Axis 5: Quality
- Axis 6: Just in Time
- Axis 7: Leadership

Step 1-3: Leanness and performance indicators: in third step, the focus is on definition of leanness objectives and organizational performance indicators in each axis of maturity model. Leanness objectives should be defined particularly based on the way of implementing lean in each organization. The general concepts and principles to be considered in a production cell in each axis of LMM have been discussed in third step of model development. But, to develop and examine a comprehensive LMM, leanness and performance objectives should be defined in a real scenario. Thus, a case study is used in Chapter five in order to customize the proposed general model.

Step 1-4: Lean enablers: in last section of Chapter four, lean tools and methods are proposed to support development of lean principles through maturity levels. Lean tools and techniques are extracted from the review of the literature and classified based on the requirements of each axes. The classification provides a general guideline for selection of appropriate lean tools and techniques in each axis of LMM to define the action plans needed for filling the gaps discovered during the lean assessment.

Four steps of LMM development, as is described in detail in Chapter four, can be used as a general framework to development a customized lean maturity model for each organization. Four levels of maturity can be used in any organization to implement lean philosophy gradually in different organizational levels. Lean axes may be changed slightly based on the structure of cells in other sections out of manufacturing industry. Lean and performance objectives and enablers in step 1-3 and 1-4 should be tailored based on the organizational strategy and the way the firm is applying lean tools and techniques in each company.

3.3 Measurement Phase

Defining and measuring of leanness indicators and performance measures is a part of developing LMM which will not happen unless the model adapted to a real case. Thus, a case study is needed to adjust the general proposed framework to a detailed and customized lean assessment model. Furthermore, data is needed to examine the capability of the model in evaluation of lean effectiveness.

A case-study approach was selected because it is a recognizable form of validation in research when detailed "How" and "why" questions are posed about a current set of events (Yin, 2003). A case study is chosen to conduct LMM as an evaluation tool for assessing the leanness of two production cells in different workshops of an automotive company where lean has been practiced for more than seven years. Both quantitative and qualitative methods can be applied for collecting data in academic research. In order to define and collect the data required for assessment of leanness as well as measurement of performance, following steps have been pursued. It is suggested that lean practitioners apply this approach to develop the customized leanness and performance indicators based on each organization's requirements.

Step 2-1: Definition of leanness indicators: based on the specifications of each axis and characteristics of each level as described in detail in Chapter four, in the first step of measurement, leanness indicators in each axis-level of LMM are defined. This step is a very important part of model in development phase and lean assessment in implementation phase. The leanness indicators measure the compliance of lean implementation with the desired level of standard. They should be defined precisely in order to reflect the requirements of each axis-level for a sustainable lean implementation. For each lean indicators, then, the main control items are defined which clarify the indicator to be measured. The output of this step is the lean assessment guidelines which include leanness indicators and associated main control items in each level of maturity for each axis of LMM.

Step 2-2: Development of checklists for measurement of leanness indicators: In the second step of measurement, data collection instruments are developed. Each of qualitative lean indicators represents the progression of implementing different aspects of a lean practice. Thus, it is difficult to measure them by using a single formula. For a more comprehensive assessment of each lean practice, different checklists are developed in this step. Each checklist consists of questions which addressed the requirements of each lean indicator.

Each checklist consists of two main parts to document both general information of audit and detailed results of assessment. On the top right side of the table, general information about the checklist such as name of the related indicator or control item from guideline was provided. At top left side of the table, information should be written about time and place of audit. The questions associated to the indicator are listed in the second part of the checklist. In order to quantify the result of audits, for each question, a 4-grades scoring system includes 0,1,3,5 is used. Score 0 is assigned to the items without any evidence of application (absence of implementation). More than 3 major non-conformances also consider as zero. Score 1 is assigned to major non-conformances such as wrong application of a part of system. Score 3 was used for minor non-conformances which represents single observed lapse in some parts of system. More than 5 minor non-compliances also consider as major. Finally, score 5 was given to a complete accomplishment of an item's requirements. Depends on the importance of each question in the checklist, the value of the questions may be weighted based on an evaluation weighting system. In the case of using such a system to assess the progress, a weighted sum of audit results should be regarded as the final indication of progress. Appendix A shows a sample checklist format used to collect the qualitative information of all leanness indicators.

Step 2-3: Definition of performance indicators: The main purpose of lean initiative is to achieve the organization's main objectives. Measuring the performance of production cells related to lean practices is important in order to show the effectiveness of lean implementation. However, performance results are influenced by numerous factors. Thus, creating a one-to-one link between leanness indicators and performance measures is almost impossible. Some performance indicators such as OEE (Overall Equipment Efficiency) are even related to more than one dimension of lean. On the other hand, focusing on the fewer but most important and most relevant performance measures helps the team to focus on achievement of organization's objectives. The proposed LMM provides the possibility of measuring the effectiveness of lean practices in each dimension of lean model. Further analysis then can be applied to address the principal causes of ineffectiveness.

The performance measures used in each axis of LMM may vary from firm to firm. They can also change to more relevant and more precise indicators when organization becomes more mature. In the third step of data collection, performance measures are defined for each axis of LMM in each production cell of case study. Same as leanness indicators, performance measures are specifically defined in each organization based on their priorities and objectives. In the case study, performance measures are selected based on availability of data and relation of indicators to lean practices. The detail information on performance measures selected in each axis of LMM is described in Chapter five.

Step 2-4: Data collection: in any empirical research, data collection is an important and time consuming phase. Accuracy of data plays a decisive role in the results of research. Several methods of data collection such as direct and indirect observations, audits, interviews, historical analysis and questionnaire can be used for this purpose. The main objective of data gathering is to gather as accurate information as possible related to each indicator of lean implementation in deferent levels-axis of maturity model. In this case study, a structured data gathering approach through observation is used.

To assess the proposed qualitative indicators of lean implementation, direct observation and data gathering through audits are used. Audit is a systematic way to check the evidences and to evaluate them in order to measure the extent to which predefined criteria are met (Chiesa, et al., 1996). Audit also provides the opportunity to address the gaps and coach the involved people to fill them. Audits are conducted for each leanness indicator of developed guidelines by certified lean senior instructors using the checklists developed in the step 2 of measurement phase. In each axis of LMM, audits are conducted first for leanness indicators in maturity level one. Based on the average leanness of each level, then, further audits are conducted for upper levels of each axis. As a generally accepted rule, when the average result of all indicators in a level was equal or less than 70%, the evaluation of production cells stopped in that axis-level.

For collection of data on the quantitative measures of lean and performance, historical data was gathered from case study's production cells and database of Balance Scorecard.

3.4 Analysis Phase

In most of the studies related to the lean assessment, performance measures are used as the indicator of leanness (e.g. Bhasin, 2008; Pakdil & Moustafa Leonard, 2014; Behrouzi & Wong, 2013). Although considering performance indicators is necessary to evaluate the effectiveness of lean implementation, understanding, evaluating and improving the system in which performance is created is also crucial. Understanding the difference and interaction between these two sets of indicators are necessary for assessment of overall lean success. While lean metrics focus on level of lean maturity, performance indicators show how much lean efforts help organization to attain its key objectives. Thus, in this study, the leanness and performance indicators are calculated separately and then compared together in each axis of LMM in order to analyze the effectiveness of lean practices. In order to analyze the results of lean assessment more effectively, the groups of structured data obtained from case study is analyzed descriptively in following steps:

Step 3-1: Calculation of overall leanness: first, data of audits is used to calculate the result of each leanness indicators in two production cells of case study. Based on the number of non-conformances observed during the audits, one of the 0, 1, 3 and 5 scores is given to each question of the checklist. Evidence-based scoring system is used to minimize the perception bias of different auditors. Finally, based on the results of audit which are summarized in the checklists, leanness of each lean indicator is calculated in the scale of 0 to 1. The minimum of the averages leanness indicators in each level is used to calculate the overall leanness of each LMM level. The overall leanness of each axis is also calculated based on the sum of leanness scores up to the first uncompleted level of each axis. Finally, overall leanness of each production cells is suggested as the minimum of overall leanness between seven axes of LMM. Calculations are described in detail in Chapter five.

Step 3-2: Calculation of overall performance in each axis of LMM: Different sets of performance measures with different scales are proposed to measure the performance of each manufacturing cells. Due to the complexity of manufacturing systems, measuring the impact of each practice on performance is very difficult. However, both the results and the practices can be categorized in 7 dimensions of production cells. Performance measurement is a multidimensional concept (Bhasin, 2008). Therefore, a method is needed to synthesize their various dimensions with different scales into a unified index. Referring back to the review of literature on lean assessment models, a fuzzy synthetic index as a composite indicator (Zani, et al., 2013) can be used to calculate the overall performance of each lean dimension.

Fuzzy logic is a form of many-valued logic in which everything is a matter of degree (Zadeh, 1965). Behrouzi and Wong (2013) suggested using fuzzy membership functions to quantify the lean performance of manufacturing systems. They proposed comparing the current performance of the system to the benchmarks determined by historical data. This method is also applicable and useful for measurement of manufacturing cell's performance related to the lean initiatives in each axis of proposed LMM. The following basic definitions of fuzzy logic are used to calculate the overall performance of production cells:

Definition 1 (Kaufmann & Gupta, 1991): A fuzzy set $\widetilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates with each element x in X a real number in the interval [0, 1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\widetilde{A}$.

$$\widetilde{A} = \{(x, \mu_{\tilde{A}}(x)) | x \in X, \ \mu_{\tilde{A}}(x) \in [0,1]\}$$

Definition 2 (Klir & Yuan, 1995)**:** Membership function in a Trapezoidal-shape fuzzy set is defined as $\mu_{\tilde{A}}$(x; a,b,c,d):

$$\mu_{\tilde{A}}\,(x;a,b,c,d): \begin{cases} 0 & if \quad x \leq a \quad or \quad x > d \\ \dfrac{x-a}{b-a} & if \quad a < x \leq b \\ 1 & if \quad b < x \leq c \\ \dfrac{d-x}{d-c} & if \quad c < x \leq d \end{cases}$$

Definition 3 (Klir & Yuan, 1995)**:** In an R-shape Trapezoidal fuzzy set $a = -\infty$ and in an L-shape Trapezoidal fuzzy set $d = +\infty$

To apply the fuzzy logic in calculation of performance, expected value of target and worst case value of each performance measure are required. In the case study, the target and worst case values are defined based on the historical and benchmarking data as desired and minimum expected value of each indicator. Both the targets and worst cases are assigned to two boundaries of lean maturity levels. Accordingly, worst cases reflects the initial situation of production cell in level 0 of maturity (a non-lean production cell) and targets are selected based on the expectation of team from a production cell in level 4 of lean maturity (a lean production cell). The targets and worst case values were used as the threshold of each indicator.

Different performance measures may be used in each axis of LMM. Each represents one aspect of production cell and can be used to fulfill one of the organization's KPIs. Thus, a composite indicator based on the fuzzy membership function is used to condense all the performance measures into a scale of 0 to 1. Composite indicators used to aggregate the multidimensional concepts (Zani, et al., 2013). Then, Intersection of fuzzy membership indicator is selected to calculate the overall performance of each lean dimension. In a comprehensive lean system, all of each level's objectives should be met simultaneously. Therefore, minimum of fuzzy membership values among all the performance measures of each axis shows the overall performance of production cells in that axis. This allows to focus on the gaps in each level of maturity and to fulfill the requirements of each level before going further to the higher levels. It makes the foundation of the system stable enough for sustainable improvements when organization becomes more mature.

Step 3-3: Analysis of lean effectiveness

Finally, the overall leanness indicator in each axis of LMM is compared to the result of overall performance of that axis in order to evaluate the effectiveness of lean practices on the achievement of production cell's objectives. Results of analysis are discussed in detail in Chapter six.

3.5 Verification Phase

Any conceptual model can be validated at many different levels from short-term validation such as analysis of individual professional's feedbacks to a longer term applications in a real case. Considering both the validity of results and time factor, the theoretical development of model initially is examined by comparing its elements with general design principles of maturity models (Pöppelbuß & Röglinger, 2011). The theoretical development phase is completed at the academic level by collecting the information through a comprehensive review of the existing literature and applying them according to the design principles. Pöppelbuß and Röglinger (2011) proposed a pragmatic checklist as a guideline to design maturity models. The guideline consists of three groups of principles: “Basic Design Principles”, “Design Principles for Descriptive Purpose of Use” and “Design Principles for Prescriptive Purpose of Use”. During the development of conceptual model and forming the structure of LMM, these principles are used as the guidelines to develop and to justify the model.

Along with the verification of model requirements in theory, the model is also validated practically in an industry scenario as it is discussed in Chapter five. The case study has been conducted to examine the applicability of proposed model in a real case. Two production cells of the case study are selected based on the different times they had started to implement lean. Considering the factor of time, being in different stages of lean implementation provides variant sources of data for validation and generalizability of model in two samples.

Finally, findings of research are summarized along with its applicability from descriptive, perspective and comparative perspectives. Also, research limitations and recommendations are presented and potential opportunities for further research are discussed in last chapter.

Chapter 4: DEVELOPMENT OF CONCEPTUAL FRAMEWORK

This chapter describes the main steps of developing a maturity model of leanness in manufacturing cells. The model is developed according to the requirements of lean implementation in workstations at the operational level, which is based on the analysis of the RPS information from literature review. Moreover, the following important findings which are borrowed from analysis of LAI and Shingo models, makes the proposed LMM a comprehensive approach for a sustainable lean implementation:

- Necessity of customizing the model to production cells specifications
- Priority of lean principles and objectives over lean tools and techniques
- Consideration of organizational culture, empowerment and involvement of operators and change management as the fundamental principles of lean implementation in production cells
- Importance of clear link between leanness indicators and performance objectives
- Importance of distinguish between short term and long term objectives in evaluation of leanness
- Consideration of design principles of maturity models in development of LMM

4.1 First Step: Maturity Levels

In the first major part of maturity model development, we focus on determining the levels of lean maturity in production cells. Maturity levels in the proposed model are sequential steps needed to be followed in production cells in order to achieve the leanness and performance objectives. Production cells are like small dependent organizations with their own structure and objectives. So they can be assessed based on the characteristics of lean maturity levels.

Developing the generic definitions and the main characteristics of each maturity level are important for assessment (LAI-MIT, 2001). In order to define the levels of maturity, the characteristics of maturation on both sides of the maturity border is required. Typically, in an immature organization, policies and goals are not clearly defined or employees are unaware of them. Moreover, work is done better by individuals than teams. Processes are not standardized. Thus, work is done by different people in different ways. Solving the problems in an immature organization usually is done by focus on fire-fighting rather than prevention and without any referring to previous experiments. There is a little understanding of the action's effects on the final results. Customer dissatisfaction and poor quality despite high level of cost are expected results in such organizations.

On the other hand, in a mature organization, organization's objectives and customers' value are clearly defined and understood by all level of organization. Tasks are done based on standardized and best practice methods and through team working by either existing or newly-assigned staff. Problems are solved based on the analysis of real data and fact and by referring to the existing problem solving knowledge. Consequently, organization is achieving its objectives in the terms of quality, cost and delivery.

Nearly half of the participants of a survey conducted by Capgemini (2010) have listed "Resistance to change" and "Organizational culture" as the key barriers in their lean journeys. Undoubtedly, the behavioural changes toward lean are not easy to achieve and require considerable time and energy. In organizational language, culture can be defined as the sum of individuals' work habits (Mann, 2005). Emily Lawson and Price (2003) pointed out changes in the mind-set and behaviour of employees as a deepest and most difficult level of change. They suggested four conditions for changing mind-set namely "A purpose to believe in", "Reinforcement systems", "The skills required for change", and "Consistent role models". John Kotter (Kotter, 1966) also proposed a model for leading the major change. His model includes the following eight steps:

1. *Establishing a Sense of Urgency*
2. *Creating the Guiding Coalition*
3. *Developing a Vision and a Strategy*
4. *Communicating the Change Vision*
5. *Empowering Broad-Based Action*
6. *Generating Short-term Wins*
7. *Never Letting Up*
8. *Incorporating Changes into the Culture*

Cultural changes are primarily the result of a prolonged and repeated activity by all members of a society which leads to new habits gradually. Habits are the series of observable actions sometimes generate by the activator (Parry & Turner, 2006). The new habits develop new mind-sets and increase the probability of reoccurrence of the action in the future. Consequently, it resulted in new culture (Figure 12).

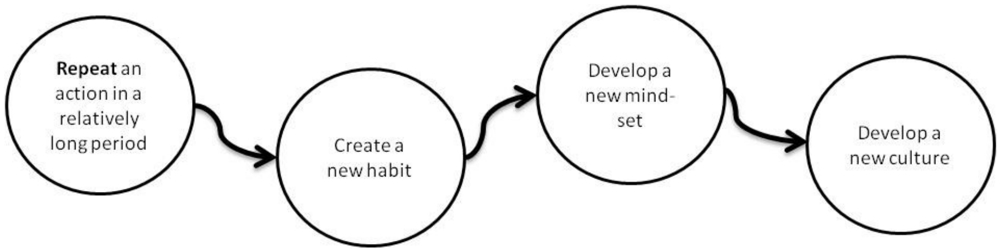


Figure 12: Gradual development of new culture

Applying the characteristics of maturity borders to the scope of production cells and considering the aforementioned transformation principles, the maturity levels are suggested for the level of operation as follows:

- Understanding
- Implementation
- Improvement
- Sustainability

4.1.1 Understanding (Training, Standardization, Stability)

Empowered employees are able to make right decisions and improve the processes based on their appropriate ideas (Miller, 2012). The first phase of proposed model focuses on building the capability of people, machines, processes and all other manufacturing cell's inputs as the infrastructures of lean implementation. This phase of lean implementation is very closely linked to Learning and growth perspective of Balance Scorecard. However, in the proposed lean model, the focus is not only on capability of employee, but also on minimum required capability of other process's inputs such as machines, working conditions and processes.

As we can expect from the purpose of this phase, a significant part of training and coaching is carried out in this phase. These include individual development, on-the-job training, leadership development and training on lean tools and concepts. By concentrating on development of lean capabilities, team members become continuously better in lean practices while creating a learning environment that foster a lean culture (Jørgensen, et al., 2007).

Standardization of activities is another aspect of this level. Standardization is one of the most important principles of lean implementation. Capability of production cell depends strongly on precision of local standards such as workstation procedures, autonomous maintenance processes, control plans and inspection processes. Considering this key element of change management, to measure the progression of standardization in the production cells, two consecutive but overlapped stages is recommended in this research: quantitative and qualitative progression.

At the first level, it is recommended to evaluate the progression of standardization. For example, in the axis Production Processes, percentage of standardized tasks written in Standard Operating Procedure (SOP) can be considered as an initial subject of monitoring, regardless of how precise and correct the workstation standards are. Coaching and monitoring the precision of SOPs, however, start before one-hundred percent progression of first step. For all the axes of LMM, evaluating the qualitative progression of lean standardization should be start in the middle of assessing the quantitative progression. To measure the qualitative progression of standardization in each axis, a precise assessment system should be designed and developed as a part of overall lean evaluation system. To do so, the coaching and monitoring checklists may be developed. Referring to our previous example about SOPs, correctness and precision of SOPs are assessed and improved in this stage.

4.1.2 Implementation (Effectiveness)

Although a significant time has been spent on training of team leaders and members in the first phase of LMM, deep understanding of the system is created through putting in practice all those theories and principles in daily activities at shop-floor. Effectiveness of the trainings depends on the immediate implementation of the concepts in a real situation. While the focus of the first level is on standardizing and stabilizing of processes and increasing the capability of people, the second phase is time to benefit from the created capability to apply the established standards. Several checklists can be developed to measure the implementation of lean principles in each axis.

Since the implementation of lean practices is the main focus of this level, in addition to the leanness measurement, effectiveness of lean initiatives is also measured. Considering the purpose of LMM in this study, effectiveness of lean initiatives is measured based on the desired level of achievement in internal objectives, mainly quality, safety, cost, and delivery. To keep all levels of organization encouraged, performance measures are not suitable indicators for short term evaluation of the program. In turn, we have to assess progression of lean implementation step by step through shop-floor audits. Generating short term wins is one of the guiding points of organizational change (Kotter, 1996). Short-term objectives are required to assess the progression of project and at the same time to encourage the team members to go further in implementation.

4.1.3 Improvement (Efficiency)

Achievement of the production cells' objectives is the main goal of second level of proposed LMM. When lean practices and application of lean tools and procedures become routine of team and part of their daily activities, it is time to focus on efficiency of results. In definition, effectiveness is an indicator of doing the right work (Drucker, 1987) which means the extent to which organizational objectives are met. Efficiency is a measure of doing the work right (Drucker, 1987) which means how economically the resource are utilized to achieve organizational objectives. Nottingham (2009) suggested giving the priority to effectiveness over efficiency as a principle of enterprise thinking during organizational transformation. Obviously, the organization should first focus on selecting the correct way and performing the right activities before improving the set of inputs to achieve best set of outputs during the lean implementation.

4.1.4 Sustainability (Autonomy)

Although lean approach is rapidly spreading in all sectors, many companies face difficulties to sustain their existing lean status. As a result of a survey done by Capgemini in 2010, sustainability of lean over long term has been suggested as the top challenge of lean implementation (Capgemini Consulting, 2010). Considering the difficulties of major transformational changes, many maturity models have been developed. However, their focus is more on measuring the capability to implement change and to become mature. In this study, our focus, in the last level of maturity, is on sustainability of lean program in production cells. While organizations can use the project-based maturity model as a roadmap toward leanness, their lean practices will not finish in the last level of maturity, but in turn, they will start to work in a leanness lifestyle which is not project-based. The last level of maturity in this study has been proposed as a transition stage to this way of life.

While the first step of proposed maturity model focus on the capability and the second and third level concentrate on the performance result both in terms of effectiveness and efficiency, in the last level, the high level of autonomy and self-regulation in production cells is at the center of attention. Autonomy refers to the right and capability given to a group of people to organize its own activities (Cambridge advance learner dictionary, third edition). In a lean organization, solving the problems and improvement of working condition can happen closer to the source by giving more responsibility and autonomy to the working teams (Fernando & Cadavid, 2007). In the last level of maturity according to the LAI model as an example, it is expected that employees get involved actively in setting the goals and planning the required actions for their own production cells (Mize, et al., 2000).

Flexibility of manufacturing cells is another important capability in this level. Integration of processes, lean practices, and information in the production cells in order to increase their responsiveness to internal and external changes is one of the main goals of lean implementation. Multi-skilled operators, flexible manufacturing technology, flexible production plan and availability of multiple work- machine arrangements for different set of products are some elements of a mature flexible production cell.

4.1.5 Maturity Levels - Conclusion

In summary, the proposed levels of maturity are designed based on the principles of lean manufacturing and change management and adapted to the characteristics of production cells. Performance measurement is the process of measuring efficiency, effectiveness and capability of a system against defined objectives (Fortuin & Korsten, 1988). Sinke and Tuttle (1989) maintained three dimensions of the measurement as effectiveness, efficiency and capability. In proposed model, these three dimensions have been considered in first the three levels and have been used as the key Prerequisite for sustainability in the last level.

The proposed four levels of maturity adapted to the requirements of production cells along with expected level of implementation, main focus of each level, expected level of result and brief description of each level are summarized in Table 7.

Table 7: Four levels of lean maturity model in production cells

Focus of the level	Expected level of perception/implementation	Expected level of results	Description
Capability of people, machine and processes	Understanding	Quantitative progression of standardization	Quantitative progress in deploying the tools/concepts to raise awareness of the issue
		Qualitative Progression of standardization	Qualitative progress in deploying the tools/concepts in order to deepen understanding of the issue
Results and Performance	Implementation	Effectiveness	Deployment of tools/concepts in a way that is conducive to the achievement of expected results.
	Improvement	Efficiency	Deployment tools/concepts in a way that achieving the expected results and simultaneously uses resources efficiently.
Autonomy and flexibility	Sustainability	Daily Excellence	Deployment tools/concepts and improve results continuously and autonomously

4.2 Second Step: Maturity Axis

Our objective in the second step is to determine the main axes of maturity model in production cells. These axes are used as a basic structure of lean development and assessment. Any factor defined as a criterion to assess leanness of a manufacturing cell is based on one of these axes. Many maturity models have been developed based on the multi-dimensional frameworks (Fraser, et al., 2002). The multi-dimensional approach helps practitioners to avoid focusing on one axis without considering the others. By defining the axes as a structure of our evaluation model, we verify that manufacturing cells grow in all pillars simultaneously. Moreover, a multi-dimensional framework helps us to define more precise assessment measures both to evaluate the leanness and to plan the required improvement actions.

Depending on the objectives and scope of the lean program, various maturity axes can be defined. For different purposes, the axes may include leadership, strategy, processes, products, services, people, infrastructures, project requirements and technology. For example in LESAT, capability maturity model used to assess organization in three main pillars namely "Enterprise Leadership", "Life Cycle Processes" and "Enabling Infrastructural Processes" (LESAT, 2001). In LESAT model, each pillar consists of some subsets. For example, in Life Cycle Processes, product and process development, supply chain management, distribution and support are examined (LESAT, 2001). In both above mentioned models, as being expected from their scopes, the pillars have been defined in the enterprise level. On the other hand, in RPS model, eight operation-related axes have been defined which include: "Standardization", "Professionalism", "Visual Management", "Quality", "Working Condition", "Performance", "Delay" and "Cost Control" (SPR, 2004). Since the RPS model has been built for assessment of production system in the manufacturing, it is analyzed in details to define the pillars of proposed LMM.

A general definition of process is a sequence of interrelated activities, methods and practices used to change a set of inputs to desired outputs. According to this definition, a manufacturing process can be modelled using the basic IPO. IPO model illustrates the three fundamental component parts of a process: Input, Process and Output (Figure 13). Scope of process can be varied from the main steps of job in a workstation to the whole processes of a factory.

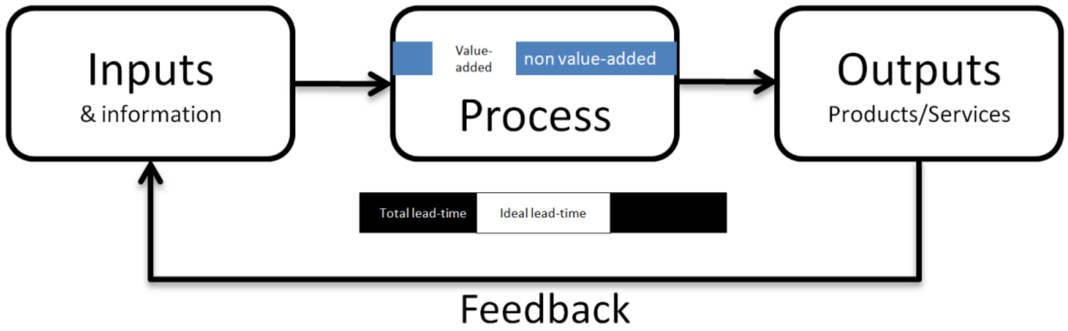


Figure 13: IPO Model

Jayaram *et al* (2010) described four sources of variance in a process: "Part or Products", "People or Personnel", "Procedure or Methods" and, "Equipment or Machine". They also added another category and addressed environmental factors such as "Weather" and "Pollution" as its elements. Using the simple concept of 5M from lean lexicon, manufacturing resources can also be classified into Man, Machine, Material, Method and Milieu (Environment). In agreement with this assumption, our desired output, which is right product/service at the right time and in the right quantity, is result of a well-designed and well-performed process in a manufacturing cell, where 5Ms are arranged and managed for the best possible outcome. Vinodh and Chintha (2011) maintained leanness as a measure of utilising fewer inputs to achieve better outputs. Lemieux *et al* (2013) also defined lean as "doing more with less" by elimination of wastes and optimization of organizational resource. To sum up, the underlying premise of successful lean implementation in the manufacturing cells is largely determined by the quality of the inputs and precision of the methods which applied and integrated into desired product or service.

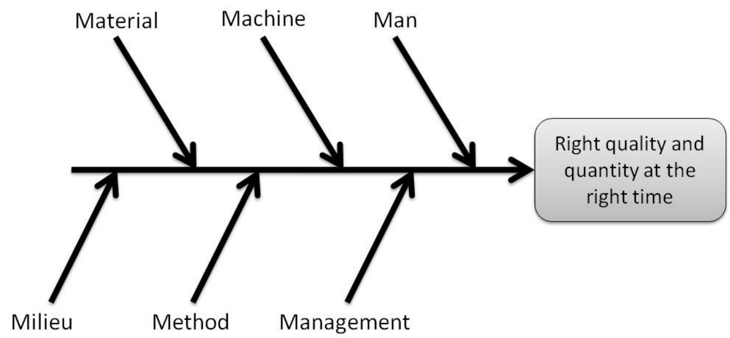


Figure 14 : Inputs of a typical manufacturing process

Analysis of the RPS shows the application of approximately same approach in development of RPS roadmap. In RPS model, Professionalism is related to the development of team within the manufacturing cells. Therefore, it is associated with "Man" in Figure 14. Quality axis in the RPS model is related to the necessary activities for controlling the quality of the material, work in progress and finished goods. Working condition is the same as Milieu in the Fishbone diagram. Axis of Performance indicates the sort of activities necessary to increase the availability and reliability of facilities. Axis of standardization demonstrates the requirements of standardization in production procedures. However, the term standardization is not a good indication of method since it is one of the main inputs of production cells. As it can be seen from the terminology of lean, principles are timeless and incontestable rules which apply to all activities of the organization. Standardization, as it was discussed, is one the lean principles and therefore should be applied in all axis of model. The same logic can be used for two other axis of the RPS model: visualisation (animation in Figure 8) and cost control. Visualisation and Cost control as the principles of lean are applicable for the all axes.

Looking at the lean concept from resource perspective and considering the axes of RPS operational excellence model, we can customize and define the axes of the LMM to the scope of manufacturing cells. As a result, seven pillars have been suggested: People (Man, Management), Facilities (Machine), Working Condition (milieu), Production Processes (methods), Quality (material), JIT, and Leadership. The first view of proposed LMM model is illustrated in Figure 15. What follows is a description of each axis's elements.

Figure 15 : lean Maturity model - Axes

4.2.1 People

Basic production teams are one of the most important aspects of lean at shop-floor. It includes direct production and quality operators, supervisor and other supportive members of manufacturing cell for quality, maintenance, logistics, etc. Production cells can be varied in the terms of size, responsibilities, and authority depends on the function of the team, organizational chart, and scope of the activities. However, to lead a team effectively and efficiently, it has been suggested to arrange the teams of 12 to 20 members for any production cell (SPR, 2004).

Successful implementation of lean in manufacturing cells depends on the commitment of workstation's members. The evidences emphasize on the importance of employee's involvement and their motivation for sustainable organizational change and particularly successful lean implementation (Beale, 2004). According to Jayaram *et al* (2010), fatigue, improper training and lack of motivation are the three main causes of variation in the system performance. For successful implementation of lean, involvement of all organizational level is necessary. Pettersen (2009) indicated "Employee

Involvement" as one of the most frequently mentioned characteristics of lean production. To do the right job, team leader should ensure that team members are completely trained, motivated and empowered to make suitable changes (Capgemini, 2005). From the review of the literature, the main elements of the people axis in LMM are empowerment, involvement, motivation and team work.

Empowerment

Team members in the manufacturing calls should be equipped with required skills, knowledge, and attitude to involve with daily practices of lean. Training, undoubtedly, provides the required capabilities. It is linked to enhancement of organizational commitment (Bartlett, 2001). Although a considerable training is required, it should not be considered as the only way of empowerment. In fact, learning is deeper than classroom training. Successful transition to lean requires a deep understanding of lean principles and practices. The focus of learning efforts must be on changing mental models, beliefs, behaviors, and attitudes of team members.

Members of each production cell should be competent in both technical skills of their specific roles and general and social skills such as team working and problem solving. Technical skills development, however, should not be limited to a single role. A multi-skilled development plan is needed for each cell. This element enhances development of other Human Resource aspects s such as motivation, career path planning, and employee involvement. Moreover, working in internal supplier and customer stations within the production line, and even beyond, broaden the knowledge of the operators on source of problems and customer requirements.

In Japanese manufacturing system, as Spear and Bowen (1999) pointed out in *Decoding the DNA of the TPS*, performance improvement must be made under the guidance of a teacher. The term "Sensei" is used in lean lexicon to refer to this role. The term "guidance" in description of this role means not only be a teacher in cooperation training, but also to help and guide people during the daily activities in the shop-floor. In LEM (LAI) this position is referred as "Change Agent", and defined as an individual who possesses the knowledge and interpersonal skills required to facilitate transformation and change during lean implementation (Mize, et al., 2000). In RPS, this role is called "Senior Instructor".

Involvement

Macduffie (1995) identified three primary roles for workers in lean production systems: physical labour or "doing" work, cognitive input or "thinking" work and member of a social entity or "team" work. More involvement of team members is demanded in lean practices. Consequently, Cognitive and social role of team members is more highlighted through lean activities such as kaizen, 5s and problem solving. Involvement is accelerated through application of suggestion system, regular meeting in manufacturing cell such as pre-shift meetings, participative decision making, problem solving, and improvement practices such as Kaizen and 5s. Evidences show that the numbers of problem-solving suggestions and their implementation rate per employee are higher in lean production environment (Macduffie, 1995).

Motivation

There is a close, yet fragile link between the motivation and other factors of lean implementation such as training and involvement. Based on the results of a research conducted by Beale (2004), motivation for lean is directly affected by employee attitudes, their perceived ability and social pressures. Reward system is one of most frequently used approach for increasing the motivation. It can motivate employees for short term objectives. However, long term programs such as lean implementation requires more sophisticated methods. In facts, by providing the opportunity of learning through training, experience and participation, sense of choice will be increased. Furthermore, supporting the team to achieve the desired targets, they will feel more competent, thus become willing for further improvements. The encouragement by participation and respect establish a corporate culture that benefit from employee`s individual potential as well as the strength of collaboration. Application of some techniques such as annual performance appraisal can help to officially determine and document the team's and individual's targets.

Team work

In RPS system, forming of elementary working teams is perquisite of implementing the production system. Consequently, the system is built on team working. The procedures and interactions are organized and objectives are then set to support the elementary working team. Lean practices also should be designed such that promotes team working. Daily meetings at the beginning of each shift, Kaizen events in collaboration with operators, giving more weight to the suggestions proposed by teams than individual and common targets are some example of these activities. In the book *Toyota Culture, the Heart and Soul of the Toyota Way*, Liker and Hoseus (2007) described the importance of the team working:

> *"At Toyota there are small rewards at the team level and the potential of more significant bonuses shared by everyone if the plant and company perform well. Delving deeper into the values and assumptions of the Toyota culture, we can see this approach reflects the value placed on teamwork. More broadly, Toyota wants its team members to develop the highest level of accountability and ownership and as such to understand that their fate is tied to the company." (p. 8-9)*

4.2.2 Facilities Management

Most important objectives of lean implementation are directly affected by performance of operation's facilities. Facilities management includes all the tools, methods, procedures and activities designed to maintaining the production facilities and optimizing overall performance of enterprise's installations. These sorts of activities are generally organized in the framework of TPM (Total Productive Maintenance) in organization. The idea of Total Productive Maintenance was introduced by Seiichi Nakajima In 1969 as a fundamental part of Toyota Production System (McBride, 2004). By increasing interest of lean manufacturing in the world, more attention has been turned to TPM.

Nakajima (1988) introduced Overall Equipment Effectiveness (OEE) as a key performance indicator of TPM. OEE represents a unique indicator as combined effects of equipment availability, performance and quality. OEE is suggested by Gibbons and Burgess (2010) as an indicator of lean six sigma capability. Based on a study of similarities and differences between lean and TPM, Arashpour *et al* (2010) revealed that OEE improvement serves lean principles like Flow and Perfection.

Involvement of all organization's level from top management to workers on the shop floor is demanded in TPM. Operators in production cells play a critical role in implementation of TPM. In fact, moving from reactive centralized maintenance to a preventive, predictive and proactive maintenance by participation of all organization's level is one of the main objectives of TPM. Activities suggested below can help the achievement of this objective:

- Developing the knowledge and skills of team members to identify and signal the anomalies, analyze and eliminate the root causes, and propose and implement daily maintenance tasks
- Promoting active participation of team members in elimination of equipment's waste and anomalies
- Standardization of daily maintenance activities designed for operators, such as machine clean up, lubricating, general inspection and basic maintenance
- Collaboration between maintenance support team and operation's team to improve TPM activities. For example: training of operators by maintenance staff
- Preparing off-line facilities in which operators have the possibility of practice
- Documenting the knowledge of problem solving associated with machines in the production cells

4.2.3 Working Condition

Working condition of manufacturing cell from the lean point of view can be discussed in two perspectives: First, improvement of operators' working condition due to the application of lean principles and techniques such as ergonomics analysis and safety assessment; Second, assessment and improvement of working conditions from the environmental perspective. Since the proposed maturity model in this study is subjected to production cells, both perspectives are addressed by focusing on the role and condition of production teams on the issues.

Safety and Ergonomics

Employees' productivity is one of the main objectives of lean manufacturing. Employee's health is the main objective of safety and ergonomics programs in organization. By comparison, none of these two objectives can be achieved in the absence of other one. Ergonomics involve the design, evaluation and improvement of activities, work load, working environments, devices and methods that fit the human body and its cognitive abilities to optimize human safety and health (Helander, 2013). On the other hands, based on the lean principle of waste elimination, any source of safety risk and ergonomics problems leads to waiting and cost, therefore, should be eliminated. "Respect every individual" is another principle of lean manufacturing. There is no greater evidence for respect humility than creating a healthy and safe work environment (Miller, 2012). As a result, effective ergonomics is a necessary part of sustainable and correct lean transformation (Walder, et al., 2007). To apply ergonomics programs and safety risk analysis as a key component of lean process, one should consider them, as waste reduction and value creation, as the core values of lean implementation.

Lean manufacturing tools and principles such as visual management and standardization help to create a visibility on potential ergonomics challenges (Walder, et al., 2007). Technical ergonomic analysis should be performed by an ergonomist. However, similar to the other lean principles, participation of production team is necessary. Some practices to encourage the engagement of production teams suggested as follows:

- Ergonomics metrics should be a part of lean measures
- Improvements should be evaluated against their affects on safety risk factors and ergonomic problems
- Basic ergonomics and safety rules should be included in training programs

- Basic ergonomics and safety analysis should be performed by supervisor of manufacturing cell
- Employees should be educated about the potential risks and hazards in their activities
- Safety requirements should be considered as the initial and crucial requirements of operations
- 5S, visual management and Poka Yoke are the powerful tools of safety risk reduction
- Safety and ergonomics improvement should be placed at the top of the kaizen list

Environmental Conditions

Increasing demand of sustainable, durable, and recyclable products and growing need to use renewable energy sources has been considered as the top challenges of future value chains (Forum, 2013). The recent increasing interest in environmental issue together with the grounded interest of enterprises in lean principles have introduced a new perspective of study which consider lean and green (Environmental Management Systems) as a two side of the same coin. Studies show a strong coherence between lean and green manufacturing activities (Bergmiller, 2006).

Elementary working teams of production as a core of manufacturing performance play an importance role in environmental initiatives. The strong emphasis of lean manufacturing on waste elimination incorporates environmental impacts (Herrmann, et al., 2008). However, some specific actions can be designed and implemented to enhance improvement of environmental issues. As an example, some specific kaizen events might be carried out in order to reduce the negative environmental effects of wastes in manufacturing cells. To promote the production team attention to the environmental issue, the suggestions can be also assessed based on their impacts on the environmental issue.

4.2.4 Production Processes

In their famous Harvard article, *Decoding the DNA of Toyota Production System,* Spears and Bowen (1999), explained four rules as DNA of TPST. Their first rule is "standardization of content, sequence, timing and outcome of all organization's activities". The workstations are the adding value stage of supply chain. Hence, standardization of production process in production cells should be at the top of the list of major activities of lean. Most of the remaining lean activities require standardized procedures in manufacturing cells. For instance, assessment of safety risk and ergonomics problems in an inconsistent process or improvement of a process which is done differently by different operators seems ineffective. Also, without using standardized processes, on-the-job training and continuous improvement is not possible.

In addition to standardization as a powerful tool to increase the capability of production process, other source of variations should be analyzed and reduced. Statistical analysis of process capability and analysis of process and product variation are generally the parts of Six Sigma program. Six Sigma is a set of analytical tools and techniques for elimination of variation problem solving (Fursule, et al., 2012). While the focus of lean is on elimination of waste to serve the value based on the customer requirements, Six Sigma, on the other hand, provides an analytical framework for problem solving and analysis of the variations. Many practitioners have benefited from the integration framework of lean Six Sigma. Same as the other lean practices, high involvement of manufacturing team leader and team members is recommended in analysis of variations.

4.2.5 Quality

Getting quality right at the first time is one of the main principles of lean manufacturing (Liker, 2004). Application of Six Sigma in lean manufacturing as a powerful technique of quality analysis has been discussed before. However, in production cells, Six Sigma is not a simple, quick technique to solve daily quality problems. In RPS system, for example, quality control has been defined as a part of the lean implementation which consists of simple and basic quality tools and problem solving techniques tailored for application in production cells (SPR, 2004).

Quality management in manufacturing cells is divided into two main categories: quality control and reactivity system. Quality control manages and monitors key process and product quality parameters. It includes the standardization, implementation and improvement of quality control activities which are done either by production operators in the form of self-control or by quality operators who work under the supervision of team leader. It is recommended to create quality at the source by concentrating on preventive quality activities such as Statistical Process Control (SPC), Failure Mode and Effects Analysis (FMEA) and Poka Yoke. Reactivity system is about problem solving with focus on root cause and non-conformity management. Same as the TPM, all the members of operation and supportive teams are encouraged to use standardization, statistical tools and basic quality techniques to solve the quality problems. Management of non-conform products/parts is a part of reactivity system as well.

4.2.6 Just In Time (JIT)

JIT was designed by Toyota to eliminate keeping of large inventory between processes (Womack & Jones, 2003). JIT is one of the two main pillars of Toyota Production System (Figure 3). It includes a major part of the lean manufacturing tools and concept such as establishing flow, pull system and level out the workload. In RPS, JIT is one of the three elements of RPS rocket (Figure 5). Some elements of JIT such as Value Stream Map (Womack & Jones, 2003) should be followed in the framework of lean transformation at the enterprise level. The structure of production cells are affected largely by JIT at the enterprise level. Consequently, some other JIT practices should be carried out directly within production cells. In the proposed LMM, the second group of JIT activities is considered.

Reduction of inventory is the main objective of JIT process. Depends on the scope of JIT, inventory can be eliminated from supplier chain, door to door manufacturing facilities as well as production cells. Inventory in production cells can be reduced or eliminated by application of continuous flow principles and techniques such as Kanban and heijunka box. By reducing the level of inventory and minimizing the non-value added activities in the workstations, production team can contribute to achievement of JIT objectives. Supervisor should facilitate and monitor the correct application of JIT techniques and synchronization of activities according to planned cycle time in the production cell.

4.2.7 Leadership

Successful implementation of lean depends strongly on management commitment and engagement (Hines & Taylor, 2000). The role of leadership in implementation of lean can be discussed in two stages: The role of leadership in lean transformation in enterprise level and as it is related to this study, the leadership's role in level of operation. The role of leaders to foster the change in the organization culture has been described in detail in other comprehensive research such as in Shingo model (Miller, 2012). Considering the purpose of the LMM in this study, we examine the daily role of leadership in successful implementation of lean in manufacturing cells. In a successful lean project, leaders and top managers are involved in lean daily activities. Their role is not limited to setting long-term goals and strategies and monitoring of progression. Rather, they participate in training and review meetings, they work as a role model and coach, and they are engaged directly in daily lean practices.

In development of lean principles at shop floor level, role of production supervisor is very important. In mass production environment, supervisors focus on daily activities within supervisory area. However, in lean environment, their role is to change the culture of production cell. In this term, their activities are not limited to the daily supervision of workstation, in turn; a great amount of time should be spent for analyzing of past data and planning for future. Concerning their importance role to lead the transformation, they should be competent in both technical and management skills. From the technical perspective, they should know about the details of all of the processes in the production cell. From the management perspective, they should be aware of company's policies, strategies and general rules and transfer them to team members. Furthermore, they should be knowledgeable in lean practices. From the leadership point of view, they need to be equipped with necessary skills to communicate effectively, to train the team members, to lead working teams and projects, and to support the change process.

4.3 Third Step: Lean and Performance Objectives

Setting and planning overall targets of lean implementation and their consistency to organization's objectives and business strategy is necessary for successful implementation of lean. Strategic business objectives, along with lean implementation metrics, are conveyed to all levels of the organization (Mize, et al., 2000). Production cells as the core of the industrial performance are not exception to this rule. A practical maturity model describes current and future maturity levels as well as respective improvement measures (Pöppelbuß & Röglinger, 2011). In the first two steps of model development, the maturity axes and maturation levels of lean have been suggested as a structure of the model which is applicable for all type of production cells. The third step is dealing with the leanness objectives and key performance indicators (KPIs) relevant to lean initiatives which may be customized in each firm.

The lean objectives such as setup time reduction, pull system and shorter lead time have strong positive contribution toward performance (Tupa, 2013). But when it comes to measurements, they don't provide enough information about root causes of problems. Thus, establishing leading targets align with overall objectives of project is essential. While most of the articles published in recent years paid more attention to performance of lean management systems (Stone, 2012), it is difficult to find a study in which midterm targets and their relations to different maturity levels were investigated. Most of the main and as expected, long term objectives of lean such as financial targets are not precise in short term measurements. Therefore, the link between financial and non-financial measures is not easy to perceive. Without considering the leading and as expected midterm indicators, we hardly are able to find our position in the long journey of lean.

Furthermore, if the success of the project is measured by achievement of final objectives at the early stages, the motivation among employees will be faded. Definition of inappropriate metrics can mislead the improvement initiatives and encourage the wrong type of behavior (Bhasin, 2008). As suggested in previous section, in the early stages of lean implementation, targets should be more related to learning and growth, in other words, the capability of people and processes. As we go further through the levels of maturity, the objectives should be more focused on the performance results in production cell, namely: safety, quality, cost and delivery.

Performance indicators are selected based on organizations' strategy. Thus, the KPIs may be different from organization to organization and even from production cell to production cell in each organization. Accordingly, associated leanness objectives also are different. This is what makes the LMM and related production systems (XPS) a unique roadmap for each organization despite the common approach as it is suggested in this study. However, as a common way of measurement, gathering the historical data on performance indicators and application of checklist through monitoring to assess the way production cells applied the lean tools and principles is suggested in this study.

Development of coaching and assessment checklists is part of design and customization of lean development model for each organization. Number of checklists, their content, type of questions, weighting and scoring methods and assessment schedule should be customized accordingly. Regardless of the format and content of each checklist, quantifying the qualitative progression of multiple lean factors in each dimension is essential for evaluation of production cell leanness. A wide range of scoring methodologies such as simple Yes/No or Likert scale can be used to conclude to a unique score for any indicator of proposed LMM. To put the proposed LMM into practice, a case study is conducted and the customized leanness measure and performance indicators are defined in the next chapter.

To evaluate performance of production cell, different targets can be set for each performance indicators at various stages of lean implementation. Demonstrating the leanness status and performance position of production cell in each axis of LMM provide visibility on how effectively lean implementation leads to achieve organization's objectives in each lean dimension. By adding the performance indicators to lean maturity matrix, following visual framework (Figure 16) is suggested to use as a production cell's management dashboard of both leanness and performance indicators.

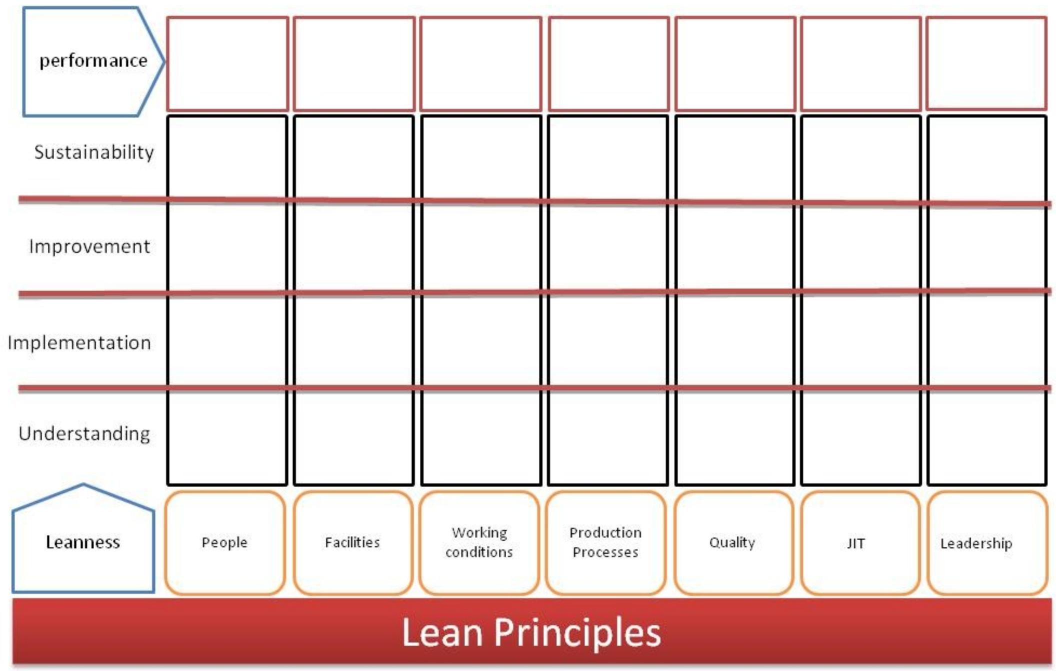


Figure 16: Performance indicators in LMM

Based on the information gathered from the review of the literature on lean objectives (Table 5 Chapter two), those metrics which are most related to the scope of production cells are categorized in 7 axis of LMM in Table 8.

Table 8: Suggested performance metrics in each axis of LMM

People	Absenteeism rate Saving benefits of suggestions Multifunctional operators indicator Employees satisfaction rate
Facilities	MTTR (mean time to repair) MTBF (mean time between failures) OEE (overall equipment efficiency) Availability × Efficiency × Quality Maintenance cost / net asset value Total maintenance cost / unit produced Down time (can be categorized based on down time causes)/ working time
Working Conditions	Safety metrics (e.g. average safety risk factor, Percent of job conditions with medium or high safety risk) Ergonomics metrics (e.g. Percent of job conditions with medium or high ergonomic risk, ergonomics severity index) Workers compensation costs Injuries rate / incident rate Percentage of lost workdays % energy use reduction /unit of product
Production Process	Value-added rate (Value added time / Total leadtime) Workers hours per unit produced Non-value-added hours per unit produced Waiting time / Total leadtime Balance efficiency (Processing time / Number of operators * cycle time)
Quality	PPM (of the manufacturing cell's product) Cost of Quality Customer return for non-conformities with the root causes in manufacturing cell (internal and external customers) First passed yield Rework time / total working time Scrap rate
Just In Time	Inventory turnover WIP value On-time delivery Right quantity delivery Waiting time for sharing tools Waiting time for materials Product stock outs
Leadership	All the KPIs' indicators of manufacturing cell

4.4 Fourth Step: Enablers

In the first two sections of this chapter, lean dimensions and maturity levels have been developed which forms the basic structure of LMM. In third section, based on the requirements of production cells, most applicable leanness indicators and related performance metrics have been proposed which can be adapted and customized to the industry and specifications of organization. In this section, based on the analysis of literature review, lean enablers related to each axis of maturity matrix are investigated and added to the model to form the final structure of lean transformation system in production cells. Maturity models should focus on enablers to drive evolution and change (King & Kraemer, 1984). The lean enablers, as discussed in literature review, are divided into principles and tools.

Although extensive research has been carried out on lean tools and principles, most of the definitions and classifications have failed to define the differences between lean principles and lean tools and techniques. In some cases, even there is not a clear distinction between lean tools, principles, and lean metrics. Principles and tools both are used to improve the lean metrics. However, in architecture of model, it is important to eliminate the ambiguity concerning the classification of lean parameters into these two concepts. Principles are common rules that drive the organizational culture into lean thinking, while improvement tools are point solutions and specific means for enabling a system to perform its intended purposes (Miller, 2011). For example, levelled production is a general guiding principle of lean which means producing in smaller batches in order to reduce the level of inventory. To do so, organization can use Heijunka box as a tools.

Most common-used tools and techniques of lean manufacturing have been summarized in Table 3 (Chapter two). It is important to link the tools and techniques to purposes; otherwise, the firm's objectives will be replaced by tools-oriented goals. Comparing the list of tools prepared in the literature review with the indicators suggested in previous section, following matrix (Table 9) is suggested as a general guideline of applicable tools and techniques in each axis of proposed LMM. Some techniques such as kaizen and benchmarking can be used in all dimensions, whereas, some other tools such as Kanban and TPM can be assigned to a specific axis.

Table 9: Lean techniques-maturity level matrix

List of techniques	People	Facilities	Quality	Production processes	Working condition	JIT	Leadership
PDCA	✓	✓	✓	✓	✓	✓	✓
Kaizen	✓	✓	✓	✓	✓	✓	✓
Goal alignment/Policy deployment/Hushin kanri							✓
Daily review meetings	✓						✓
Benchmarking	✓	✓	✓	✓	✓	✓	✓
Root cause analysis (5Whys)		✓	✓	✓	✓	✓	
Statistical Process Control (SPC)		✓	✓				
Basic quality tools (Pareto chart, cause and effect diagram, decision making matrix, etc)	✓	✓	✓	✓	✓	✓	✓
Problem solving methodology(A3, DMAIC, QC Story)	✓	✓	✓	✓	✓	✓	✓
Poka Yoke		✓	✓		✓		
Reactivity and non-conformity control			✓				
Self control			✓				
Check man workstation			✓				
Voice of Customer			✓			✓	
FMEA			✓			✓	
Control plan			✓				
Setup time reduction (SMED)		✓				✓	
Standardized work (SOPs, routing, travel paths)		✓	✓	✓			
Value Stream Mapping (VSM)						✓	✓
Stability study (Cpk, Cp)			✓	✓			
Cross functional teams	✓						
Ergonomics analysis/audit	✓				✓		
Employee surveys	✓						
Safety analysis/audit	✓				✓		
Environmental analysis/audit					✓		
Suggestion system	✓						
Workstation audit		✓		✓	✓		
Individual development plan	✓						
On-the-job training (on-line)	✓						
Basic skill training (off-line)	✓						
Multi-skill personnel	✓						
process control boards			✓	✓			
Andon system		✓	✓			✓	
QCD board/visual board	✓						✓
Cost-benefit analysis							✓
5S		✓			✓		

Table 9- Lean techniques-maturity level matrix, continued.

List of techniques	People	Facilities	Quality	Production processes	Working condition	JIT	Leadership
Point of use storage				✓		✓	
Inventory control (Supermarket, line side organization, ...)						✓	
Operator balance chart / analysis	✓					✓	
Kanban/Pull system Production						✓	
leveling/Heijunka						✓	
EDI						✓	
Just-In-Time						✓	
Takt Time				✓		✓	
FIFO						✓	
Cellular manufacturing							✓
Time/work study				✓		✓	
Cross-Docking						✓	
Elementary Working Teams	✓						✓
Total Productive Maintenance (Autonomous maintenance, losses analysis, preventive maintenance, OEE analysis, ...)		✓					
Supplier involvement/development (work's unit supplier)			✓			✓	
Customer involvement (work's unit customers)			✓			✓	
Jidoka / Automation				✓		✓	

Lean tools and techniques can be assigned to each axis of LMM based on the proposed leanness indicators. However, lean principles are common guiding rules. Understanding the relationship between principles and tools is important. Some lean principles are applicable when implementing lean in enterprise level, for example "Identifying the entire value stream for each product or product family", whereas, some others such as "Pursue perfection" can be applied in all level as well as in production cells.

5 Chapter 5: DATA COLLECTION AND ANALYSIS

Development of LMM, as discussed in Chapter four, is a part of designing a customized lean transformation system for each company. The leanness measures for each axis-level of LMM should be defined based on the way company satisfy the requirements of each maturity level. Therefore, a case study is conducted within a large automotive manufacturing organization where lean principles have been applied for more than 7 years (hereafter referred to as ABC). The ABC Company is selected based on the company's background in implementation of RPS. RPS is one of the main three lean models which are reviewed in this study. Considering the organization's background in implementation of manufacturing systems, most of the information required for gathering the data on lean main control items and performance measures was available. Therefore, the focus was on organizing data and collecting them through direct observation and audit. This potential capacity of selected sample was important to collect the accurate data in the minimum amount of time. Otherwise, lots of time was needed to generate the required data.

Two production cells are selected to conduct a series of observations, audits and data collection. The focus is to assess the production cells thoroughly in all dimensions of LMM. The advantage of focusing on a limited number of production cells is to invest more time on considering all perspectives of production cells while at the same time to overcome the limitations of typical case studies such as time and budget. However, it may create some problems with its generalizability. To overcome this drawback, two production cells are selected from two production lines in different stages of lean implementation (time from the beginning of lean manufacturing project is selected as a factor of progression). One manufacturing cell is selected from assembly shop where lean has been implemented for more than six years and another manufacturing cell is selected from paint shop where lean has been applied for less than three years. Each of the production cells are assessed based on the seven lean axes.

As discussed in Chapter three, in step 3 and 4 of Design Phase, lean maturity model in production cells should be customized based on the organizational objective and priorities. The general framework discussed in this study can be used during the development and customization of LMM. Since the lean maturity levels and lean axis (step 1 and 2 of design phase) can be used generally as the framework of all production cells in manufacturing industry, the case study start with step 3 of design phase which is definition of leanness indicators and performance measures.

5.1 Definition of Leanness Indicators:

Definition of leanness indicators is part of development of LMM (phase 3 of design phase). The result of measuring the leanness indicators shows how likely the company follows the defined path of lean implementation and how correctly they apply lean tools and techniques as they are standardized in company's production system. Therefore, leanness indicators cannot be defined precisely unless a real case is considered. In the first step of data collection in the case study, leanness indicators are defined based on the specifications of each axis-level of LMM. Therefore, leanness indicators in level 1 reflect the understanding and standardizing of lean practices in each axis of LMM. Consequently, indicators of level 2 focus on implementation of tools and techniques required in each axis of LMM and in level 3, improvement of those practices is considered. Finally, leanness indicators of level 4 emphasize on autonomy and flexibility of production teams in application of lean tools and methods which leads to sustainability of results.

Leanness indicators are defined for each axis of LMM in the form of guidelines. For each leanness indicator, main control items are added in the guideline which helps better understanding of the indicators and indicates the items which should be investigated during the audit. Table 10, for example, shows the guideline of axis Facilities which is developed for the ABC Company. The guidelines for all axis of LMM are presented in Appendix B.

Table 10 : Leanness indicators of axis Facilities

Level	Indicators	Main control items
1.Understanding	A. Progression of **standardizing maintenance tasks** in manufacturing cell (**stability** of machines)	- Percentage of standardized maintenance tasks by supervisor (target 100%) - Standards are available and updated - Quality of prepared standards (e.g. clarity, using visual descriptions, validation , time associated) – control by checklist
	B. Progression of **training** on maintenance tasks in manufacturing cell (**stability** of machines) and Progression of training on types of losses in manufacturing cells (**capability** of employees in analysis of loses)	- 100% training on corrective execution of maintenance tasks - Operators knowledge on maintenance tasks, key safety points, key maintenance points, control limits, etc - Operators knowledge on defined types of losses
	c. Progression of standardizing **set-up/shutdown** processes in manufacturing cell (improve **flow**)	- Percentage of standardized set-up/shut down tasks by supervisor (target 100%) - Standards are available and updated - Quality of prepared standards (e.g. clarity, using visual descriptions, validation , time associated) – control by checklist
	d. Progression of training on **set-up/shutdown** processes in manufacturing cell (improve **flow**)	- 100% training on corrective execution of set-up/shut down tasks - Operators knowledge on set-up/shut down tasks, key set-up/shut down points, etc
2.Implementation	A. Corrective execution of maintenance task in manufacturing cell according to standards (**stability** of machines)	- Percentage of compliance (e.g. sequence, time, safety points) using checklist
	B. Accomplishment of maintenance task in manufacturing cell according to schedule (**stability** of machines)	- Percentage of compliance with schedule
	C. Percentages of anomalies detected by supervisors/ operators in manufacturing cell (**capability** of employees in analysis of loses)	- Number of anomalies detected by supervisor or operator / total number of anomalies detected
	D. Percentages of **set-up/shut down** processes done by operators in manufacturing cell according to standards (improve **flow**)	- Number of set-up/shut down processes done by operator / total number of set-up/shut down processes
3.Improvement	A. Improvement of maintenance task standards	- Percentage of reduction in time of maintenance task
	B. Percentage of Preventive maintenance task to corrective maintenance tasks	- Preventive maintenance hours / corrective maintenance hours
	C. Improvement of set up/shut down task standards (improve **flow**)	- Percentage of reduction in set up/shut down time
	D. Improvement of internal schedule maintenance based on the past data history	- Total time of maintenance task

Table 10: Leanness indicators of axis Facilities, continued.

Level	Indicators	Main control items
4.Sustainability	A. Calculation and improvement of **maintenance cost** by team members according to analysis of KPIs in manufacturing cell (encourage collaboration and autonomy)	- Maintenance work hours - Cost of missing production due to down time - Cost of inspection - Cost of parts/material
	B. Percentage of losses eliminated by team members within manufacturing cell through **analysis** and problem solving processes (encourage collaboration and autonomy)	- Percentage of losses eliminated by team members / total number of losses
	C. Calculation and improvement **set up/shutdown cost** by team members according to analysis of KPIs in manufacturing cell (encourage collaboration and autonomy)	- Set up/shutdown cost in manufacturing cell
	D. Steady trend of improvement on facilities' **stability** and performance indicators such as downtime and OEE through internal and external (if applicable) benchmarking of maintenance best practices (sustainable improvement of **stability in machines**)	- Facilities management indicators

5.2 Development of Checklists for Measurement of Leanness Indicators:

Many items should be checked in different stages of lean assessment in order to evaluate the leanness of each axis. To facilitate the evaluation, use of specific checklists is recommended in which for each qualitative leanness parameter, a series of questions should be posed during the audit. To gather the information on the qualitative indicators of leanness, various audit checklists were developed during the case study. An assessment process to evaluate the progress of lean existed in the ABC Company which was very useful in development of checklists in this phase.

Table 11 shows the questions used in the form of checklist to gather the information related to the first indicator of Axis "Production Processes" in level of "Understanding". The corresponding indicator is: Progression of standardizing production tasks in a production cell. When developing the leanness guideline, this indicator is supported by three main control items. The first control item is "Percentage of standardized production tasks" which is a quantitative indicator and can be calculated using historical data. The second and third control items measure the correct preparation of Standard Operating Procedures (SOPs) developed in production cell which should be checked through control of various items and verification of evidences during an audit.

Table 11: sample of questions used for measurement of leanness indicators

Control Item: Standard Operating procedure (SOP) Axis: 4 - Production Processes Level: 1- Understanding Control Item Code: L_{141}						
Questions	**Score**					**Evidence**
	0	**1**	**3**	**5**	**N/A**	
Are the standards up to date?						
Are the standards available in production cells?						
Are the key points written precisely?						
Are the reasons of key points written clearly?						
Are the works broken down into reasonable steps?						
Are the main steps detailed enough? e.g. way of picking up and grasp						
Are all fields of standard completed correctly?						
Are the sequences of operations clearly defined?						
Are the time of each main steps and total time calculated precisely?						
Are visual descriptions used in documentation of work description?						
Are the engineering specifications written in accordance with engineering requirement?						

5.3 Definition of Performance Indicators:

To evaluate the effectiveness of lean implementation in achievement of organizational objectives, performance measures are defined for each axis of LMM in two production cells of case study. Suggested table of performance measure in Chapter four is used as a reference. However, the list is filtered to select the most relevant indicators based on the current situation of lean in two production cells and availability of data in the system. Considering the company's priorities and availability of data, a team consists of author, lean project leader, lean senior instructors, workshop manager and supervisors have selected the performance objectives of sample production cells through a discussion session. In selection of performance measures, application of cost-related and most lean-related measures is highly preferred. However, some restrictions existed due to lack of historical data on calculation of some performance measures. As an output of the meetings, an action plan was also defined to provide the system of data recording for desired lean performance indicators.

Considering the methodology suggested in this study to analyze and calculate the overall performance of each axis of LMM, target value and worst case value of each performance indicator is also required. Since Balance Scorecard was used in the company , targets had been set in each manufacturing cell for some of the selected performance measures. For the remaining indicators, targets and worst case values were set by the same team who defined the performance measures.

5.4 Collecting the Data of Leanness and Performance

In this case study, two methods of data gathering were used to assess the leanness and performance of selected production cells: audit using checklists (CL) for qualitative indicators, and historical data (HD) for quantitative measures.

For gathering the data of qualitative measures a comprehensive series of audits were conducted for all axes of maturity model namely People, Facilities, Quality, Production Processes, Working Condition, JIT and Leadership. The audits were principally conducted by five senior instructors of a team who was responsible for lean implementation in the company. Production line managers, production cell's supervisors and operators were engaged as required. For leanness indicators, main control items were used as a guideline for auditors to look for required information and related evidences in production cells. In collaboration between the lean assessment team and author, all ambiguities were resolved before the data gathering.

Different leanness indicators are used in each axis-level of LMM to evaluate different perspectives of lean progression. Also, various performance measures are used to show the degree of effectiveness in each proposed axis of lean implementation. To facilitate the process of data collection and analysis, a coding system is used in this study in which for each leanness indicator and performance measure, a unique code is assigned. Table 12 with the help of visualisation shows the main parameters used in calculation of leanness and lean effectiveness. Following notations describe each parameter.

Table 12: Coding of leanness indicators and performance measures

Performance P_{JK}	$P_{11}, P_{12}, \dots, P_{1k}$ $k = 1,2,\dots,n_1$	$P_{21}, P_{22}, \dots, P_{2k}$ $k = 1,2,\dots,n_2$	$P_{31}, P_{32}, \dots, P_{3k}$ $k = 1,2,\dots,n_3$	$P_{41}, P_{42}, \dots, P_{4k}$ $k = 1,2,\dots,n_4$	$P_{51}, P_{52}, \dots, P_{5k}$ $k = 1,2,\dots,n_5$	$P_{61}, P_{62}, \dots, P_{6k}$ $k = 1,2,\dots,n_6$	$P_{71}, P_{72}, \dots, P_{7k}$ $k = 1,2,\dots,n_7$
Sustainability $i = 4$							
Improvement $i = 3$					L_{351}, L_{352}, …, L_{35m}		
Implementation $i = 2$							
Understanding $i = 1$		L_{211}, L_{212}, …, L_{21m}					
Lean Maturity Levels (i)	People $j = 1$	Facilities $j = 2$	Working Conditions $j = 3$	Production Processes $j = 4$	Quality $j = 5$	JIT $j = 6$	Leadership $j = 7$

L_{ijm} *example*:

$m = 1,2,\dots,n_{ii}$

Notations:

i	Level of maturity $i = 1,2,3$ *or* 4
j	Axis of LMM $j = 1,2,3,\dots,7$
L_{ijm}	m^{th} leanness indicator of level i axis j
L_{ij}	Leanness of level i axis j
LA_j	Overall leanness of axis j
LL_i	Overall leanness of level i
L	Overall leanness of a production cell
P_j	Overall performance of axis j
P_{jk}	k^{th} performance indicator of axis j
n_j	Number of performance indicators in axis j
n_{ij}	Number of leanness indicators in level i axis j
$a_{P_{jk}}$	Target value of performance indicator P_{jk}
$b_{P_{jk}}$	Worst case value of performance indicator P_{jk}
$r_{P_{jk}}$	Real value of performance indicator P_{jk}

In order to help normalize the result of observations, all the leanness indicators are converted to the scale of 0 to 100. During a review meeting in collaboration with senior instructors (auditors), lean leader, production line managers and manufacturing cell's supervisors, targets were revised or, if necessary, were defined. For qualitative indicators, equation (1) was used to quantify the results of each audit in a scale of 1 to 100. Based on the results of the audits, the number of items in each checklist with major non-conformances, minor non-conformances and without non-conformances

($a_1, a_2,$ and a_3 respectively) were counted. Then, according to equation (1) the score of each main control item was calculated. Whenever a question was not applicable in a production cell, it was not used in calculation.

$$L_{ijm} = \frac{a_1 + 3a_2 + 5a_3}{5 \times Number\ of\ applicable\ questions\ in\ the\ checklist} \times 100 \quad (1)$$

a_1: $Number\ of\ items\ with\ major\ non-conformances$

a_2: $Number\ of\ items\ with\ minor\ non-conformances$

a_3: $Number\ of\ items\ without\ non-conformances$

Whenever the historical data was available in the system regarding a leanness indicator or a performance measure, it was used in data collection process. Data was used from either two manufacturing cells' management dashboards or workshops' database of Balance Scorecard reports. Historical data is also used for quantitative main control items. For example, to gather data related to "Percentage of standardized rework tasks" which is one of the main control items of level "Understanding" in axis "Quality" (see Appendix B), the list of rework tasks was compared with the standards accomplished for rework tasks. So, the related control item was simply calculated using the following equation:

$$\frac{Number\ of\ standardized\ rework\ tasks}{Total\ number\ of\ rework\ tasks} \times 100$$

A unique code in the format of L_{ijm} is formed by using the indices as shown above. For example, $i = 3, j = 5$ and $m = 1$ forms the code *L351* which correspond to the first indicator of axis 5 (Axis Quality) in level 3. Results of leanness indicators obtained through audits and direct observation of two production cells are summarized in Tables 13 and 14.

Table 13: Leanness indicators – production cell 1

	People		Facilities		Working Condition		Production Processes		Quality		JIT		Leadership	
	Indicator code	MC1-ASSEMBLY	Indicator code	MC1-ASSEMBLY	Indicator code	MC1-ASSEMBLY	Indicator code	MC1-ASSEMBLY	Indicator code	MC1-ASSEMBLY	Indicator code	MC1-ASSEMBLY	Indicator code	MC1-ASSEMBLY
Level 1	L111	100	L211	100	L131	100	L141	100	L151	100	L161	100	L171	85
	L112	100	L212	100	L132	100	L142	100	L152	100	L162	100	L172	100
	L113	100	L213	87	L133	100	L143	100	L153	100	L163	100	L173	100
	L114	100	L214	70	L134	100			L154	100	L164	100	L174	100
	L115	100			L135	100			L155	100	L165	100		
					L136	N/A			L156	100				
					L137	N/A			L157	100				
									L158	100				
									L159	100				
									L1510	100				
									L1511	100				
	Avg	100	Avg	89.25	Avg	100	Avg	100	Avg	100	Avg	100	Avg	96.25
Level 2	L211	100	L221	69	L231	90	L241	87	L251	82	L261	86	L271	0
	L212	70	L222	100	L232	84	L242	100	L252	85	L262	100	L272	100
	L213	65	L223	72	L233	100			L253	100	L263	87	L273	84
	L215	100	L224	100	L234	60			L254	79	L264	100	L274	73
	L216	100			L235	N/A			L255	90	L265	76		
									L256	100	L266	90		
	Avg	87	Avg	85.25	Avg	83.5	Avg	93.5	Avg	89.3	Avg	89.8	Avg	64.25
Level 3	L311	80	L321	58	L331	80	L341	69	L351	60	L361	45	L371	0
	L312	100	L322	35	L332	24	L342	40	L352	0	L362	32	L372	0
	L313	80	L323	0	L333	63			L353	60	L363	100	L373	0
	L314	15	L324	0	L334	23			L355	0	L364	0		
	L316	0			L335	N/A			L356	0	L366	100		
					L336	N/A					L367	15		
											L368	54		
	Avg	55.0	Avg	23.3	Avg	47.5	Avg	54.5	Avg	24.0	Avg	38.5	Avg	0.0
Level 4	L411	0	L421	0	L431	0	L441	0	L451	0	L461	0.0	L471	0
	L412	0	L422	0	L432	0	L442	0	L452	0	L462	0.0	L472	0
	L413	0	L423	0	L433	0	L443	0	L453	0	L463	0.0	L473	0
	L414	0	L424	0	L434	0			L454	0	L464	0.0		
	L415	0			L435	0								
	Avg	0	Avg	0	Avg	0	Avg	0	Avg	0	Avg	0	Avg	0

During the data collection process, some modifications have been proposed in both method of data gathering and content of evidences subjected to collect. In some cases, due to problem faced while gathering some of quantitative data, checklist was proposed to collect data. One of the most significant improvements was to combine the checklists of different levels for the same subject of assessment. For instance, instead of using 4 checklists, each for one of the maturity levels to assess the performance of individual development plan and individual performance review in the axis of “People”, a single checklist was used in which, the requirements, results and calculations were categorized in 4 levels. This helps auditors to conduct a more effective assessment. It also provides an overall view of requirements related to the main control items.

Table 14: Leanness indicators – production cell 2

	People		Facilities		Working Condition		Production Processes		Quality		JIT		Leadership	
	Indicator code	MC2-PAINT	Indicator code	MC2-PAINT	Indicator code	MC2-PAINT	Indicator code	MC2-PAINT	Indicator code	MC2-PAINT	Indicator code	MC2-PAINT	Indicator code	MC2-PAINT
Level 1	L111	100	L211	100	L131	100	L141	100	L151	100	L161	100	L171	60
	L112	80	L212	100	L132	100	L142	100	L152	100	L162	100	L172	100
	L113	100	L213	100	L133	100	L143	100	L153	100	L163	100	L173	100
	L114	100	L214	100	L134	100			L154	100	L164	100	L174	80
	L115	100			L135	100			L155	100	L165	100		
					L136	73			L156	88				
					L137	60			L157	100				
									L158	76				
									L159	55				
									L1510	60				
									L1511	100				
	Avg	96	Avg	100	Avg	90.4	Avg	100	Avg	89	Avg	100	Avg	85
Level 2	L211	64	L221	100	L231	100	L241	75	L251	70	L261	61	L271	0
	L212	100	L222	100	L232	80	L242	88	L252	100	L262	100	L272	85
	L213	73	L223	100	L233	100			L253	65	L263	62	L273	68
	L215	60	L224	100	L234	20			L254	54	L264	100	L274	69
	L216	53			L235	0			L255	43	L265	80		
									L256	100	L266	55		
	Avg	70	Avg	100	Avg	60	Avg	81.5	Avg	72	Avg	76.3	Avg	55.5
Level 3	L311	64	L321	100	L331	0	L341	51	L351	40	L361	30	L371	0
	L312	30	L322	73	L332	0	L342	0	L352	0	L362	0.0	L372	0
	L313	54	L323	100	L333	0			L353	40	L363	64	L373	0
	L314	20	L324	57	L334	0			L355	0	L364	0		
	L316	0			L335	0			L356	0	L366	100		
					L336	0					L367	0		
											L368	36		
	Avg	33.6	Avg	82.5	Avg	0.0	Avg	25.5	Avg	16.0	Avg	15.0	Avg	0.0
Level 4	L411	0	L421	0	L431	0	L441	0	L451	0	L461	0.0	L471	0
	L412	0	L422	15	L432	0	L442	0	L452	0	L462	0.0	L472	0
	L413	0	L423	0	L433	0	L443	0	L453	0	L463	0.0	L473	0
	L414	0	L424	0	L434	0			L454	0	L464	0.0		
	L415	0			L435	0								
	Avg	0	Avg	3.75	Avg	0	Avg	0	Avg	0	Avg	0	Avg	0

5.5 Data Analysis Plan and Implementation

Leanness indicators proposed in this study are used to illustrate the capability of production cells in different dimensions of lean implementation. They are applied to assess the inputs and processes from different perspectives and demonstrate maturity of production cells in implementation of lean. On the other hand, performance measures evaluate the outputs of production cells. They show the effectiveness of lean initiatives in achievement of organization's objective. Analyzing these two groups of indicators helps us to assess the overall lean success.

Despite multiple factors both in leanness and performance of each axis of LMM, in order to assess the leanness and lean effectiveness of each production cell, it is suggested to end up with a single indicator of progression. This will provide a general view on the status of production cell on lean transformation journey and shows the roadblocks in each level of maturity. Following two sections describe the methods which are used in this study to calculate the overall leanness and overall performance of each production cell.

5.6 Overall Leanness

The ultimate objective is to calculate the overall leanness of each PC, but first we start calculating the leanness of each axis at each level. There is more than one way of doing this calculation. One can use the minimum value of the indicators hence using the weakest indicator to characterize the leanness of an axis at a certain level. Alternatively, one can calculate the average of leanness indicators and interpret the results accordingly.

On one hand, using the weakest indicator while assessing the capability of production cells from the beginning could be discouraging for the team of production cells who initiate lean implementation. To facilitate the change, team members have to be encouraged by highlighting the results and quick wins (Schaffer & Thomson, 1992). For example, in the axis of Leadership in level 2, the averages of leanness indicators are 64.25 and 55.5 in PC1 and PC2, respectively. Using the minimum value of leanness indicators, the leanness of this axis at the level 2 of both PCs will be zero (L_{271}) which shows neither the progress of each PC, nor the difference between them. On the other hand, the average approach does not show the extreme values, which means the indicators with less progress will remain hidden by the indicators with higher value of progress in the same axis-level. Getting back to the example axis Leadership at level 2, the average does not unravel the zero progress at L_{271} in PC1 and PC2.

Considering the advantages and drawbacks of two methods, in this study we adopt the former approach, which would give the average leanness and hence highlight the progress of lean initiatives in different PCs. At the same time, to overcome the drawback of this approach and emphasize on the need for major improvements in the indicator(s) with less progress, in calculation of overall leanness of each maturity level in the next section, the minimum leanness of each axis is used. Using equation (2), the averages of leanness indicator in each axis j at level i ($\bar{L}_{ij}$) are calculated. Averages leanness indicators are also divided by 100 in order to change them to the scale of 0 to 1 which is the major gridline of maturity levels. The minimum, average and standard deviation of each level are also calculated. Table 15 shows the result of calculations.

$$\bar{L}_{ij} = \left(\sum_{m=1}^{n_{ij}} L_{ijm}\right) / (n_{ij} \times 100) \qquad (2)$$

Table 15: leanness indicators of each axis

Manufacturing Cell 1

Axes	1	2	3	4	5	6	7	Average	STDEV	min
	$\bar{L}_{ij}$									
Level 1	1	0.89	1.00	1.00	1.00	1.00	0.96	0.98	0.04	0.89
Level 2	0.87	0.85	0.84	0.94	0.89	0.90	0.64	0.85	0.10	0.64
Level 3	0.55	0.23	0.48	0.55	0.24	0.39	0.00	0.35	0.20	0.00
Level 4	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00

Manufacturing Cell 2

Axes	1	2	3	4	5	6	7	Average	STDEV	min
	$\bar{L}_{ij}$									
Level 1	0.96	1	0.90	1	0.9	1	0.85	0.94	0.06	0.85
Level 2	0.7	1	0.6	0.82	0.7	0.76	0.56	0.74	0.15	0.56
Level 3	0.34	0.825	0.00	0.26	0.2	0.2	0.00	0.26	0.28	0.00
Level 4	0.00	0.038	0.00	0.00	0.00	0.00	0.00	0.006	0.01	0.00

Average progress of lean in each level of the production cells (Table 15, Average) are plotted in Figure 17. As can be seen from the trends, two samples almost follow the same pattern of progress in four level of maturity. The gradual implementation of lean production should be considered as a transformation principle during the development of audit checklists and implementation of assessments. Building a solid foundation in understanding and standardizing of the lean concepts and processes in level 1 is required for sustainable improvement results during and after implementation of lean tools and principles.

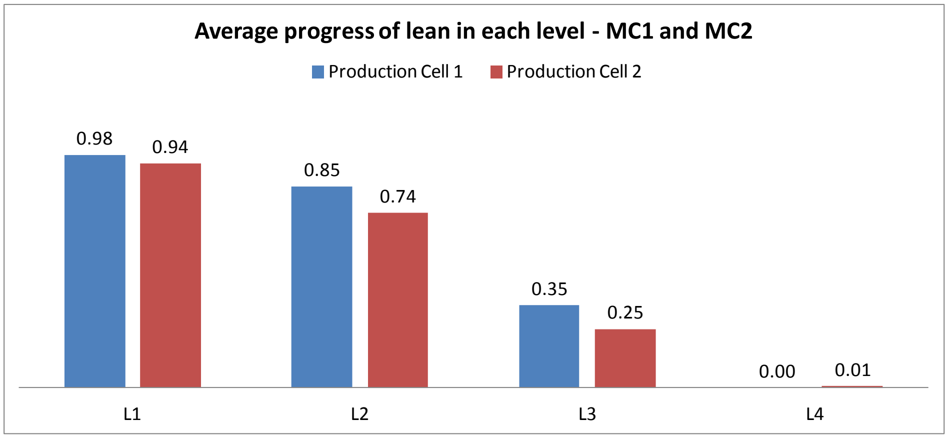


Figure 17: Progression of lean in each level

So far, average, standard deviation and minimum leanness of each level are calculated. Standard deviation can be used as an indicator of variation between the progressions of lean in different axis of LMM which represents the imbalance of lean progression. To analyze the leanness of PCs, first, the results of calculations for production cell 1 and production cell 2 are transferred to the visual form of LMM as depicted in the Figures 18 and 19. LMM visual format as represented in these figures can be used to analyze the progress of implementing lean tools and principles in each dimension of lean in a production cell through four levels of maturity. Visual presentation of leanness in each level gives an insight into how lean initiatives resulted in understanding, implementation, improvement and sustainability of lean principles. Ten lean principles are also selected and summarized by lean implementation team. They are projected in the visual model as the basis of lean implementation.

As can be seen from the Figure 3, in PC1, good progress was made to achieve the leanness objectives in level 1 and level 2. However, there are still some activities to be done in the axes "Facilities" and "Leadership", in which the leanness index at Level 1 is 0.89 and 0.96, respectively. By referring back to the Table 6, we can identify the source of non-conformances. As data in the table demonstrates, failure to achieve the level 1 is related to three main control items: L_{213} and L_{214} in the axis of Facilities and L_{171} in the axis of leadership. By further analysis of these indicators and revision of audit results, appropriate actions can be defined and implemented to fill up the gaps.

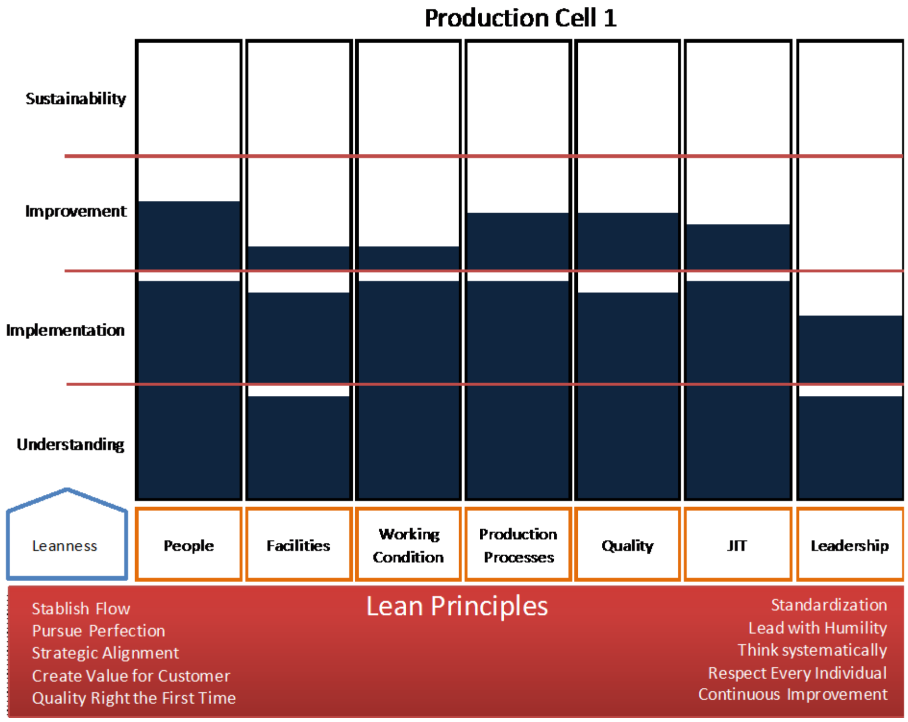


Figure 18: leanness results – Production Cell 1

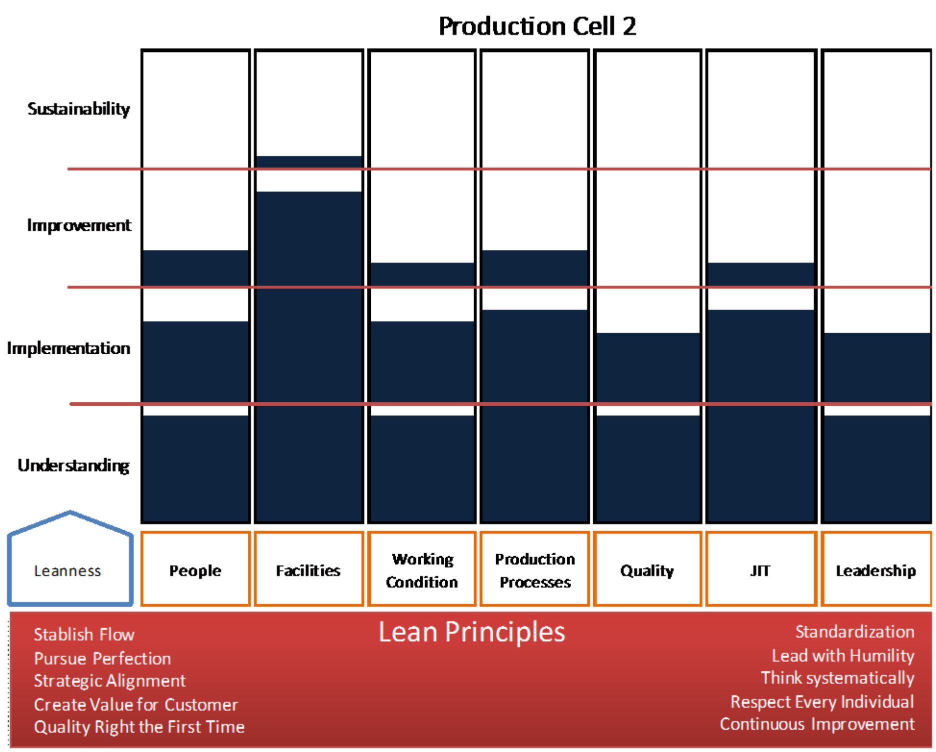


Figure 19: leanness results – Production Cell 2

Figure 19 illustrates the results of assessment in production cell 2. The bar chart shows less progression in level1, 2 and 3 in comparison with production cell 1 in Figure 17. These results are expected due to the difference between the times when lean had been applied in paint shop and assembly shop. Despite the fact that assembly shop had started to apply lean principles almost three years sooner than paint shop, difference between progresses of lean between two samples is not noticeable. Two main reasons are identified after further investigation and discussion of subject with lean implementation team: First, leveraging the knowledge and skills acquired from lean practices in assembly shop to implement lean in pain shop, and second, assigning some paint shop supervisory positions to people who worked as supervisor in assembly shop before. Despite the further overall progress of lean in assembly shop, bar chart shows more progress in axis of Facilities in paint shop. Focus of TPM implementation in machine-dominated lines of paint shop is indicated as the main reason of this difference.

Overall Leanness of Each Maturity Level (LL_i):

One of the main objectives of developing a multi-dimensional lean maturity model is to make progress simultaneously in all dimensions of lean. This balance between the lean dimensions is very important to achieve the organization's objectives. For example, control of inventory level has to be done in the axis of JIT. However, without high machine reliability, which is controlled in axis of Facilities, we won't be able to reduce the level of inventory. Lots of machine breakdowns will force us to keep more inventories in order to avoid stockout. Turning back to the production cell 1, as an example, most of the requirements for level 1 have been met, but there are still small gaps in axes 2 and axes 7. Therefore, production cell 1 cannot be considered as level 1 of maturity.

Considering balanced progress of lean as a basic principle of implementation, minimum score between all axes of LMM is suggested as an overall leanness of each level. Thus, according to equation (3), $LL_i s$ are considered as overall indicator of PC's leanness in each level. This approach encourages the associated team of PC to focus on the dimensions which lack progress in a certain level and resolve the existing shortcomings before going forward in other dimensions where progress is more. In the case of PC1, if the small current non-conformances in the axes Facilities and Leadership eliminated, overall leanness will change from 0.89 (which is the minimum of the leanness indicators in level 1) to 1 which shows the completion of level 1.

For each level i: $LL_i = \min\{\overline{L}_{ij};\ j = 1, \dots, 7\} \qquad i = 1,2,3,4$ (3)

As expected, when we go to the upper levels of maturity, overall score of leanness becomes less. This is due to the characteristics assigned to each level of maturity which is based on the transformation principles and maturation concept in business process improvement (see Chapter Four, first section: Maturity Levels).

<u>Overall Leanness of Each Maturity Axis (LA_j):</u>

Leanness indicators as are defined in the design phase, provide the possibility of assessing the implementation of lean in each axis of LMM step by step from understanding to implementation and improvement and finally, to sustainability of lean as a way of life. During the implementation of lean in production cells, various activities may be done simultaneously which belong to different levels of maturity. Some member of production team, for example, can be assigned to work on autonomous maintenance activities following their training, while the training is still in progress for other members of the team. Also, some part of improvements may be happened from the commencement of implementation. The result of assessments in case study shows a similar situation. Despite some gaps in level 1, some progress has been made in level 2 and level 3. One of the important roles of lean assessment is to highlight the gaps in each level of maturity. Consequently, action plans can be defined and prioritized in order to fill the gaps and create a synchronized and balanced continuous progress.

In order to focus on the mentioned gaps, completion of each level's activities is considered in calculation of overall leanness of each axis. For instance, in production cell 1, the average leanness of level 1 and 2 in the axis Quality is 1 and 0.89 respectively (Figure 18). Thus, the overall leanness of axis Quality is equal to 1.89 (1+0.89). Since the level 2 is not yet completed, the score of 0.24 in the level 3 is not added in calculation of overall leanness in the axis Quality. In another example, according to the results of assessment in production cell 2 in the axis of Facilities, requirements of level 1 and 2 are satisfied. Therefore, the overall leanness of axis Facilities in this cell is equal to 2.83 (1+1+0.83) in which 0.83 is the progress of lean in level 3.

Equation (4) can be used to calculate the overall leanness of each axis based on the suggested rule. The results of calculations are summarized in Table 16.

For each axis:

$$
\begin{array}{lllll}
if & \bar{L}_{1j} < 1 & \rightarrow & LA_J = \bar{L}_{1j} & otherwise \\
if & \bar{L}_{2j} < 1 & \rightarrow & LA_J = 1 + \bar{L}_{2j} & otherwise \\
if & \bar{L}_{3j} < 3 & \rightarrow & LA_J = 2 + \bar{L}_{3j} & otherwise \\
 & & & LA_J = 3 + \bar{L}_{4j} &
\end{array}
\qquad (4)
$$

$j = 1,2,3,4,5,6,7$

It should be noted that leanness of maturity axis *LAj* is on a scale of 0 to 4, meaning that an axis which completes its current lean journey will have a value of 4. The results of calculations are summarized in Table 16. As the results show, axes 1, 3, 4, 5, 6 are about to reach maturity level 2, whereas more effort is necessary in axes 2 and 7 which have not reached level 1 yet.

Table 16: leanness indicators of each axis

Manufacturing Cell 1

Axes	1	2	3	4	5	6	7
	$\bar{L}_{ij}$						
Level 1	1	0.89	1.00	1.00	1.00	1.00	0.96
Level 2	0.87	0.85	0.84	0.94	0.89	0.90	0.64
Level 3	0.55	0.23	0.48	0.55	0.24	0.39	0.00
Level 4	0	0.00	0.00	0.00	0.00	0.00	0.00
LA_j	1.87	0.89	1.9	1.94	1.8	1.9	0.96

Manufacturing Cell 2

Axes	1	2	3	4	5	6	7
	$\bar{L}_{ij}$						
Level 1	0.96	1	0.90	1	0.9	1	0.85
Level 2	0.7	1	0.6	0.82	0.7	0.76	0.56
Level 3	0.34	0.825	0.00	0.26	0.2	0.2	0.00
Level 4	0.00	0.038	0.00	0.00	0.00	0.00	0.00
LA_j	0.96	2.83	0.9	1.82	0.9	1.8	0.85

Overall Leanness of Production Cell (L):

In order to emphasize on balanced progress of lean in all axis of LMM and focus the effort on the axes with less progression, minimum of leanness between all axes (minimum of $LA_j s$) is suggested as the indication of overall leanness in a production cell. Referring back to the results of leanness indicators in each axis of LMM in Table 16, according to equation 5, the overall leanness of production cells 1 and 2 are 0.89 and 0.85, respectively. However, it should also be noted that overall leanness measure L is on a scale of 0 to 4.

$$L = \min \{LA_j \, ; j = 1,2, \dots ,7\} \tag{5}$$

5.7 Overall Performance

A comprehensive study has been carried out in literature review on performance measures related to lean implementation. The results are summarized in Table 5 Chapter two (See Literature Review: lean Principles, Tools and Metrics). As it can be seen from the table, a wide range of performance measures can be considered as lean metrics. This is not unexpected due to holistic nature of lean concept as the management philosophy of organization. During the development of lean maturity framework in Chapter four, the performance measures were categorized into proposed seven lean axes. Finally, using the list of performance measures as a reference, performance measures of the case study are defined prior to data collection process. Table 17, depicts the performance indicators of seven axes of LMM along with their targets and worst case values determined for the production cells of case study. Symbols ↑ and ↓ in the table shows the desired direction in which the value of performance is expected to change.

Table 17: Performance measures of production cells 1 and 2

Production Cell 1

Axis (j)	Performance Measure (k)	performance code (P_{jk})	Equation	Desired trend	Target value	Worst case value
People	Absenteeism Rate	P11	Total number of mandays lost due to absenteeism in last 12 months / Total number of working mandays available in last 12 months	↓	0.03	0.07
	Multifunctionality of Operators	P12	Total number of operators with skill level 3 in more than 3 workstations in production cell, skill level 3 in 1 workstation in supplier's production cell and 1 workstation in customer's production cell / total number of operators in production cell	↑	1	0
Facilities	Uptime	P21	(Total number of working hours in last 12 months – total downtime hours with the cause inside production cell in last 12 months)/ Total number of working hours in last 12 months – planned maintenance in last 12 months	↑	0.97	0.85
	MTBF	P22	Total up time in last 12 months / Tootal number of breakdowns	↑	170	100
	MTTR	P23	Total downtime hours for maintenance in last 12 months / Total number of breakdowns in last 12 months	↓	0.5	2
Working Conditions	Safety Risk Factor	P31	3* Number of high risk WS + Number of medium risk WS / Total number of WS	↓	0	0.3
	Ergonomics Risk Factor	P32	3* Number of high risk WS + Number of medium risk WS / Total number of WS	↓	0	0.6
Production Processes	Value-added Rate	P41	Value-added time / Total processing time	↑	0.9	0.65
	Balance Efficiency	P42	Processing time / Number of operators * cycle time	↑	0.9	0.7
Quality	Scrap Rate	P51	Total number of parts scraped in last 12 months / Total number of parts produced or used	↓	0	0.03
	Rework	P52	Total rework hours in last 12 months / Total working hours	↓	0.02	0.08
	FPY	P53	units of products completed in production cell with no rework in last 12 months / total units of products entering production cell in last 12 months	↑	0.97	0.85
JIT	On-time Delivery	P61	(3*Sum absolute value of tardiness in hours + Sum absolute value of earliness) / Total deliveries in last 12 months	↓	0	1
	Inventory Turnover Ratio	P62	Cost of goods sold in last 12 months/ Average inventory in last 12 months (calculated just for parts group A in production cell)*	↑	195	160
Leadership	Average Performance	P71	average percentages of meet target value of each performance measure	↑	0.25 0.5 0.75 1	0 0.26 0.51 0.76

* Inventory Turnover ration was calculated based on the group A parts in production cell. As a result the value is bigger than what is usually calculating for a company

WS: Work Station

MTBF: Mean time between failures

MTTR: Mean Time To Repair

FPY: First pass yield

Table 17: Performance measures of production cells 1 and 2, continued.

Production Cell 2

Axis (j)	Performance Measure (k)	performance code (P_{jk})	Equation	Desired trend	Target value	Worst case value
People	Absenteeism Rate	P11	Total number of mandays lost due to absenteeism in last 12 months / Total number of working mandays available in last 12 months	↓	0.03	0.07
	Multifunctionality of Operators	P12	Total number of operators with skill level 3 in more than 3 workstations in production cell, skill level 3 in 1 workstation in supplier's production cell and 1 workstation in customer's production cell / total number of operators in production cell	↑	1	0
Facilities	Uptime	P21	(Total number of working hours in last 12 months – total downtime hours with the cause inside production cell in last 12 months)/ Total number of working hours in the period in last 12 months – planned maintenance in last 12 months	↑	0.97	0.85
	MTBF	P22	Total up time in last 12 months / Total number of breakdowns in last 12 months	↑	185	100
	MTTR	P23	Total downtime hours for maintenance in last 12 months / Total number of breakdowns in last 12 months	↓	0.8	3
Working Conditions	Safety Risk Factor	P31	3* Number of high risk WS + Number of medium risk WS / Total number of WS	↓	0	0.3
	Ergonomics Risk Factor	P32	3* Number of high risk WS + Number of medium risk WS / Total number of WS	↓	0	0.6
Production Processes	Value-added Rate	P41	Value-added time / Total processing time	↑	0.9	0.65
	Balance Efficiency	P42	Processing time / Number of operators * cycle time	↑	0.9	0.7
Quality	Scrap Rate	P51	Total number of parts scraped in last 12 months / Total number of parts produced or used	↓	0	0.03
	Rework	P52	Total rework hours in last 12 months / Total working hours in last 12 months	↓	0.03	0.08
	FPY	P53	units of products completed in production cell with no rework in last 12 months / total units of products entering production cell in last 12 months	↑	0.97	0.85
JIT	On-time Delivery	P61	(3*Sum absolute value of tardiness in hours + Sum absolute value of earliness) / Total deliveries in last 12 months	↓	0	1
	Inventory Turnover Ratio	P62	Cost of goods sold in last 12 months/ Average inventory in last 12 months (calculated just for parts group A in production cell)	↑	210	175
Leadership	Average Performance	P71	average percentages of meet target value of each performance measure	↑	0.25	0
					0.5	0.26
					0.75	0.51
					1	0.76

* Inventory Turnover ratio was calculated based on the group A parts in production cell. As a result the value is bigger than what is usually calculating for a company

WS: Work Station

MTBF: Mean time between failures

MTTR: Mean Time To Repair

FPY: First pass yield

The results of data collection on performance indicators of case study are presented in Table 18 where P_{jk} represents the performance indicator for axis j and measure k. For example, P_{11} represents Absenteeism in People axis. Furthermore, the desired trend as demonstrated by symbol ↓ is to decrease this measure which is currently at 0.06 (6%) in PC1 and has the next target and worst case values as 0.03 (3%) and 0.07 (7%), respectively. Unlike the leanness indicators in which the parameters are assigned to each axis-level of LMM, performance measures are only assigned to each axis of LMM and midterm targets for each indicator are defined for different levels.

According to the suggested performance measure, in axis Leadership, average achievement of targets in all performance measures in each level was suggested as an indicator of progression in that level. This suggestion is to emphasis on the role of leadership in leading of lean initiatives toward production cell's objectives.

Table 18: Data collection results on performance measures

Performance Indicator (P_{jk})	Desired Trend	Production Cell 1			Production Cell 2		
		Actual Value ($r_{P_{jk}}$)	Next Target Value	Worst case Value	Actual Value ($r_{P_{jk}}$)	Next Target Value	Worst case Value
P_{11}	↓	0.06	0.03	0.07	0.05	0.03	0.07
P_{12}	↑	0.8	1	0	0.4	`1	0
P_{21}	↑	0.92	0.97	0.85	0.95	0.97	0.85
P_{22}	↑	125	170	100	162	185	100
P_{23}	↓	1.05	0.5	2	1.5	0.8	3
P_{31}	↓	0.22	0	0.3	0.27	0	0.3
P_{32}	↓	0.4	0	0.6	0.5	0	0.6
P_{41}	↑	0.8	0.9	0.65	0.75	0.9	0.65
P_{42}	↑	0.85	0.9	0.7	0.6	0.9	0.7
P_{51}	↓	0.012	0	0.03	0.05	0	0.03
P_{52}	↓	0.06	0.02	0.08	0.12	0.03	0.08
P_{53}	↑	0.92	0.97	0.85	0.88	0.97	0.85
P_{61}	↓	0	0	1	0	0	1
P_{62}	↑	180	195	160	192	210	175
P_{71}	↑	0.40	0.25	0	0.33	0.25	0
			0.5	0.26		0.5	0.26
			0.75	0.51		0.75	0.51
			1	0.76		1	0.76

As it is demonstrated in Table 18, different performance measures with different scales are used to measure the lean performance in each dimension of LMM. As suggested in Chapter Methodology (step 3-2), a fuzzy membership function as a composite indicator is used in this research to synthesize the different scales of performance measures into a unified index. To calculate the fuzzy membership function, expected target value and worst case value of each performance measure as described in measurement phase are defined which are indicated in Table 18. As explained in Chapter Methodology, target and worst case values are defined based on the available historical and benchmarking data for level 0 and level 4 of maturity. For instance, the worst case value of absenteeism rate (P_{11}) is 7%. Any absenteeism rate equal or more than 7% also consider as the worst case. Therefore, 0.07 is used as the worst case of absenteeism rate. Since absenteeism has a negative effect on overall performance, 0.07 is considered as the upper acceptable limit of fuzzy membership function. Zero absenteeism is the best value which can be assigned to this indicator. However, 3% is set as the achievable target for level 4 of maturity model. Consequently, 0.03 is set as the lower limit of fuzzy membership function. In some performance measures, the value of target and/or worst case is set differently in two production cells. For example, target value of P_{22} which is performance indicators of MTBF is larger in production cell 2. This is due to importance role of machine failures in final result of paint shop process in comparison with assembly shop.

Based on the definitions of fuzzy membership functions presented in the Chapter Methodology, two types of fuzzy functions should be applied in order to fuzzify the performance indicators (P_{jk}) of the case study:

For the performance measures P_{11}, P_{23}, P_{31}, P_{32}, P_{51}, P_{52} and P_{61} in which the worst cases are the upper acceptable limit of performance measure, a Trapezoidal R-function is used. The target level is defined as $c_{P_{jk}}$ and the lower threshold is defined as $d_{P_{jk}}$. Equation (6) is used to calculate the fuzzy membership values of these performance measures. The defined target of P_{32} is 0 and its worst case is 0.6, which means the fuzzy membership value of the actual value of P_{32} (which is 0.4) is $\mu(0.4)$ =(0.6-0.4/0.6)= 0.33. For the performance measures the results of calculations related to PC1 is shown in Figure 20.

$$\mu_{\tilde{A}}\,(r_{P_{jk}}) = \begin{cases} 0 & r_{P_{jk}} > d_{P_{jk}} \\ \dfrac{d_{P_{jk}} - r_{P_{jk}}}{b_{P_{jk}} - c_{P_{jk}}} & c_{P_{jk}} \le X_k \le d_{P_{jk}} \\ 1 & r_{P_{jk}} < c_{P_{jk}} \end{cases} \tag{6}$$

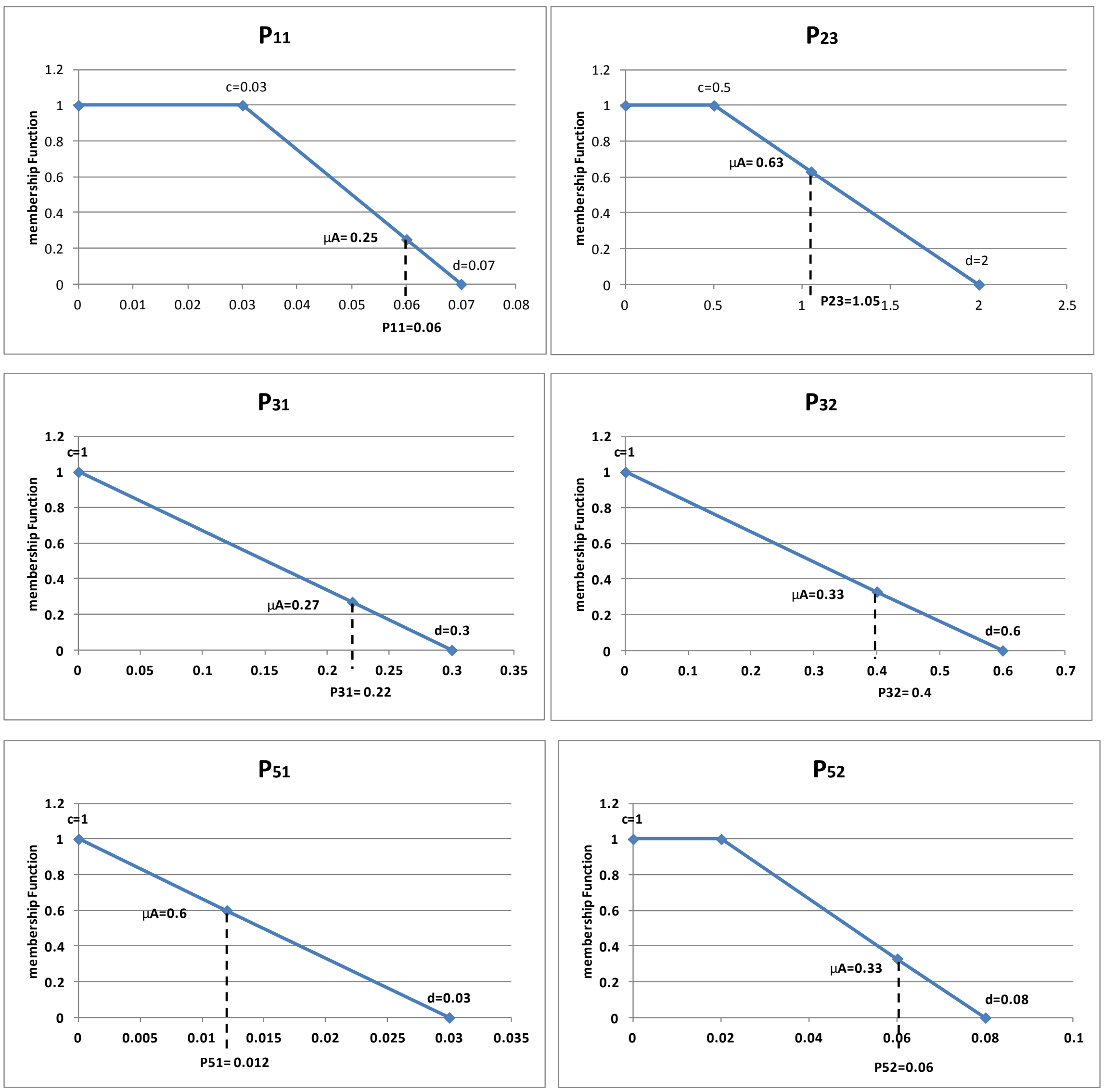


Figure 20: Fuzzy membership function of *P11, P23, P31, P32, P51,* and *P52* in production cell 1

For the performance measures P_{12}, P_{21}, P_{22}, P_{41}, P_{42}, P_{53}, and P_{62} in which the worst cases are the lower acceptable limits, Trapezoidal L-function is used. The lower acceptable level is defined as $a_{P_{jk}}$ and the target is defined as $b_{P_{jk}}$. Equation (7) is used to calculate the fuzzy membership function of mentioned performance measures. The target of P_{12} is 1 and its worst case is 0 which means the fuzzy membership value of P_{12} is equal to real value of P_{12} which is 0.8. For the remaining performance measure, the results of calculations are plotted in the Figure 21.

$$\mu_{\tilde{A}}\,(r_{P_{jk}}) = \begin{cases} 0 & r_{P_{jk}} < a_{P_{jk}} \\ \dfrac{r_{P_{jk}} - a_{P_{jk}}}{b_{P_{jk}} - a_{P_{jk}}} & a_{P_{jk}} \leq r_{P_{jk}} \leq b_{P_{jk}} \\ 1 & r_{P_{jk}} > b_{P_{jk}} \end{cases} \tag{7}$$

Using the equation (6) and (7), the fuzzy membership values were also calculated for the performance measures in the production cell 2 (See Appendix C). Result of calculations for both production cells are summarized in Table 19 ($\mu_{\tilde{A}}\,(r_{P_{jk}})$ and $\mu_{\tilde{A}}\,(r_{P_{jk}})$).

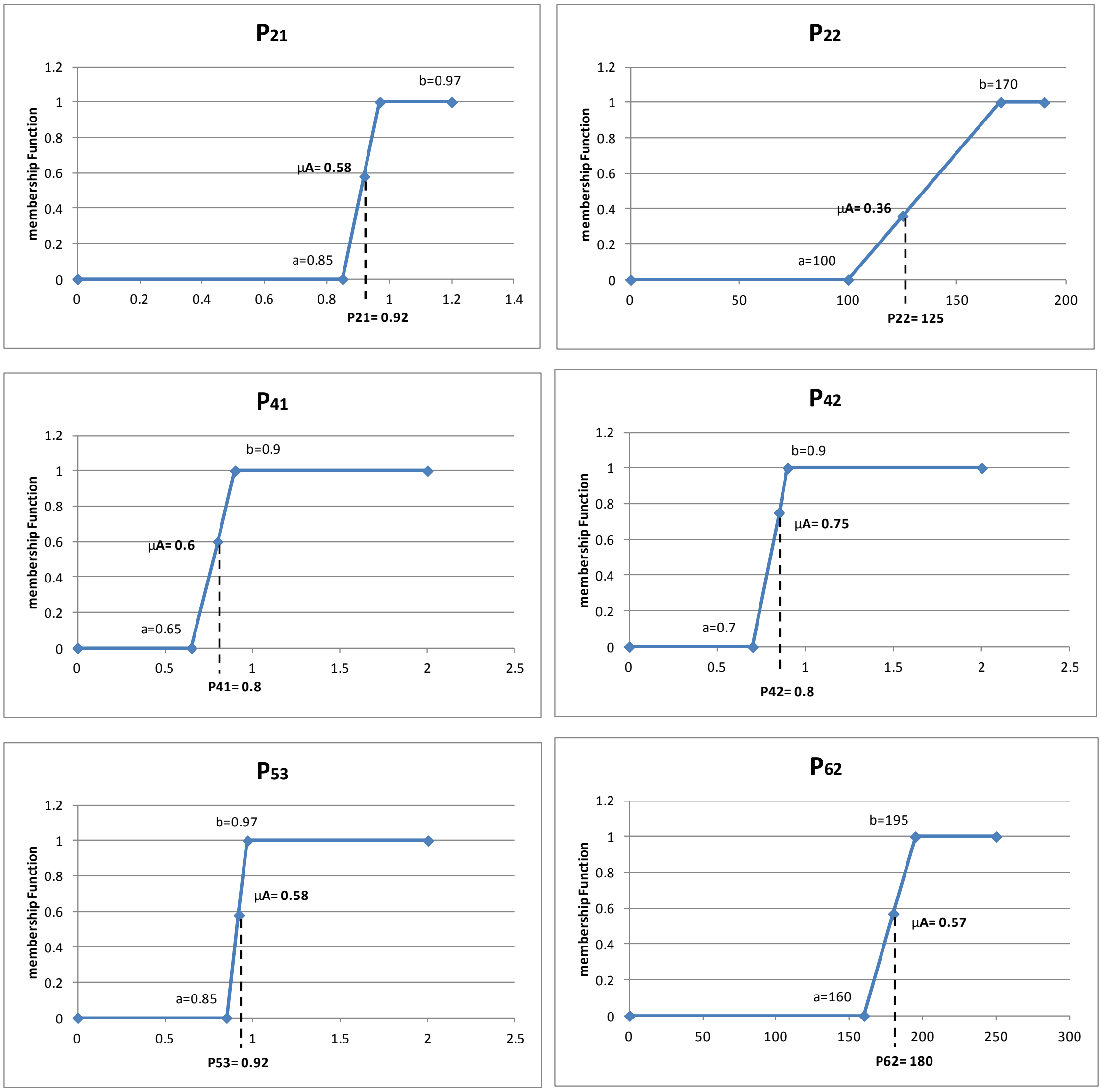


Figure 21: Fuzzy membership function of performance measures *P21, P22, P41, P42, P53,* and *P62* in production cell 1

Various performance indicators are defined to measure the different perspectives of each LMM's axis. In a comprehensive lean system, achievement of all defined objectives up to a certain level should be considered in each step in order to make progress in all dimensions simultaneously. Therefore, as indicated in Chapter Methodology, the minimum of fuzzy membership functions in each axis of LMM is suggested as the overall performance of that axis. In other words, according to equation (8) a conjunctive fuzzy composite indicator is suggested as the overall performance of each lean dimension. The results of P_j calculations for two production cells are listed in the Table 19 and plotted in Figure 22.

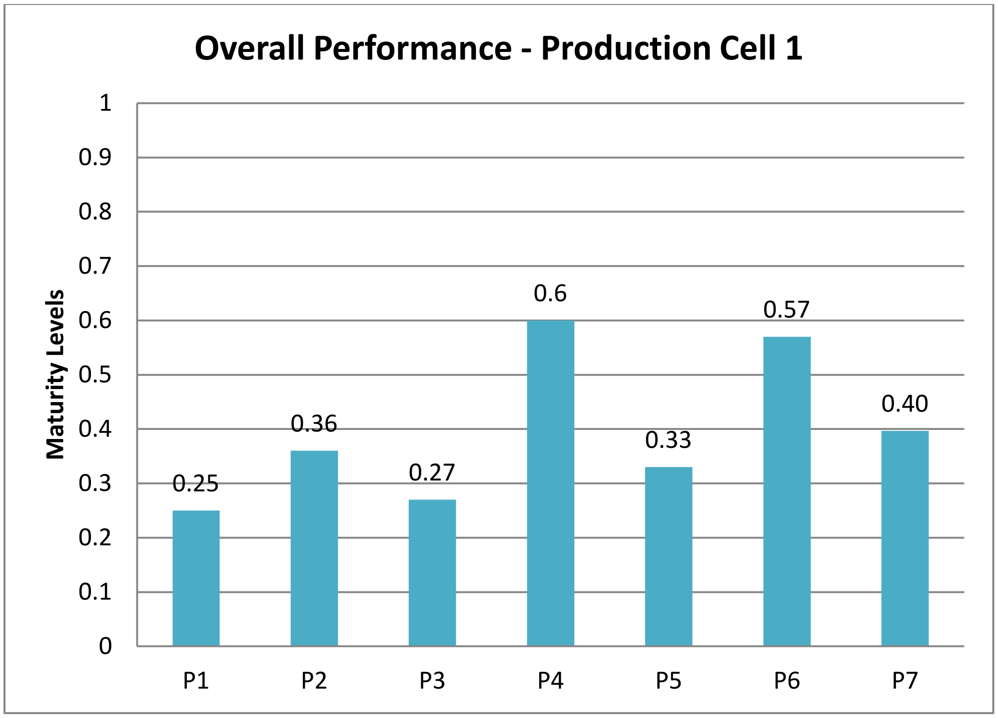
For each axis j $\quad P_j = \min\{\mu_{\tilde{A}}(r_{P_{jk}}); k = 1,2,3,\dots,n_j\} \qquad j = 1,2,\dots,7$ (8)

Table 19: Overall performance of each axis based on minimum fuzzy membership function

Axis (j)	Performance Indicator $r_{P_{jk}}$	Production Cell 1		Production Cell 2	
		$\mu_{\tilde{A}}(r_{P_{jk}})$	P_j	$\mu_{\tilde{A}}(r_{P_{jk}})$	P_j
1-People	P11	0.25	0.25	0.5	0.4
	P12	0.8		0.4	
2- Facilities	P21	0.58	0.36	0.83	0.68
	P22	0.36		0.73	
	P23	0.63		0.68	
3- Working Condition	P31	0.27	0.27	0.1	0.1
	P32	0.33		0.17	
4- Production Processes	P41	0.6	0.6	0.4	0.3
	P42	0.75		0.3	
5-Quality	P51	0.60	0.33	0	0
	P52	0.33		0	
	P53	0.53		0.88	
6-JIT	P61	1	0.57	1	0.49
	P62	0.57		0.49	
7-Leadership	P71	0.40	0.40	0.33	0.33

One may be interested to give different weight to different performance measures. In such a case, a weighted generalized mean is suggested based on equation (9) (Zani, et al., 2013). However, using this equation, the performance measures with higher value neutralize the effect of those with poor performance. As a result, the final indicator does not show the imbalance of progression in different aspects of a lean dimension. In equation (8), W_k is the weight of k^{th} performance measure of axis j.

For $j = 1,2,\dots,7$ $\qquad P_j = \sum_{k=1}^{n_j} \mu_{\tilde{A}}(r_{P_{jk}}) \times W_k$ (9)



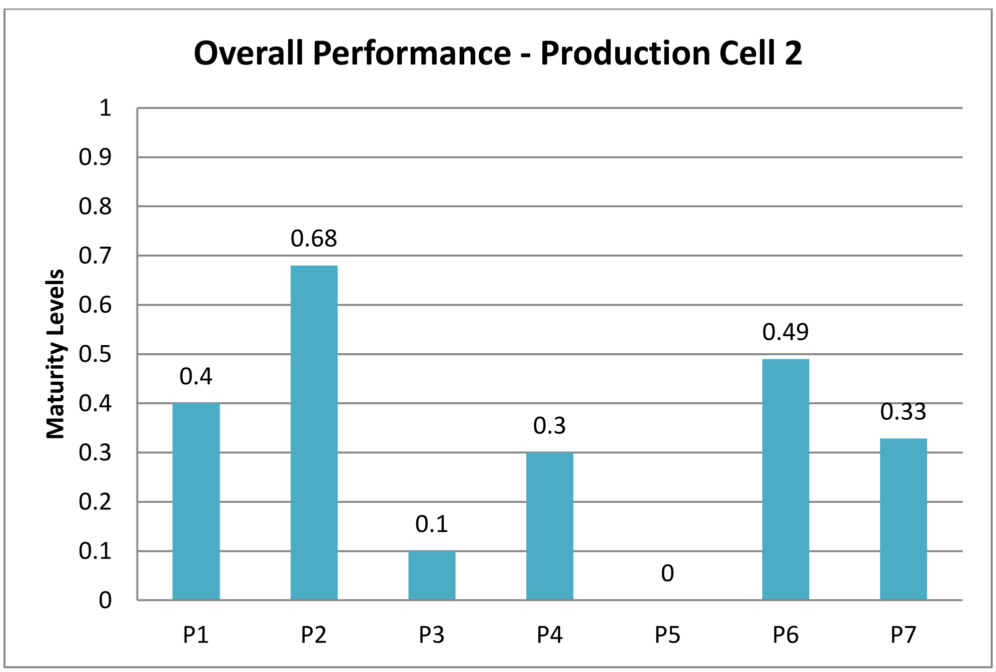


Figure 22: Overall performance (P_j)

Chapter 6: RESULTS AND DISCUSSION

In data analysis phase, data collected through audit and direct observation of the production cells. The overall leanness was calculated based on the accomplishment of each maturity level's requirements. Then, data on performance measures related to each dimension of proposed LMM were collected and by using the targets and worst cases as the boundaries, fuzzy membership value of each performance indicator was calculated. In this chapter, the results of overall leanness and performance are used to evaluate the effectiveness of lean practices.

6.1.1 Leanness Indicators vs. Performance Measures

In order to analyze the results, the data of leanness assessment in Figure 18 and 19, and the data of measured performance in Figure 22 are combined together in a single visual format as demonstrated in Figure 23 and 24 for production cell 1 and 2 respectively.

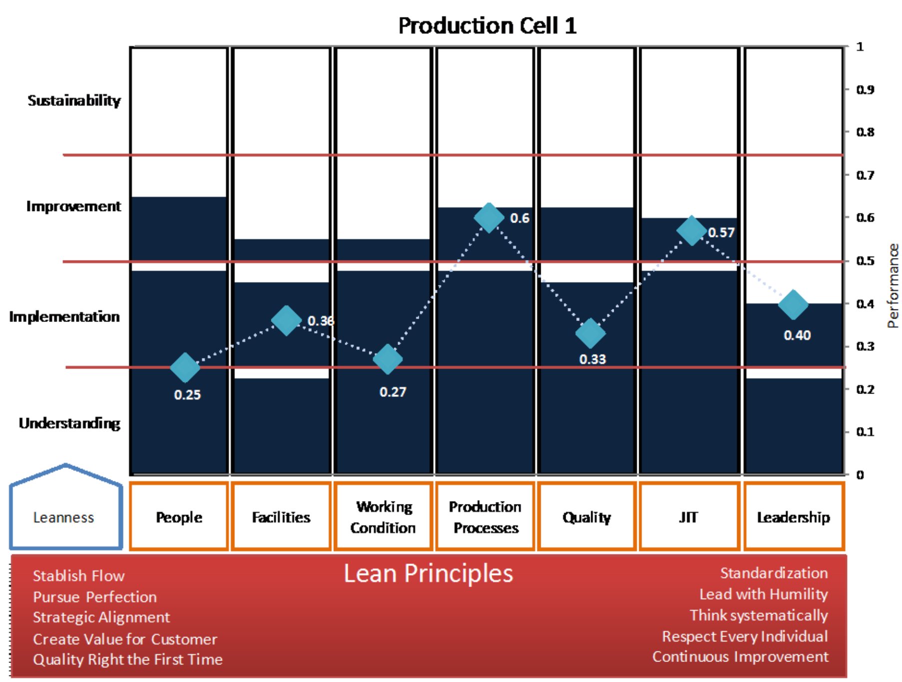


Figure 23: leanness and performance assessment – Production cell 1

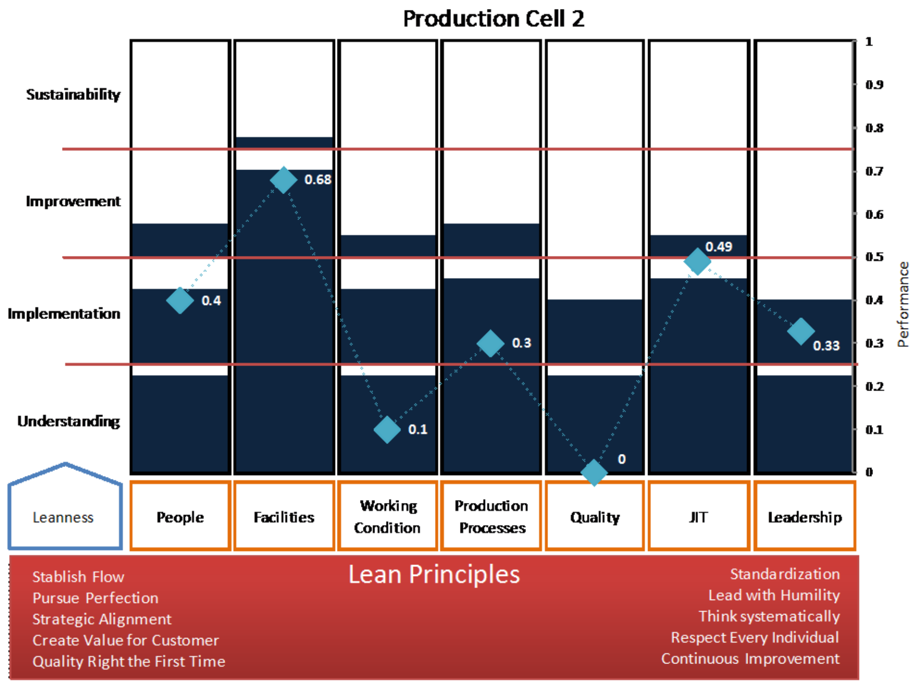


Figure 24: leanness and performance assessment – Production cell 2

Comparing the result of leanness and performance in each axis visually gives us an overall idea on effectiveness of lean initiatives in that axis. With a quick overview of graph in Figure 23 we realized that lean practices in axes Facilities, Production Processes, JIT and Leadership resulted in a desired level of performance in production cell 1. On the other hand, in axis People, Working Condition and Quality, there is a gap between the two types of results. To analyze the gap between the leanness and performance, one can refer back to the records of performance and leanness.

Going backward in details, it can be seen that the low performance in the axis of "Working Condition", for example, is related to the performance measures P_{31} and P_{32}, which are safety and ergonomics risk indices. Analysing the result of leanness indicators in the same axis, also shows that 10% gap between the leanness indicators and the target of level 2 in the axis of Working Condition is mostly related to the main control items L_{232} (84 of 100) and L_{234} (60 of 100). L_{232} is the control item of leanness in level 2 which is related to the safety audit and L_{234} is the control item of basic ergonomics analysis. Comparing the results in this example shows that by corrective execution of safety audit and ergonomic analysis in production cell 1, we can reach the leanness level of 2 (2.2, more precisely) and at the same time we can fill up the gap between the existing and desired performance of axis "Working Condition".

In addition to visual analysis of results, the effectiveness of lean initiatives in each axis of LMM can be analyzed more precisely by comparing the current performance of each dimension with its expected performance based on the current level of leanness. Conjunction of fuzzy membership functions are used to calculate the overall performance of each axis as identified by P_j in table 19. The result is a fuzzy membership value between 0 and 1 indicating the degree with which the targeted performance is reached.

As for the expected performance based on the current level of leanness, it is interpreted that the expected level of performance in level 0 start from 0 and reaches value 1 in level 4. According to equation (4) leanness of axis LAj is defined on a scale of 0 to 4 and hence needs to be mapped to a scale of 0 to 1. This mapping can be done by a simple trapezoidal L-function with $a = 0$, $b = 4$ and $c = d = \infty$, as shown in equation (10).

$$\mu_{\widetilde{EXP}}\,(LA_j) = LA_j/4 \qquad (10)$$

For example, the level of leanness in the axis of Production Process (LA_4) in PC1 was calculated as 1.94 (see Table 16). By using equation (10), this corresponds to a membership value of 0.48 which indicates that the expected overall performance of axis Production Process in PC1 is about half of the target, which now can be compared with the actual performance.

The values of expected overall performance and actual performance of PC1 and PC2 are calculated and plotted in Figure 25 and 26. For example, comparing the expected value of overall performance (0.48) with its real value (0.6) in Figure 25 shows that the actual performance in the axis of Production Processes exceeded the expected value. Subsequently, the level of target achievement in percentage scale is calculated using equation (11).

$$Level\ of\ Target\ Achievement = \frac{P_j - \mu_{\widetilde{EXP}}\,(LA_j)}{\mu_{\widetilde{EXP}}\,(LA_j)} \times 100 \qquad (11)$$

Figures 25 and 26 compare the expected level of overall performance with its current level in each dimension of lean in production cells 1 and 2. The bar chart in the graph shows the level of target achievement – in the form of overachievement (+) or underachievement (-). Wherever performance objectives are not met in an axis of LMM, the bar in the negative part of vertical axis indicates the percentage that objective is behind the target - underachievement. If the current value of a performance is bigger than expected, a bar in the positive part of vertical axis shows the percentage that objective is exceeded - overachievement. The value of zero in the level of target achievement shows no difference between the target and real value of overall performance, which means the objective is met by the exact value.

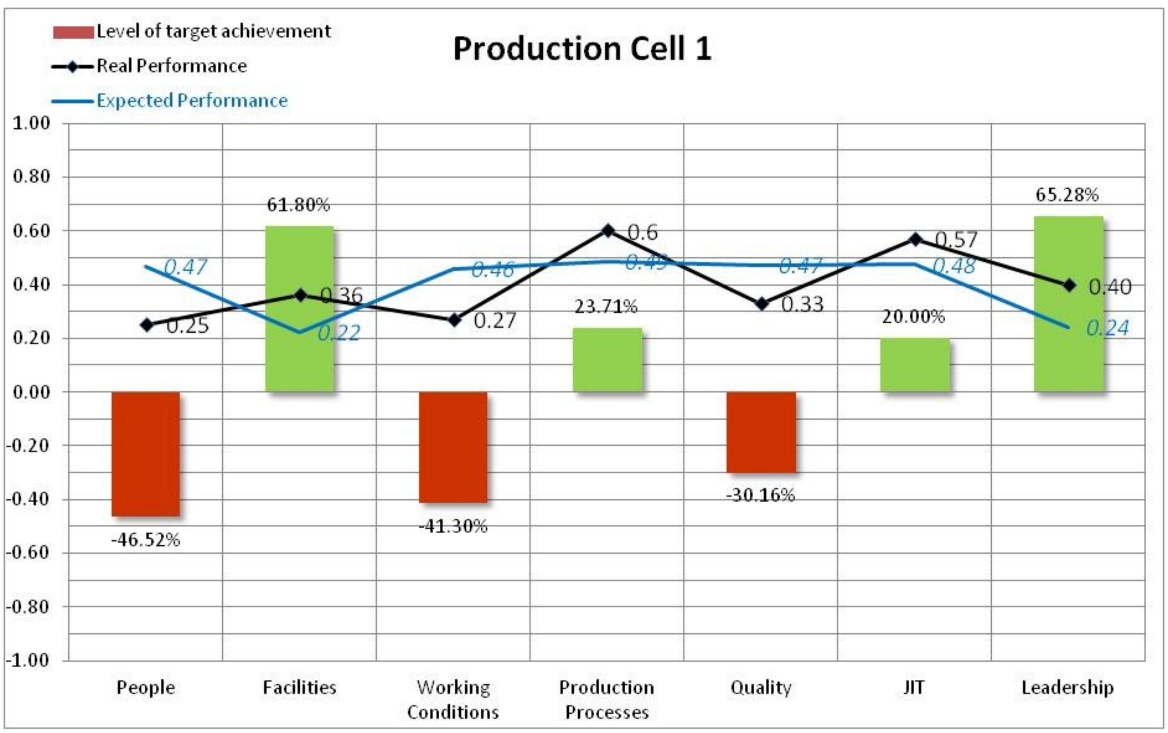


Figure 25: Level of target achievement – Production Cell 1

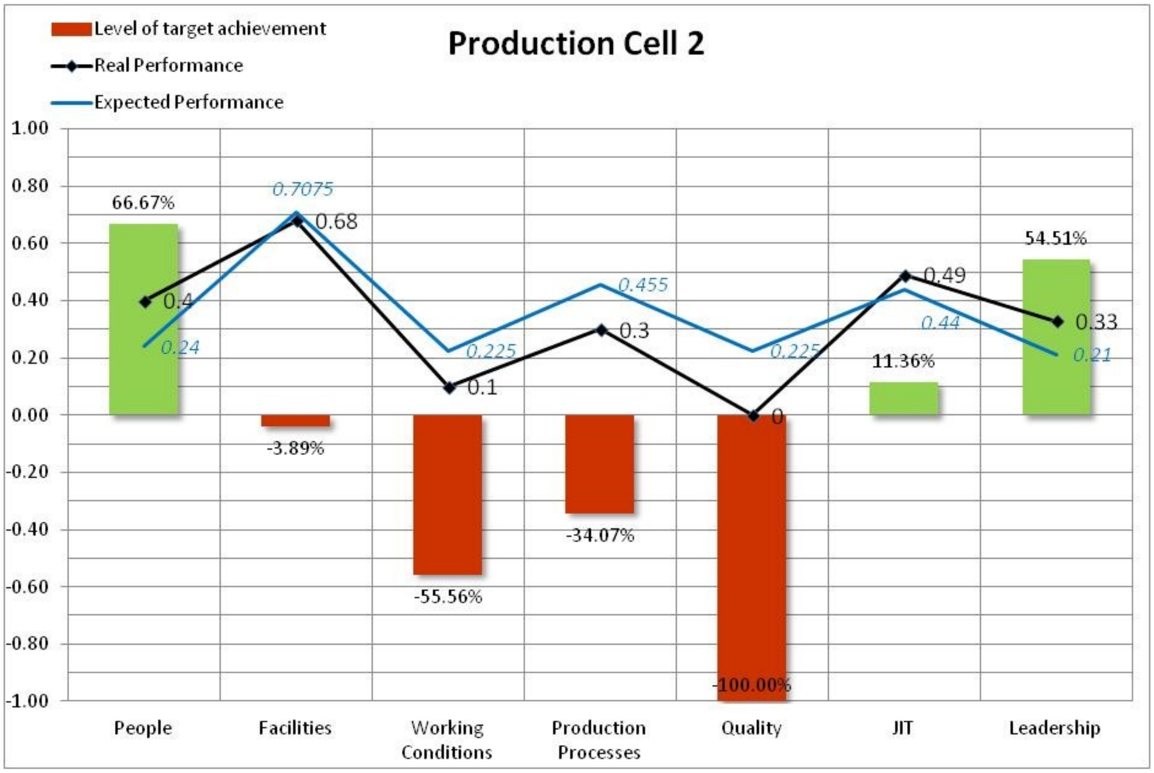


Figure 26: Level of target achievement – Production Cell 2

Referring back to the research questions, analysis of the data provided in the graphs helps organization to evaluate and improve the effectiveness of lean practices in achievement of each PCs' performance measures. Differentiating between the axes where the targets have been achieved with those where lean has not resulted in the desired objectives, leads the PC team to focus on the major gaps. In this regard, defining and implementing of the action plans to resolve the problems in the axes with the higher value of underachievement will resulted in the better achievements in shorter period of time. As the diagrams depicted, in the order of importance, the axes People, Working Condition and Quality should be addressed in PC1. However, in PC2, Quality is the most the important issue, and then Working Condition, Production Processes and Facilities should be analyzed respectively.

In production cell 1, as discussed, the focus should be more on the axis of people. Despite the overall leanness (LAj) of this axis is 1.87, it has the highest value of underachievement in PC1 (46.52%). Two indicators have been used to measure the leanness of axis people, P_{11} and P_{12} which represent the absenteeism rate and multifunctionality of operators, respectively. According to Equation 8, P_{11} has been selected as overall performance (P_j) of this axis in PC1. The expected performance value based on the overall leanness is 0.47 while the real fuzzy membership value of absenteeism rate is equal to 0.25. The gap between the actual and expected performance shows that the lean initiatives was not successful as it is related to the improvement of absenteeism rate. Referring back to the list of leanness indicators (Appendix B), two indicators are directly linked to the absenteeism rate in PC1: L_{114} and L_{115} which corresponds to 1- progress of standardizing the production cell's rules (and absenteeism rule as one of them) and 2- progress of training on manufacturing cell's rules. Other leanness indicators such as Satisfaction (L_{218}) may also affect absenteeism rate. Consequently, a problem solving approach is recommended to consider all the possible causes and to focus on those with higher impact on the final results.

The poor performance results in the axis of Quality in PC2 (Figure 26), as another example, shows the need of immediate analysis and appropriate action plans in this axis. Comparing the quality performances data in PC2 shows that the good result (0.88 of 1) of **F**irst **P**ass **Y**ield (P_{53}) has been achieved at the cost of high scrap rate and rework inside the production cell. The overall performance value of zero in this axis is derived from the value of zero of performance indicators Scrap rate (P_{51}) and Rework (P_{52}). By analyzing the data of quality in details and using statistical analysis and problem solving methods, members of PC1 can find and eliminate the root causes of high rate of scraps and rework hours in workstations.

The result of overall leanness and overall performance can be also presented in the form of Radar chart for benchmarking purpose. Radar chart is a powerful visual reporting technique for graphing multivariate data. For a production cell to be benchmarked as a best practice in each axis of lean, it is important to excel both in leanness and performance. Therefore, Multiplication of two indicators was proposed as the overall indicator of lean-performance for benchmarking purpose. The data of overall leanness of each axis in Table 10 and the data of overall performance based on the fuzzy membership functions in Table 13 are used to calculate the overall lean-performance benchmarking criteria using equation (12). Results of calculations for production cells 1 and 2 is summarized in Table 20 and plotted in Figure 27. As graph shows, by considering only the two production cells, JIT and Production Processes in production cell 1 and Facility Management in production cell 2 are the best practices of the case study.

For $j = 1,2, \dots, 7$ Lean-Performance Benchmarking criterion = $LA_j \times P_j$ (12)

Table 20: Lean-Performance Benchmarking criterion – Production cells 1 and 2

Production Cell 1	People	Quality	Facilities	Production Processes	Working Conditions	JIT	Leadership
LA_j	1.87	0.89	1.89	1.94	1.84	1.9	0.96
P_j	0.25	0.36	0.33	0.6	0.27	0.57	0.4
$LA_j \times P_j$	0.47	0.62	0.32	1.164	0.50	1.08	0.38
Production Cell 2	People	Quality	Facilities	Production Processes	Working Conditions	JIT	Leadership
LA_j	0.96	2.83	0.9	1.82	0.9	1.76	0.85
P_j	0.4	0.68	0	0.3	0.1	0.49	0.33
$LA_j \times P_j$	0.38	0	1.92	0.55	0.09	0.86	0.28

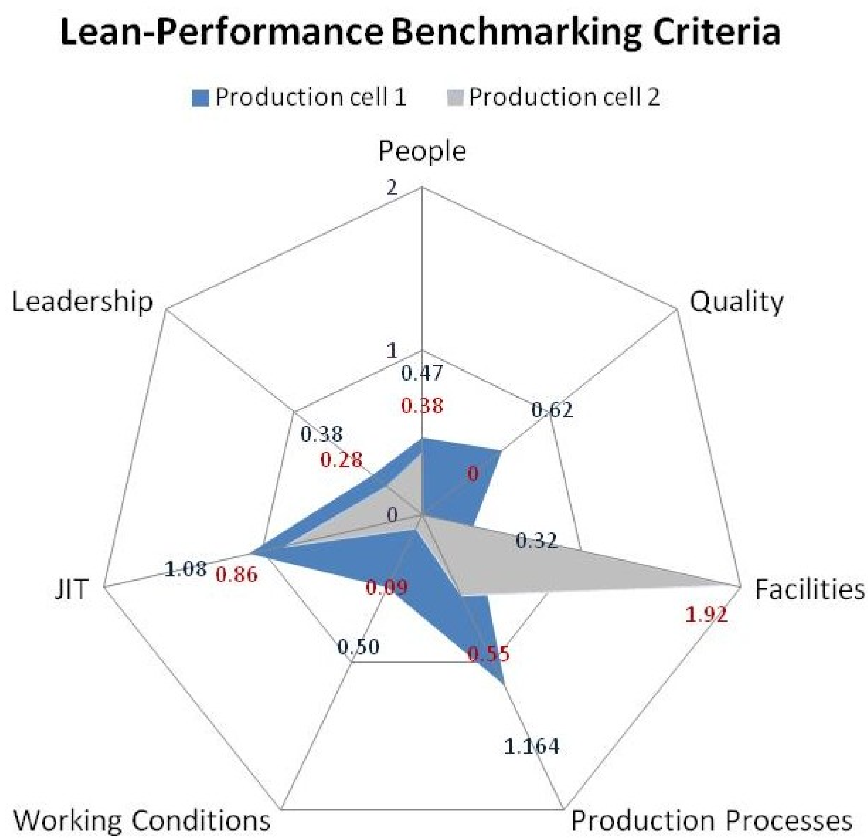


Figure 27: lean – Performance Benchmarking Criterion – Production Cells 1 and 2

6.1.2 Application of Model

The major accomplishment of this research is the development of a visual, data-driven lean maturity model in production cells by considering both the qualitative leanness metrics and the quantitative performance measures. Pöppelbuß & Röglinger (2011) suggested three groups of design principles for development of maturity models: “Basic principles”, “Principles for descriptive purpose” and “Principles for prescriptive purpose”. In development of lean maturity model in this research, these principles have been used as a guideline. The contributions of this research to develop and implement lean principles in functional level are listed below.

Descriptive Application of Model

A set of assessment criteria is required for each level of maturity in a model intended to use for descriptive purpose (Gottschalk, 2009). Proposed LMM provides detailed assessment criteria both for leanness and performance of production cells. The criteria are divided into 7 dimensions of lean implementation which are extracted from review of lean literature and can be applied as a general framework of lean implementation in operation. Each axis criteria is also categorized in four levels of maturity which are characterized by review of literature on maturity models and organizational transformation. Four levels of maturity are used in general framework of lean implementation in operational level. Finally, based on the review of RPS model and author’s experience, lean indicators and main control items related to each axis-level of model are suggested. Main control items can be customized to the specifications of each organization who intended to use the proposed LMM as a general framework of lean transformation. As-is assessment of two production cells in a case study provided data to test applicability of model through analysis of audit’s evidence and historical data in explanation of current leanness and lean effectiveness.

Prescriptive Application of Model

The proposed lean maturity model provides a step by step guideline on implementation of lean principles in production cells. Although extensive research has been carried out on lean assessment, no study exists which adequately covers the necessary elements of lean principles in production cells. Visual presentation of leanness in each dimension provides a guideline on improvement measures. The generic progression scales provide a clear insight of current situation and clearly indicates potential opportunity of improvement in each axes. Furthermore, using a single checklist for assessment of each main control item in all four levels of maturity assists production cell's supervisor to work on accomplishment of the higher levels' requirements, while improving the current status. Comparing the result of the leanness and the performance also provides data to analyze the effectiveness of current lean practices. It also helps lean practitioner to evaluate and improve the effectiveness of lean assessment system.

Comparative Application of Model

Since different organizations have been using different methods to assess the leanness, the result of assessment is not comparable and therefore not appropriate to benchmark. On the other hand, external best practices exists for some common used lean performance measure such as OEE, value-added time ratio and on-time delivery. Proposed lean maturity model provide both the possibility of self-benchmarking of leanness and external benchmarking of performance. Calculation of proposed lean-performance benchmarking indicator provides a criterion of best practices in each axis of lean maturity model for the purpose of self-benchmarking. On the other hand, targets and worst cases to calculate the fuzzy membership function of each performance measure can be defined based on the historical data as well as external best practices of frequently used performance measure.

Chapter 7: CONCLUSION

7.1 Overall Summary of Findings

For more than three decades now, lean manufacturing has been used widely as a popular management system in both manufacturing and service industries. Recently, considerable attention has been paid to assessment of organization leanness. However, in most studies assessment has been carried out in enterprise level and by measurement of organizational performance indicators. Although, performance metrics can be used to assess the effectiveness of lean practices, evaluation and improvement of system's inputs and processes is crucial for lean success. Moreover, the elements of lean in functional level are different from those in level of enterprise. Same as overall lean program, a roadmap and a model of lean implementation adapted to overall lean program and customized to their specific environment is needed in production cells.

The main objective of this research is to develop a multidimensional lean maturity model for production cells. This research provides a framework to implement gradually and to evaluate systematically lean practices in all dimensions of production cells in proposed four level of lean maturity. A case study is carried out to validate the model. Data collected from lean assessment and performance evaluation of two production cells as samples is analyzed to assess the overall leanness and performance in each axis of LMM. The proposed visual LMM provides a simple visual answer to two questions: "how lean the production cell is?" and "how effective the lean is to achieve production cell's objectives?" The visual, data-driven format of maturity model helps lean practitioners, production supervisors and production cell's team to find easily and quickly the gaps between requirements of leanness and results of their practices, and to fill that gap by focusing on the areas of strength and those needing improvement.

7.2 Conclusion

Neely *et al* (2005) proposed a periodic re-evaluation of the established performance measures to continuously improve the organization's situation in the competitive environment. In a learning organization, the knowledge of employees increases continuously during practice of lean tools and methods and application of lean principles. The proposed LMM for the functional level is designed based on the reviewing the lean concept from different perspectives (tools, principles, objectives, maturity levels) and reviewing the best practices of lean and operational excellence models. The knowledge of employees increase based on learning through practices of lean elements. The system will be improved then using the created knowledge. The proposed visual maturity model and suggested methodology to assess leanness of production cells is a framework to develop lean gradually and continuously at shop floor level. The model can be practiced by lean practitioners and can be improved in details based on the created knowledge (Figure 28).

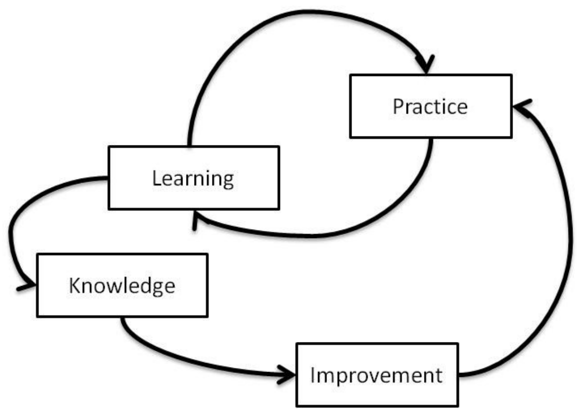


Figure 28: Improvement through lean practice

7.3 Limitations and Delimitations

Certain limitations and delimitations associated with the methodology developed in this research are listed as follows:

1) This study represents a general model of lean maturity for the Production cells. Considering unique circumstances of every organization, it is recommended that each organization customize the model based on their special situation. Consequently, assessment checklists, lean indicators, main control items, performance measures and performance targets can be developed based on company's requirements and strategies.

2) In order to implement lean as a management philosophy in an organization, several steps must be taken to set directions and policies and engage all stakeholders. The LMM presented in this study focuses on the necessary activities needed in the level of operations as a most important part of a value stream. As an important prerequisite of the proposed model, organization must provide an overall enterprise lean transformation plan (one such LESAT-LAI).

3) During the case study, the process of evaluating leanness of each axis in each production cell stopped at a point where a score of less than 70% was obtained. Initial efforts to assess the main control items of level 3 and 4 shows zero score in most axes. Therefore, there was not the opportunity to evaluate all main control items, especially those of level 3 and level 4. Considering the assessment system as a dynamic process, this limitation would not affect the result of analysis on applicability of the model. Assessment system can be modified and improved during the lean implementation.

4) Some main control items of lean can only be evaluated qualitatively. The checklists were used to evaluate some qualitative items such as corrective execution of lean practices through a series of audits. Although audits conducted by certified senior lean instructors, bias of judgments may sometimes affect the results of leanness. However, in practice, comparing the result of leanness with the overall performance of production cells in each axis, the process of audit can be verified if necessary.

5) Although the scope of this study is limited to production cells, by applying some modifications, the framework, methodology, and the results can be used for the operation cells in service industries. The maturity levels proposed in this study are general in both manufacturing and services industries. The axis of “Production Processes” should be replaced by “Operation Processes” and Information Technology requirements should be highlighted in the “Facilities

Management" axis. To determine the lean control items, performance metrics and lean enablers, the model should be customized for each case.

6) One can discuss about the contradiction of lean as a continuous improvement method and a never-ending evolution with LMM which is limited to a number of maturity levels and definite targets. Lean is a long-term journey, not a short term project (Drew, et al., 2004). In order to resolve the possible ambiguity in this area, we have to differentiate between establishing of a lean culture in the organization as a project as we discuss in this study (development phase of lean) and taking advantages of created potential of lean to improve performance of organization continuously (deployment phase of lean).

7) Analyzing the results obtained from assessment of lean using detailed checklists and comparing them with the corresponding performance measures help lean practitioners to evaluate and improve the system of lean assessment. Inconsistency between leanness results and performance outputs shows the problems of lean assessment system. Any of the following reason may create such kinds of inconsistencies:
   - Error in the calculations
   - Inaccuracy in performing audit
   - Inaccuracy of checklists
   - Lack of standardization after improvements
   - Auditors are not calibrated

Although, leanness assessment checklists are developed through development of lean program, a dynamic assessment system is suggested in which the evaluation system and its related checklists can be continuously improved by using the feedbacks of the previous assessments and by analyzing of leanness results in comparison with performance of production cells.

7.4 Recommendation and Future Research

The goal of this research is to develop a multi-dimensional lean maturity model for functional level and production cells in particular. By assessment of both leanness and performance of production cells, lean practitioners can assess the effectiveness of lean initiatives. In the future, the methodology can be further enhanced in the following areas.

- **Testing of leanness control items in a longer term empirical study:** leanness indicators and main control items proposed in this study is based on the background of ABC company and experience of author. Test the variability of main control items needs longer term implementation of assessment method in practice. Suggested main control items can be used as an initial guideline. A dynamic assessment methodology is proposed in which the assessment elements will be improved continuously through analysis of leanness results and production cells' performance.

- **Including Cost-related performance:** In definition of performance measures in this study, a maximum effort was made to select the most lean-related and cost-based performance measures. However, when production cells are the subject of assessment, type of goals may vary and data related to cost may not be available. When applying the model as an assessment framework, it is suggested to provide the potential to record and collect data related to the cost, quality and delivery in production cells at the early stages of lean project.

- **Applying LMM on Other Environments:** The proposed leanness maturity model is developed for production cells in manufacturing environment. Since the lean principles are almost same in other environment, the same model with small modifications can be applied to other circumstance such as service sector. Customization of model and definition of leanness elements related to each industry can be a subject of further research.

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APPENDICES

Appendix A:

Sample of Data Collection Instrument

for audit of production cells

lean Maturity Assessment

Control Item: Axis: Level: Control Item Code:	Date: Shift: Department; Production cell:

Question:	**0**	**1**	**3**	**5**	**N/A**	**Evidence**	**Action Plan**	**Due Date**	**Pilot**
Maximum score: Sum:		a_1	a_2	a_3		Audit Score:		Audit Score: / 100	
0 - Not Conform 1 - Major Non-conformance 3 - Minor Non-conformance 5 - Conform		Supervisor:					Auditor:		

Appendix B:

Sample of Guidelines for lean Assessment

Axis 2: Facilities

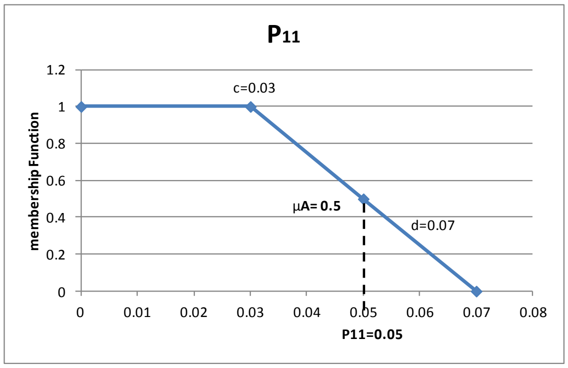
Level	Indicators	Main control items
1.Understanding	A. Progression of **standardizing maintenance tasks** in manufacturing cell (**stability** of machines)	- Percentage of standardized maintenance tasks by supervisor (target 100%) - Standards are available and updated - Quality of prepared standards (e.g. clarity, using visual descriptions, validation , time associated) – control by checklist
	B. Progression of **training** on maintenance tasks in manufacturing cell (**stability** of machines) and Progression of training on types of losses in manufacturing cells (**capability** of employees in analysis of loses)	- 100% training on corrective execution of maintenance tasks - Operators knowledge on maintenance tasks, key safety points, key maintenance points, control limits, etc - Operators knowledge on defined types of losses
	c. Progression of standardizing **set-up/shutdown** processes in manufacturing cell (improve **flow**)	- Percentage of standardized set-up/shut down tasks by supervisor (target 100%) - Standards are available and updated - Quality of prepared standards (e.g. clarity, using visual descriptions, validation , time associated) – control by checklist
	d. Progression of training on **set-up/shutdown** processes in manufacturing cell (improve **flow**)	- 100% training on corrective execution of set-up/shut down tasks - Operators knowledge on set-up/shut down tasks, key set-up/shut down points, etc
2.Implementation	A. Corrective execution of maintenance task in manufacturing cell according to standards (**stability** of machines)	- Percentage of compliance (e.g. sequence, time, safety points) using checklist
	B. Accomplishment of maintenance task in manufacturing cell according to schedule (**stability** of machines)	- Percentage of compliance with schedule
	C. Percentages of anomalies detected by supervisors/ operators in manufacturing cell (**capability** of employees in analysis of loses)	- Number of anomalies detected by supervisor or operator / total number of anomalies detected
	D. Percentages of **set-up/shut down** processes done by operators in manufacturing cell according to standards (improve **flow**)	- Number of set-up/shut down processes done by operator / total number of set-up/shut down processes
3.Improvement	A. Improvement of maintenance task standards	- Percentage of reduction in time of maintenance task
	B. Percentage of Preventive maintenance task to corrective maintenance tasks	- Preventive maintenance hours / corrective maintenance hours
	C. Improvement of set up/shut down task standards (improve **flow**)	- Percentage of reduction in set up/shut down time
	D. Improvement of internal schedule maintenance based on the past data history	- Total time of maintenance task

Axis 2: Facilities

Level	Indicators	Main control items	Indicator code	data collection method
4.Sustainability	A. Calculation and improvement of **maintenance cost** by team members according to analysis of KPIs in manufacturing cell (encourage collaboration and autonomy)	- Maintenance work hours - Cost of missing production due to down time - Cost of inspection - Cost of parts/material	L421	CL
	B. Percentage of losses eliminated by team members within manufacturing cell through **analysis** and problem solving processes (encourage collaboration and autonomy)	- Percentage of losses eliminated by team members / total number of losses	L422	HD
	C. Calculation and improvement **set up/shutdown cost** by team members according to analysis of KPIs in manufacturing cell (encourage collaboration and autonomy)	- Set up/shutdown cost in manufacturing cell	L423	HD
	D. Sustainable improvement of stability in machines - Steady trend of improvement on facilities' **stability** and performance indicators such as downtime and OEE through internal and external (if applicable) **benchmarking** of maintenance best practices	- Facilities management indicators	L424	CL

Appendix C:

Fuzzy Membership Function of Performance Measures in production Cell 2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0.05
0.06
0.07
0.08
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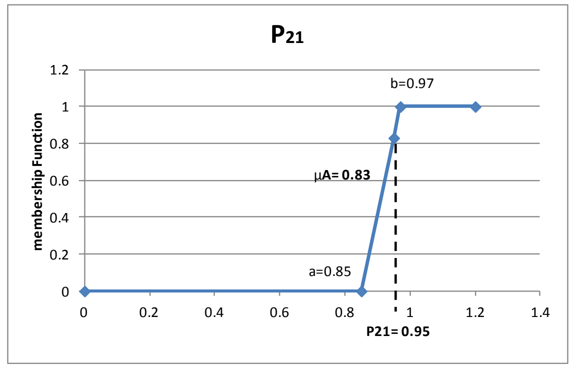
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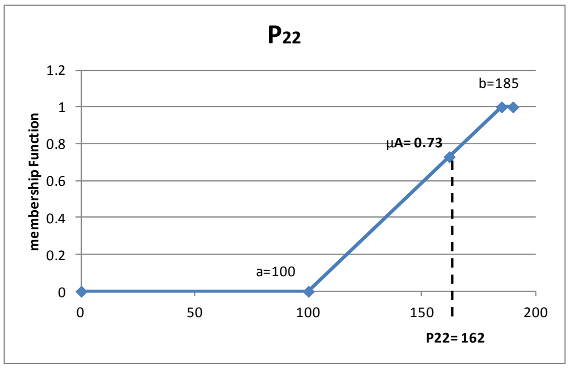
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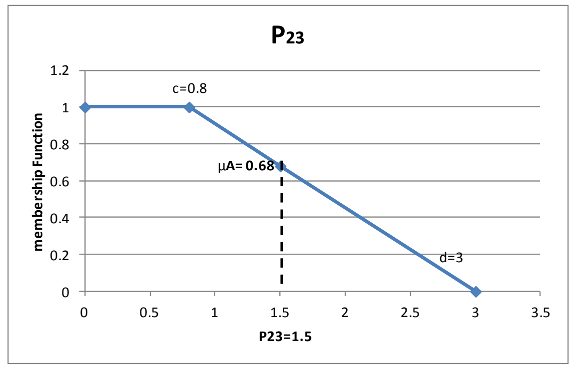
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3.5
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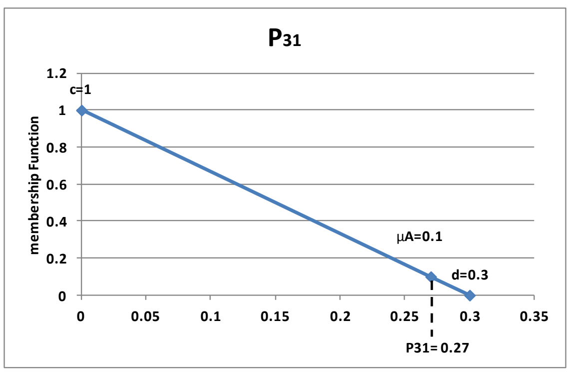
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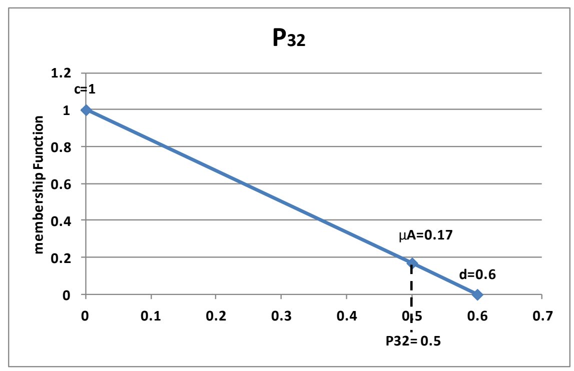
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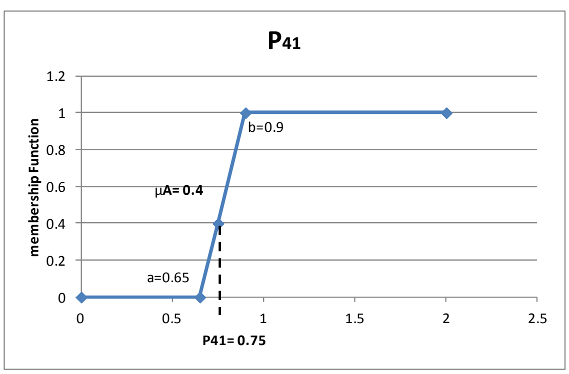
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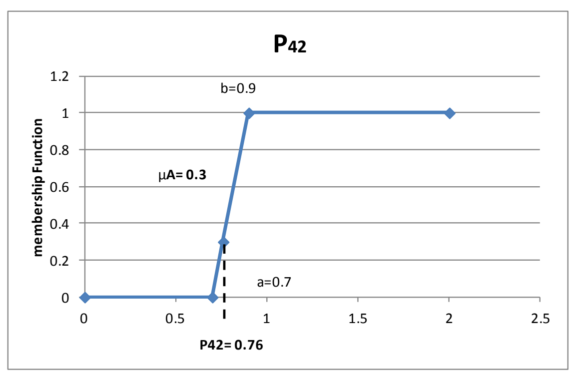
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2.5
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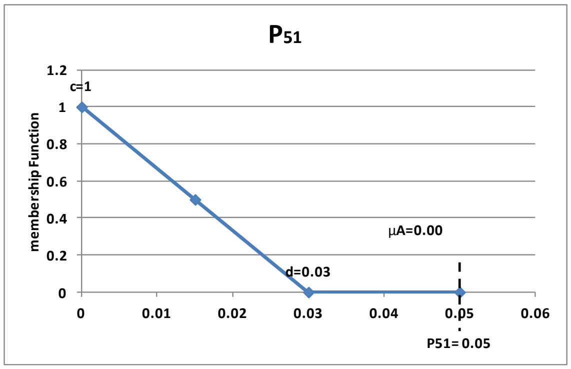
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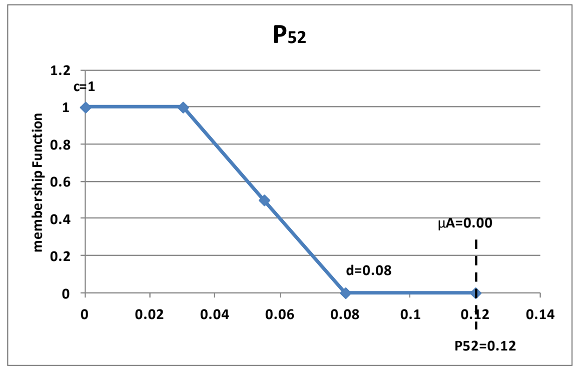
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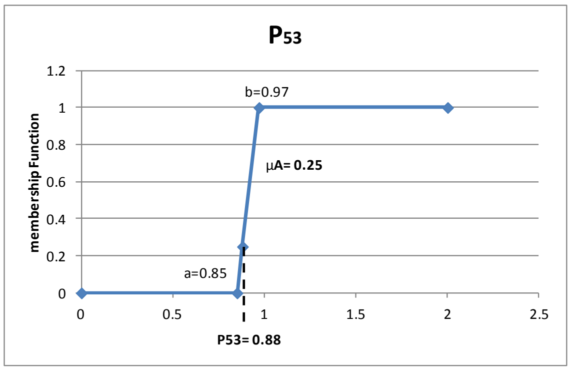
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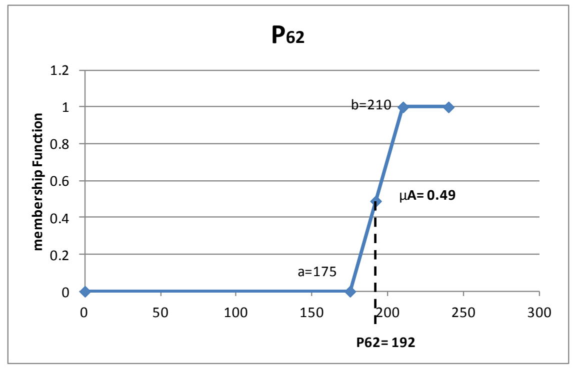
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