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Title: A Conceptual and Strategy Map for Lean Process Transformation

Abstract approved:

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Since the introduction of lean manufacturing by Toyota and publication by Womack and Jones, organizations have realized sizeable gains through lean process improvement. The spread of lean practices across organizations and industries – from manufacturing to healthcare and construction – requires adjustments of the lean process and, in the case of construction engineering, modification of the traditional lean paradigm (stationary product versus the traditional mobile product). Consequently, success in lean manufacturing projects is closer to 20%, and less than 2% of manufacturing jobs in the United States are truly lean. Previous studies show that this unsatisfactory result occurs because mangers use inappropriate practices and rely solely on financial measures and consequent performance measures. This leads to an overall lack of synchronization between lean goals and actual practices. Given the challenges associated with adopting lean and synchronizing strategy beyond financial measures, this study attempts to resolve the confusion surrounding lean implementation by providing a systematic, clear description of effective and efficient

routes through which organizations in different industries (or sectors) can adopt appropriate lean strategies. The following steps are taken to resolve the confusion in lean implementation: (a) a literature review of lean principles, lean practices, performance measures and performance measurement system; (b) an investigating of lean principles to integrate the literature with a survey of lean experts; (c) creation of a lean conceptual map that integrates lean principles with lean practices and performance measures; (d) incorporation of the lean balanced scorecard as a performance measurement system based on validated performance measures obtained through a survey of different manufacturing sectors in the United States; (e) identification of causal relationship between lean principles using Decision Making Trial Evaluation Laboratory method (DEMATEL), to construct an industry-specific strategy map with information from a survey of lean manufacturing companies in the United States (f) an investigating of the difference between the strategy maps constructed for each sector, and the cause and the central factors for each lean sector; and (g) a suggestion of an effective lean strategy for each sector. This thesis identifies a path for management to better invest resources in the aspects of lean implementation that are in acute need of improvement, by focusing on the most salient and central lean objectives. Such a tool could result in more effective and efficient lean implementation.

A Conceptual and Strategy Map for Lean Process Transformation

by
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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Waleed Mirdad, Author

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To my wife Shefaa for her continuous support, and infinite love.

To my parents for their endless praying.

To my advisor Chinweike I. Eseonu for his valuable advice.

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1 Introduction

This chapter outlines the motivation for this research, the contribution of this research to the literature on lean change management and engineering management, research objectives, methodology, and conclusions.

There is substantial literature devoted to resolving the issue of lean implementation failure. Much of this work states, but does not address the confusion in lean nomenclature that is often at the root of misunderstanding and failed implementation attempts. There is a need for research that addresses the confusion in lean concepts. There is also a need to standardize this clarification in a strategy map that can help decision makers avoid lean failures through an effective lean strategy.

The development of the study includes: (a) a literature review of lean principles, lean practices, performance measures and performance measurement system; (b) an investigating of lean principles to integrate the literature with a survey of lean experts; (c) creation of a lean conceptual map that integrates lean principles with lean practices and performance measures; (d) incorporation of a lean balanced scorecard as a performance measurement system based on validated performance measures obtained through a survey of different manufacturing sectors in the United States; (e) identification of causal relationship between lean principles using Decision Making Trial Evaluation Laboratory method (DEMATEL) to construct an industry-specific strategy map with information from a survey of lean manufacturing companies in the United States (f) an investigating of the difference between the strategy maps constructed for each sector, and the cause and the central factors for each lean sector; and (g) a suggestion of an effective lean strategy for each sector. This thesis identifies a path for management to better invest resources in the aspects of lean implementation that are in acute need of improvement, by focusing on the most salient and central lean objectives. Such a tool could result in more effective and efficient lean implementation.

1.1 Motivation

The increasing strength of competition in the global market and the customer demand are threatening and challenging companies in the international market. Therefore, companies are exploring practical methods to increase their competitiveness by using advanced manufacturing systems (Rawabdeh, 2005). Lean manufacturing is recognized as an effective approach for achieving and maintaining competitive advantage through an improved manufacturing process (Chapman & Carter, 1990; Foster & Horngren, 1987; Fullerton, McWatters, & Fawson, 2003; Sakakibara, Flynn, & Schroeder, 1993). By applying lean manufacturing principles, organizations can increase value for customers, while improving organizational profitability and citizenship behavior by employees (Karim & Arif-Uz-Zaman, 2013).

Organizations aim to reduce non-value adding activity by using lean principles and lean tools. However, a survey by Industry Weekly (2007) shows that only 20% of lean manufacturing projects are successful. Sheridan (2000) also indicates that less than 2% of manufacturing jobs in the United States are truly lean. Previous studies show that lean implementation failure is correlated with incomplete or ineffective implementation of lean principles, practices, and tools. Examples of ineffective implementation include selecting inappropriate lean strategies, using the wrong tool to solve the problem, sole reliance on financial measures and consequent performance measures, and an overall lack of synchronization between lean goals and actual practices (Anvari, Zulkifli, Yusuff, Ismail, & Hojjati, 2011; Goyal & Deshmukh, 1992; Karim & Arif-Uz-Zaman, 2013; Nakamura, Sakakibara, & Schroeder, 1998; Norris, 1992; Pavnaskar, Gershenson, & Jambekar, 2003).

The motivation for this research was derived from identification of significant variability in lean nomenclature by lean authors, and the confusion. This variation propagates among adopters/practitioners who seek to adopt lean principles. This study attempts to resolve the confusion surrounding lean implementation by providing a clear conceptual map that connects lean principles and practices with financial and non-financial performance measures. The study will use the balanced scorecard as a performance management system to help construct a lean strategy map. Organizations can use the strategy map to drive focus on the most important criteria for lean implementation.

1.2 Contribution

This research contributes to existing literature on lean conceptualization, implementation, and sustainability. It is also relevant to practicing engineering managers about to undertake or ensure lean process improvement. The main objective of this study was to help the organizations avoid lean implementation failures.

1.2.1 Contribution to the Literature

Since the introduction of lean manufacturing by Toyota and publication by Womack and Jones, organizations have realized sizeable gains through lean process improvement. Recent studies show that a high percentage of organizations are not successful in implementing lean manufacturing. From the literature, lean implementation failure is associated with conceptual confusion about lean principles, practices, and performance measures. Consequently, lean adopters often select inappropriate lean strategies, use the wrong tool to solve problems, rely solely on financial measures, and lack synchronization between lean goals and actual practices (Anvari et al., 2011; Goyal & Deshmukh, 1992; Karim & Arif-Uz-Zaman, 2013; Nakamura et al., 1998; Norris, 1992; Pavnaskar et al., 2003). In the effort to solve these problems, the literature tries to suggest different resolutions for each problem. There are studies that attempt to clarify lean concepts (Anand & Kodali, 2009; Karlsson & Ahlström, 1996; Liker & Kaisha, 2004; Sánchez & Pérez, 2001; Shah & Ward, 2007; Womack, Jones, & Roos, 1990a), lean performance measures (Anvari, Zulkifli, & Yusuff, 2013; Bayou & de Korvin, 2008; Christiansen, Berry, Bruun, & Ward, 2003; Fullerton & McWatters, 2001; Fullerton et al., 2003; Koufteros, Vonderembse, & Doll, 1998; Rawabdeh, 2005; Sánchez & Pérez, 2001; Taj, 2005), and lean strategy (Ahlström, 1998; Anvari et al., 2011; Black, 2007; Karim & Arif-Uz-Zaman, 2013). Figure 1-1 depicts the disjointed lean conceptual landscape that results from this piecemeal approach.

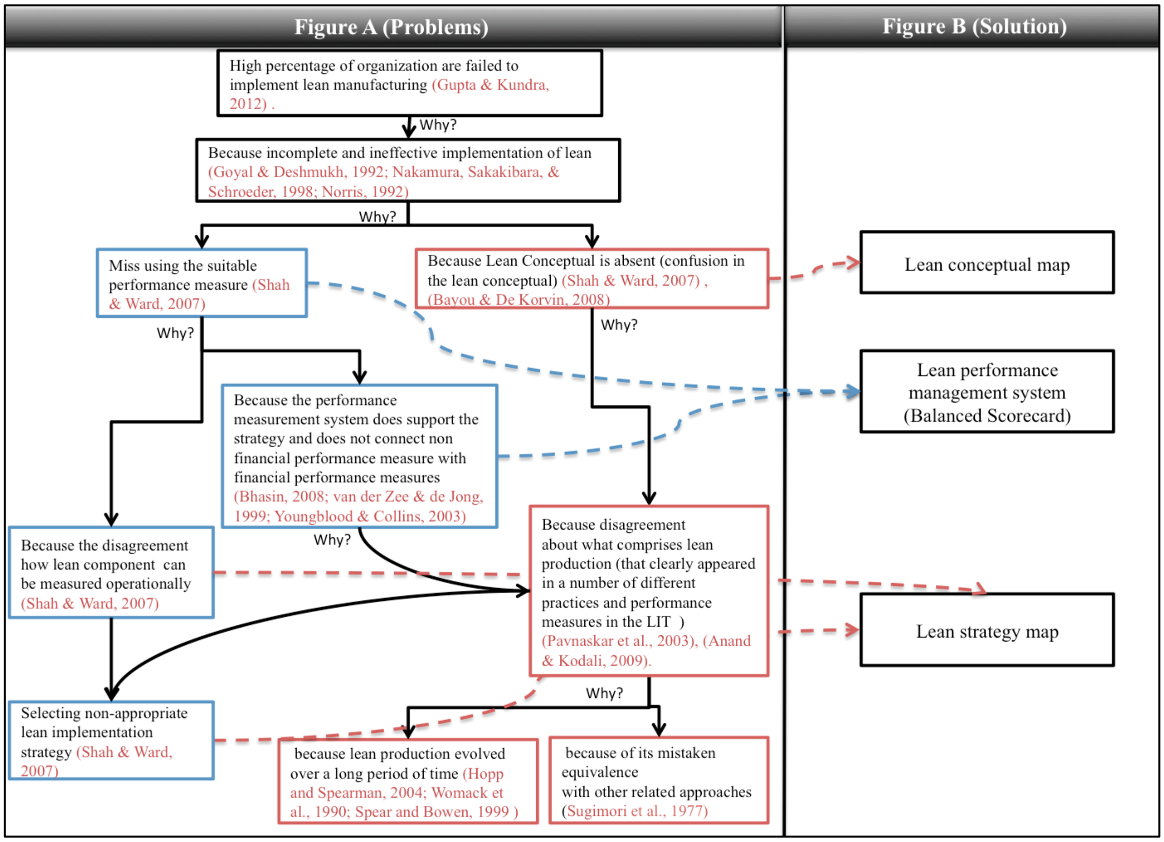


Figure 1-1 problem analysis by using 5 why techniques

This piecemeal approach also leads to lack of agreement in the literature about lean principles, performance measures, and practices. Several authors give different definitions of lean, alongside differing descriptions of lean principles, practices, and performance measures. The significant variability in specification of lean nomenclature by lean authors, propagates confusion among adopters/practitioners who seek to adopt lean principles.

Two hundred practices were collected from 22 different articles, alongside 250 different lean performance measures. This wealth of lean approaches could allow an adopter to accidentally apply the wrong tools to resolve a problem, posing successful lean implementation.

Additionally, Effective strategy management requires clear performance management systems. The literature provides a variety of methods to evaluate the lean performance such as: surveys, review of historical data, and other qualitative (Doolen & Hacker, 2005; Soriano-Meier & Forrester, 2002; Upton, 1998), and quantitative approaches. Quantitative methods such as simulation, (Detty & Yingling, 2000; Lummus, 1995), fuzzy logic (Bayou & de Korvin, 2008; Behrouzi & Wong, 2011), and linear programming (Wan & Frank Chen, 2008) are also used. These performance management methods proposed in the literature are not integrated with lean strategy implementation.

Previous studies show that organizational characteristics are a determinant in the selection of the appropriate practices to build the lean implementation strategy (Dilworth, 1987; Gilbert, 1990; Harber, Samson, Sohal, & Wirth, 1990; Im & Lee, 1989; Shingō, 1989; Sohal, Keller, & Fouad, 1989) . Consequently, organizational characteristics must be considered in the discussion of lean strategy. However, the literature does not consider the organizational characteristics during evaluation or selection of lean strategy.

This study highlights the disagreement among lean experts through a literature review to document lean principles, lean practices, performance measures, and performance measurement system. Additional investigation was conducted to explore and validate the high level of variability in lean terminology among lean experts. The resulting information was synthesized in a conceptual map, which was created to allow non-experts to visualize the inter-twined relationships between principles, practices, and performance measures. The classifications in the conceptual map were derived from a survey of lean experts.

Sustained change is an important part of successful initiative. Performance measures are an important means of incentivizing process transformation. The conceptual map was used to build the performance measurement system. The study provides a lean balanced scorecard that is validated by the practitioners from different manufacturing sectors. The suggested balance scorecard could help organizations/scholars compare or adopt different performance measures.

Additionally, a lean strategy map was created and the logical links between lean principles were identified. The strategy map was constructed using the validated balanced scorecard. The organizational characteristics were considered in the evaluation of the lean strategy. The lean strategy map is a result of integrated principles, performance measures, and practices that fill the gap in the literature. The map could also help reduce lean implementation failure due to lean confusion.

1.2.2 Relevance for Practitioners and Engineering Managers:

The decision support tools designed in this thesis will help reduce confusion about lean nomenclature. Reduced confusion will result in better understanding of underlying principles, as opposed to a focus on practices. The conceptual map helps the adopter select a suitable practice to solve the problem. This thesis uses a survey of lean experts to clarify the lean nomenclature and provide a visual map to guide system transformation managers, or lean champions, who seek to implement lean manufacturing processes.

Successful change management requires clear specification of objectives, execution plans, and performance metrics. This is true in kaizen event teams (Farris, Van Aken, Doolen, & Worley, 2009), innovation and new product development (Russell & Tippett, 2008), assessing the effectiveness of design tools (Farris, Van Aken, Letens, Ellis, & Boyland, 2007), and managing efficient and effective training progress (Wiseman, Eseonu, & Doolen, 2014).

In their review of performance metrics for supply chain management, Elrod, Murray, & Bande (2013) identify the lack of clear specification as a hindrance to effective performance measurement and supply chain management. The tendency to get “lost in a sea of data” is also prevalent in attempts to implement lean manufacturing principles. Managers are often faced with lofty principles and find conflicting directions in the literature on corresponding practices and performance measures. The conceptual map developed here addresses this challenge. It applies the lean principle of “flow” through visual workplace practices to develop a poka yoke decision making tool for lean implementation.

Abdulmalek, Rajgopal, & Needy (2006) express the need for lean implementation in process industries. They highlight broad lean aims of *faster delivery, higher quality*, and *lower cost* as key success factors. They also list *employee empowerment, utilize less to create more,* and *elimination of non value adding activities* as principles. The conceptual map developed in this study provides a complementary tool that will reduce the likelihood of erroneous lean implementation once a determination of lean suitability has been made using the model developed by Abdulmalek, Rajgopal, & Needy.

Farris, et al., (2008) identified input, process and output factors that determine kaizen event success. Some input factors included *goal clarity,* and *event planning process*. Process factors included items like *tool appropriateness,* and output factors included *attitude, kaizen capabilities,* and *overall perceived success.* A visual tool, like the conceptual map developed here, improves goal clarity and facilitates kaizen event planning by clearly linking desired end goals (lean principles) to methods (lean practices) for achieving said goals, and providing performance measures associated with each end goal.

The map improves process determinants of success by aligning appropriate tools with desired lean principles. This framework can ultimately promote participant confidence in the outcomes of process improvement events, increase self-efficacy of the process improvement team, and by extension, the overall perception of event success. Employee buy-in is an important aspect of process improvement initiatives. The lean conceptual map assists engineering and process transformation managers in explaining the impact of lean practices on an employee's workspace – through associated performance measures. It can also be a useful tool for developing incentive schemes.

The conceptual map highlights the critical success factor for lean implementation in product development teams. Previous research looked at the need for assessment frameworks that could guide process improvement in new product development. Lean new product development is an emerging area of research and practice. This paper extends previous work on NPD tool and process assessment to promote the accurate application of lean concepts in NPD processes. It increases a manager's ability to match a desired principle with the right assessment tool and provides a visual communication tool that can be used to design effective and efficient training programs.

Wiseman et al., (2014) developed a framework for pre-emptive evaluation of continuous improvement training programs. They identified *communication, resources,* and *time* as the most important determinants of successful continuous improvement training. The association of performance measures with specific lean practices and principles increases a manager's ability to communicate proposed lean-induced changes. It facilitates resource allocation for planned change, and assists in setting performance measurement targets.

Decision makers are usually restricted by limited time and resources. This thesis presents a strategy map that integrates lean principles and practices with performance measures. The strategy map can help organizations focus on the most important factors to effectively and efficiently achieve process improvement objective. The strategy map identifies paths for engineering managers to leverage the 80/20 rule by focusing on tools that sustain the most significant (main cause) lean principle.

It is important to note that each organization has a unique strategy map for implementing lean manufacturing. Each strategy map depends on the culture, policies, and organizational characteristics (Anvari et al., 2011). Therefore, the suggested strategy map is only a general guide to give the logical path for implementing lean manufacturing principles.

Good engineers are often promoted to management positions without training in personnel and process management. The engineering management literature can provide easily accessible tools that reduce wasted time and effort and increase the chances of successful initiatives by engineering managers. This thesis has provided a clear link that would allow engineering managers effectively carry out planning, organizing, leading, and controlling functions in lean transformation projects.

1.3 Research Objectives:

The objective of this research is to help the organization avoid the common mistakes that lead to lean implementation failure. Figure 1-1 part b identifies the suggested solutions, developed in this study, to avoid lean implementation failure. Table 1-1 shows the objectives of this research.

Table 1-1: Research objectives

	Objectives
Paper 1	Highlight and validate the conceptual disagreement among lean experts.
	Identify lean principles that reduce conceptual confusion and on which most experts agree.
	Investigate and clarify direct association between lean principles, practices, and performance measures
Paper 2	Determine what organizational characteristics influence the implementation of lean practices. In this study, the organizational characteristics are examined through investigation of the following hypotheses: • The organizational size (large or small) affects the level of implementation of lean practices. • The nature of the market (local or global) affects the level of implementation of lean practices. • The perception of competiveness (high, medium or low) affects the level of implementation of lean practices. • The volume of production (high volume, medium volume, or low volume) affects the level of implementation of lean practices. • The level of product variation (high, medium, or low mix) affects the degree of implementation of lean practices. • The level of demand uncertainty (high, medium or low) affects the level of implementation of lean practices. • The level of process flexibility (flexible, not flexible, or mixed) affects the level of implementation of lean practices. • The level of variation (or mix) of raw materials (high variety, or low variety) affects the level of implementation of lean practices. • Organizational sector (industry) is a determinant of the level of lean implementation.
	Identify suitable measures for a performance measurement system based on the balanced scorecard.
	Create a lean strategy map for each significant organizational characteristic and suggest the cause factor and the central factor for implementing lean manufacturing.

1.4 Research Methodology

Three different surveys were conducted to achieve the objectives of this study. Additionally, non-parametric tests (Mann-Whitney U, and Kruskal–Wallis) ware used to investigate the effects of the different impacts. In addition to that, the Decision Making Trial and Evaluation Laboratory (DEMATEL) method was used to help to investigate the complicated causal relationships between lean principles for building up the strategy map based on the balanced scorecard. Figure 1-2 summarizes the study outline.

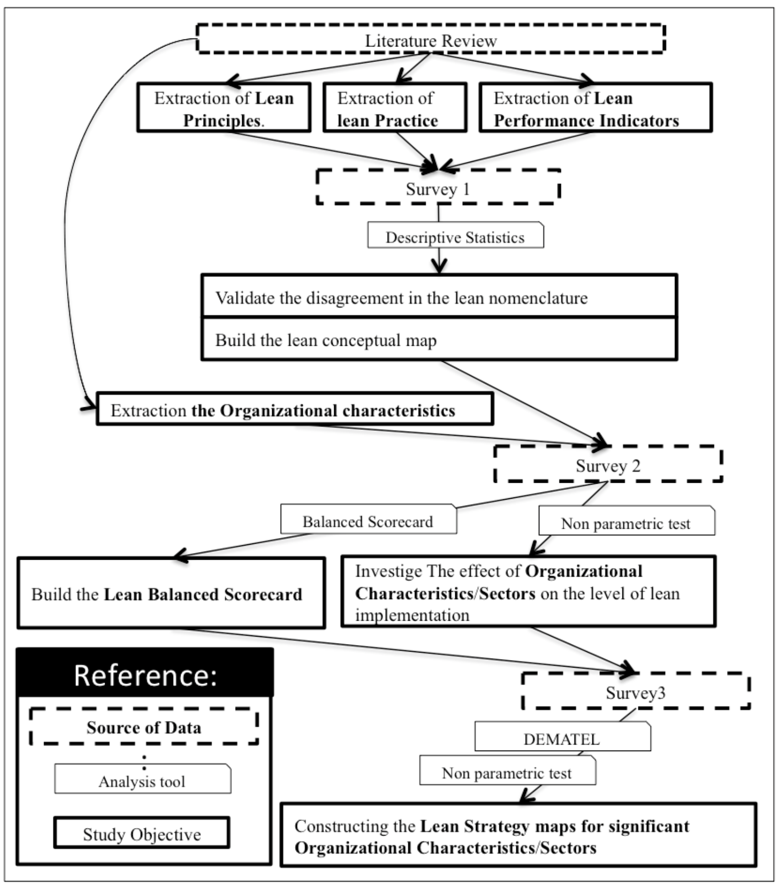
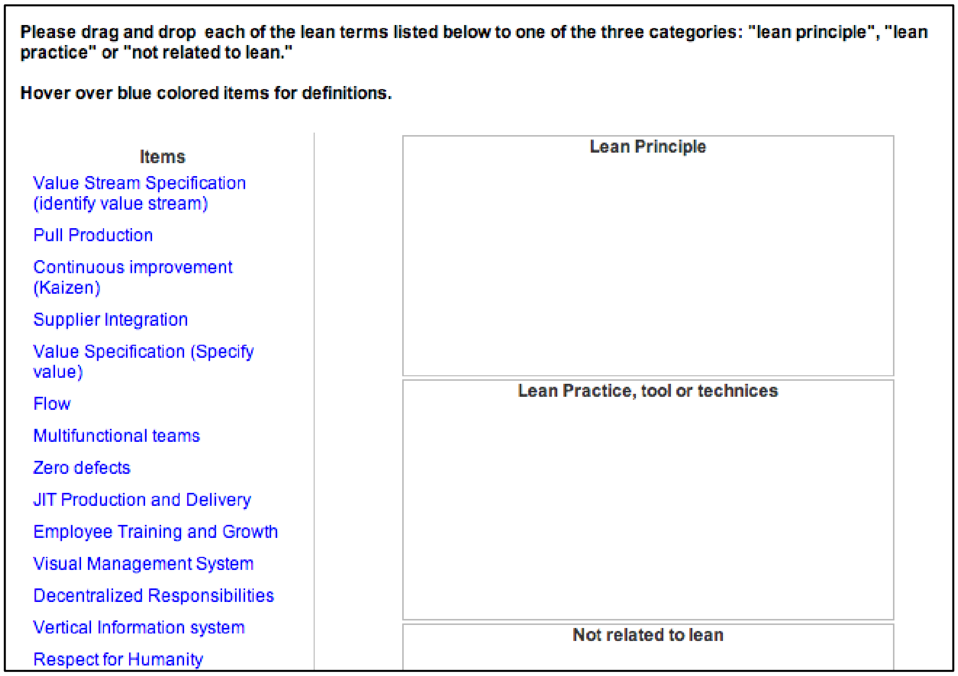


Figure 1-2: Research outline

The literature review was the first source for extracting lean principles, practices, and performance measures. Approximately 200 practices and 250 different lean performance measures were collected from the literature. Due to the large number of practices and performance measures, only the most frequent constructs were used in this work. The frequency of practice or performance measure was defined as the number of times a practice or performance measure was listed in the reviewed articles.

The lean conceptual map was constructed based on a survey of lean experts. The survey was designed using Qualtrics (Web-based survey software), 49 experts (individuals who have authored at least one peer reviewed article related to lean manufacturing) responded to the survey. In the survey, the experts were asked to differentiate between lean principles and lean practices .The definitions of items were provided in the survey. The experts then grouped items into three categories: "Lean principle", "Lean practice", and "Not related to lean". The result was then used to identify lean principles. Figure 1-3 shows an example of the survey sturcture.



Please drag and drop each of the lean terms listed below to one of the three categories: "lean principle", "lean practice" or "not related to lean."

Hover over blue colored items for definitions.

Items
Value Stream Specification (identify value stream)
Pull Production
Continuous improvement (Kaizen)
Supplier Integration
Value Specification (Specify value)
Flow
Multifunctional teams
Zero defects
JIT Production and Delivery
Employee Training and Growth
Visual Management System
Decentralized Responsibilities
Vertical Information system
Respect for Humanity

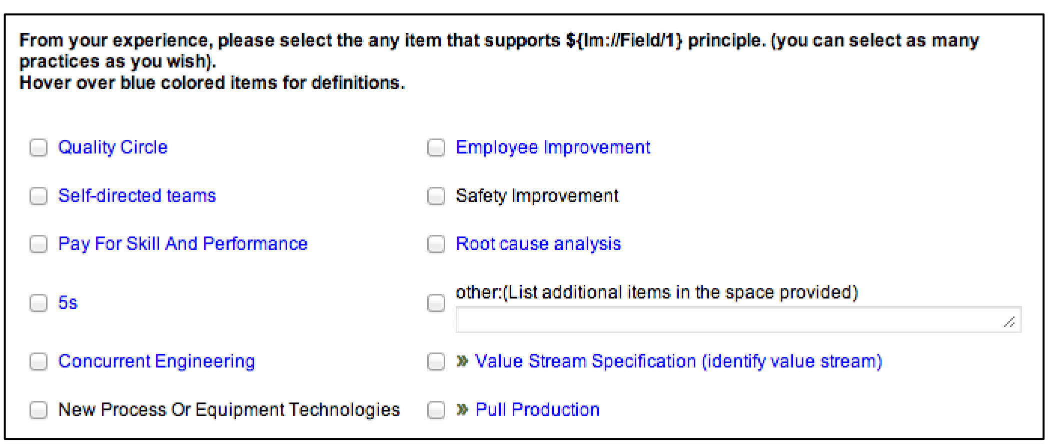
Lean Principle

Lean Practice, tool or techniques

Not related to lean

Figure 1-3: Example of the survey used in the lean conceptual map validation process.

Based on the experts' selections, lean principles were specified. Next, experts were asked to add, change, or delete lean practices and to assign practices from their chosen list to previously selected principles (Figure 1-4). Each expert could select multiple practices for each principle. In the result, we obtained five lean principles and 48 lean practices grouped under lean principles.



From your experience, please select the any item that supports ${lm://Field/1} principle. (you can select as many practices as you wish).
Hover over blue colored items for definitions.

Quality Circle
Employee Improvement
Self-directed teams
Safety Improvement
Pay For Skill And Performance
Root cause analysis
5s
other:(List additional items in the space provided)
Concurrent Engineering
» Value Stream Specification (identify value stream)
New Process Or Equipment Technologies
» Pull Production

Figure 1-4: Example of the survey in the lean conceptual map validation process.

The second survey concentrates on investigating the level of impact of different organizational characteristics and different manufacturing sectors on the implementation of lean practices. In the survey, the respondents were asked to identify the rate of implementation of the proposed practices associated with lean principles within their organization (Figure 1-5). This was accomplished using a five-point Likert scale:

- No Implementation (0 percent);
- Little Implementation (25 percent);
- Some Implementation (50 percent);
- Extensive Implementation (75 percent);
- Complete Implementation (100 percent);

Indicate the level of implementation of each of the following practices to the facilitate the Pull Production principle

Hover over blue colored items for definitions.

	No Implementation (0%)	Little Implementation (25%)	Some Implementation (50%)	Extensive Implementations (75%)	Complete Implementation (100%)
Kanbans	○	○	○	○	○
Standard Work	○	○	○	○	○
Value Stream Mapping	○	○	○	○	○
Supplier Integration	○	○	○	○	○

Figure 1-5: Example of the survey question for “pull” related practices

The “Shapiro-Wilk” test for normality (Razali & Wah, 2011; Shapiro & Wilk, 1965), histograms, and normality plots showed that the data was not normality distributed. This was true for all categorized groups. Therefore, non-parametric test was conducted to investigate the effect of organizational characteristics on the implementation of lean practices.

In addition to the previous questions, another type of question was asked to validate the adopted lean performance measure that was implemented according to the lean principles (Figure 1-6). Respondents were asked to identify the level of use of performance measures to evaluate each lean principle within their organization. This was accomplished using a five-point Likert scale (Not used, Used on limited basis, Some Use, Extensive use and Used across organization). The ultimate goal of these questions was to validate lean performance measures and apply lean performance measures into a balanced scorecard framework.

Indicate the level of use of each of the following performance measures to the facilitate Pull Production

	Not used	Used on a limited basis	Some use	Extensive use	Used across orgnaization
Number of Kanbans	○	○	○	○	○
Number of S.O.Ps and Regulation (Standardization)	○	○	○	○	○
The number of stages in the material flow that use pull(backward requests) in relation to the total number of stages in the material flow	○	○	○	○	○
Frequency of Production is pulled by the shipment of finished goods	○	○	○	○	○
Frequency of production at stations is pulled by the current demand of the next station	○	○	○	○	○

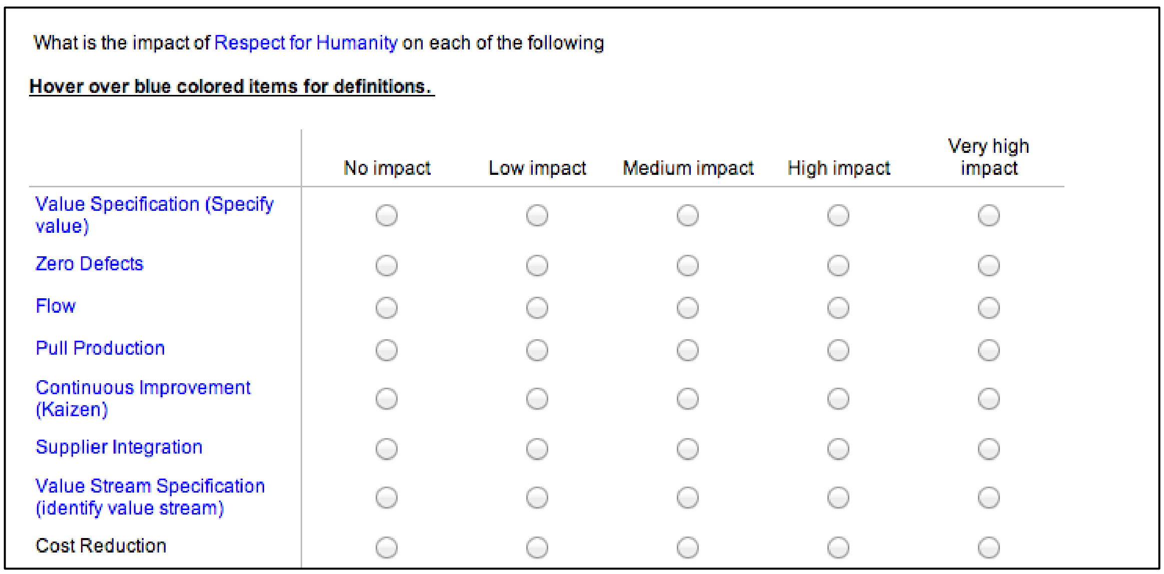
Figure 1-6: Example survey of lean performance measures questions

The third survey was created to identify the level of impact of one lean principle on another by using Decision Making Trial and Evaluation Laboratory (DEMATEL). The DEMATEL method is used to understand complex the complicated relationships between items in a system (Wu, 2012) . The survey is divided to two parts. The first part includes demographic information (Organizational Characteristics, and Sector of Operation). The second part includes DEMATEL questions. All questions were structured in the following form: “What is the impact of ‘X principles’ on each of the following”. Figure

1-7 shows an example of the questions. Responders were asked to specify the level of impact by a selecting one of the following responses:

- No impact (0 score)
- Low impact (1 score)
- Medium impact (2 score)
- High impact (3 score)
- Very high impact (4 score)

The goal of the survey is to draw a causal relationship between lean principles by using the DEMTAL technique to construct a strategy map.


What is the impact of Respect for Humanity on each of the following

Hover over blue colored items for definitions.

	No impact	Low impact	Medium impact	High impact	Very high impact
Value Specification (Specify value)	○	○	○	○	○
Zero Defects	○	○	○	○	○
Flow	○	○	○	○	○
Pull Production	○	○	○	○	○
Continuous Improvement (Kaizen)	○	○	○	○	○
Supplier Integration	○	○	○	○	○
Value Stream Specification (identify value stream)	○	○	○	○	○
Cost Reduction	○	○	○	○	○

Figure 1-7: Example survey of DEMATEL question

1.5 Findings and Conclusion:

Fundamentally, the challenges and difficulties that occur during the implementation of lean manufacturing translate into a high rate of failure. This study attempted to resolve the confusion surrounding lean implementation by providing a clear conceptual map that connects lean principles and practices to financial and nonfinancial performance measures.

The final lean conceptual map summarizes the categorization of lean practices under the five lean principles (Flow, Continuous Improvement, Pull, Zero Defect, Specify Value, and Respect of Humanity). The surveys were conducted to understand the level of confusion, provide clarification, and develop tools to prevent further confusion. The first survey was used to clarify the lean nomenclature and provide a visual map to guide system transformation managers, or lean champions, who seek to implement lean manufacturing processes. In addition, more investigation has been conducted to explore and validate the high level of variability in lean terminology between lean experts and to create a conceptual map that can allow non-experts to visualize the inter-twined relationships between principles, practices, and performance measures. Such a map is essential because performance measures are an important means of incentivizing process transformation. The conceptual map helps adopters select suitable practices to solve lean problems. In addition, the lean conceptual map encourages implementing lean manufacturing as an integrated system, as opposed to the prevalent pitfall of random tools selected depending on individual opinions.

From the second survey, the researchers based the result only on the organizations that formally implemented lean manufacturing. It is interesting to note that almost all manufacturing sectors are formally adapting lean manufacturing. The level of lean adoption differs from one sector to another based on organizational characteristics. In this study, we examined the level of lean adoption based on different organizational characteristics and found that the ideal organizational characteristics for adapting lean manufacturing practices are:

- Large organizational size (more than 500 employees)
- Highly competitive environment

- High-Medium volume production level (more than 20,000 units per year)
- Flexible processes (The organization can easily change the layout and process sequence).

A lean balanced scorecard (BSC) is one of the outcomes of the second survey. The BSC was validated through a survey of practitioners from different manufacturing sectors. The suggested balance scorecard could help organizations/scholars compare or adopt items (principles, practices, and performance measures) in lean manufacturing projects.

From the third survey, a strategy map was created to identify logical links between lean principles. The strategy map was constructed using the validated balanced scorecard from the second survey. In order to create the strategy map, one must identify the causal relationships between lean principles. In this study DEMATEL techniques were used in place of the rule of thumb to define the relationship between the principles. The results provide value for practitioners.

2 Literature Review

2.1 History of Lean Process Improvement Systems

Global competition and customer demand are pose significant challenges for companies in the international market in the international market. Consequently, companies are exploring practical methods of increasing their competitiveness by using advanced manufacturing systems (Rawabdeh, 2005). Therefore, manufacturing systems have undergone significant changes over the past century. This transformation began with industrialization (i.e. craft manufacturing) and extends to modern industrial systems such as lean manufacturing (Ozelkan & Galambosi, 2009).

Craft production was the first approach to manufacturing. In craft manufacturing environments, highly skilled operators crated products that ware customized for customer requirements (Ozelkan & Galambosi, 2009). This resulted in high products variety, and high sales prices (Ozelkan & Galambosi, 2009). The owner of the job shop coordinates the system and is in direct contact with everyone in the job shop: employees, customers, and suppliers (Womack et al., 1990a). Job shops boast a high level of specialization. However, high level of customization, leads to product variability. Quality is highly dependent on the skill level of workers in the job shop (Ozelkan & Galambosi, 2009). Job shops are unable to satisfy high demand rates without exorbitant labor expense. Companies began to seek practical ways in which they could address the limitations of job shops to meet customer demand in reasonable time frames.

Henry Ford introduced mass production in a bid to escape the limitation of job shops. The first assembly line was designed for Ford’s model T in 1908 (Jiang, Lee, & Seifert, 2006). Mass manufacturing uses standardization to achieve economics of scale, higher efficiencies, and lower sales prices. Therefore, the variability and flexibility of products are limited (Ozelkan & Galambosi, 2009). Ford achieved standardization and economics of scale by reducing human effort in assembly line. Consequently, Ford reached peak production of 2 million cars in 1920s (Womack et al., 1990a).

The concept of lean manufacturing originated in Japan after the World War II. The Toyoda Family which had practiced manufacturing techniques since the 19th century diversified to the automobile industry in the late 1930s. In an attempt to understand automobile manufacturing, Toyoda took a three month trip to Ford's Rouge plant. Toyoda and Ohno recognized that mass production was unsuitable for the Japanese market (Womack, Jones, & Roos, 1990).

Toyoda and Ohno sought to combine the advantage of craft manufacturing (high customization) with the advantages of mass manufacturing (high production volume), and add new concepts to generate what became the Toyota Production System (TPS) (Womack et al., 1990b).

Lean can mean 'less' in terms of waste, design time, cost, organizational layers and the number of suppliers per customer. However, lean can also mean 'more' in terms of employee empowerment, flexibility and capability, productivity, quality, customer satisfaction and long-term competitive success (Comm & Mathaisel, 2003).

2.2 Diffusion of Lean Manufacturing

Lean manufacturing was initially applied to the global automotive industry (Womack et al., 1990b). The success of lean companies has led to the application of lean manufacturing in different industrial sectors (Anand & Kodali, 2009), which has also seen significant improvements in process performance (Jon, Detty, & Sottile, 2000).

Dunstan et al (2006) In the mining industry, Dunstan et al (2006) identified effects of lean that included reduction in absenteeism from 3.4% to 1.8% and savings $2 million (Dunstan, Lavin, & Sandford, 2006). Other studies have found improvement, such as a 50% reduction in lead time in the steel indusry (Dhandapani, Potter, & Naim, 2004). The literature shows huge profit gaining as result of implementing lean, and consider it as frequent assumption outcome (Rosemary R. Fullerton et al., 2003), such as Allway & Corbett (2002) when they realized 15 to 20 times annual sales growth and total return (Allway & Corbett, 2002). Ferdousi (2009) mentioned Improvement between 10%-60% in the productivity.

The successful application of various lean practices has also been documented in other industries, such as aerospace, computer engineering, and automotive assembly (T. L. Doolen & Hacker, 2005; Parry & Turner, 2006). The benefits of lean expanded to include non-process industries, all aspects of supply chain, to business process such as project management, construction and design (Melton, 2005).

Lean manufacturing implementation improved performance adopters (Jon et al., 2000). 95% of corporate executives consider lean manufacturing as a critical factor for achieving world class manufacturing (Sakakibara et al., 1993).

Table 2-1 shows a list of lean manufacturing benefits from selected literatures. The lean-induced benefits include higher and faster throughput, better product quality, on time delivery of finished goods, better product quality, reduced inventory levels, customer satisfaction, and shorten lead time (Eswaramoorthi, Kathiresan, Prasad, & Mohanram, 2010; Goyal & Deshmukh, 1992; Norris, 1992).

Table 2-1: Benefits of lean and their appearance in key references

	(Detty & Yingling, 2000)	(Bayou & de Korvin, 2008)	(Allway & Corbett, 2002)	(A. M. N. Rose, Deros, Rahman, & Nordin, 2011)	(Ferdousi, 2009)	(Pavnaskar et al., 2003)	(Melton, 2005)	(Karlsson & Ahlström, 1996)	(Cumbo, Kline, & Bumgardner, 2006)	(R. R. Fullerton & McWatters, 2001)	(Eroglu & Hofer, 2011)	(R. R. Fullerton & McWatters, 2001)	(Ahls, 2001)	(Barker, 1994)	(Emiliani, 1998)	(Ross, 2003)	(Womack & Jones, 1996)
Reduced inventory levels	x			x		x	x			x	x		x	x		x	x
Effictive production control and scheduling systems	x						x	x			x						
Supplier improvement	x					x	x										
Customer satisfaction	x						x			x	x	x				x	
Lead time reduction		x		x	x	x			x	x		x	x	x		x	x
Waste elimination		x				x											
Improved employee performance		x	x														
Annual sales growth and total return			x			x											
Improved knowledge management				x			x										
Product development				x				x									
Product quality improvement					x	x				x	x	x	x	x		x	x
Reduction in changeovers						x									x		

Despite the benefits listed in table 2-1, some industries or sectors report only limited success in using lean manufacturing to increase competitiveness (Doolen & Hacker, 2005; Eroglu & Hofer, 2011). The literature outlines the characteristics that limit lean manufacturing in different industrial sectors, such as demand variability, inability to control production, rigid organizational structures, and changing economic conditions (Anvari et al., 2011; Cumbo et al., 2006; Doolen & Hacker, 2005).

The literature also supports that organizational characteristics impact the success of lean implementation. For example, some studies show that product volume and variety is an improvement determinant of successful implementation (Jina, Bhattacharya, & Walton, 1997). In addition, White et al. (1999) suggest that lean manufacturing is more applicable in large U.S. manufacturers than in their smaller counterparts. They show a higher percentage of applicable practices in large manufacturers. Shah & Ward (2003) also support the argument that plant size and plant age are determinates of lean implementation success (Shah & Ward, 2003).

Despite the numerous benefits of lean as mentioned previously, only 10% or fewer, organizations are successful in lean manufacturing implementation (Gupta & Kundra, 2012). Anvari, Zulkifli, Yusuff, Ismail, & Hojjati (2011) show that very few companies truly sustain lean because they have incomplete or wrong lean implementation strategies. This finding supports the emphasis Womack et al. (1990) place on system-wide lean implementation (Womack et al., 1990b). Several authors consider lean a fragile system because trivial problems in the system can seriously affect the performance (Biazzo & Panizzolo, 2000). As a result, organizations require a conceptual (system level) understanding of lean in order to avoid the problems of failed implementation due to faulty strategies or misunderstanding. The literature supports that lean implementation failure is associated with the confusion in the lean nomenclature, which often leads adopters to select inappropriate lean strategies, use the wrong tools or performance measures on financial measures. This leads to an overall lack of synchronization between lean goals and actual practices (Anvari et al., 2011; Goyal & Deshmukh, 1992; Karim & Arif-Uz-Zaman, 2013; Nakamura et al., 1998; Norris, 1992; Pavnaskar et al., 2003).

2.3 Lean Conceptual Literature

The following sections present a summary of the literature on lean nomenclature. Figure 2-1 represent the outline of this section.

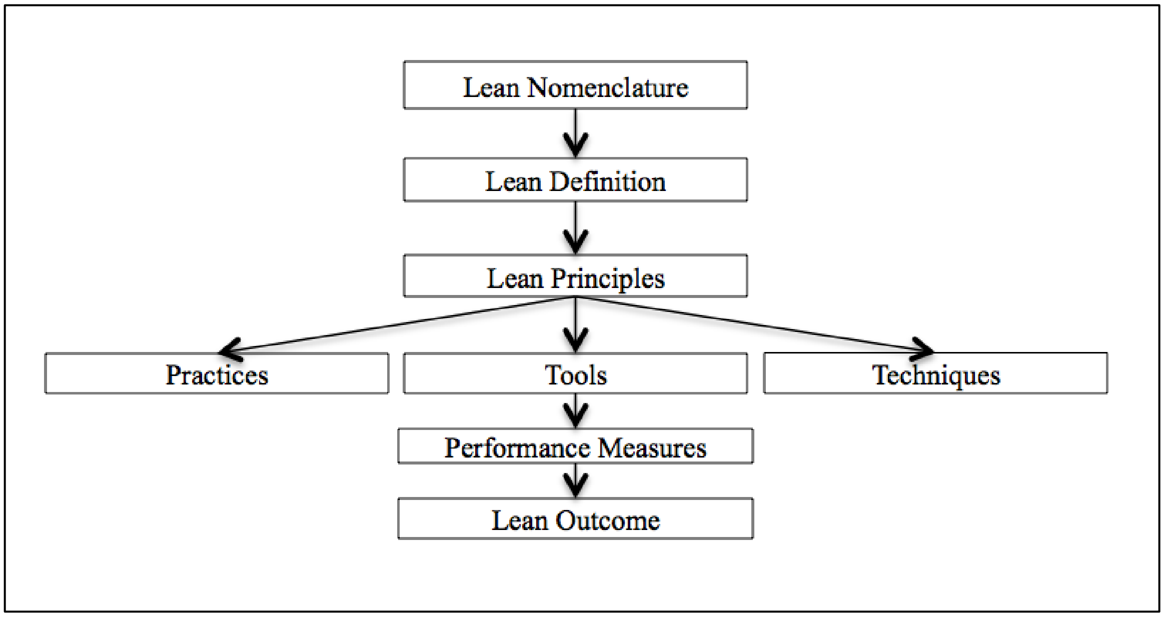


Figure 2-1: Lean conceptual outline

2.3.1 Lean definition

Lean manufacturing is a product of Toyota Production System (TPS). According to (Spear & Bowen, 1999) the TPS was part of tacit organizational knowledge at Toyota that resulted from 5 years of tinkering. Consequently, there was no written document to teach outsiders about process. This is arguably the root cause of the current confusion. Figure 2-2 shows the long period of lean evolution, as well as the introduction of lean manufacturing to the United States. Organizations did not seek to become truly lean till the attendant benefits were highlighted in Toyota's success. In accordance with the nascent spread of lean, various authors have tried to describe lean in terms of the objectives and principles, which vary from article to article and firm to firm (Bayou & de

Korvin, 2008). The result is the confusion in lean nomenclature, this study is aimed at clarifying.

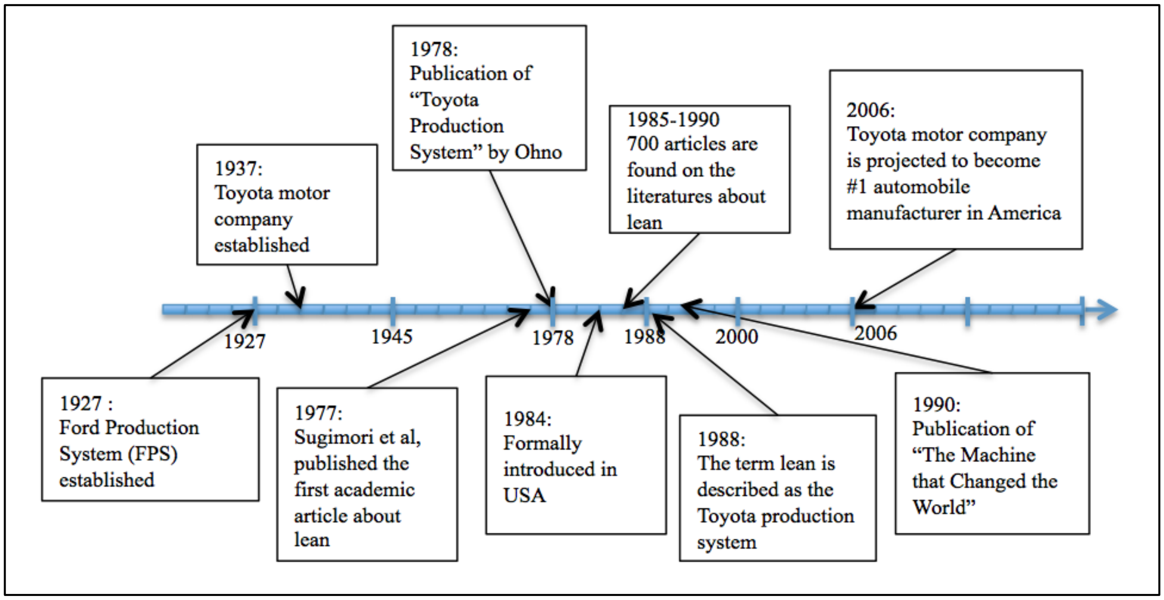


Figure 2-2: Lean historical critical phases

Bayou & De Korvin (2008) investigated the lean definitions in research literature and realized that the most of the definitions failed to accurately represent lean, and do not add sufficient knowledge. One of the reasons is that, the lean definitions in the literature are largely based on the lean benefits (the output of the system). The definitions do not show the requirement (input) to achieve the lean system, as example "a manufacturing philosophy to shorten lead times (output) and reduce costs (output) by redirecting waste (output) and improving employee performance (output), alongside employee skills and satisfaction (output)". Bayou & De Korvin (2008) argue that lean researchers must combine the input and output dimensions with the mindset of continuous improvements to efficiency and effectiveness, to get a true definition of lean. They define lean as" a strategy that allow organizations use less input to produce better output in pursuit of the organization's goals. Bayou & De Korvin define ''input'' as the physical quantity and cost of resources used. ''Output'' refers to the quality and quantity of the products sold and the corresponding customer service". While this definition addresses the underlying drive for effective, efficient process, it is too broad. Bayou & De Korvin definition does not differentiate lean approach from other systems. Waker (2004) lists characteristics of the conceptual definition to includeclarity, differentiability, communicability, consistency, parsimony, inclusivity and exclusivity (Wacker, 2004).

Shah and Ward (2007) suggest lean manufacturing definition closer to the Waker criteria: "lean production is an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability ". This definition provides a clear, context, specific, linkage between desired output and requires practices found in the literature (Shah & Ward, 2007).

There is widespread failure in lean implementation. This is due to variation in the definition and classification of lean principles, practices and performance measures. The lack of agreement in the literature about lean principles, and practices remains a major obstacle to successful lean implementation. Several authors give different definitions of lean, alongside differing descriptions of lean principles, practices and performance measures. The following section highlights the challenge of identifying lean principles in the literature.

2.3.2 Lean Principles

Lean production is an integrated socio-technical system that contains a set of principles, tools, practices and techniques. The main objective of lean manufacturing principles is to eliminate waste through continuous improvement (Gupta & Kundra, 2012; Mehta & Shah, 2005; Shah & Ward, 2007). According to Nicholas (2011), lean principles are a set of beliefs and assumptions that drive operational decisions and actions about products and processes. One must note that these definitions hinge on underlying cultural principles. In essence, the organizational culture and principles that undergird the change are the test of true lean process improvements. To this end, Womack & Jones (2003) identified five key principles for achieving a lean production system.

1. **Specify value:** identify what customers want (and/or are willing to financially support).
2. **Identify the value stream:** identify activities that, when performed correctly, satisfy customer "wants" (activities that provide value).
3. **Flow:** create continuous, interruption-free work processes across value adding activities
4. **Pull:** produce only in response to customer demand.
5. **Continuous improvement:** Generate, test, and implement process refinements in an ongoing drive for perfection.

Principles are made up of a set of practices, which are activities to improve an organization (Dean & Bowen, 1994; Karlsson & Åhlström, 1997). Karlsson & Ahlström (1996) used *The Machine that Changed the World* to develop a model of nine lean principles (elimination of waste, continuous improvement, zero defect, just in time, pull instead of push, multifunctional teams, decentralized responsibilities, integrated function and vertical information system). Sánchez & Pérez (2001) built on Karlsson & Ahlström work to design a checklist with 36 indicators that measure lean performance. Sánchez & Pérez (2001) suggested an addition of supplier integration to Karlsson & Ahlström's principles. Subsequently, Anand & Kodali (2009) questioned the basis of Karlsson & Ahlström's principles. They disagree with principles such as multifunctional teams, information system, and decentralization, because those "principles" are also used by other approaches like TQM and Six Sigma. Anand & Kodali proposed "respect for humanity", "visual management system", "customer focus", and "supplier integration", as suitable substitutions.

After two decades of research and investigation at a Toyota facility, Liker & Kaisha (2004) published *The Toyota way: 14 Management Principles from the World's Greatest Manufacturer*. The book discusses the key principles that drive the techniques and tools of the Toyota Production System and the management of Toyota. Shah & Ward (2007) present 10 factors that represent the operational complement to the philosophy of lean production and characterize 10 different dimensions of a lean system. Table 2-2 summarizes the most important principles listed by Liker & Kaisha (2004), Shah & Ward (2007), and other seminal (based on number of citations and initiation of new ideas or approaches) works on lean manufacturing.

Table 2-2: Lean principles and frequency of occurrence in key references

	(Womack & Jones, 2003)	(Liker & Kaisha, 2004)	(Shah & Ward, 2007)	(Karlsson & Ahlström, 1996)	(Sánchez & Pérez, 2001)	(Anand & Kodali, 2009)	Frequency
Define the value stream	*		*	*	*	*	5
Pull	*	*	*	*		*	5
Continuous Improvement	*	*		*	*	*	5
Supplier Integration		*	*		*	*	4
Value specification	*		*			*	3
Flow	*	*	*				3
Multifunction teams		*		*	*		3
Zero defect		*		*		*	3
Production and delivery JIT				*	*		2
Team leaders		*		*			2
Visual management system		*				*	2
Decentralization				*			1
Functional Integration				*			1
Vertical information system				*			1
Respect of humanity						*	1
Low setup time			*				1

	(Womack & Jones, 2003)	(Liker & Kaisha, 2004)	(Shah & Ward, 2007)	(Karlsson & Ahlström, 1996)	(Sánchez & Pérez, 2001)	(Anand & Kodali, 2009)	Frequency
Controlled process			*				1
Productive maintenance			*				1
Employee Involvement			*				1
Long-term philosophy		*					1
Level out the workload (heijunka).		*					1
Standardized tasks and processes		*					1
Use only reliable, thoroughly tested technology		*					1
Go and see for yourself to thoroughly understand the situation (genchi genbutsu).		*					1
Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly (nemawashi).		*					1

Table 2-2 shows that the five principles listed by Womack & Jones, in addition to supplier integration, multifunctional teams and zero defect represent approximately 60% of the principles identified in the selected literature. However, it is important to highlight the apparent confusion on individual principles, such as visual management system. Anand & Kodali (2009) and Liker & Kaisha (2004), list value management system as a lean principle. Others considers value management system a lean practice (e.g. Black, 2007; Fliedner & Mathieson, 2009; Gupta & Kundra, 2012; Mejabi, 2003). It is important to clarify disagreements of this nature in the bid to develop poka-yoke methods of lean implementation in which the fewest underlying principles give rise to context specific practices and performance measures.

The healthcare industry is central to one of the recent iterations of lean manufacturing principles and practices. Healthcare managers – who are often promoted healthcare practitioners – need clear poka-yoke introductions to lean principles, which should then drive understanding of lean practices, and ultimately inform use of tools and techniques in their organizations. The current system engenders confusion, which will propagate the dismal levels of successful implementation seen in manufacturing environments, to the healthcare industry. This is an undesirable potential outcome, given the ongoing changes in healthcare systems management in the United States.

In this study, more investigation has been conducted to explore and validate the high level of variability in lean terminology between lean experts, and to create a conceptual map that can allow non-experts visualize the inter-twined relationships between principles, practices, and performance measures.

2.3.3 Lean Practices, Tool or Techniques

The literature interchangeably uses terminology, like practice, tool or techniques. Quality circles which is described as tool and as a practice in other studies, Table 2-3 shows two different examples of this confusion. Karlsson & Åhlström (1997) mentioned the importance of distinguishing between principles, practices, and techniques in accordance with their definition of lean as a concept, which incorporates a system of principles, practices, tools, and techniques. The principles are made up of a set of practices, which are the tangible activities undertaken to improve the organization. The practices in turn are made up of wide array of techniques. Techniques are detailed steps that ensure efficient execution of lean practices (Dean & Bowen, 1994; Karlsson & Åhlström, 1997).

Table 2-3: Examples of the confusion between practices and tools in the lean literature

Item	Mentioned as practice	Mentioned as tool
Total productive maintenance (TPM)	(T. L. Doolen & Hacker, 2005; Koufteros et al., 1998; Panizzolo, 1998; A. M. N. Rose et al., 2011; Shah, Chandrasekaran, & Linderman, 2008)	(Case, 2004; Fliedner & Mathieson, 2009; Gupta & Kundra, 2012; Pavnaskar et al., 2003)
Quality circles	(Fliedner & Mathieson, 2009; Olsen, 2004; A. M. N. Rose et al., 2011; R. E. White et al., 1999)	(Case, 2004; Deshmukh, Upadhye, & Garg, 2010; Pavnaskar et al., 2003)

Anand & Kodali (2009) suggest corresponding tool, practice or techniques to elements. Each element has to support each other with the purpose of achieving full benefits of lean (Rose, Deros, & Rahman, 2009). Anand & Kodali (2009) show an example to describe that from Shingo, which is to achieve zero defect principles, the organization apply practices such as 100% inspection which is in turn prevented by a techniques such as pokayoke to ensure that no human mistakes is happening (Anand & Kodali, 2009). The pervious statements by Anand & Kodali (2009) and Karlsson & Åhlström (1997) are adapted from total quality management concept (Dean & Bowen, 1994). In the lean literature, no clear reasons are presented to differentiate between the terminologies (practices, tools, and techniques). Consequentially for the purpose of this study, the terms “practice”, “tools” and “technique” are equivalent.

2.3.4 Lean Practices

Lean principles are implemented by applying lean practices and performance measures to improve process flow and overall performance (Álvarez, Calvo, Peña, & Domingo, 2008; Deshmukh, Upadhye, & Garg, 2010). The underlying goal is to optimize production processes by eliminating waste, and enhancing the “leanness” of a manufacturing system.

In support of the continuous improvement nature of lean manufacturing, new tools and techniques continue to be created and proposed until today (Green & Dick, 2001; Liker, 1997; Womack et al., 1990a). This continuous change has resulted in redundancy and confusion in communication between lean researchers and practitioners. For example, some authors refer to value steam mapping as process mapping (Pavnaskar et al., 2003) while others see process maps as a different, arguably less informative, means of depicting process . Differing nomenclature is problematic in this case, because process maps, as defined by the latter group, do not require the level of detail and system wide analysis that value stream maps provide. The resulting confusion can hinder efforts to implement lean.

Previous studies suggest that the companies seeking to apply lean should implement all or most lean practices – a system of lean practice – to ensure successful implementation and performance improvement (Bhasin & Burcher, 2006; Liker & Kaisha, 2004; Sánchez & Pérez, 2001). Supporting this notion, White & Prybutok (2001) argue that the benefits of lean will not be apparent until all elements are integrated. Citing the challenge of this stance, Pavnaskar et al. (2003) list over a hundred practices used by different lean organizations. To reduce confusion, Pavnaskar et al. suggest a classification system to match lean manufacturing tools with specific manufacturing problems or measurement needs. This classification could avoid misapplication of tools, such as using a wrong tool to solve a problem, or resource wastage. Pavnaskar et al. support that the categories should provide performance information at the following levels: the system level, product state, production task, nature of task, resources, resource evaluation and tool application (Pavnaskar et al., 2003). In addition, Case (2004) validates and verifies the content of the classification put forward by Pavnaskar et al. Case concludes that this classification is able to address all activities within manufacturing, and can accurately classify lean practices. In order to sustain change, participants must understand the connection between proposed changes, organizational goals, and their specific tasks. However, previous studies do not connect lean practices to performance measures, financial goals and organizational strategy. This disconnect does not help organizations realize the effect of selected lean tools on short and long term goals. Consequently, the selected tool could contradict organizational strategy.

The literature review for this study highlighted 200 practices from 22 different articles (Appendix 1). This amount seemingly uncategorized lean approaches could lead an adopter to accidentally apply the wrong tools to resolve a problem. Consequently, there remains a need to relate lean practice with lean principles, and to regularly measure performance to validate the use of a selected practice. Performance measures are an important means of incentivizing process transformation. The following section is a discussion of performance measurement system to support clarified practices and reinforce lean principles.

2.4 Lean Performance Measurement System

The goal of lean system management is to improve organizational performance. Bhasin (2008) argues that disjointed lean implementation causes suboptimal performance because waste and WIP are passed to other stakeholders to the detriment of the entire plant. The transformation to lean requires changes in organizational culture. Decision makers require effective metrics to:

a) Incentivize desired behavior, and
b) Evaluate progress improvements

It is important to highlight the difference between the terminologies: performance measurement, performance measures, and performance measurement systems, which are described by Neely, Gregory, & Platts (1995):

- Performance measurement is defined as the process of quantifying the efficiency and effectiveness of action;
- Performance measure is defined as metric used to quantify the efficiency and/or effectiveness of an action; and
- Performance measurement system is defined as the set of metrics used to quantify the efficiency and effectiveness of an action.

The terms efficiency and effectiveness are central to previous definitions of performances. Effectiveness can be defined as the extent to which customer requirements are met, while efficiency is a measure of how economically a firm's resources are utilized when providing a given level of customer satisfaction (Andy Neely et al., 1995).

Mohamed (2003) suggests that performance measures must be understandable, achievable, valid, and user focused. Table 2-4 is a checklist for effective performance measures. The items in the checklist were gathered from the literature (Globerson, 1985; Kaplan, 1983; Andy Neely et al., 1995; Stefan Tangen, 2002, 2004). The main objective of this checklist is to select/create a holistic and integrated set of performance measures. The checklist was used to examine the lean performance measures from the identified extant lean literature.

Table 2-4: Performance Measure Checklist

Does the measure (or measurement system)…		
Calculate the cost of measurement?	Yes	No
Help define stakeholders (who will use the measures?)	Yes	No
Fit into current time requirements (do we have the time resources to collect data)?	Yes	No
Provide useful external benchmarks with peer and aspirant organizations?	Yes	No
Have specified targets?	Yes	No
Have specified timeframe for target achievement?		
Provide department specific measures, if needed?	Yes	No
Provide a simple and easily accessible means of evaluation?	Yes	No
Have a clear purpose "what is the benefit the performance measure provides?"	Yes	No
Have clearly defined data collection methods?	Yes	No
Have ratio based performance criteria? (ratio based is preferred over absolute numbers)	Yes	No
Is the measure (or measurement system)…		
Selected from the company objectives?	Yes	No
Selected through discussion with people (customers, employee, and managers)?	Yes	No
Achievable?	Yes	No
Valid?	Yes	No
User focused?	Yes	No

A set of reinforcing performance measures constitutes a performance measurement system. An effective performance measurement system is a cornerstone of successful lean implementation. Bourne et al. (2002) outline factors that affect performance measurement system implementation. Supportive factors include *effective performance measures, top management support, minimal time or effort required, consequence of activities of the internal and external facilitators, and juxtaposition of the performance measures intervention with other projects*. Barriers to implementing an effective performance measurement system include *data inaccessibility, high time and effort requirements, difficulties with updating and developing measures* (Bourne, Neely, Platts, & Mills, 2002).

A number of organizations use traditional performance measurement systems (e.g. traditional management accounting system) to evaluate performance based on short-term financial goals. Such systems alone are unsuitable for satisfying organizational goals and client, while manufacturing a motivated workforce and incentivizing personal development (Taj, 2008). The literature suggests that traditional measures do not reveal problems until before performance/productivity is compromised. This is because most traditional measures are lagging indicators that focus on past events and profit levels. These measures are not synchronized with strategy (Bhasin, 2008; van der Zee & de Jong, 1999; Youngblood & Collins, 2003). Therefore, it is not logical to use the performance measures from traditional management accounting systems in the early stages of lean implementation, because productivity decreases during initial adjustment to lean (Ahlström, 1998).

Lean advanced manufacturing operations require agile measurement systems and feedback from the shop floor to ensure continuous improvement to increase customer value (Fisher, 1992). Potter & Banker (1993) list feedback as a success requirement in JIT firms. Meaningful feedback strengthens performance by acting as a tool for strategy implementation and helping workers understand the effect of their roles on organizational strategy (Earley, Northcraft, Lee, & Lituchy, 1990; Ilgen, Fisher, & Susan, 1979). Effective advanced manufacturing systems require high reliance on non-financial performance indicators (Abdel-Maksoud, Dugdale, & Luther, 2005; Rosemary Fullerton, McWatters, & Fawson, 2003).

Additionally, traditional performance measurement systems fail to measure intangible assets (Kaplan & Norton, 1992, 1993; Lawson, Stratton, & Hatch, 2003; Shah & Ward, 2003) such as customer perception of product quality, or skilled workers. These intangible assets are one of the major drivers of competitive advantage (Neely, Gregory, & Platts, 2005). The ability to quantify these intangible assets remains a research challenge. Quantification is essential in order to understand cause-effect relationships between intangible assets, such as knowledge and other factors to create customer value, or between knowledge and financial outcomes.

There is true value in the synergy derived when intangible assets are applied in tandem with tangible assets. As an example of intangible assets, a new growth focused firm requires customer knowledge, training for sales, new information databases, and an organizational structure. Failure to secure any one of these assets could jeopardize the growth strategy. (Bhasin, 2008). Consequently, to achieve financial growth, the firm must secure or improve intangible assets such as processes associated with customer care, employee engagement and management, supplier relationships, and organizational effectiveness (Arora, 2002; Gautreau & Kleiner, 2001; S. Tangen, 2005).

Intangible, non-financial performance measures have been shown to positively affect performance of JIT firms (Baines & Langfield-Smith, 2003; Fullerton & Wempe, 2009; Said, HassabElnaby, & Wier, 2003; Upton, 1998). Non-financial performance measures have also been shown to provide superior financial results (Fisher, 1992), and increase achievement of performance objectives (Fullerton et al., 2003). Consequently, intermediate indicators (non-financial performance measures) are required to measure performance in all stages (Sánchez & Pérez, 2001).

Adapting traditional performance measures is important to support JIT firms (incorporate non financial performance with financial performance indicators) and significantly increase the level of market return (Said et al., 2003). Moreover, using a combination of financial and non-financial performance measures increase the breadth of performance measures (Callen, Morel, & Fader, 2005; Dixon, Nanni, & Vollman, 1990; Ittner & Larcker, 1998; R. S. Kaplan & Johnson, 1987; Rappaport, 1999). Finally, effective performance measures must be adaptable to short and long term, perspectives for organizational health. This includes several dimensions of health, like financial, customer, internal process, supplier and external process, competitors and innovations (Kaplan & Norton, 1993; Stefan Tangen, 2004).

Real time, accurate information is a significant factor in building an integrated performance measurement system. These performance measures provide fast feedback to help decision makers make effective decisions (Rosemary R. Fullerton et al., 2003; Mangaliso, 1995; Maskell, 1992). Bond (1999) and Teach (1998) highlight the challenge of information overload that is accompanied by an absence of effective systems that translate information into organizational knowledge and useful strategy. There is a need for decision support systems that highlight important causal relationships between an organization's objectives and performance measures. Such a system would collect and analyze data and provide pertinent information at the right time to allow the right person more efficiently identify root causes of problems (Bhasin, 2008; Stefan Tangen, 2004).

The literature-soured checklist in Table 2-5 is a summary of performance measurement system requirements. Checklists of this nature can help identify the cause-effect relationships between objectives and performance measures (sources include the following: Globerson, 1985; Kaplan, 1983; Andy Neely et al., 1995; Stefan Tangen, 2002, 2004).

Table 2-5: Performance Measurement System Checklist

Support organization strategy		
The performance measures are derived from the company's objectives	Yes	No
Translate the strategic objective into tactical and operational objectives	Yes	No
The performance measurement system is consistent with strategic objectives at each level of the organization	Yes	No
Balance between different performance measures:		
Balance between short and long term results	Yes	No
Various organizational level (global and local performance)	Yes	No
Financial & non-financial	Yes	No
Tangible & intangible assets		
Location and context, relevant	Yes	No
Cover various perspectives:		
Customer	Yes	No
Shareholder	Yes	No
Competitor	Yes	No
Internal Process	Yes	No
External Process		
Suppliers	Yes	No
Innovation	Yes	No
Learning and Growth	Yes	No
Cover different types of performance:		
Cost	Yes	No
Quality	Yes	No
Delivery	Yes	No
Flexibility	Yes	No
Dependability	Yes	No
Should provide fast and accurate feedback		
Have limited number of performance measures	Yes	No
Information easily accessible	Yes	No
Diagnose the problem for the current situation	Yes	No
Timely and comprehensive information to provide critical decision	Yes	No
Translate the information into organizational knowledge and useful strategy	Yes	No
Real time accurate information	Yes	No
Give important information, at the right time, to the right person	Yes	No
Support continuous improvement		
Stimulate continuous improvement rather than simply monitor	Yes	No
Easy to update (flexible)	Yes	No
Guard against sub-optimization		
The measures are not contrary the corporate goal	Yes	No
Measures improvement in one area does not lead to deterioration in another	Yes	No

As a summary, it is important to show a process to develop an effective performance measurement system. In this study, the nine step process proposed by Wisner & Fawcett (1991) for developing performance measurmnet systems is integrated to the performance measure checklist (Table 2-5) and performance measurment sytem checklist (Table 2-6). The propsed model is shown in Figure 2-3. Figure 2-3 is presented as a tool to help lean adopters create uniqe performance meaures commensurate with the characteristics of lean adopter organizations, Figure 2-3 is also a tool to ensure that performance measures are derived from organizational strategy.

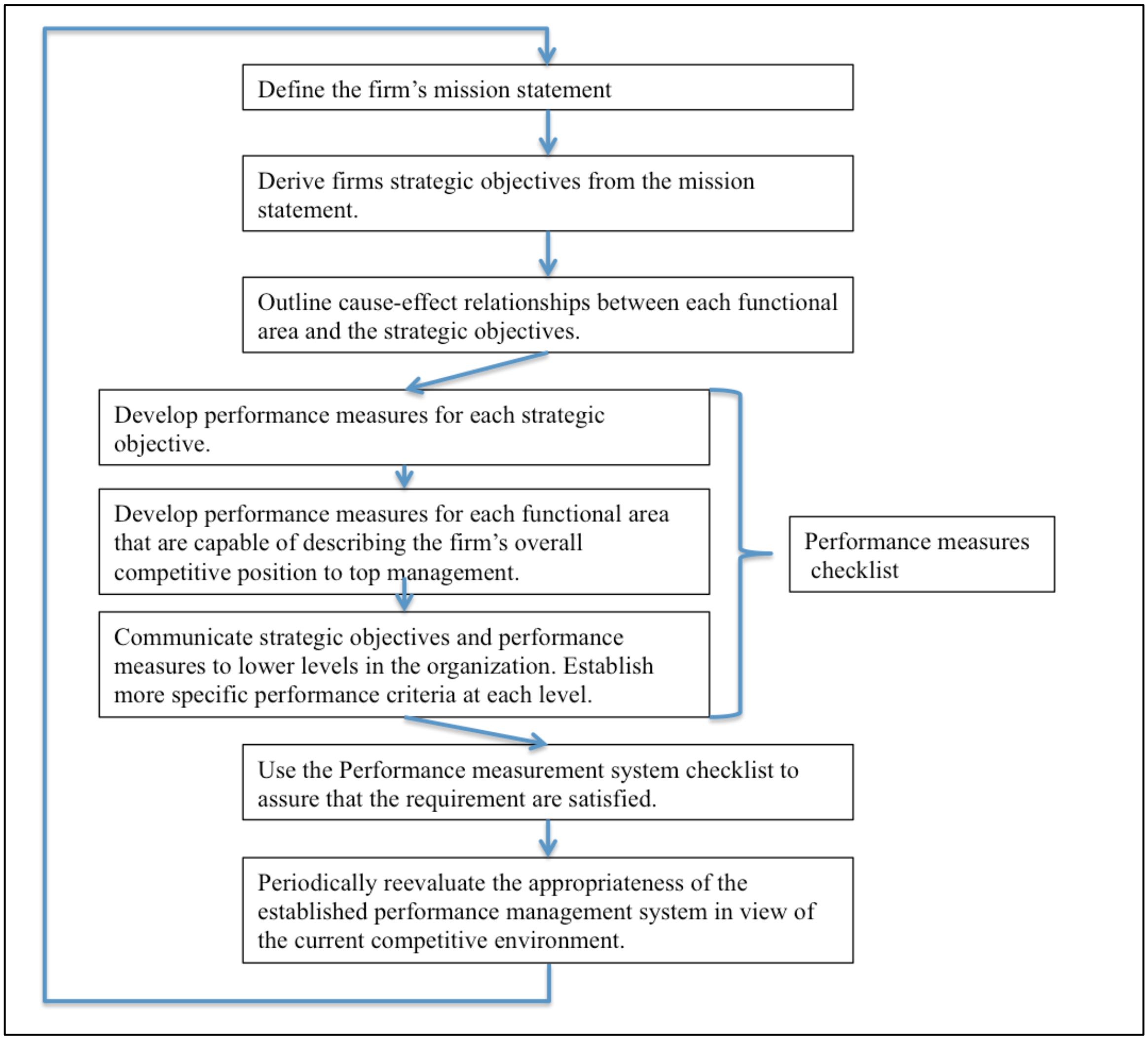


Figure 2-3: Adapted from Wisner & Fawcett (1991) Model for developing performance measurement system

The literature shows numerous ways and performance indicators used to measure lean manufacturing. As part of the literature review for this study, a list of 250 different lean performance measures was collected (Appendix 2). As part of effort to reduce confusion in the lean nomenclature, the following section discusses intuitive performance measurement system that links key business perspectives with performance measures.

2.5 The Balanced Scorecard

Kaplan and Norton developed the Balanced Scorecard as performance measurement system that provides a rapid and comprehensive view of pertinent business activities that drive organizational performance (Kaplan & Norton, 2001a; Liberatone & Miller, 1998). The balanced scorecard uses a business-perspectives approach that focus a basis for organizational strategy maps (Kaplan & Norton , 2004).

Balanced scorecards have been regarded as a means of integration between financial and non-financial performance measures, short and long term objectives, lagging and leading indicators, and between external (customer and shareholder) and internal (business process, innovation and learning) performance perspectives (Kaplan & Norton, 1993; Mohamed, 2003). The scorecard helps translate firm strategy and mission into a planning tool that clearly links performance measures to organizational strategy. By allowing stakeholder more easily identify their impact on organizational strategy and performance, the scorecard helps achieve organizational objectives (Hsuan-Lien Chu, Chen-Chin Wang, & Yu-Tzu Dai, 2009; Robert S. Kaplan & Norton, 2001a) .

The IT balanced scorecard is a modified balanced scorecard created by mapping the causal relationships between performance measures and objectives into a strategy map. These links help organizations successfully implement strategy and show employees how their actions impact organizational objectives (Kaplan & Norton, 2004). Appendix 3 shows an evaluation of balanced scorecard using the performance measurement checklist provided in Table 2-5. The balanced scorecard covers most of the criteria of an effective performance measurement system. However, the previous result does not guarantee absolute success of the balanced scorecard as a result of bad execution such as selecting incorrect performance measures. Therefore, Figure 2-3 is recommended to avoid selecting unsuitable performance measures. Additionally, the balanced scorecard has limited drawback such as ignoring the competitor perspective, and future perspectives (Bhasin, 2008; Neely et al., 2005; Smith, 1998). Also, the balanced scorecard does not link between the performance measures and the strategy, unless the balanced scorecard is accompanied by strategy maps. The following section outlines the role of strategy map in streamlined lean implementation.

2.6 Strategy Maps

Kaplan & Norton (1996) discuss strategy maps as a supplement to the BSC, that clarifies the link between strategy and performance measurement systems, and between objectives and performance measures (Kaplan & Norton, 2000). Strategy maps are dynamic visual tools that describe and link organizational strategy to performance measurement system. Strategy maps show how intangible assets result in tangible outcomes (Chiung-Ju Liang & Lung-Chun Hou, 2006). (Kaplan & Norton, 2000, 2004; Robert Kaplan & Norton, 2001b, 2004).

The strategy can be developed and deployed and then achieved optimally over time by understanding the causal relationship in the strategy map (Wu, 2012). The strategy maps used here based on the four perspectives balanced scorecard (Financial, Customer, internal process, and learning and growth). The strategy map is based on several principles (Kaplan & Norton, 2004):

- Strategies should be balanced against each other,
- Strategy should be based on the basis of value,
- Value should be created through internal process,
- Strategies should complement and simultaneous each other,
- Strategic alignment determines the values of intangible assets.

3 Research Methodology

The objective of this research is to help organizations avoid the common mistakes that lead to lean implementation failure. The literature shows that lean implementation failure is correlated with ineffective implementation include selecting inappropriate lean strategies, using the wrong tool to solve the problem, sole reliance on financial measures., and an overall lack of synchronization between lean goals and actual practices. In this study we summarized the causes of lean failures in three major causes:

1. Confusion in the lean nomenclature
2. Misusing of suitable performance measures
3. Selecting inappropriate lean strategy.

Consequently, this study aimed to find a suitable solution for the previous causes, in turn to help the lean adopter to avoid lean manufacturing failure.

Three different surveys were conducted to achieve the objectives of this study. A number of statistical tests were used to analyze the survey data. The tests included non-parametric tests (e.g. Mann-Whitney U, and Kruskal–Wallis) to investigate the effects of the different organizational characteristics in the lean adoption. In addition to that, the Decision Making Trial and Evaluation Laboratory (DEMATEL) method was used to help to investigate the complicated causal relationships between lean principles for building up the strategy map based on the balanced scorecard. Figure 3-1 summarizes the study outline.

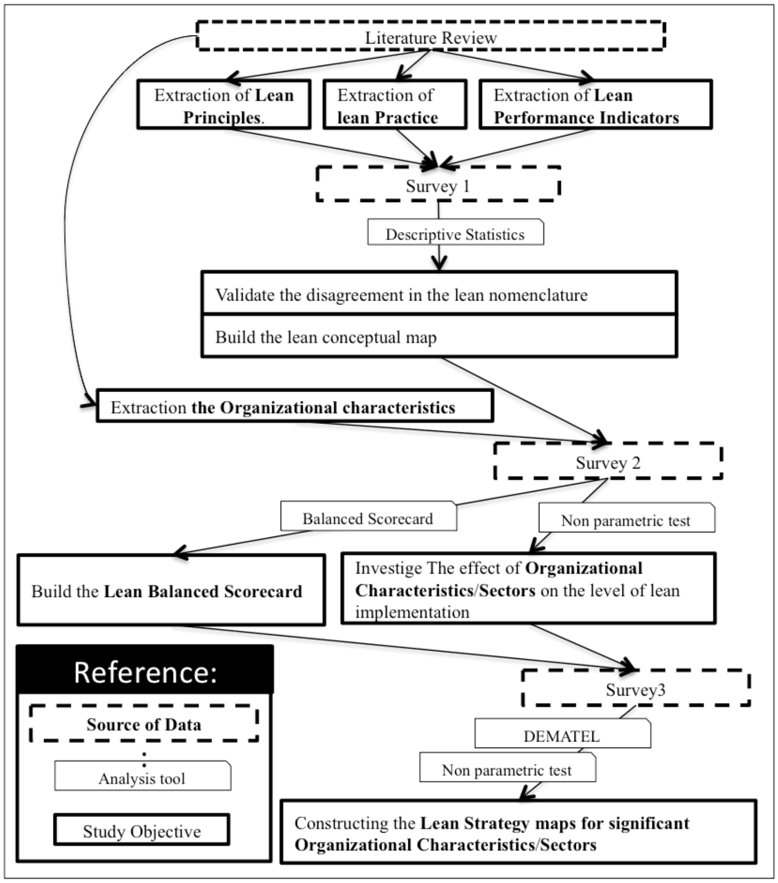


Figure 3-1: Research outline

Literature Review: The literature review was the first source for extracting the lean principles, practices and performance measures. Papers were accessed using the EBSCO, Web of Science, and other databases available through the Oregon State University library system. Keywords used in the searches include: lean implementation, lean performance measures, and lean transformation. Papers that discussed lean principles were selected from publications between 1997 and 2012 based on the number of citations (over # number of articles). Lean nomenclature were collected and categorized based on the classifications provided by the authors in these seminal articles. Approximately 200 practices and 250 different lean performance measures were collected from the literature.

Due to the large number of practices and performance measures, only the most frequent constructs were used in this work (The frequency of practice or performance measure is defined as number of times the a practice or performance measures is listed in the reviewed articles).

The lean conceptual map was constructed based on a survey of lean experts. The survey was designed using Qualtrics (Web-based survey software). 49 experts (individuals who have authored at least one peer reviewed article related to lean manufacturing) responded to the survey. An article was considered “related to lean” if it had “lean” in its title or in the keywords. Lean related articles on process improvement and performance measurement were also identified during the literature review. The sample size are obtained from 3 different sources (based on the lean publication, based on the people who participated and presented in related lean lean conferences, and based on the university websites) to successfully represent the target population.

In the survey, the experts were asked to differentiate between lean principles and lean practices (The definitions of the items were provided in the survey). The experts then grouped items into three categories: "Lean principle", "Lean practice", and "Not related to lean". Participants were asked to drag the items listed in a column on the left side into one of the three boxes on the right. The result was then used to identify lean consensus principles. Figure 3-2 shows an example of the survey question.

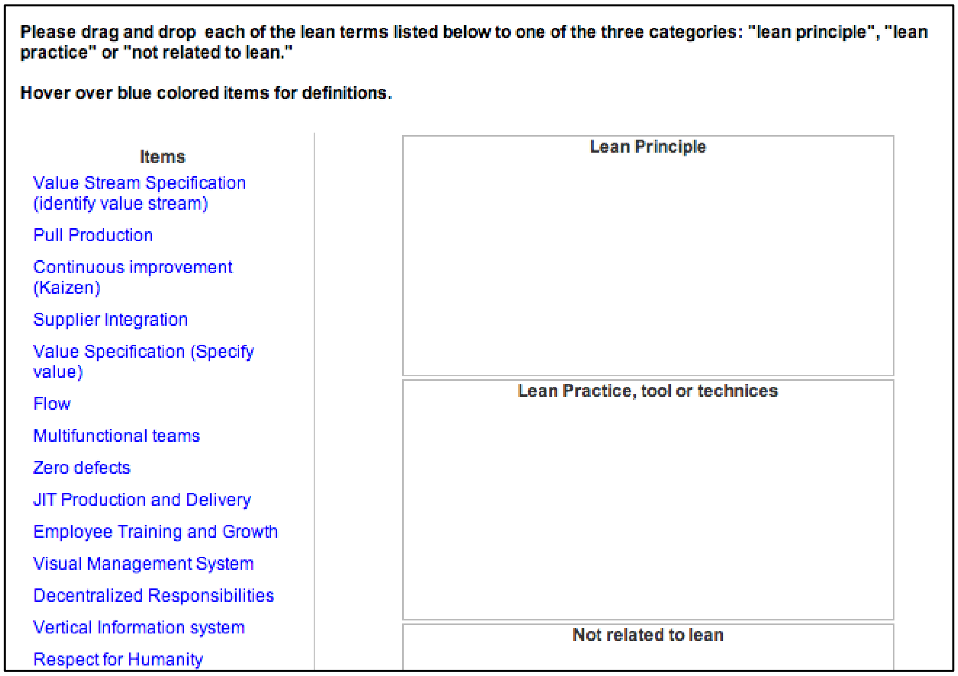


Figure 3-2: Example of the survey in the lean conceptual map validation process.

Based on the experts' selections, lean principles were specified. Next, experts were asked to add, change, or delete lean practices and to assign practices from their chosen list to previously selected principles (Figure 3-3). Each expert could select multiple practices for each principle. In the result, we obtained 5 lean principles, and 48 lean practices grouped under lean principles.

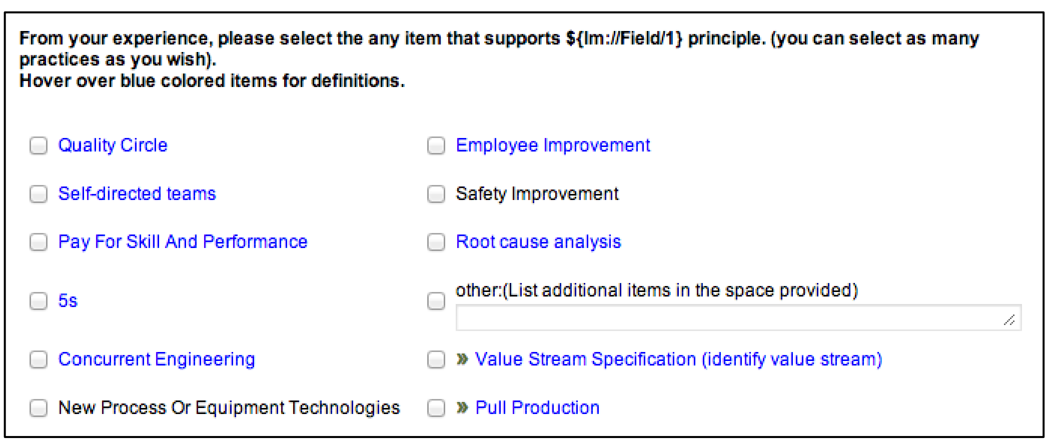
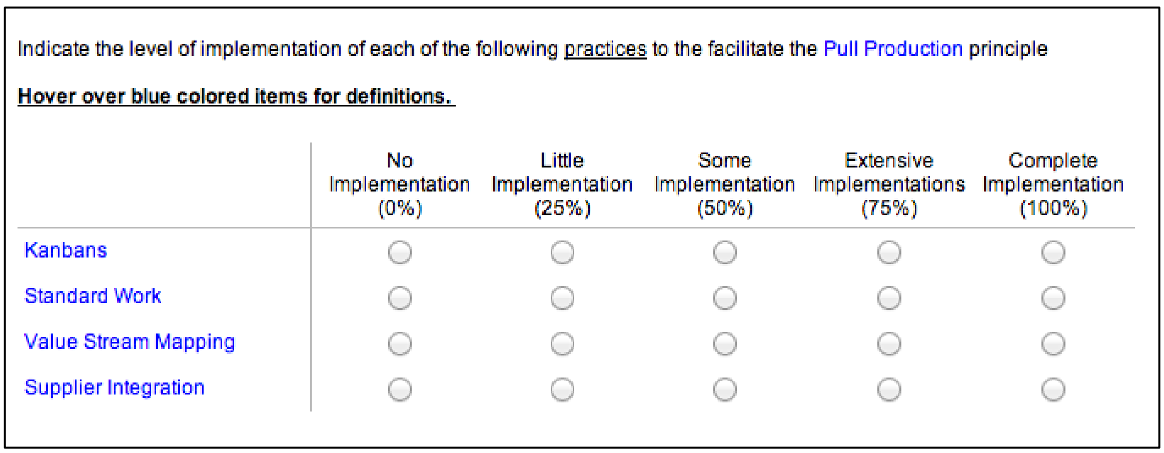


Figure 3-3: Example of the survey in the lean conceptual map validation process.

The second survey concentrates on investigating the level of impact of different organizational characteristics and different manufacturing sectors on implementation of lean practices. In the survey, the respondents were supposed to identify the rate of implementation of the proposed practices associated with lean principles within their organization (Figure 3-4). This was accomplished using a five-point Likert scale:

- No Implementation (0 percent);
- Little Implementation (25 percent);
- Some Implementation (50 percent);
- Extensive Implementation (75 percent);
- Complete Implementation (100 percent);


Indicate the level of implementation of each of the following practices to the facilitate the Pull Production principle

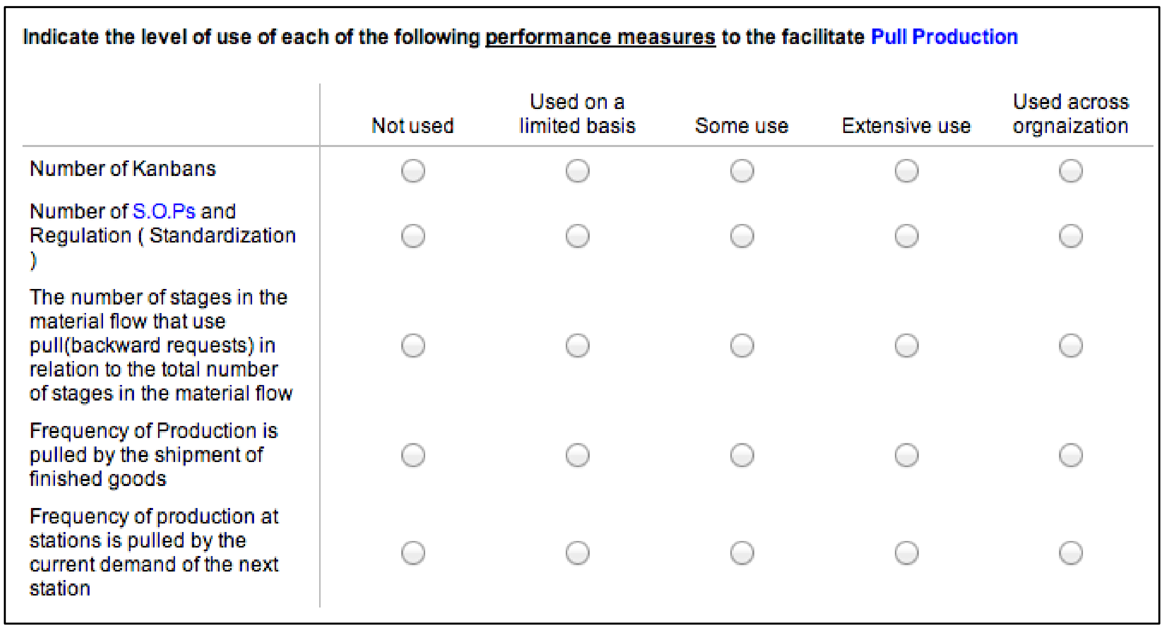
Hover over blue colored items for definitions.

	No Implementation (0%)	Little Implementation (25%)	Some Implementation (50%)	Extensive Implementations (75%)	Complete Implementation (100%)
Kanbans	○	○	○	○	○
Standard Work	○	○	○	○	○
Value Stream Mapping	○	○	○	○	○
Supplier Integration	○	○	○	○	○

Figure 3-4: Example of the survey question for "pull" related practices

The "Shapiro-Wilk" test for normality (Razali & Wah, 2011; Shapiro & Wilk, 1965), visual histogram, and normality plots showed that the data was not normality distributed. This was true for all categorized groups. Therefore, non-parametric test was conducted to investigate the effect of organizational characteristics on the implementation of lean practices.

In addition to the previous questions, another type of question was asked to validate the adopted lean performance measure that was implemented according to the lean principles (Figure 3-5). Respondents were asked to identify the level of use of performance measures to evaluate each lean principle within their organization. This was accomplished using a five-point Likert scale involving the following items: Not used, Used on limited basis, Some Use, Extensive use and Used across organization. The ultimate concern of these questions was to validate the lean performance measures and apply it in the balanced scorecard.


Indicate the level of use of each of the following performance measures to the facilitate Pull Production

	Not used	Used on a limited basis	Some use	Extensive use	Used across orgnaization
Number of Kanbans	○	○	○	○	○
Number of S.O.Ps and Regulation (Standardization)	○	○	○	○	○
The number of stages in the material flow that use pull(backward requests) in relation to the total number of stages in the material flow	○	○	○	○	○
Frequency of Production is pulled by the shipment of finished goods	○	○	○	○	○
Frequency of production at stations is pulled by the current demand of the next station	○	○	○	○	○

Figure 3-5: Example survey of lean performance measures questions

The survey was designed using the Qualtrics Web-based survey software. The population of the survey is manufacturing organizations in United States. Based on County Business Patterns (2011) there are 254941 manufacturing organizations in the United States. To get sufficient sample size from the manufacturing organization, the following formula is used:

$$N_S = \frac{(N_P)(P)(1-P)}{(N_P-1)\left(\frac{B}{C}\right)^2 + (P)(1-P)}$$

Where: N_s = The desired sample size

N_p=the size of the population

P= the proportion of the population expected to choose one of two response categories

B=margin error

C= Z score associated with the confidence level.

In this study, as mentioned before the population size is 254941 manufacturing organizations. 150 sample size surveys is needed to be sure that the estimate of interest will be within +/- 8 percentage points 95% of the time. 207 surveys are obtained, and 141 finished the entire survey at a response rate of 68%. The design of this survey was developed to give room to utilization of data that characterizes incomplete surveys. The survey was convenient enough to enable participation through online responses enabled by a web link conveyed by an email. To ensure more understanding of terms used, the purpose of the study was provided alongside definitions for lean principles, and practices. The target participants were Industrial engineers, process engineers, lean engineers, and manufacturing engineers.

The third survey was created to identify the level of impact of one lean principle on another by using Decision Making Trial and Evaluation Laboratory (DEMATEL). The DEMATEL method is used to draw the complicated relationship between the items in the system (Wu, 2012) (in our case the lean principles). The survey is divided to two parts. The first part includes the demographic information (Organizational characteristics, and Sector of operation). The second part includes the main DEMATEL questions. All questions were in the following form: "What is the impact of 'X principles' on each of the following". Figure 3-6 shows an example of the questions. Responders were asked to specify the level of impact by a selecting one of the following answer:

- No impact (0 score)

- Low impact (1 score)
- Medium impact (2 score)
- High impact (3 score)
- Very high impact (4 score)

The goal of the survey is to draw the causal relationship between lean principles by using DEMTAL technique to construct the strategy map.

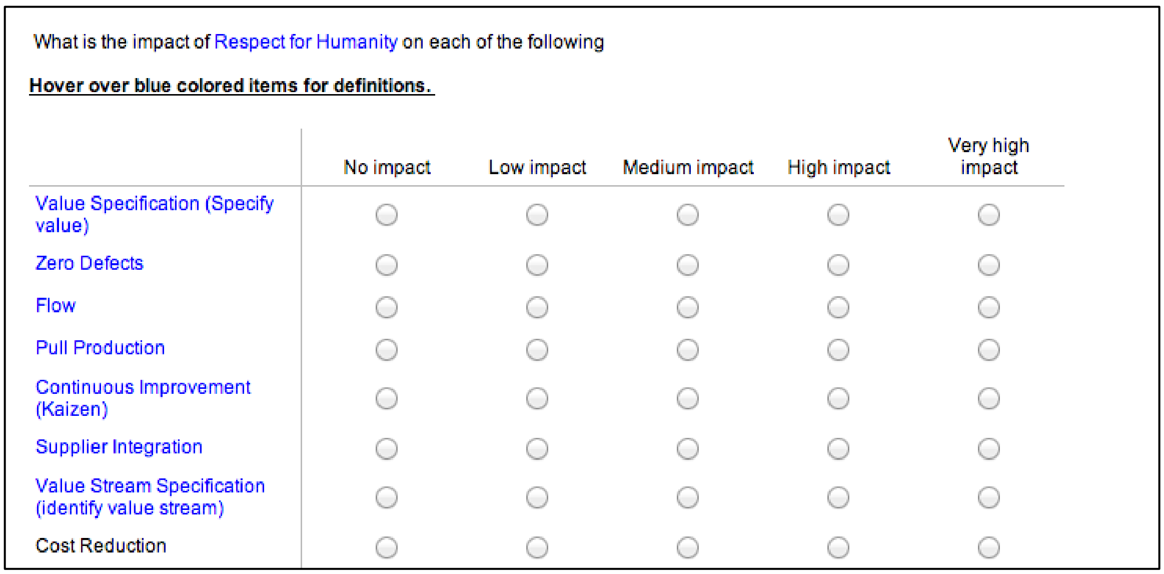


Figure 3-6: Example survey of DEMATEL question.

The population of the study is the manufacturing organization in the United States. The participants could respond online by using a web link provided in the email for convenience. To ensure uniform understanding of terms used, the purpose of the study and definitions of terms were provided. Industrial engineering, process engineering, Lean engineering, manufacturing engineering were the target recipients of the mailed survey. The previous equation was used to calculate the sufficient sample size. A total of 134 engineers completed the survey, which means we are sure that the estimate of interest will be within +/- 8.5 percentage points 95% of the time. Table 3-1 summarizes the sample sizes for each survey used in this study.

Table 3-1: Summary of the sample sizes for each survey in the study

	Survey 1	**Survey 2**	**Survey 3**
Targeted sample size	156 By email (the email include the name of the person) 3 reminders Prize was offered (kindle fire)	2400 By email (the email include the name of the person) 3 reminders Prize was offered (kindle fire)	2300 By email (the email include the name of the person) 3 reminders Prize was offered (kindle fire)
Number of started surveys	49	209	198
Number of completed surveys	35	141	134
Target population	Lean experts (any person who authored peer reviewed article about lean	Engineers (Lean, process, industrial, manufacturing production and process)	Engineers (Lean, process, industrial, manufacturing production and process)
Method of target selection	1-CV from the universities websites 2- emails in the lean publication 3- Conference (ASEM)	From online database Manufacturing organization in the USA	From online database Manufacturing organization in the USA
Missing data	Not considered in the analysis	Not considered in the analysis	Not considered in the analysis
Non-complete survey	Consider the answered questions only	Consider the answered questions only	Consider the answered questions only
Deleted Survey	Inconsistence answers	Any organization does not implement lean formally	Any organization does not implement lean formally
Distribution of the data	Not required	Non-normal	Non-normal
Analysis	Based on the frequency	Non Parametric	Non parametric DEMATEL

The following the section (chapter 4) include the manuscript of the first study. The first study was used the first survey in turn to validate the lean nomenclature confusion and to build the lean conceptual map (a map that contains different principles, practices and performance measures to clarify the lean nomenclature confusion and help the adopter to avoid selection of wrong items in lean project). Chapter 5 involves the manuscript of the second study. The second study was used second and third survey. The second survey was used to build the balanced scorecard in turn to help the adopter to avoid wrong performance measures selection. The third survey was aimed to identify the impact of the lean principles in each other, in turn to use the DEMATEL method to identify the causal relationship between the lean principles.

A Conceptual Map for Lean Process Transformation: Untangling the web of confusion in lean research and practice

by
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Submitted for Journal publication

4 A Conceptual Map for Lean Process Transformation: Untangling the web of confusion in lean research and practice

4.1 Abstract

Lean manufacturing processes have afforded manufacturing organizations sizeable gains in capacity, customer satisfaction, employee engagement, and overall productivity. Consequently, organizations in other industries, such as healthcare, education, and construction, have sought to implement lean. The literature suggests that only 10% or less of these organizations have been successful in their attempts. Companies often select inappropriate lean strategies, use incorrect lean tools, or rely solely on financial measures. The authors identify the lack of synchronization between lean goals and actual practices as a possible causal factor for unsuccessful lean attempts. This paper looks to resolve the confusion surrounding lean implementation by providing (a) a summary of lean principles, practices, performance measures, and performance measurement systems; (b) integrating lean principles from the literature with those identified by lean experts; and (c) suggesting a lean conceptual map that integrates lean principles and practices with performance measures; This research identifies paths for engineering managers to leverage the 80/20 rule by focusing on tools that sustain the most significant (main cause) lean principle.

4.2 Introduction

The concept of lean manufacturing originated in post World War II Japan. In comparison to craft and mass production, lean manufacturing emphasizes customer value, smooth operational flow, and employee involvement in improvement. Toyoda and Ohno used these concepts to combine the advantage of craft manufacturing with those of mass manufacturing. They also added new concepts such as just-in-time and zero inventory to generate the Toyota production System (TPS) (Womack, Jones, & Roos, 1990a).

Lean manufacturing is recognized as an effective approach for achieving and maintaining competitive advantage through an improved manufacturing processes (Anvari, Zulkifli, & Yusuff, 2013; Chapman & Carter, 1990; Foster & Horngren, 1987; Fullerton, McWatters, & Fawson, 2003; Sakakibara, Flynn, & Schroeder, 1993). By applying lean manufacturing principles, organizations can increase value for customers while improving their profitability alongside citizenship behavior by employees (Karim & Arif-Uz-Zaman, 2013). Organizations aim to reduce non-value adding activity by using lean principles and practices. However, only 10%, or fewer, organizations are successful in lean implementation (Gupta & Kundra, 2012). To this end, Sheridan (2000) indicates that less than 2% of manufacturing jobs in the United States are truly lean. Previous studies show that this unsatisfactory result, for lean manufacturing implementation, is often due to incomplete and ineffective implementation of lean principles, practices, and tools. Examples of ineffective implementation include selecting inappropriate lean strategies, using the wrong tool to solve the problem, sole reliance on financial measures and consequent performance measures, and an overall lack of synchronization between lean goals and actual practices (Anvari, Zulkifli, Yusuff, Ismail, & Hojjati, 2011; Goyal & Deshmukh, 1992; Karim & Arif-Uz-Zaman, 2013; Nakamura, Sakakibara, & Schroeder, 1998; Norris, 1992; Pavnaskar, Gershenson, & Jambekar, 2003).

Given the challenges of adopting lean and synchronizing strategy beyond financial measures, this paper attempts to resolve these shortcomings by providing a clear conceptual map that connects lean principles and practices to financial and non-financial performance measures. This is accomplished through the steps outlined in Figure 4-1.

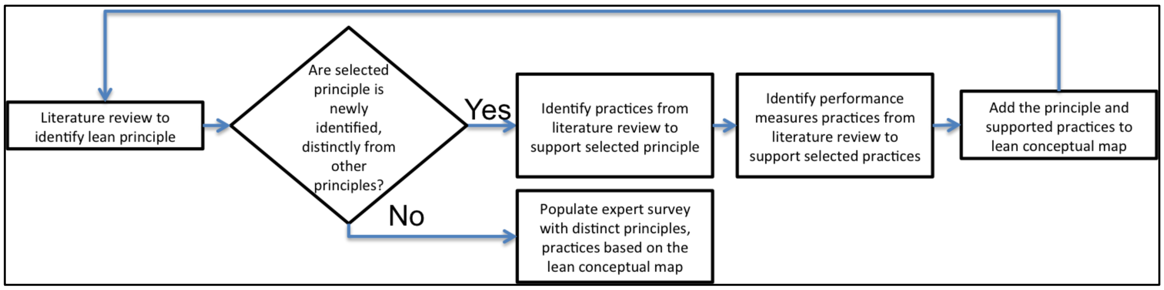


Figure 4-1: Article outline

The following section includes an explanation of lean concepts, principles, practices, and the performance measures used to sustain lean practices. The third section summarizes the validation process, used for the lean conceptual map. Finally, conclusions are presented, alongside limitations of the study, and suggestions for future research.

4.3 Literature and propositions

4.3.1 Lean manufacturing

Organizations are increasingly faced with unpredictably dynamic global competition and increasingly specific and sophisticated customer demand. As a result, companies are exploring practical means to increase their competiveness. Advanced manufacturing systems are one such tool (Rawabdeh, 2005). Lean manufacturing is recognized as an effective approach to achieving and maintaining competitive advantage through advanced manufacturing processes (Anvari et al., 2013; Chapman & Carter, 1990; Foster & Horngren, 1987; Fullerton et al., 2003; Sakakibara et al., 1993). .

Lean manufacturing was initially created to be applied in the automotive industry (Womack et al., 1990a). However, the application of lean manufacturing has spread to different industrial sectors (Anand & Kodali, 2009) and shows significant improvements in different sectors of industries (Jon, Detty, & Sottile, 2000). Dunstan et al (2006) examined application of lean manufacturing in the mining industry. Their results indicated reduction in absenteeism from 3.4% to 1.8% and savings of $2 million (Dunstan, Lavin, & Sandford, 2006). Dhandapani et al.,(2004) highlighted a case study in which lean thinking was applied in the steel industry. Their results showed lead time reduction by 50% (Dhandapani, Potter, & Naim, 2004). The successful application of various lean practices has also been documented in other industries, such as aerospace, computer engineering, and automotive assembly (Doolen & Hacker, 2005; Parry & Turner, 2006). The benefits of lean also extend to non-process industries, all aspects of supply chain management and to business processes such as project management, construction, and design (Melton, 2005).

Lean is often associated with higher and faster throughput, better product quality, and on time delivery of finished goods (Eswaramoorthi, Kathiresan, Prasad, & Mohanram, 2010; Goyal & Deshmukh, 1992; Norris, 1992). The literature also lists common benefits of lean to include better product quality, reduced inventory levels, customer satisfaction, shorter lead time, lower cost of quality, and overall improvements in competitive advantage (Fullerton & McWatters, 2001; MacDuffie, Sethuraman, & Fisher, 1996; Shah & Ward, 2003). Table 4-1 shows the most frequently listed lean manufacturing benefits from key articles reviewed in preparation for this study. Key articles were selected based on salience (number of citations, new ideas and approaches, etc). in the lean literature.

Table 4-1: Benefits of Lean: Frequency in Lean Literature

	(Detty & Yingling, 2000)	(Bayou & de Korvin, 2008)	(Allway & Corbett, 2002)	(Rose, Deros, Rahman, & Nordin, 2011)	(Ferdousi, 2009)	(Pavnaskar et al., 2003)	(Melton, 2005)	(Karlsson & Ahlström, 1996)	(Cumbo, Kline, & Bumgardner, 2006)	(R. R. Fullerton & McWatters, 2001)	(Eroglu & Hofer, 2011)	(R. R. Fullerton & McWatters, 2001)	(Ahls, 2001)	(Barker, 1994)	(Emiliani, 1998)	(Ross, 2003)	(Womack & Jones, 1996)
Reduced inventory levels	x			x		x	x			x	x		x	x		x	x
The effectiveness of production control and scheduling systems	x						x	x			x						
Supplier improvement	x					x	x										
Customer satisfaction	x						x			x	x	x				x	
Lead time reduction		x		x	x	x			x	x		x	x	x		x	x
Waste elimination		x				x											
Improved employee performance		x	x														
Annual sales growth and total return			x			x											
Improved knowledge management				x			x										
Product development				x				x									
Product quality improvement					x	x				x	x	x	x	x		x	x
Reduction in changeovers						x									x		

Despite the numerous benefits of lean, only 10% or fewer, organizations are successful in lean manufacturing implementation (Gupta & Kundra, 2012). Previous studies show that unsatisfactory results for implementing lean manufacturing are correlated with incomplete and ineffective implementation of lean (Goyal & Deshmukh, 1992; Nakamura et al., 1998; Norris, 1992). Anvari, Zulkifli, Yusuff, Ismail, & Hojjati (2011) show that very few companies truly sustain lean because they have incomplete or wrong lean implementation strategies. This finding supports the emphasis Womack et al. (1990) place on system-wide lean implementation (Womack et al., 1990a). Several authors consider lean a fragile system because trivial problems in the system can seriously affect the performance (Biazzo & Panizzolo, 2000). As a result, organizations require a conceptual (system level) understanding of lean in order to avoid the problems of failed implementation due to faulty strategies or understanding.

Lean techniques hold promise for organizational and system managers. However, the challenge of failed implementation will persist without clarification of lean principles, practices, and performance measures. The lack of agreement in the literature about lean principles and practices remains a major obstacle to successful lean implementation. Several authors give different definitions of lean, alongside differing descriptions of lean principles, practices, and performance measures. This paper uses a survey of lean experts to clarify the lean nomenclature and provide a visual map to guide system transformation managers, or lean champions, who seek to implement lean manufacturing processes.

4.3.2 Lean Principles

Lean production is an integrated socio-technical system that contains a set of principles, tools, practices and techniques. The main objective of lean manufacturing principles is to eliminate waste through continuous improvements (Gupta & Kundra, 2012; Mehta & Shah, 2005; Shah & Ward, 2007). According to Nicholas (2011), lean principles are a set of beliefs and assumptions that drive operational decisions and actions about products and processes. One must note that these definitions hinge on principles. In essence, the test of true lean process improvements is the organizational culture and principles that undergird the change. To this end, Womack & Jones (2003) identified five key principles for achieving a lean production system.

1. **Specify value:** identify what customers want (and/or are willing to financially support).
2. **Identify the value stream:** identify activities that, when performed correctly, satisfy customer "wants" (activities that provide value).
3. **Flow:** create continuous, interruption-free work processes across value adding activities
4. **Pull:** produce only in response to customer demand.
5. **Continuous improvement:** Generate, test, and implement process refinements in an ongoing drive for perfection.

Principles are made up of a set of practices, which are activities to improve an organization (Dean & Bowen, 1994; Karlsson & Åhlström, 1997). Karlsson & Ahlström (1996) used *The Machine that Changed the World* to develop a model of nine lean principles (elimination of waste, continuous improvement, zero defect, just in time, pull instead of push, multifunctional teams, decentralized responsibilities, integrated function and vertical information system). Sánchez & Pérez (2001) built on Karlsson & Ahlström work to design a checklist with 36 indicators that measure lean performance. Sánchez & Pérez (2001) suggested an addition of supplier integration to Karlsson & Ahlström's principles. Subsequently, Anand & Kodali (2009) questioned the basis of Karlsson & Ahlström's principles. They disagree with principles such as multifunctional teams, information system and decentralization, because those principles are used by other approaches like TQM and Six Sigma. Anand & Kodali proposed "respect for humanity", "visual management system", "customer focus" and "supplier integration", as suitable substitutions.

After two decades of research and investigation at a Toyota facility, Liker & Kaisha (2004) published *The Toyota way: 14 Management Principles from the World's Greatest Manufacturer*. The book discusses the key principles that drive the techniques and tools of the Toyota Production System and the management of Toyota. Shah & Ward (2007) present 10 factors that represent the operational complement to the philosophy of lean production and characterize 10 different dimensions of a lean system. Table 4-2 summarizes the most important principles listed by Liker & Kaisha (2004), Shah & Ward (2007), and other seminal (based on citations and initiation of new ideas or approaches) works on lean manufacturing.

Table 4-2: Frequency of occurrence of lean principles in key references.

	(Womack & Jones, 2003)	(Liker & Kaisha, 2004)	(Shah & Ward, 2007)	(Karlsson & Ahlström, 1996)	(Sánchez & Pérez, 2001)	(Anand & Kodali, 2009)	Frequency
Define the value stream	*		*	*	*	*	5
Pull	*	*	*	*		*	5
Continuous Improvement	*	*		*	*	*	5
Supplier Integration		*	*		*	*	4
Specify value	*		*			*	3
Flow	*	*	*				3
Multifunction team		*		*	*		3
Zero defect		*		*		*	3
Production and delivery JIT				*	*		2
Team leaders		*		*			2
Visual management system		*				*	2
Decentralized				*			1
Integrated Function				*			1
Vertical information system				*			1
Respect of humanity						*	1
Low setup time			*				1
Controlled process			*				1
Productive maintenance			*				1
Employee Involvement			*				1
Base your management decisions on a long-term philosophy		*					1

	(Womack & Jones, 2003)	(Liker & Kaisha, 2004)	(Shah & Ward, 2007)	(Karlsson & Ahlström, 1996)	(Sánchez & Pérez, 2001)	(Anand & Kodali, 2009)	Frequency
Level out the workload (heijunka).		*					1
Standardized tasks and processes		*					1
Use only reliable, thoroughly tested technology		*					1
Go and see for yourself to thoroughly understand the situation (genchi genbutsu).		*					1
Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly (nemawashi).		*					1

Table 4-2 shows that the five principles listed by Womack & Jones, in addition to supplier integration, multifunctional teams and zero defect represent approximately 60% of the principles identified in the selected literature. However, it is important to mention that the confusion apparent in that some principles such as visual management system, which is considered a lean principle by Anand & Kodali (2009) and Liker & Kaisha (2004), is listed as a practice in other studies (Black, 2007; Fliedner & Mathieson, 2009; Gupta & Kundra, 2012; Mejabi, 2003).

The healthcare industry is central to one of the recent iterations of lean manufacturing principles and practices. Healthcare managers – who are often promoted healthcare practitioners – need clear poka-yoke introductions to lean principles, which should then drive understanding of lean practices and ultimately inform use of tools and techniques in their organizations. The current system engenders confusion, which will propagate the dismal levels of successful implementation in manufacturing environments to the healthcare industry. This is an undesirable potential outcome, given the ongoing changes in healthcare system management in the United States.

The significant variability in specification of lean nomenclature by lean authors, propagates confusion among adopters/practitioners who seek to adopt lean principles. In this article, more investigation has been conducted to explore and validate the high level of variability in lean terminology between lean experts and to create a conceptual map that can allow non-experts visualize the inter-twined relationships between principles, practices, and performance measures. Performance measures are an important means of incentivizing process transformation.

4.3.3 Lean practices

Lean practices are implemented by applying lean tools and performance measures to improve process flow and overall performance (Álvarez, Calvo, Peña, & Domingo, 2008; Deshmukh, Upadhye, & Garg, 2010). The underlying goal is to optimize the production process by eliminating waste, and enhancing the leanness of a manufacturing system.

Numerous lean tools and techniques have been developed since the introduction of lean manufacturing practices. In support of the continuous improvement nature of lean manufacturing, new tools and techniques are still being created and proposed until today (Green & Dick, 2001; Liker, 1997; Womack, Jones, & Roos, 1990b). This continuous change has resulted in redundancy and confusion in communication between lean practitioners. For example, some authors refer to value steam mapping as process mapping (Pavnaskar et al., 2003). Differing nomenclature is problematic in this case, because process maps, in some practice and research circles, do not require the level of detail and system wide analysis that value stream maps provide. The resulting confusion hinders efforts to implement lean.

Previous studies suggest that the companies seeking to apply lean should implement all or most of lean practice – a system of lean practice – to ensure successful implementation and performance improvement (Bhasin & Burcher, 2006; Liker & Kaisha, 2004; Sánchez & Pérez, 2001). White & Prybutok (2001) argue that the benefits of lean will not be apparent until all elements are integrated. Pavnaskar et al. (2003) list over a hundred practices used by different lean organizations. They suggest a classification system to match lean manufacturing tools to specific manufacturing problems or measurement needs. To avoid misapplication of tools, such as using a wrong tool to solve the problem or wastage in the resources, the categories should provide performance information at the following levels: the system level, product state, production task, nature of task, resources, resource evaluation and tool application (Pavnaskar et al., 2003). In addition, Case (2004) validates and verifies the content of the classification put forward by Pavnaskar et al. Case concludes that this classification is able to address all activities within manufacturing, and can accurately classify lean practices. In order to sustain change, participants must understand the connection between proposed changes, organizational goals, and their specific tasks. However, previous studies do not connect lean practices to performance measures, financial goals and organizational strategy. This disconnect does not help organizations realize the effect of selected lean tool on the short and long term goals. Consequently, the selected tool could contradict organizational strategy.

The literature review for this study highlighted 200 practices from 22 different articles, This wealth of lean approaches could allow an adopter to accidentally apply the wrong tools to resolve a problem. Due to space constraints, a list of the most frequent listed lean practices is provided in the Table 4-3 alongside a summary of key references in which these practices appear. In addition, to achieving lean principles, the organization must determine their needs and apply appropriate lean practices. To this end, lean performance indicators are required to help the organization effectively diagnose organizational weaknesses. Consequently, there remains a need to relate lean practice with lean principles, and to regularly measure performance to validate the use of a selected practice.

Table 4-3: Lean Practice most frequent list

Practice	Related Literature	Frequency
Total productive maintenance	(Anand & Kodali, 2009); (Deshmukh, Upadhye, & Garg, 2010); (R. E. White, Pearson, & Wilson, 1999); (Olsen, 2004); (Panizzolo, 1998); (Fliedner & Mathieson, 2009); (Black, 2007); (Rose et al., 2011); (Shah, Chandrasekaran, & Linderman, 2008); (Jon et al., 2000); (Saurin, Marodin, & Ribeiro, 2011); (Gupta & Kundra, 2012); (Shah & Ward, 2003); (T. L. Doolen & Hacker, 2005); (Rosemary R. Fullerton et al., 2003); (Koufteros, Vonderembse, & Doll, 1998); (Sakakibara et al., 1993); (Mejabi, 2003); (Pavnaskar et al., 2003)	19
Cellular manufacturing	(Anand & Kodali, 2009); (Deshmukh et al., 2010); (Olsen, 2004); (Panizzolo, 1998); (Black, 2007); (Rose et al., 2011); (Shah et al., 2008); (Shah & Ward, 2003); (T. L. Doolen & Hacker, 2005); (Koufteros et al., 1998); (Sakakibara et al., 1993); (Lewis, 2000); (Pavnaskar et al., 2003)	13
Set up time reduction	(Anand & Kodali, 2009); (Deshmukh et al., 2010); (R. E. White et al., 1999); (Olsen, 2004); (Panizzolo, 1998); (Black, 2007); (Rose et al., 2011); (Sahoo, Singh, Shankar, & Tiwari, 2007); (Saurin et al., 2011); (T. L. Doolen & Hacker, 2005); (Rosemary R. Fullerton et al., 2003); (Sakakibara et al., 1993); (Lewis, 2000); (Pavnaskar et al., 2003)	13
Kanban	(Anand & Kodali, 2009); (R. E. White et al., 1999); (Olsen, 2004) ;(Fliedner & Mathieson, 2009); (Black, 2007); (Rose et al., 2011); (Worley & Doolen, 2006); (Gupta & Kundra, 2012); (Shah & Ward, 2003); (Rosemary R. Fullerton et al., 2003); (Sakakibara et al., 1993); (Lewis, 2000); (Pavnaskar et al., 2003)	13
Standardization	(Anand & Kodali, 2009); (Deshmukh et al., 2010); (Fliedner & Mathieson, 2009); (Black, 2007); (Rose et al., 2011); (Jon et al., 2000); (Saurin et al., 2011); (T. L. Doolen & Hacker, 2005); (Sakakibara et al., 1993); (Pavnaskar et al., 2003)	10
Small lot production	(Anand & Kodali, 2009); (Deshmukh et al., 2010); (Panizzolo, 1998); (Black, 2007); (Rose et al., 2011); (Sahoo et al., 2007); (Shah et al., 2008); (Shah & Ward, 2003); (T. L. Doolen & Hacker, 2005); (Sakakibara et al., 1993)	10
Single-minute exchange of dies	(Anand & Kodali, 2009); (Deshmukh et al., 2010); (Fliedner & Mathieson, 2009); (Black, 2007); (Shah et al., 2008); (Worley & Doolen, 2006); (Gupta & Kundra, 2012); (Shah & Ward, 2003); (Mejabi, 2003); (Pavnaskar et al., 2003)	10
Mistake proofing	(Anand & Kodali, 2009); (Deshmukh et al., 2010); (Panizzolo, 1998); (Fliedner & Mathieson, 2009); (Black, 2007); (Shah et al., 2008); (Gupta & Kundra, 2012); (T. L. Doolen & Hacker, 2005); (Mejabi, 2003); (Pavnaskar et al., 2003)	10
5S	(Anand & Kodali, 2009); (Deshmukh et al., 2010); (Panizzolo, 1998); (Rose et al., 2011); (Worley & Doolen, 2006); (Saurin et al., 2011); (Gupta & Kundra, 2012); (Pavnaskar et al., 2003)	9
Total quality management and control	(Anand & Kodali, 2009); (R. E. White et al., 1999); (Rose et al., 2011); (Shah et al., 2008); (Gupta & Kundra, 2012); (Shah & Ward, 2003); (T. L. Doolen & Hacker, 2005); (Rosemary R. Fullerton et al., 2003); (Sakakibara et al., 1993)	9

4.3.4 Lean Performance Indicators

Surveys are a common method of evaluating lean performance in the literature. Most surveys measure the adoption and level of implementation of lean principles (Doolen & Hacker, 2005; Soriano-Meier & Forrester, 2002; Upton, 1998). Because of the subjectivity of qualitative methods, scholars create quantitative models to reduce the effect of respondents' bias. The quantitative models calculate the score that represents lean adoption by using techniques such as simulation (Detty & Yingling, 2000; Lummus, 1995), fuzzy logic (Bayou & de Korvin, 2008; Behrouzi & Wong, 2011) or linear programming (Wan & Frank Chen, 2008), as well as other methods/approaches.

The literature shows numerous ways and performance indicators used to measure lean manufacturing. As part of the literature review for this study, a list of 250 different lean performance measures was collected. The need to investigate the most frequent performance indicators (number of times that performance measure appeared in lean performance measure article) is important to help the adopter stay focused. Due to space constraints, Table 4-4 contains a list of the most frequently listed lean performance indicators are compiled, alongside key references in which the indicators appear.

Table 4-4: Frequency of occurrence of lean performance measures in key references.

Performance Measures	Related Literature	Frequency
Setup time	(Anand & Kodali, 2008); (Sánchez & Pérez, 2001); (Karlsson & Ahlström, 1996); (Bhasin, 2008); (Mejabi, 2003); (Detty & Yingling, 2000); (Pavnaskar et al., 2003); (Cumbo et al., 2006); (Srinivasaraghavan & Allada, 2005); (Koufteros et al., 1998); (Shah & Ward, 2007); (R. R. Fullerton & McWatters, 2001); (Sakakibara et al., 1993); (Upton, 1998); (Hofer, Eroglu, & Rossiter Hofer, 2012); (Rosemary R. Fullerton et al., 2003); (Jina, Bhattacharya, & Walton, 1997); (Koh, Sim, & Killough, 2004); (Christiansen, Berry, Bruun, & Ward, 2003); (Kojima & Kaplinsky, 2004); (Wafa & Yasin, 1998).	21
Scrap and rework costs	(Anand & Kodali, 2008); (Sánchez & Pérez, 2001); (Karlsson & Ahlström, 1996); (Mejabi, 2003);(Brown, Collins, & McCombs, 2006); (Abdel-Maksoud, Dugdale, & Luther, 2005); (Srinivasaraghavan & Allada, 2005); (R. R. Fullerton & McWatters, 2001); (Shah & Ward, 2003); (Upton, 1998); (Jina et al., 1997); (Koh et al., 2004); (Christiansen et al., 2003); (Crute, Ward, Brown, & Graves, 2003); (Wafa & Yasin, 1998)	15
Finished goods inventory	(Anand & Kodali, 2008); (Bhasin, 2008); (Mejabi, 2003); (Detty & Yingling, 2000); (Pavnaskar et al., 2003); (White et al., 1999); (Cumbo et al., 2006); (Taj, 2005); (R. R. Fullerton & McWatters, 2001); (Christiansen et al., 2003); (Kojima & Kaplinsky, 2004); (CHU & SHIH, 1992); (Lewis, 2000); (Wafa & Yasin, 1998)	14
Supplier or delivery lead time	(Anand & Kodali, 2008); (Sánchez & Pérez, 2001); (Pavnaskar et al., 2003); (T. Doolen, Traxler, & McBride, 2006); (Koufteros et al., 1998); (Shah & Ward, 2007); (Sakakibara et al., 1993); (Upton, 1998); (Hofer et al., 2012); (Rosemary R. Fullerton et al., 2003); (Dong, 1995); (Kojima & Kaplinsky, 2004); (Oliver, Delbridge, & Barton, 2002); (Wafa & Yasin, 1998)	14
Percentage on time delivery	(Anand & Kodali, 2008); (Bhasin, 2008); (Cumbo et al., 2006); (Abdel-Maksoud et al., 2005); (Srinivasaraghavan & Allada, 2005); (Taj, 2005); (T. Doolen et al., 2006); (Koh et al., 2004); (Christiansen et al., 2003); (Oliver et al., 2002); (CHU & SHIH, 1992); (Lewis, 2000)	12
Throughput time or manufacturing lead time	(Anand & Kodali, 2008); (Bhasin, 2008); (Mejabi, 2003); (R. E. White et al., 1999); (Cumbo et al., 2006); (R. R. Fullerton & McWatters, 2001); (Jina et al., 1997); (Dong, 1995); (Koh et al., 2004); (Christiansen et al., 2003); (CHU & SHIH, 1992); (Crute et al., 2003)	12
Percentage of defective parts adjusted by production line workers	(Anand & Kodali, 2008); (Sánchez & Pérez, 2001); (Karlsson & Ahlström, 1996); (Brown et al., 2006); (Pavnaskar et al., 2003); (Abdel-Maksoud et al., 2005); (Taj, 2005); (Koh et al., 2004); (Oliver et al., 2002); (Lewis, 2000)	10
Labor productivity	(Anand & Kodali, 2008); (Bhasin, 2008); (Mejabi, 2003); (R. E. White et al., 1999); (Shah & Ward, 2003); (Dong, 1995); (Oliver et al., 2002); (Crute et al., 2003)	8
WIP inventory	(Anand & Kodali, 2008); (Bhasin, 2008); (R. R. Fullerton & McWatters, 2001); (Jina et al., 1997); (Christiansen et al., 2003); (Kojima & Kaplinsky, 2004); (CHU & SHIH, 1992); (Lewis, 2000)	8
The number of stages in the material flow that uses pull in relation to the total number of stages in the material flow	(Karlsson & Ahlström, 1996); (Cumbo et al., 2006); (Koufteros et al., 1998); (Shah & Ward, 2007); (Hofer et al., 2012); (Dong, 1995); (Koh et al., 2004) ; (Crute et al., 2003)	8
Frequency of preventive maintenance	(Anand & Kodali, 2008); (Taj, 2005); (Koufteros et al., 1998); (Sakakibara et al., 1993); (Rosemary R. Fullerton et al., 2003); (Koh et al., 2004); (Christiansen et al., 2003)	7
Manufacturing cost per unit	(Anand & Kodali, 2008); (Bhasin, 2008); (Mejabi, 2003); (R. E. White et al., 1999); (Shah & Ward, 2003); (Koh et al., 2004); (CHU & SHIH, 1992)	7
Number of kanbans	(Anand & Kodali, 2008); (Koufteros et al., 1998); (Shah & Ward, 2007); (Hofer et al., 2012); (Rosemary R. Fullerton et al., 2003); (Kojima & Kaplinsky, 2004); (Wafa & Yasin, 1998)	7
Number of suggestions per employee per year	(Anand & Kodali, 2008); (Sánchez & Pérez, 2001); (Karlsson & Ahlström, 1996); (Koufteros et al., 1998); (Shah & Ward, 2007); (Hofer et al., 2012); (Oliver et al., 2002)	7
Percentage of unscheduled downtime	(Anand & Kodali, 2008); (Sánchez & Pérez, 2001); (Karlsson & Ahlström, 1996); (Pavnaskar et al., 2003); (Taj, 2005); (R. R. Fullerton & McWatters, 2001); (Wafa & Yasin, 1998)	7

4.4 Methodology for Conceptual Map Validation

4.4.1 Item generation and pre test

The first step toward clarification of the lean nomenclature was a holistic review of past literature to identify the key lean articles. Articles were accessed using databases such as EBSCO host and the Oregon State University Valley Library. Keywords used as search terms included lean conceptual, lean performance, lean implementation, lean measures, lean context, and lean framework. The second step was identification of relevant studies by using online academic citation indexing and search services such as Web of Science by Thomson Reuters. Web of Science was used to identify the number of citations and to generate the citation map, which allowed the research team to visually identify two generations of citations in both directions. Finally, Google Scholar was is used to validate the number of the citations from the previous step and to identify any new, related publications. Google Scholar often includes more citation counts than Web of Science, which helps ensure that no important articles were ignored.

As previously mentioned, approximately 200 practices and 250 different lean performance measures were collected from the literature. The lean performance measures were listed in a Microsoft Excel spreadsheet and filtered by frequency of occurrence in the literature. Due to the large number of practices and performance measures, only the most frequent constructs are used in this work. The frequency of practice or performance measure defined as number of times the practice or performance measures appeared in the selected articles. Figure 4-2 presents a sample of the two-levels of details of the initial lean conceptual map. The initial lean conceptual map contains principles, practices and performance measures, which were obtained from the literature. Due to space constraints, the conceptual maps are divided into four detailed maps and included in Appendix 4. The maps are initially categorized by Womack's principle (Specify value, Identify value stream, Pull, Flow, and Continuous improvement). This classification (initial lean conceptual map) is based on the lean literature. The goal of the conceptual map is to help organize the lean constructs (principles/practices/performance measures), and to create a clearer, validated lean conceptual map.

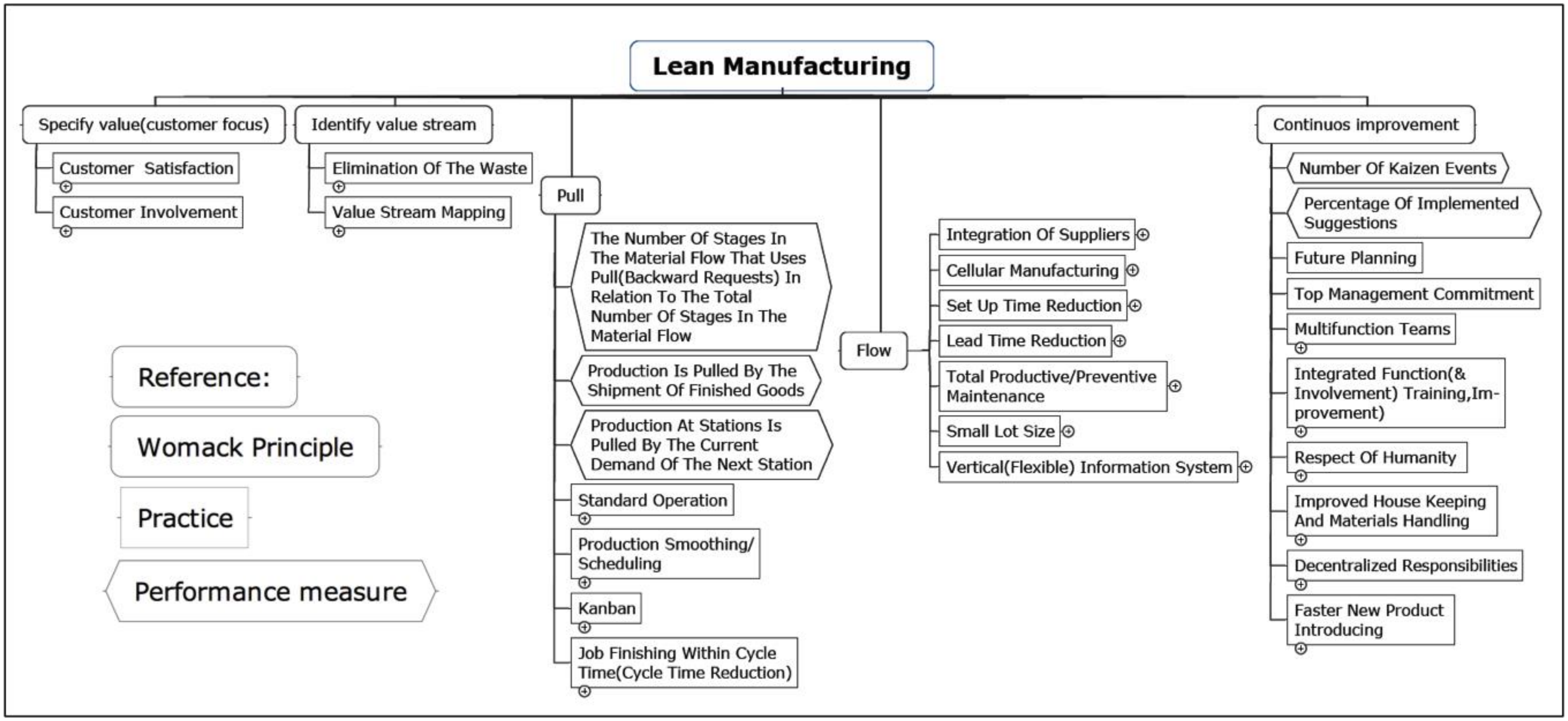


Figure 4-2: Initial lean conceptual map.

To provide more validity to the initial conceptual map presented in Figure 4-2, the map was sent to lean experts along with an online survey. The survey was designed using Qualtrics (Web-based survey software) and then electronically mailed to 156 lean experts. The participants could respond online by using a web link provided in the email for convenience. To ensure more understanding of terms used, the purpose of the study and terms definitions were provided. We define a lean expert as someone who has authored at least one peer-reviewed article related to lean manufacturing. Most of the lean experts in this study are also individuals working in the academic field. 49 experts responded to the survey - a 31% response rate. The survey was designed to allow use of data provided in incomplete surveys. For instance, information provided by participants who only selected lean principles remains useful for populating the list of principles in the lean conceptual map.

In the survey, the experts were asked to differentiate between lean principles and lean practices. They were then to group items into three categories: "Lean principle", "Lean practice", and "Not related to lean". Participants were asked to drag the items listed in a column on the left side into one of the three boxes on the right. The result was then used to identify lean consensus principles (Figure 4-3).

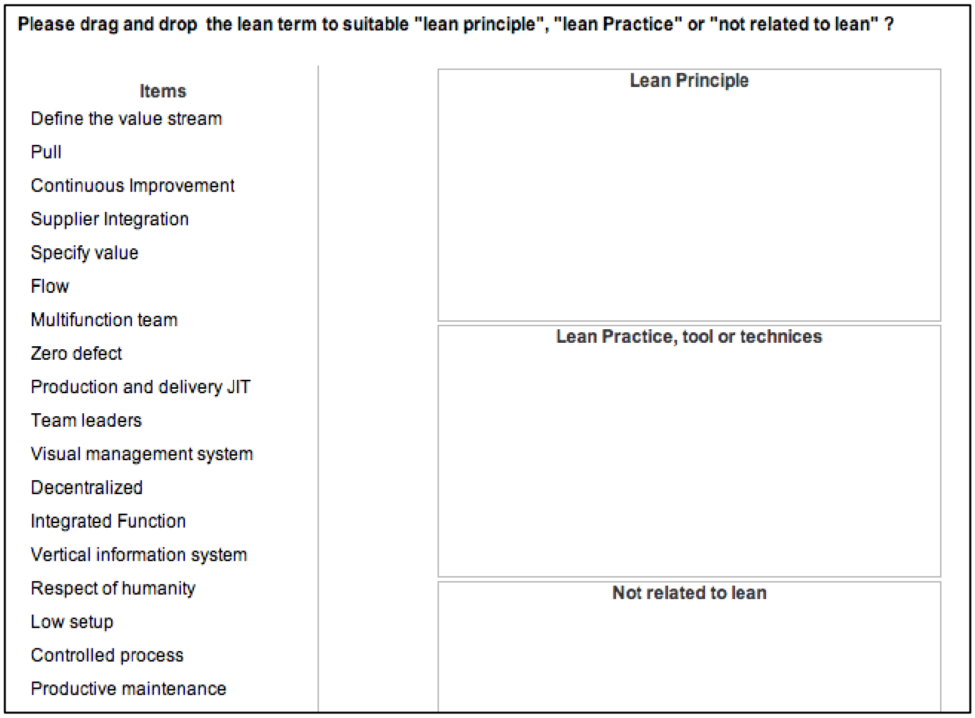
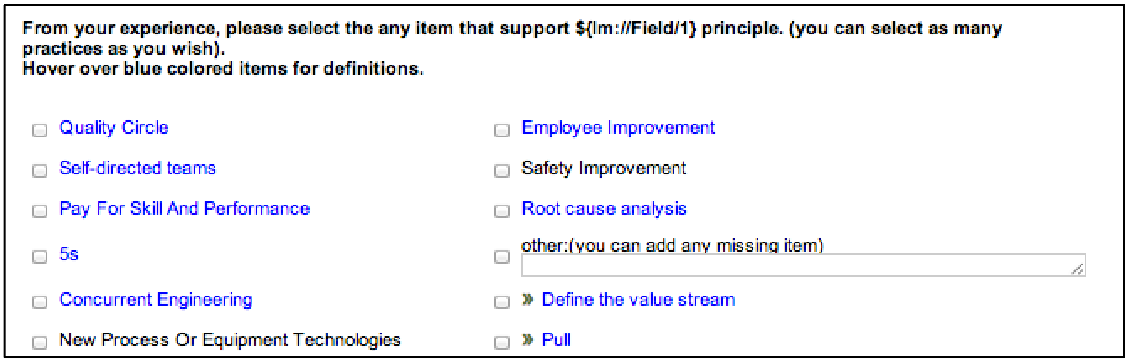


Figure 4-3: Example of the survey in the lean conceptual map validation process.

Based on the experts' selections, lean principles were specified. Next, experts were asked to add, change, or delete lean practices and to assign practices from their chosen list to previously selected principles (Figure 4-4). Each expert could select multiple practices for each principle. The outcome of Figure 4-4 was used to identify lean practices. In the result, we obtained five lean principles and 48 lean practices grouped under these lean principles, which are discussed in the following section.



From your experience, please select the any item that support ${lm://Field/1} principle. (you can select as many practices as you wish).
Hover over blue colored items for definitions.

- [ ] Quality Circle
- [ ] Self-directed teams
- [ ] Pay For Skill And Performance
- [ ] 5s
- [ ] Concurrent Engineering
- [ ] New Process Or Equipment Technologies
- [ ] Employee Improvement
- [ ] Safety Improvement
- [ ] Root cause analysis
- [ ] other:(you can add any missing item)
- [ ] » Define the value stream
- [ ] » Pull

Figure 4-4: Example of the survey in the lean conceptual map validation process.

4.4.2 Problem Validation/Lean Principle Analysis

After data from the earlier step was collected and analyzed, the results show the confusion among lean experts. Figure 4-5 clearly presents the disagreement between lean experts on the main lean constructs (principles, practices/tool/techniques). As indicated, no item received 100% agreement from the experts; while Flow principle represents the highest agreement percentage (85% of the experts consider it as a lean principle).

The results in Figure 4-5 are of interest because all the items in the survey are presented as ‘lean principles’ in the literature, even though only five items are considered lean principles by the lean experts surveyed (Figure 4-5, Group1). On the other hand, there are five items that are difficult to categorize because of the high disagreement noted between lean experts (Figure 4-5, Group 3). For example, “Long-term philosophy” is considered a lean principle by 44% of the experts but considered as “not related to lean” by 48% of the experts surveyed. Figure 4-5, Group 2 includes 10 different items representing lean practices. Total Productive Maintenance is considered a practice by 93% of the experts; this represents the highest agreement in the group. Employee involvement is considered a practice by 51.85%, the lowest in the group. Figure 4-5, Group 4 includes two items grouped as "not related to lean" (vertical information system, and reliable technology). This is an interesting finding because Karlsson and Ahlström (1996) consider "vertical information system" a lean principle. Karlsson and Ahlström (1996) define "vertical information system" as providing timely information continuously and directly to all stakeholders and employees in the production line. The second item "Use only reliable, thoroughly tested technology that serves your people and processes" is presented by Liker and Kaisha (2004) as using technology to support people, not to replace people, and support the process, not conflict with your culture or that might disrupt stability, reliability, and predictability.

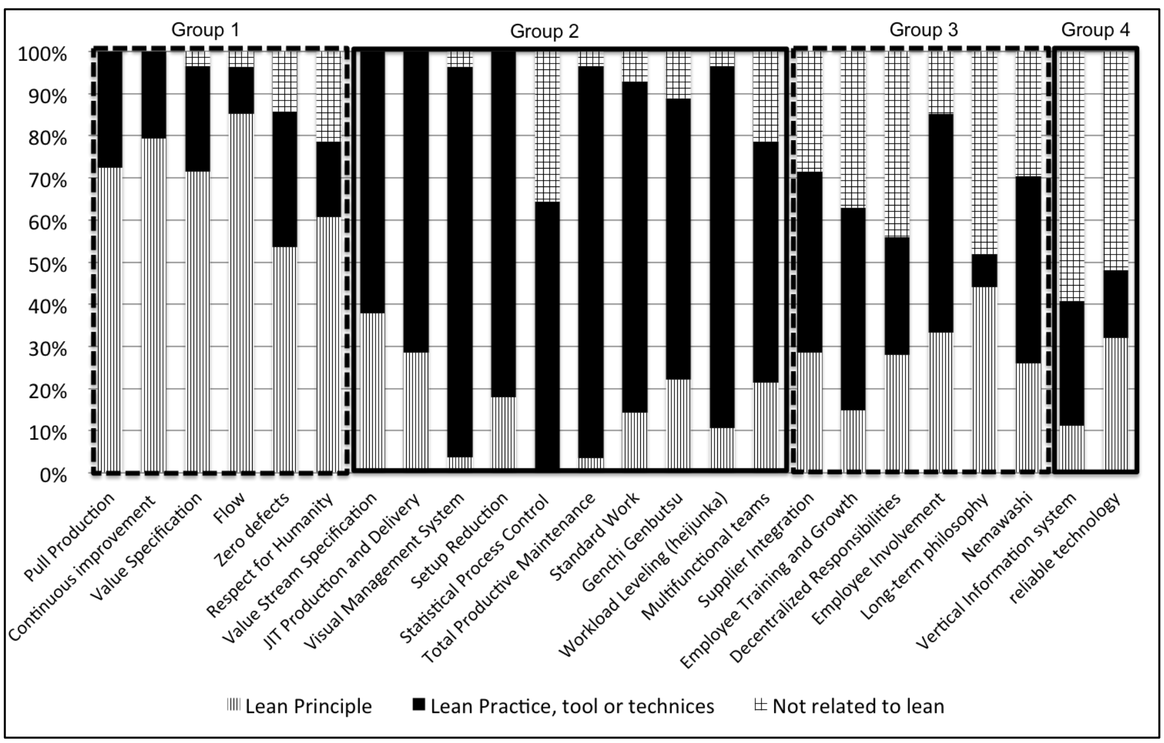


Figure 4-5: Lean items categorization

In the effort to understand the cluster of the items, they were categorized into 4 groups: {lean principle (group1), lean practices/tool/techniques (group2), difficult to categorize (group3), and not related to lean (group4)}. Each of the items was assigned to one group depending on the flow chart shown in Figure 4-6.

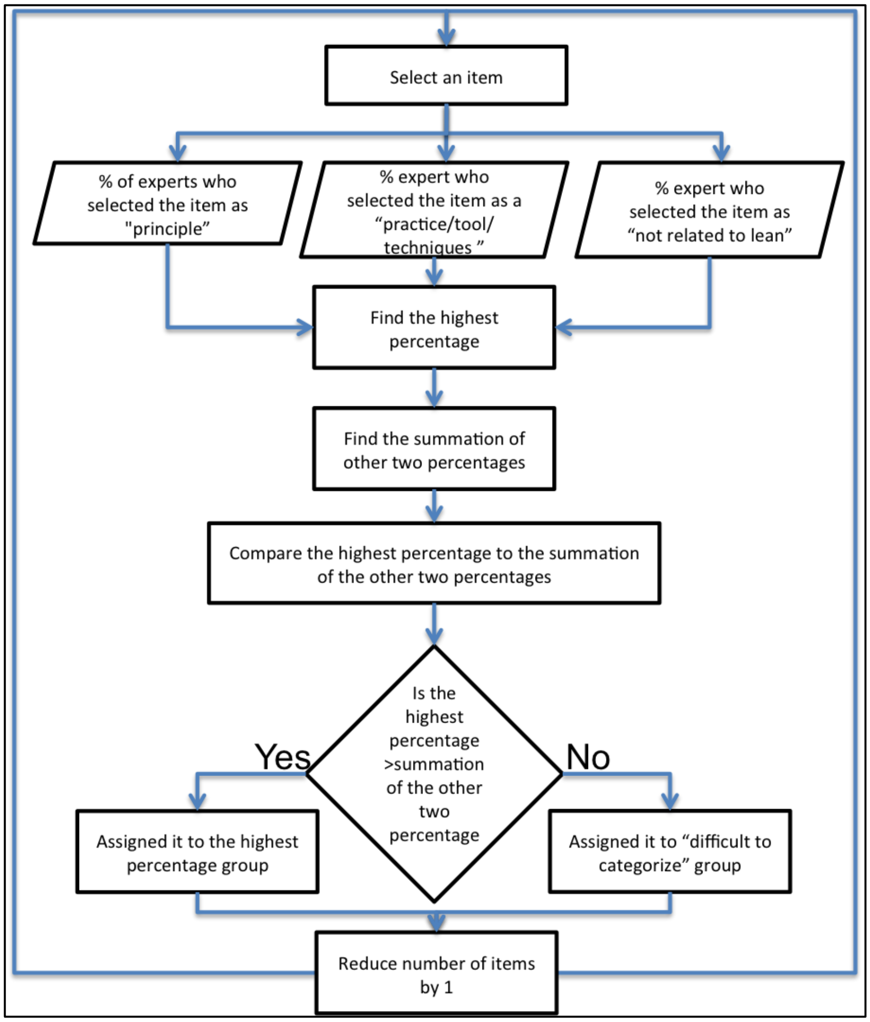


Figure 4-6: Criteria to categorize the items

For example, value specification is considered a "lean principle" by 71.43% of the experts, a "lean practice" by 25%, and as "not related to lean" by 3.57%. As a result, value specification is categorized as a lean principle because 71.43% is more than the summation of 25% and 3.75%. However, it is difficult to categorize employee training and growth because the highest percentage is 48.15% (lean practices), which is lower than the summation of 14.81% (lean principle) and 37.04% (not related to lean). Figure 4-5 summarizes the final categorization depending on the previous criteria.

The first group (pull; continuous improvement; value specification; flow; zero defect; respect of humanity) represents lean principles based on lean experts. Surprisingly, "define the value stream" is not considered a lean principle by the experts even though it is considered a principle by Womack and Jones (2003).This could be because "value specification" encompasses the principle of value focused operations. Comparing the literature with the experts' opinions highlights the confusion in conceptual understanding of lean (Table 4-5). For instance, literature defines value stream, supplier integration, and multifunctional teams as lean principles, while the lean experts do not support that. Also, "respect of humanity" is considered a lean principle by 60.71% of lean experts, while it is not strongly supported in the selected articles as shown in Table 4-5.

Table 4-5: Comparison between lean principle from the literature and the lean experts

	Expert Opinions (Experts agreement percentage)	(Womack & Jones, 2003)	(Liker & Kaisha, 2004)	(Shah & Ward, 2007)	(Karlsson & Ahlström, 1996)	(Sánchez & Pérez, 2001)	(Anand & Kodali, 2009)	Frequency
Define the value stream	37.93%	*		*	*	*	*	5
Pull	*(72.41%)	*	*	*	*		*	5
Continuous Improvement	*(79.31%)	*	*		*	*	*	5
Supplier Integration	28.57%		*	*		*	*	4
Specify value	*(71.43%)	*		*			*	3
Flow	*(85.19%)	*	*	*				3
Multifunction team	21.43%		*		*	*		3
Zero defect	*(53.57)		*		*		*	3
Respect of humanity	*(60.71%)						*	1

4.4.3 Categorization of Lean Practices/Tools/Techniques

The data in this step was obtained from Figure 4-4, to validate the lean practices/tools/techniques that support each lean principle. It is important to remind the reader that the lean practices were obtained from the literature as shown in Table 4-3. The items in group 2 and group 3 (Figure 4-4) were added to the practices found in the literature. Altogether, this study contained 48 different lean practices. The goal was to categorize each lean practice under a suitable lean principle. Table 4-6 shows a sample of data that was obtained from Figure 4-4. Each cell in the table represents the percentage of experts who categorized practice X under principle Y, given that the expert selected Y as a principle. For example, 22% of the experts who selected pull as a principle categorized quality circle as a practice that supports pull.

Table 4-6: Sample of the data obtained from the survey

Practices	Pull	Continuous Improvement	Specify value	Flow	Zero defect	Respect of humanity
Quality Circle	22.22%	66.67%	33.33%	30.77%	87.50%	72.73%
Self-directed teams	16.67%	61.11%	25.00%	23.08%	75.00%	54.55%
Small lot sizes	61.11%	27.78%	16.67%	53.85%	62.50%	9.09%
Poka Yoke	38.89%	27.78%	8.33%	46.15%	100.00%	9.09%
Customer Relation Management	11.11%	38.89%	66.67%	0.00%	37.50%	27.27%
Value stream mapping	55.56%	44.44%	50.00%	53.85%	62.50%	9.09%
JIT Production and Delivery	38.89%	16.67%	16.67%	30.77%	12.50%	9.09%

To simplify comparing the percentages, the following procedures were used:

1- Calculate the standardized percentage for each percentage by applying the following formula:

$$Standardize\ percentage = current\ percentage \times \frac{100}{Maximum\ percentage\ for\ each\ practice}$$

For example, self-directed teams practice supports Pull principle by (16.67%), Continuous improvement (61.11%), Specify value (25%), Flow (23.08%), Zero Defect (75%), and Respect of humanity (54.55%). The maximum percentage is (75%), and by applying the formula, the standardized percentage is:

$$.16 \times \frac{100}{.75} = 25.40\%$$

Table 4-7 summarizes the result after calculating the standardized percentage for Table 4-6

Table 4-7: Sample of the data after calculating the standardize percentage

Practices	Pull	Continuous Improvement	Specify value	Flow	Zero defect	Respect of humanity
Quality Circle	25.40%	76.19%	38.10%	35.16%	100.00%	83.12%
Self-directed teams	22.22%	81.48%	33.33%	30.77%	100.00%	72.73%
Small lot sizes	97.78%	44.44%	26.67%	86.15%	100.00%	14.55%
Poka Yoke	38.89%	27.78%	8.33%	46.15%	100.00%	9.09%
Customer Relation Management	16.67%	58.33%	100.00%	0.00%	56.25%	40.91%
Value stream mapping	88.89%	71.11%	80.00%	86.15%	100.00%	14.55%
JIT Production and Delivery	100.00%	42.86%	42.86%	79.12%	32.14%	23.38%

2- Categorize each of the practices under suitable principle depends on the criteria:

   If the standardized percentage > 80%, then the practice supports the principle.

   Otherwise, the practice does not support the principle.

   For example, small lot size support Zero Defect principle, Pull, and Flow principles.

3- Validate the categorization obtained from the previous step with literature. In this step, two practices only show disagreement with literature: Mixed model production and group technology. In this case, the practices were categorized depending on the literature.

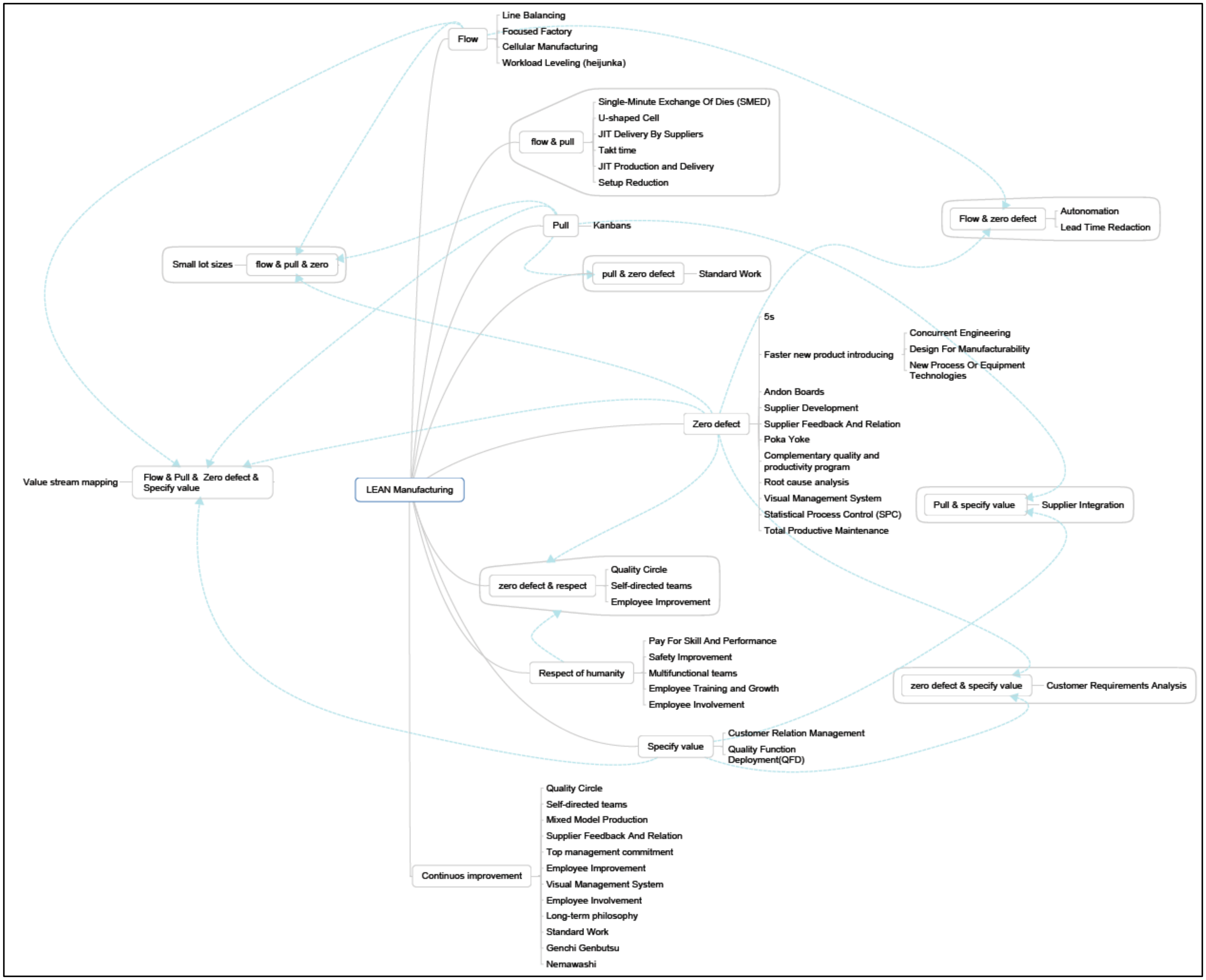


Figure 4-7: Lean conceptual map (based on experts opinions)

4.5 Results and Discussion:

Figure 4-7 summarizes the final categorization of lean practices under the five lean principles (Flow, Continuous improvement, Pull, Zero Defect, Specify Value, and Respect of Humanity). As shown, the confusion still clearly appears. In addition, there are no 100% agreements between lean experts except for “Poka Yoke”, which is considered as practice that supports Zero Defect principle. However, other practices are shared amongst more than one principle. For example, Quality Circle practice is 66.76% in support of Continuous Improvement, 87.50% support Zero Defect principle, and 72.73% support Respect of humanity principle. As a result, it is impossible to completely disjoint the lean principles from each other. This explains previous statements by Bhasin & Burcher, (2006); Liker & Kaisha (2004); Sánchez & Pérez (2001), which suggest the implementation of all or most of the lean practices to ensure successful implementation. Besides, Figure 4-7 strongly supports the fact that practices and principles in lean manufacturing must be integrated to get lean benefits. Consequently, adapting lean by ignoring some principles and implementing others, based on the personal opinion will paralyze the lean improvement progress. In fact, the lean adopter must be aware that lean manufacturing is not just a set of “tools” and “practices” to apply. Lean is an integrated socio-technical system directed by a set of principles, practices, and techniques (Mehta & Shah, 2005; Shah & Ward, 2007).

It is important to mention that Continuous improvement principle is related to each practice in lean manufacturing. Fundamentally, lean is a continuous process rather than a solution, lean is a journey, not a destination. The top management must support this philosophy, demonstrate willingness to incur initial costs of change, and continuously improve all practices (Womack et al., 1990b). The top management must also understand that there is no ideal state in lean manufacturing. In addition, Continuous improvement principle is strongly related to respect of humanity principle, which includes practices such as self-directed teams, Employee Improvement, and Employee Involvement.

Additionally, respect of humanity is one of the unique features that differentiate lean manufacturing from mass manufacturing system. The work methods in the mass manufacturing for most of the employees are boring, disturbing, and do not improve the skills because of the repetitive tasks characterizing the nature of work. On the other hand, lean manufacturing focused on multi-skilled workers at all levels in the lean organization.

Zero Defect principle plays a central role with other principles. As shown in Figure 4-7, Zero Defect is shared with pull in 3 practices: Standard work, small lot size, and value stream mapping; with Flow principle in 4 practices: Autonomation, Lead Time Reduction, Small lot sizes, and value stream mapping; with respect of humanity in three practices: Quality Circle, Self directed teams, and employee improvement; with specify value in two practices: value stream mapping, and customer requirement analysis. The importance of Zero Defect principle explains why other quality programs such as six sigma are supported and easily linked to lean manufacturing (Franco, Marins, & Silva; Timans, Antony, Ahaus, & van Solingen, 2011).

By looking at the practices, it is clear that value stream mapping practice is the central practice in lean manufacturing, which supports Flow and Pull, Zero Defect, Continuous Improvement, and Specify Value principles. Creating value stream mapping considers the flow of information and materials within the overall supply chain (Flow and pull principles) including the customer requirement (value specification) and creating the future state map, which represents the continuous improvement principle. The ultimate goal from the value stream mapping is removing all wastes in the value stream (Zero Defect principles).

4.6 Conclusions:

Fundamentally, the challenges and difficulties occurring during the implementation of lean manufacturing translated into high percentage of failure. This paper attempted to resolve the confusion surrounding lean implementation by providing a clear conceptual map that connects lean principles and practices to financial and non-financial performance measures.

The article presents the confusion that occurred in lean manufacturing between lean experts. Looking at the high percentage of failure in implementing lean manufacturing, this article validates the ambiguity of conceptual part of lean manufacturing, which is one of the major causes of lean implementation failure. In the effort to address this, the article suggested a conceptual map, which relates the lean principle with practices and performance measures. The conceptual map helps the adopter to select the suitable practice to solve the problem. In addition, the lean conceptual map encourages implementing lean manufacturing as integrated system, not just as random tools selected depending on individual opinions.

4.7 Limitations and Future Research

This study is based on responses from 49 lean manufacturing experts based on their experiences conducting research in lean process improvement. While the authors attempted to increase the size and the variety of the sample through completion prize, future studies might take steps to increasing the responses.

It is recommended that more studies need to be conducted in order to explore the factors that contribute to the relationship between the lean principles. In addition, investigating the causal relationship between the lean principles is important topics to identify the sequence of implementing the lean principle.

4.8 Implications for the Engineering Manager

Successful change management requires clear specification of objectives, execution plans, and performance metrics. This is true in kaizen event teams (Farris, Van Aken, Doolen, & Worley, 2009), innovation and new product development (Russell & Tippett, 2008), assessing the effectiveness of design tools (Farris, Van Aken, Letens, Ellis, & Boyland, 2007), and managing efficient and effective training progress (Wiseman, Eseonu, & Doolen, 2014).

In their review of performance metrics for supply chain management, Elrod, Murray, & Bande (2013) identify the lack of clear specification as a hindrance to effective performance measurement and supply chain management. The tendency to get "lost in a sea of data" is also prevalent in attempts to implement lean manufacturing principles. Managers are often faced with lofty principles and find conflicting directions in the literature on corresponding practices and performance measures. The conceptual map developed here addresses this challenge. It applies the lean principle of “flow” through visual workplace practices to develop a poka yoke decision making tool for lean implementation.

Abdulmalek, Rajgopal, & Needy (2006) express the need for lean implementation in process industries. They highlight broad lean aims of *faster delivery, higher quality,* and *lower cost* as key success factors and list *employee empowerment, utilize less to create more,* and *elimination of non value adding activities* as principles. The conceptual map developed in this study provides a complementary tool that will reduce the likelihood of erroneous lean implementation once a determination of lean suitability has been made using the model developed by Abdulmalek, Rajgopal, & Needy.

Farris, et al., (2008) identified input, process and output factors that determine kaizen event success. Some input factors included *goal clarity,* and *event planning process*. Process factors included items like *tool appropriateness,* and output factors included *attitude, kaizen capabilities,* and *overall perceived success.* A visual tool, like the conceptual map developed here, improves goal clarity and facilitates kaizen event planning by clearly linking desired end goals (lean principles) to methods (lean practices) for achieving said goals, and providing performance measures associated with each end goal. The map improves process determinants of success by aligning appropriate tools with desired lean principles. This framework can ultimately promote participant confidence in the kaizen event outcomes, increase self-efficacy of the process improvement team, and by extension, the overall perception of event success. Employee buy-in is an important aspect of process improvement initiatives. The lean conceptual map assists engineering and process transformation managers in explaining the impact of lean practices on an employee's workspace – through associated performance measures. It can also be a useful tool for developing incentive schemes.

The conceptual map highlights the critical success factor for lean implementation in product development teams. Previous literature looked at the need for assessment frameworks that could guide process improvement in new product development. Lean new product development is an emerging area of research and practice. This paper extends previous work on NPD tool and process assessment, to promote the accurate application of lean concepts in NPD processes. It increases a manager's ability to match a desired principle with the right assessment tool, and provides a visual communication tool that can be used to design effective and efficient training programs.

Wiseman et al., (2014) developed a framework for pre-emptive evaluation of continuous improvement training programs. They identified *communication, resources,* and *time* as the most important determinants of successful continuous improvement training. The association of performance measures with specific lean practices and principles increases a manager's ability to communicate proposed lean-induced changes. It facilitates resource allocation for planned change, and assists in setting performance measurement targets.

Good engineers are often promoted to management positions without training in personnel and process management. The engineering management literature can provide easily accessible tools that reduce wasted time and effort and increase the chances of successful initiatives by engineering managers. This paper has provided a clear link that would allow engineering managers effectively carry out planning, organizing, leading, and controlling functions on lean transformation projects.

A Strategy Map for Lean Process Transformation

by
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To be submitted for Journal publication

5 A Strategy Map for Lean Process Transformation

5.1 Introduction

Increased global competition and associated variations in customer demand pose threats to companies in the international market. As a result, organizations seek practical methods of increasing competitiveness through advanced manufacturing systems (Rawabdeh, 2005). Lean manufacturing is recognized as an effective approach for achieving and maintaining competitive advantage through improved manufacturing processes (Chapman & Carter, 1990; Foster & Horngren, 1987; Fullerton, McWatters, & Fawson, 2003; Sakakibara, Flynn, & Schroeder, 1993). By applying lean manufacturing principles, organizations can increase value for customers while improving organizational profitability and citizenship behavior among employees (Karim & Arif-Uz-Zaman, 2013). Organizations aim to reduce non-value adding activity by using lean principles and lean tools. However, only 10%, or fewer, organizations successfully implement lean (Gupta & Kundra, 2012). Among seemingly successful implementers in the United States manufacturing industry, less than 2% are truly lean (Sheridan, 2000). Previous studies show that these unsatisfactory results for lean implementation are correlated with incomplete and ineffective implementation of lean principles, practices, and tools.

Examples of ineffective implementation include selecting inappropriate lean strategies, using wrong tools to solve problems, sole reliance on financial measures, and an overall lack of synchronization between lean goals and actual practices (Anvari, Zulkifli, Yusuff, Ismail, & Hojjati, 2011; Goyal & Deshmukh, 1992; Karim & Arif-Uz-

Zaman, 2013; Nakamura, Sakakibara, & Schroeder, 1998; Norris, 1992; Pavnaskar, Gershenson, & Jambekar, 2003).

Given these challenges, this research attempted to resolve the confusion surrounding lean implementation by providing a balanced scorecard as performance management system and by constructing a lean strategy map helps organizations to identify the most important criteria to focus on. This effort was accomplished through the steps highlighted in Figure 5-1.

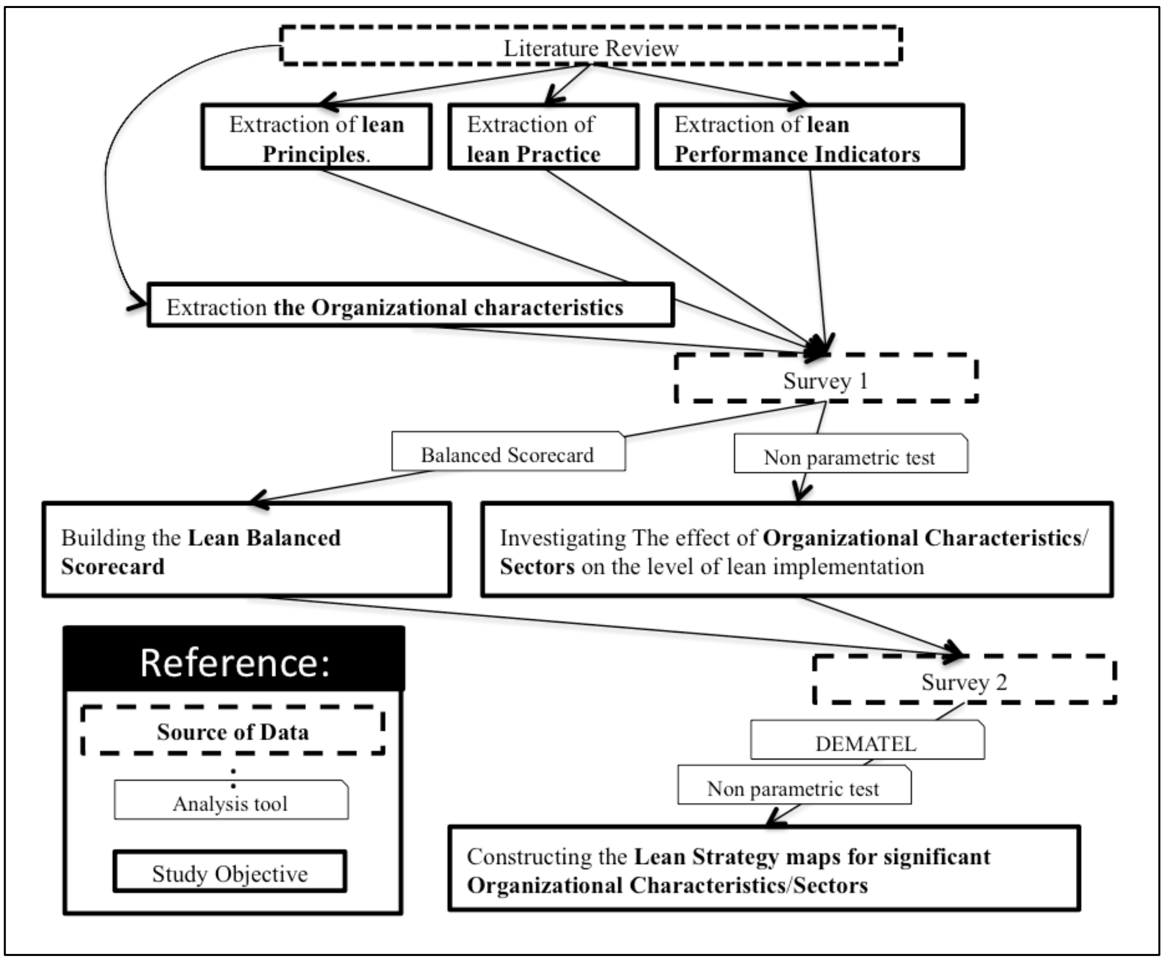


Figure 5-1: Article outline

5.2 Literature and propositions

5.2.1 Challenges with Lean Implementation

10% or fewer organizations succeed at lean manufacturing implementation (Gupta & Kundra, 2012). Previous studies link this trend to incomplete or ineffective implementation initiatives. Examples of ineffective implementation include selecting inappropriate lean strategies, using the wrong practice, sole reliance on financial measures, and an overall lack of synchronization between lean goals and actual practices (Goyal & Deshmukh, 1992; Nakamura et al., 1998; Norris, 1992).

Trivial problems in a lean manufacturing system can have considerable impact on performance of an organization (Biazzo & Panizzolo, 2000) and result in waste of organizational resources. The cascading effect of trivial problems can be frustrating for employees and can reduce their motivation to implement future lean initiatives (Marvel & Standridge, 2009). Anvari et al. (2011) show that very few companies sustain true lean practices because of mistakes made during lean implementation.

This finding supports Womack et al. (1990) on the importance of holistic lean implementation (Womack, Jones, & Roos, 1990a), and was validated by Mirdad and Eseonu (2013). Karim & Arif-Uz-Zaman (2013) highlight the need for a lean implementation strategy, or road map, that can help adopters implement lean. Such a roadmap would define a systematic implementation process and specific actions in order of precedence to form milestones in the journey from mass to lean production.

According to Anvari et al., (2011), there is no standard recipe for holistic lean implementation because every implementation attempt is context specific; each organization has unique culture, policy, and other systems that determine the nature and level of waste identified. To this end, Shah and Ward (2003) suggest unique alignment of lean implementation strategy with the specific characteristics of the organization in question. Strategy regurgitation is a recipe for failure.

Despite the dismal levels of successful lean implementation, the literature contains few attempts to develop lean implementation strategies to guide change initiatives. The literature suggests that implementation strategy should vary with industry of operation (Doolen & Hacker, 2005; Eroglu & Hofer, 2011). Table 5-1 shows the factors that influence lean implementation in different industrial sectors, and shows that different manufacturing sectors have different characteristics such as variability of demand, variability of raw materials, variability of production, ability to control production, rigid organizational structures, process type and changing economic conditions, which can affect a lean implementation (Abdulmalek, Rajgopal, & Needy, 2006; Anvari et al., 2011; Crute, Ward, Brown, & Graves, 2003; Cumbo, Kline, & Bumgardner, 2006; Detty & Yingling, 2000; Doolen & Hacker, 2005).

Table 5-1: Examples of lean implementation in different manufacturing sectors

Industry	**Author**	**Lean Applicability**	**Reasons for success or failure**	**Current characteristics and difficulties**
Mining industry	(Detty & Yingling, 2000)	Highly applicable	Easy adoption of most lean practices such as standard work, quality at the source, TPM, flexible workforce, setup reduction and continuous improvement	Some practices are not readily transferable to the mining industry: * Flow: need to take different strategies than manufacturing. Unfortunately, there are no firmly established methods for accomplishing flow in the mining industry * Pull: given the bulk nature of mining industry. Pull production differ from the regular manufacturing.
Aerospace industry	(Crute et al., 2003)	Applicable	* The low volume nature of aerospace is considered an advantage over the automotive sector, because the lower volume is closer to the lean ideal of single piece flow than a high volume environment. * The aerospace industry already uses "build to order", which represents JIT principle.	* Aerospace is considered as low volume environment, while automotive is high volume. *Different competitive priorities. *The aerospace is ten year behind automotive sector in lean manufacturing.
Process industry	(Abdulmalek et al., 2006)	Applying lean in process industry varies between process types.	The success or failure in the process industry depends on the factors: Product characteristics. Process characteristics For example: textile provide more opportunities for lean manufacturing than chemical industry	*High volume *Low variety *Fixed routing *Long change over Fixed layout.
Electronic industry	(Doolen & Hacker, 2005)	The application varies between printed circuit board, equipment manufacturers and wafer manufacturer	* Operational strategies resulting from difference in product volume and product variety. * Organizational size and type of manufacturing are significant factors to achieve the lean manufacturing.	*Rapidly rising customer expectations *Globalization of both market and competition *Acceleration pace of technological change *Rapid expansion of technology access

The information in Table 5-1 supports extant literature that lists organizational characteristics as determinants of appropriate practices to be incorporated in a lean implementation strategy (Dilworth, 1987; Gilbert, 1990; Harber, Samson, Sohal, & Wirth, 1990; Im & Lee, 1989; Shingō, 1989; Sohal, Keller, & Fouad, 1989). We apply this consideration to the current study and note that this approach of individualized consideration is not extended to the evaluation or selection of lean strategy (Karim & Arif-Uz-Zaman, 2013). It is important to identify important organizational characteristics as well as salient or common characteristics. Figure 5-2 is a summary of organizational characteristics mentioned in the literature. In this study, we evaluate the effect of organizational characteristics (Figure 5-2) on the implementation of lean practices.

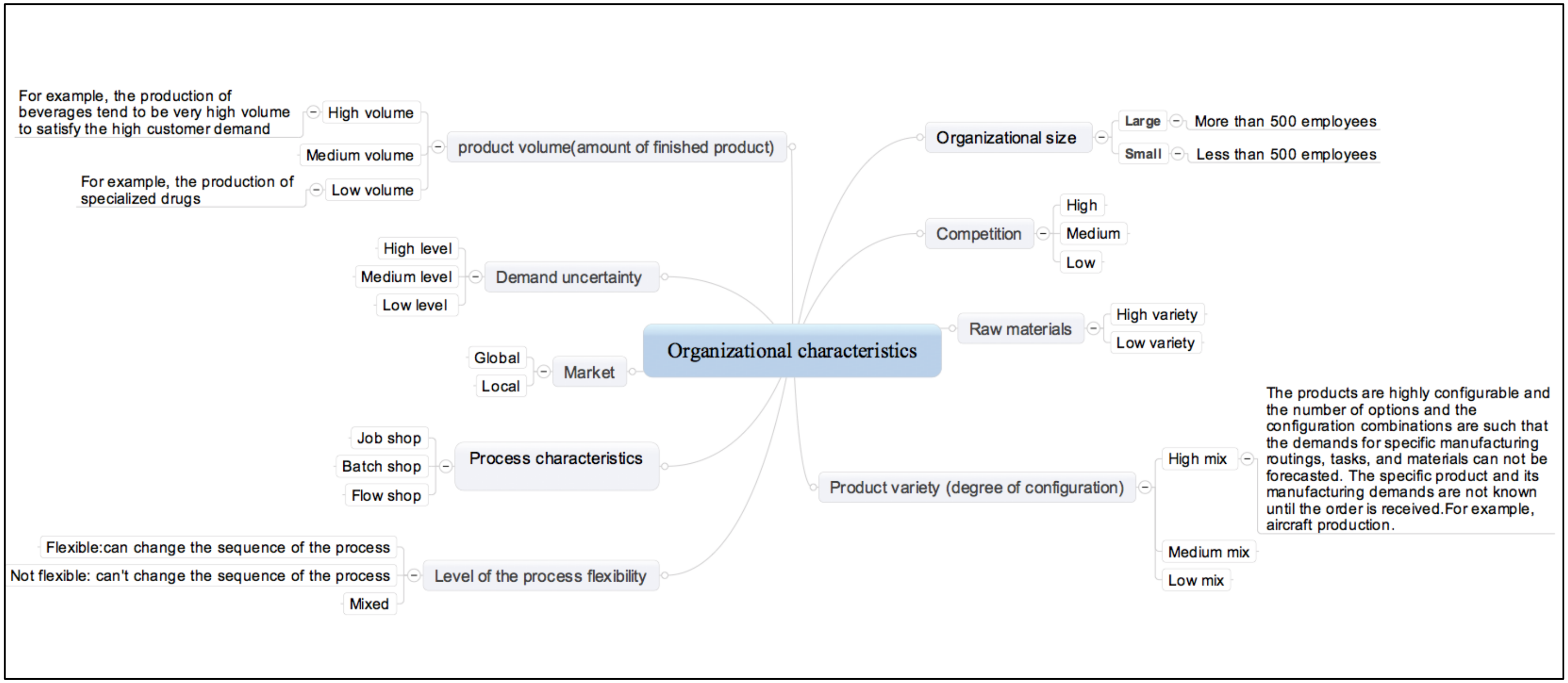


Figure 5-2: Summary of organizational characteristics, which can impact lean implementation success, as identified in the literature

Karim & Arif-Uz-Zaman (2013) argue that extant lean strategies in the literature are not based on lean principles. This apparent lack of integration between lean strategy and lean principles hinders continuous improvement and, by extension, successful lean implementation. There is a need for a systematic, clear description of effective and efficient routes that facilitate lean implementation. Such a support tool would help organizations adopt strategy-appropriate lean practices.

In order to effectively execute its strategy, an organization needs clear performance management systems. The literature provides a variety of methods to evaluate lean performance. These methods include surveys, reviews of historical data, and other qualitative (as demonstrated by Doolen & Hacker, 2005; Soriano-Meier & Forrester, 2002; Upton, 1998), and quantitative approaches. Quantitative methods include simulation, (e.g. Detty & Yingling, 2000; Lummus, 1995), fuzzy logic (e.g. Bayou & de Korvin, 2008; Behrouzi & Wong, 2011), and linear programming (e.g. Wan & Frank Chen, 2008). These performance management methods are not integrated with lean implementation strategy. Thus, these models are not appropriate in the practical environment.

5.2.2 Lean Performance Measurement System

Waste reduction and improved organizational performance are outcomes of lean systems management. Bhasin (2008) argues that disjointed lean implementation causes suboptimal organizational performance because waste and WIP are passed to other stakeholders instead of being addressed. Lean performance measurement systems can provide continuous monitoring frameworks to verify successful lean implementation. It is important to mention the difference between the terminologies: performance measurement, performance measures, and performance measurement system, which is described by Neely, Gregory, & Platts (1995):

- Performance measurement is defined as the process of quantifying the efficiency and effectiveness of action;
- Performance measure is defined the metric used to quantify the efficiency and/or effectiveness of an action; and
- Performance measurement system is defined as the set of metrics used to quantify the efficiency and effectiveness of an action.

Optimal performance is driven by effective performance measurement systems. Effective performance measurement systems reinforce organizational strategy. Table 5-2 provides a literature generated checklist for effective performance measures (Globerson, 1985; Kaplan, 1983; Andy Neely et al., 1995; Stefan Tangen, 2002, 2004). The main objective of this checklist was to select/create a holistic and integrated set of performance measures.

Table 5-2: Checklist for effective performance measures.

Does the measure (or measurement system)…		
Calculate the cost of measurement?	Yes	No
Help define stakeholders (who will use the measures?)	Yes	No
Fit into current time requirements (do we have the time resources to collect data)?	Yes	No
Provide useful external benchmarks with peer and aspirant organizations?	Yes	No
Have specified targets?	Yes	No
Have specified timeframe for target achievement?		
Provide department specific measures, if needed?	Yes	No
Provide a simple and easily accessible means of evaluation?	Yes	No
Have a clear purpose "what is the benefit the performance measure provides?"	Yes	No
Have clearly defined data collection methods?	Yes	No
Have ratio based performance criteria? (ratio based is preferred over absolute numbers)	Yes	No
Is the measure (or measurement system)…		
Selected from the company objectives?	Yes	No
Selected through discussion with people (customers, employee, and managers)?	Yes	No
Achievable?	Yes	No
Valid?	Yes	No
User focused?	Yes	No

An effective performance measurement system (series of complementary performance measures) is a cornerstone of successful lean implementation. Bourne et al. (2002) outline supports and barriers related to performance measurement system implementation. Supportive factors include *effective performance measures, top management support, time or effort, consequence of activities of the internal and external facilitators, and juxtaposition of the performance measures intervention with other projects*. Barriers to implementing an effective performance measurement system include *data inaccessibility, high time and effort requirements,* and *difficulties with updating and developing measures* (Bourne, Neely, Platts, & Mills, 2002).

5.2.2.1 Traditional Performance Measures

A number of organizations use traditional performance systems (traditional management accounting system) to evaluate performance based on short-term financial goals. Such systems alone are decreasingly sufficient for meeting organizational challenges (Taj, 2008). Most traditional measures are lagging indicators that focus on past performance.

These measures do not reveal problems until after symptoms appear (Bhasin, 2008; van der Zee & de Jong, 1999; Youngblood & Collins, 2003). As a result of these lagging indicators, it is insuffieient to rely solely on traditional management accounting systems in the early stage of lean implementation, because the inherent decline in productivity in early stages (Ahlström, 1998) will be interpreted as a failure of the lean approach.

Unfortunately, traditional measurement systems are decreasingly useful for today's critical decisions because they lack the timely and comprehensive information required to remain competitive in the current advanced manufacturing environment (Johnson, 1990; Kaplan, 1983). Moreover, traditional measurement systems focus on variance analysis and aggregating cost (Baines & Langfield-Smith, 2003), which is incompatible with advanced technologies that require detailed information about the process (Ittner & Larcker, 1998).

Lean advanced manufacturing operations require agile measurement systems and feedback from the shop floor to ensure continuous improvement and increase customer value (Fisher, 1992). Potter and Banker (1993) list feedback as a success requirement in just in time (JIT) firms. Meaningful feedback strengthens performance by acting as a tool for strategy implementation and helping workers understand the effect of their roles on organizational strategy (Earley, Northcraft, Lee, & Lituchy, 1990; Ilgen, Fisher, & Susan, 1979). Effective advanced manufacturing systems require high reliance on non-financial performance indicators (Abdel-Maksoud, Dugdale, & Luther, 2005; Fullerton, McWatters, & Fawson, 2003).

Additionally, traditional performance measurement systems fail to measure intangible assets (Kaplan & Norton, 1992, 1993; Lawson, Stratton, & Hatch, 2003; Shah

& Ward, 2003), such as customer perception of product quality, or employee skills. Intangible assets are some of the major drivers of competitive advantage (Neely, Gregory, & Platts, 2005), but quantification of these intangible assets remains a research challenge. Quantification is important because it provides useful benchmarks. Benchmarks help decision makers fully understand the cause-effect relationships between intangible assets, such as knowledge, and other factors that create customer value, or financial outcomes.

5.2.2.2 Effective Performance Measurement Systems

However, to generate value, intangible assets must be applied in tandem with other tangible assets. As an example, a new growth focused firm requires customer knowledge, training for salespeople, new information databases, and an organizational structure. Failure to secure any one of these assets could jeopardize the growth strategy. (Bhasin, 2008). Consequently, to achieve financial growth, the firm must improve processes associated with customer care, employee engagement and management, supplier relationships, and organizational effectiveness (Arora, 2002; Gautreau & Kleiner, 2001; S. Tangen, 2005).

Intangible, non-financial performance measures have been shown to positively affect performance of JIT firms (Baines & Langfield-Smith, 2003; Fullerton & Wempe, 2009; Said, HassabElnaby, & Wier, 2003; Upton, 1998). Non-financial performance measures have also been shown to provide superior financial results (Fisher, 1992), and increase achievement of performance objectives (Rosemary R. Fullerton et al., 2003). Consequently, intermediate indicators (non-financial performance measures) are required to measure performance in all stages (Sánchez & Pérez, 2001).

An effective performance measurement system would incentivize alignment with broader lean implementation and organizational strategy at the hypothetical company (Karim & Arif-Uz-Zaman, 2013; Maskell, 1992). This would only succeed where the performance measurement systems is derived from the strategic objectives of the company (Tangen, 2005). The conversion of organizational strategy to quantitative metrics poses challenges on two fronts: first, managers must create accurate quantitative representations of qualitative goals; secondly, they must design the metrics to be sufficiently flexible to account for changes due to continuous improvement (Maskell, 1992; Tangen, 2004).

Effective measurement systems also require real time, accurate, and prioritized information management to guide decision makers (Fullerton et al., 2003; Mangaliso, 1995; Maskell, 1992). Bond (1999) and Teach (1998) highlight the challenge of information overload that is accompanied by an absence of effective systems that translate information into organizational knowledge and useful strategy. This study creates a guide for lean implementation that highlights important causal relationships between an organization’s objectives and performance measures. The ideal system would collect and analyze data and provide pertinent information to the right person at the right time. Such an approach can also more efficiently identify root causes (Bhasin, 2008; Stefan Tangen, 2004).

The literature-soured checklist in Table 5-3 is a summary of performance measurement system requirements. Checklists of this nature can help identify the cause-effect relationships between objectives and performance measures (sources include the following: Globerson, 1985; Kaplan, 1983; Andy Neely et al., 1995; Stefan Tangen, 2002, 2004).

Table 5-3: Checklist to summarize the performance measurement system requirements

Support organization strategy		
The performance measures are derived from the company's objectives	Yes	No
Translate the strategic objective into tactical and operational objective to the lower level of the company	Yes	No
The performance measurement system is consistence with strategic objective at each level	Yes	No
Balance between different performance measures:		
Balance between: short and long term results	Yes	No
Various organizational level (global and local performance)	Yes	No
Between financial & non-financial	Yes	No
Between tangible & intangible assets		
The measure vary between location- one measure is not suitable for all departments or sites	Yes	No
Cover various perspectives:		
Customer	Yes	No
Shareholder	Yes	No
Competitor	Yes	No
Internal Process	Yes	No
External Process		
Suppliers	Yes	No
Innovation	Yes	No
Learning and Growth	Yes	No
Cover different types of performance:		
Cost [1]	Yes	No
Quality [2]	Yes	No
Delivery [3]	Yes	No
Flexibility [4]	Yes	No
Dependability	Yes	No
Should provide fast and accurate feedback		
Have limited number of performance measures	Yes	No
Information easily accessible	Yes	No
Diagnose the problem for the current situation	Yes	No
Timely and comprehensive information to provide critical decision	Yes	No
Translate the information into organizational knowledge and useful strategy	Yes	No
Real time accurate information	Yes	No
Give important information, at the right time, to the right person	Yes	No
Support continuous improvement		
Stimulate continuous improvement rather than simply monitor	Yes	No
Easy to update (flexible)	Yes	No
Guard against sub-optimization		
The measures are not contrary the corporate goal	Yes	No
Measures improvement in one area does not lead to deterioration in another	Yes	No

As a summary, it is important to show a process to develop an effective performance measurement system. Wisner & Fawcett (1991) proposed nine steps process for developing performance measurement system. In this study we adapted Wisner and Fawcett model and integrated this model with the suggested performance measure checklist (Table 5-2) and performance measurment sytem checklist (Table 5-3). The propsed model, shown in Figure 5-3, can help lean adopters identify context-specific performance measuresthat that reinforce organizational strategy and are commensurate with organizational characteristics.

The Balanced Scorecard (BSC) is a useful template for strategy driven performance measures. We propose the balanced scorecard as a suitable basis for lean performance measurment systems. The following section details the suitability of the BSC as the performance measurment system in this study.

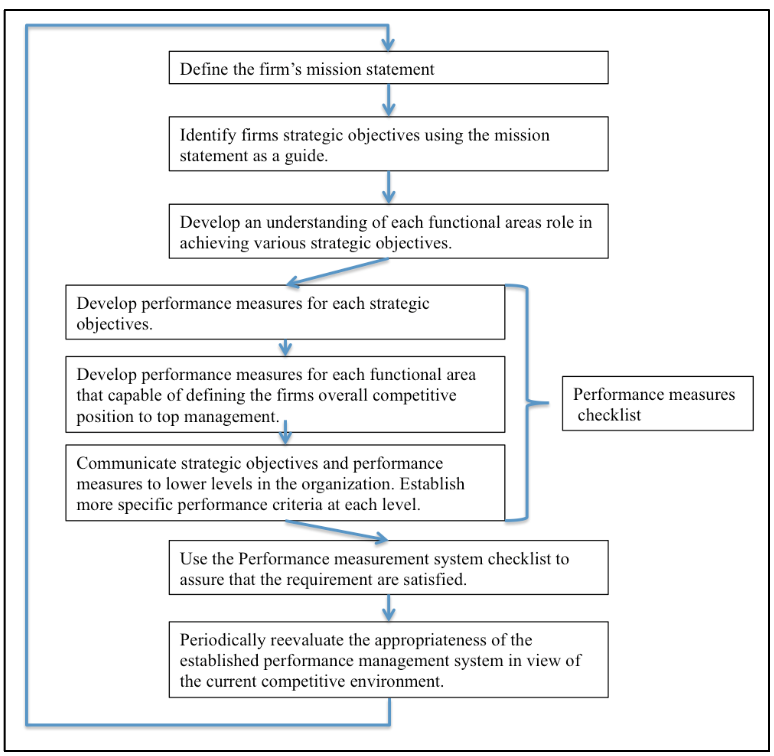


Figure 5-3: Nine steps process for developing performance measurement system by Wisner and Fawcett (1991)

5.2.3 The Balanced Scorecard

The balanced scorecard developed by Kaplan and Norton (1992) is a tool that translates firm strategy and mission into performance measures that support organizational objectives (Hsuan-Lien Chu, Chen-Chin Wang, & Yu-Tzu Dai, 2009; Kaplan & Norton, 2001a) .

Appendix 3 shows an evaluation of the balanced scorecard based on the performance measurement checklist in Table 5-3. The balanced scorecard covers most of the criteria of an effective performance measurement system. However, the previous result does not guarantee absolute success of the balanced scorecard as a result of bad execution, such as selecting inappropriate performance measures. Therefore, Figure 5-3 is recommended to avoid selecting unsuitable performance measures.

There are some challenges involved with the use of the BSC. These challenges include a lack of accounting for the competitor and future events (Bhasin, 2008; A. Neely et al., 2005; Smith, 1998) and the lack of linkage between performance measures and organizational strategy. There is a need for integrated strategy maps to incorporate the balanced scorecard framework.

5.2.4 The Strategy maps

The organizational strategy map was introduced by Kaplan and Norton (1996) as an extension of the balanced scorecard. The map links strategy with performance measurement systems by highlighting cause-effect linkages between organizational objectives and performance measures ((Kaplan & Norton, 2000). Strategy maps are dynamic visual tools that describe organizational strategy alongside a reinforcing performance measurement system. Strategy maps show how intangible assets can be converted into tangible outcomes (Chiung-Ju Liang & Lung-Chun Hou, 2006). (Kaplan & Norton, 2000, 2004; Kaplan & Norton, 2001b, 2004).

According to Wu (2012), there is a lack of analysis of the link between strategy and performance measures in construction of extant strategy maps. The causal links in the strategy map are usually constructed using rules of thumb, i.e. using expert opinion. Because expert opinion is subjective, a systematic method to determine the causal relationship between factors in the strategy map is required. In this study, DEMATEL method was used to identify and analyze causal relationships in a strategy map.

5.2.5 DEMATEL

The Battelle Memorial Institute developed the DEMATEL method to disjoint the phenomena of world societies. The literature contains a number of examples of the application of DEMATEL to management problems (Huang, Shyu, & Tzeng, 2007; Liou, Yen, & Tzeng, 2008; Tamura & Akazawa, 2005; Tzeng, Lin, & Opricovic, 2005; Tzeng, Chiang, & Li, 2007; Wu & Lee, 2007), control systems (Hori & Shimizu, 1999), and reliability engineering (Seyed-Hosseini, Safaei, & Asgharpour, 2006).

In this study, the DEMATEL method is extended to the lean systems management problem of effective and sustained lean implementation. This extension to lean systems management is accomplished through a BSC sourced strategy map. The DEMATEL method helps to identify or the roadmap to implement lean manufacturing. The DEMATEL based strategy map can be used to identify high impact resource investment opportunities. These high impact items are referred to as “central factors” and “cause factors”. Figure 5-4 shows the difference between a cause factor, a central role and an effect factor. An empirical example of using DEMATEL methods is presented in the following sections.

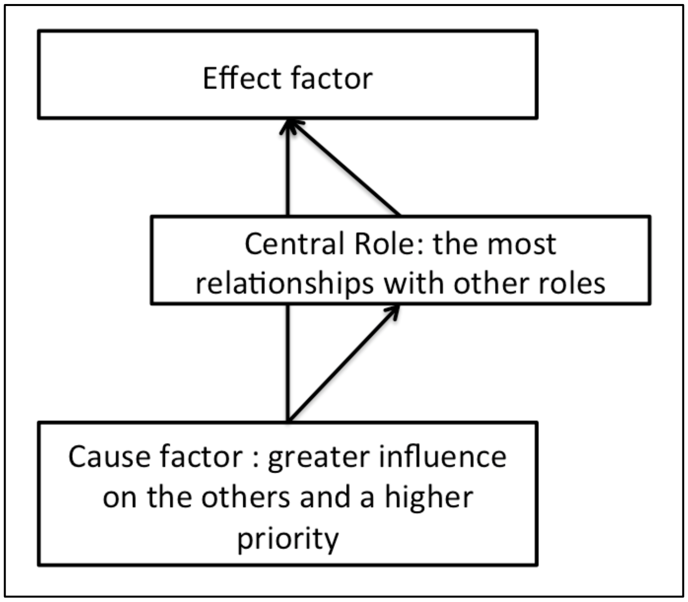


Figure 5-4: The difference between a cause factor, a central role and an effect factor

5.3 Methods (An empirical example of constructing a strategy map for lean manufacturing)

Figure 5-5 shows the proposed framework for this study. The principles, practices, and performance measures were gathered from an extensive review of 30 articles.

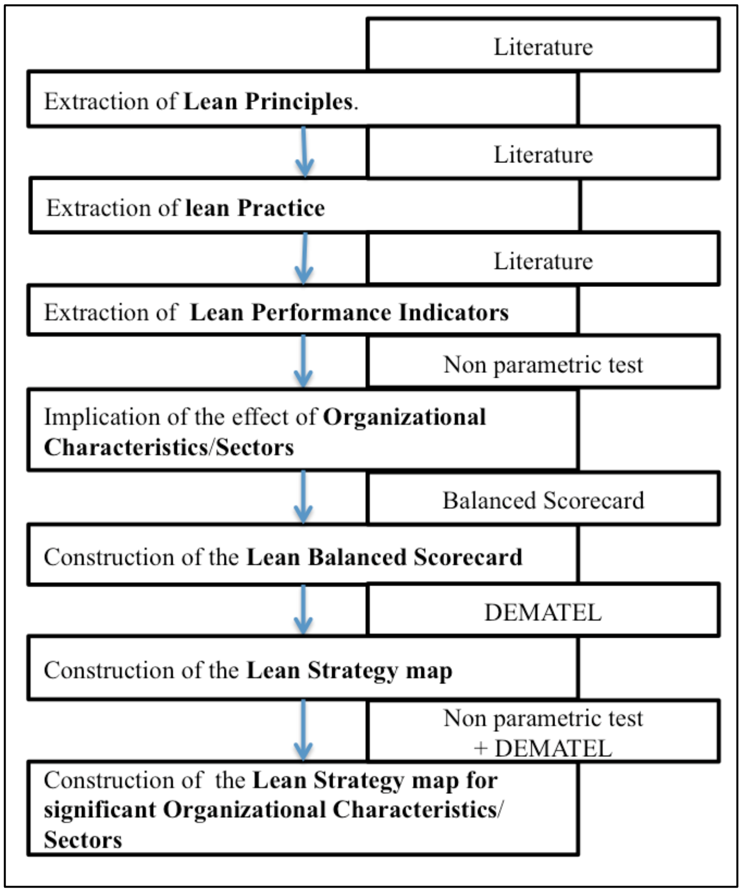


Figure 5-5: The proposed framework in this study

The lean strategy map is the end result of the process depicted in Figure 5-5. The following subsections describe each of the steps identified in Figure 5-5, including detailed definitions of terms used.

5.3.1 Item generation:

Mirdad and Eseonu (2014) proposed the lean conceptual map presented in Figure 4-7, based on an exhaustive review of lean literature and validation through a survey of lean experts from different universities. The goal of the lean conceptual map is to provide a decision support tool for practitioners that can help sustain lean implementation by (a) classifying lean terminology into the three categories of principles, practices, or performance measures, and (b) linking performance measures to practices, and practices to principles. This study adopted the lean principles, practices, and performance measures clarification from Mirdad and Eseonu (2014). The following sections include detailed explanations of the adopted lean constructs as items in the process outlined in Figure 5-5.

5.3.2 Extraction of Lean principles:

Lean manufacturing refers to a set of principles, tools, practices and techniques aimed at achieving waste elimination through continuous improvement (Gupta & Kundra, 2012; Mehta & Shah, 2005). According to Nicholas (2011), lean principles are a set of beliefs and assumptions that drive operational decisions and actions about products and processes.

There is some disagreement in the literature about lean principles. For example, visual management system which is considered a principle by Liker and Kaisha (2004) and a practice by the other authors. For instance, Anand and Kodali (2009) questioned the basis of Karlsson and Ahlström's principles. They disagree with principles such as multifunctional teams, information system and decentralization, because those principles are used by other approaches like TQM and Six Sigma. Anand and Kodali proposed, "respect for humanity", "visual management system", "customer focus" and "supplier integration", as suitable substitutions.

Given the apparent confusion, there is a need for clearer integration between principles in order to build a holistic and integrated strategy map (the goal of this paper). To this end, Mirdad and Eseonu (2014) identified lean principles from selected seminal lean research articles. A survey of lean experts was then used to differentiate lean principles from lean practices. The resulting summary of lean principles is shown in Table 5-4. The principles in Table 5-4 are considered as lean principles for this study.

Table 5-4: Lean principles used in this study

Principles	Definition
Specify Value	Identify what customers want (and/or are willing to financially support).
Respect of humanity	Reflect respect for and sensitivity to morale. Avoid making people do wasteful work. Promote true teamwork. Mentor to develop skillful people. Humanize the work and environment. Create safe and clean environment. Promote philosophical integrity among management team.
Zero Defect	Fault free product/service from beginning to end. Each person is responsible for quality assurance.
Flow	Create continuous, interruption-free work processes across value adding activities
Pull	Produce only in response to customer demand.
Continuous improvement	Generate, test, and implement process refinements in an ongoing drive for perfection.

5.3.3 Extraction of lean practices:

A system wide adoption of lean practices is necessary for lean successes. Approximately 200 practices were obtained from 22 different articles (Mirdad & Eseonu, 2014). In this study, the most important widely used and effective practices will be integrated in a lean strategy map.

This study adopted lean practices identified by Mirdad and Eseonu, (2014) as (a) being most closely able to represent the five lean principles (Specify value, Respect of Humanity, Zero Defect, Flow, Pull, and Continuous Improvement), and (b) having the highest level of agreement among surveyed lean experts. The practices are shown in Appendix (5)

In addition, to applying lean principles in an efficient manner, organizations must identify and apply appropriate lean practices. Consequently, organizations require lean performance indicators to diagnose exactly the weakness of the organization. As a result, there is a need to clearly relate practices with underlying principles and to provide an intuitive means to regularly measure performance in a manner that evaluates effectiveness of selected practices.

5.3.4 Extracting lean performance measures:

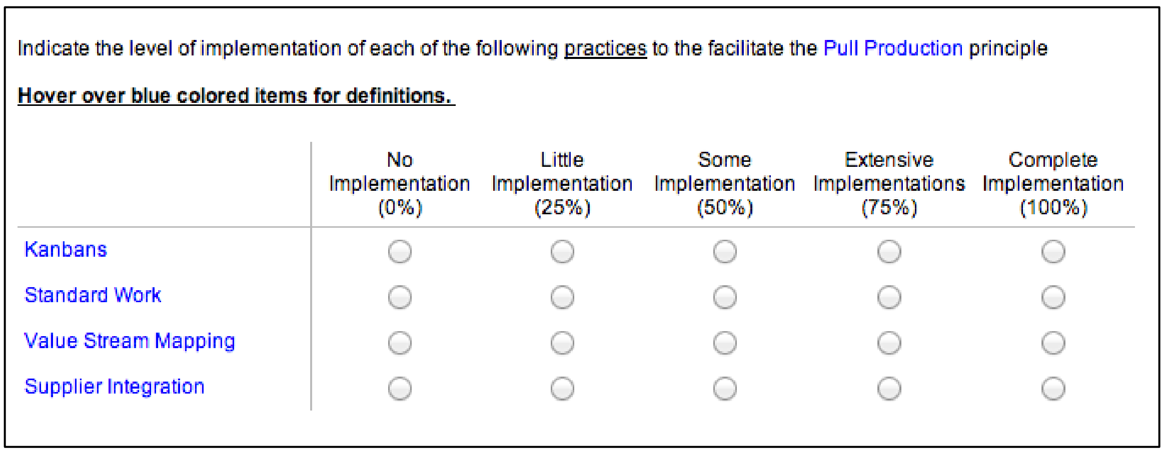
To build the lean manufacturing balanced scorecard, performance measures are required to assess the lean principles determined in the previous steps. The literature shows numerous performance indicators to measure lean manufacturing. A list of 250 different lean performance measures was presented by Mirdad and Eseonu (2014). The appropriateness of the selected performance measures was assessed using the performance measures checklist in Table 5-2. The adapted performance measures are shown in Appendix 5. A survey of lean practitioners was conducted across 141 organizations to identify the impact of organizational characteristics on the level of implementation of lean principles, based on the use of lean practices and reinforcing performance measures.

5.4 Survey Design:

This survey concentrates on investigating the impact level of different organizational characteristics (Figure 5-2) and manufacturing sectors (Table 5-5) on lean practices implementation. Previously, we looked at the practices involved in application of lean principles and identified the five lean principles which included: Identify Value, Respect of Humanity, Zero Defect, Flow, Pull, and Continuous Improvement.

In the survey, the respondents were supposed to identify the level of implementation of the proposed practices associated with lean principles within their organization. Responders were asked to indicated the level of implementation of practice using a five-point Likert scales. (Figure 5-6 shows an example of the survey questions):

- No Implementation (0 percent);
- Little Implementation (25 percent);
- Some Implementation (50 percent);
- Extensive Implementation (75 percent);
- Complete Implementation (100 percent);


Indicate the level of implementation of each of the following practices to the facilitate the Pull Production principle

Hover over blue colored items for definitions.

	No Implementation (0%)	Little Implementation (25%)	Some Implementation (50%)	Extensive Implementations (75%)	Complete Implementation (100%)
Kanbans	○	○	○	○	○
Standard Work	○	○	○	○	○
Value Stream Mapping	○	○	○	○	○
Supplier Integration	○	○	○	○	○

Figure 5-6: Example to indicate the level of implementation in pull principle

In addition, respondents were asked to identify the level of use of performance measures to evaluate the application of each lean principle within their organization. Respondents indicate the level of use of each performance measures on five-point Likert scale that included the following items: Not used, Used on limited basis, Some Use, Extensive use, and Used across organization. Figure 5-7 displays an example of the survey question on performance measures used to assess the Pull principle. The same question was applied in identification of usage performance measures for each principle in this study. The ultimate purpose of these items was to validate the lean performance measures and apply it in the balanced scorecard.

Indicate the level of use of each of the following performance measures to the facilitate Pull Production

	Not used	Used on a limited basis	Some use	Extensive use	Used across orgnaization
Number of Kanbans	○	○	○	○	○
Number of S.O.Ps and Regulation (Standardization)	○	○	○	○	○
The number of stages in the material flow that use pull(backward requests) in relation to the total number of stages in the material flow	○	○	○	○	○
Frequency of Production is pulled by the shipment of finished goods	○	○	○	○	○
Frequency of production at stations is pulled by the current demand of the next station	○	○	○	○	○

Figure 5-7: Example survey of lean performance measures questions

5.4.1 Data collection and review (Pilot study) Methodology and sample study

The survey was designed using the Qualtrics Web-based survey software. The survey was electronically mailed to different organizations in United States. Two hundred seven practitioners started the survey. However, only 141 finished the entire survey resulting in a response rate of 68%. Table 5-5 provides a breakdown of respondents by manufacturing sector. The design of this survey was developed to give room to utilization of data that characterizes incomplete surveys. The survey was convenient enough to enable participation through online responses enabled by a web link conveyed by an email. To ensure that respondent understand terms used on the survey, the purpose of the study was provided alongside definitions for lean principles and practices. The target participants were industrial engineers, process engineers, lean engineers, and manufacturing engineers.

The goal of this survey was to determine the impacts of the industrial sector in which an organization operate, and organizational characteristics on the implementation of lean practices. The survey also sought to validate lean performance measures for each lean principles.

Table 5-5: Breakdown of respondents by manufacturing sector

Industrial sector	Number
Food & Beverage Manufacturing	6
Wood Product Manufacturing	4
Paper & Printing Manufacturing	8
Petroleum and Coal Products Manufacturing	6
Chemical Manufacturing	5
Plastics and Rubber Products Manufacturing	7
Primary Metal Manufacturing	11
Fabricated Metal Product Manufacturing	18
Machinery Manufacturing	20
Computer and Electronic Product Manufacturing	15
Electrical Equipment, Appliance, and Component Manufacturing	13
Transportation Equipment Manufacturing	38
Miscellaneous Manufacturing	16
Total	161

5.4.2 Descriptive analysis

The mean was calculated for each lean practices and performance measures (Appendix 5). Each item (practice, and performance measure) was calculated based on a five–point Likert scale. For the practices, the mean represents the level of lean practice implementation in support of each principle. For example, value stream mapping has a mean of 3.57 out of 5 or a 72% level of implementation across the surveyed organizations, which indicates the implementation level of this practice in support of the zero defect principle. The five highest adapted lean practices based on the level of implementation were safety improvement (83%), 5s (78%), root cause analysis (76%), top management commitment (74%), and multifunctional teams (73%).

Additionally, The mean was calculated for lean performance measures used in the survey. The mean represents the average response of the usage of the performance measures to assess the nominating principles. For example, the "percentage of first pass yield" performance measure had a mean 3.50 out of 5, which indicates that this performance measures is extensively used (70%) by the lean firms to assess the Zero defect principle. The five highest lean performance measures, based on the level of use, are percentage of defective products shipped to customer (83%), percentage of used customer feedback on quality and delivery performance (82%), Customer lead time(82%), frequency of contact with customers (79%),and rate of customer return (79%). Appendix (5) presents the top lean practices and performance measures used by manufacturing sectors.

Additionally, as shown in Appendix 5, each principle represented by a set of practices and performance measures. In this study, the average of each set of practices was used to represent the adoption of the principle. For example, the Zero defect principle is represented by calculating the average of the practices which includes among others: 5s, Andon Boards, Supplier development and Supplier feedback.

5.5 Results and Discussion

5.5.1 The Effect of Organization Characteristics / Sectors:

As mentioned in the literature, organizational characteristics influence the implementation of lean practices. In this study, the organizational characteristics from Figure 5-2 were examined through investigation of the following hypotheses:

- H1: The organizational size (large or small) affects the level of implementation of lean practices.

- H2: The nature of the market (local or global) affects the level of implementation of lean practices.
- H3: The perception of competiveness (high, medium or low) affects the level of implementation of lean practices.
- H4: The volume of production (high volume, medium volume, or low volume) affects the level of implementation of lean practices.
- H5: The manufacturing strategy of product variation (high, medium, or low mix) affects the degree of implementation of lean practices.
- H6: The level of uncertainty in demand (high level, medium level or low level) affects the level of implementation of lean practices.
- H7: The level of process flexibility (flexible, not flexible, or mixed) affects the implementation level in lean practices.
- H8: The variety level in raw materials level (high variety, or low variety) affects the level of implementation of lean practices.
- H9: Different organizational sectors affect the level of implementation of lean practices.

The data obtained from Table 5-5 is classified according to organizational characteristics/sectors. Consequently, the average is determined for each lean principle as mentioned in the previous section. The "Shapiro-Wilk" test for normal distribution (Razali & Wah, 2011; Shapiro & Wilk, 1965), visual histogram, and normality plots the data was not distributed for all categorized groups. Therefore, non-parametric test was conducted to investigate the previous hypothesis in the following sections.

5.5.2 Organization size and nature of the market

Organizational size in this study was determined using the Small Business Administration (SBA) classification. The SBA was founded in 1953 to support and assist small business. According to SBA (2012), companies that have less than 500 employees are considered small or medium organizations. Companies with more than 500 employees are referred to as large organizations. In this study, the participants were asked to approximate the number of employees by selecting one of the following responses:

less than 500 employees, or more than 500 employees. As shown in Table 5-6, 73 organizations identified as small organizations, and 64 organizations identified as large companies. To compare the level of lean practices adoption between small and large organizations, a two sample non-parametric test (Mann-Whitney) was conducted. The test shows that the level of lean practice adoption in large organizations is significantly greater than in small organizations. This is in relation to Respect of Humanity, Pull, and Flow principles. The other principles (value specification, Zero defect, and Continuous Improvement) were not different between companies, regardless of organizational size. Table 5-6 shows the average adoption for each principle and summarizes the results of Mann-Whitney test.

Table 5-6: Effect of organizational size on adoption of lean principles

Principles	Small Companies (73)	Large Companies (64)	P- value
Value Specification	3.27	3.50	0.12
Respect of Humanity	3.23	3.57	0.03
Zero Defect	3.09	3.36	0.10
Flow	2.95	3.29	0.06
Pull	2.99	3.38	0.01
Continuous Improvement	3.02	3.21	0.29

This result supports the findings of White, Pearson, & Wilson (1999), which concluded that lean manufacturing practices (Quality circle, Total Quality control, Focused Factory, TPM, Reduced Setup Time, Group technology, uniform workload, multifunctional teams, kanban, and JIT purchasing) are implemented more by large organizations than small organizations. Doolen & Hacker (2005) support these results also. They concluded that lean manufacturing practices that support manufacturing equipment and process impact are affected by organizational size.

However, Doolen & Hacker (2005) mentioned that workforce management practices (represented by Respect of Humanity in this study) were not significantly different between different organizational sizes. Results from this study indicate differences in the implementation of practices. The findings indicate that larger organizations provide more opportunities for growth and self improvement (Employee training & Growth). This provides a better position compared to smaller organizations. Table 5-7 displays the average practice implementation scores on the implementation of practices (Multifunctional teams, employee involvement, self directed teams, quality circle, and employee involvement) for both large and small organizations. The large organization practice implementation scores are higher than the average practice implementation scores in small organizations.

Table 5-7: The average score for practices related to employee improvement for small and large organizations

	Small Organization		Large Organization	
Practices	Average out of 5	% of implementation	Average out of 5	% of implementation
Multifunctional teams	3.48	69.56%	3.92	78.40%
Employee training & growth	3.27	65.33%	3.73	74.67%
Employee involvement4	3.48	69.56%	3.65	73.07%
Quality circle	2.78	55.56%	2.93	58.67%
Self directed teams	2.93	58.67%	3.28	65.60%
Employee improvement	3.13	62.67%	3.63	72.55%

Respect for humanity was the only principle in which differences were identified related to the nature of the market (local, or global). This finding is related to previous results in which most of the global market organizations tends to be organizations that operate on a large scale basis. However, the other principles (value specification, zero defect, Flow, Pull, and Continuous Improvement) do not show any difference in the level of lean practices implementation for global or local organizations. Table 5-8 summarizes the Mann- Whitney test (p-values) and average scores for each lean principle.

Table 5-8: Effect of nature of the market on adoption of lean principles

Principles	Local (15)	Global (122)	P- value
Value Specification	3.18	3.41	0.41
Respect of Humanity	2.94	3.45	0.05
Zero Defect	3.07	3.24	0.54
Flow	2.87	3.14	0.25
Pull	2.99	3.20	0.36
Continuous Improvement	2.85	3.14	0.26

5.5.3 Competitiveness

The increasing level of competition in the global market and the resultant diminishing customer demand threaten companies in the international market. As a result, companies are exploring practical methods to increase their competiveness through advanced manufacturing mechanisms (Rawabdeh, 2005). Lean manufacturing is recognized as one of the most important approaches to achieve and maintain a competitive advantage (Chapman & Carter, 1990; Foster & Horngren, 1987; Fullerton, McWatters, & Fawson, 2003; Sakakibara, Flynn, & Schroeder, 1993). Numerous articles demonstrate that JIT implementation improves competitive performance by lowering inventory level reducing the cost of quality cost (Zero Defect Principle), reducing through put time, and increasing understanding of customer needs (Value specification principle) (Fullerton & McWatters, 2001; MacDuffie, Sethuraman, & Fisher, 1996; Shah & Ward, 2003). Therefore, the level at which lean practices is embraced is higher in competitive organizations than the non-competitive organizations as validated by Mann-Whitney test. The Mann Whitney test shows that there is a statistical significance difference in the level of implementation (Value specification, and Zero defects principles) between competitive companies and regular competitive companies (Table 5-

9). This supports the previous statements by Fullerton & McWatters (2001); MacDuffie, Sethuraman, & Fisher (1996); Shah & Ward (2003).

The value specification principle entails any process that identifies the customer demand (and/or are willing to financially support). And the zero defects refer to fault free product/service from the start to the end. Every individual is liable for any quality assurance concerns.

Table 5-9: Effect of Competitiveness on adoption of lean principles

Principles	High (96)	Medium (39)	P- value
Value Specification	3.53	3.06	0.004
Respect of Humanity	3.44	3.27	0.201
Zero Defect	3.32	2.99	0.039
Flow	3.18	2.93	0.158
Pull	3.25	3.01	0.170
Continuous Improvement	3.20	2.89	0.086

5.5.4 Volume Produced

The amount of finished output that is produced in the organization is investigated in the survey. The respondents were supposed to identify an appropriate selection between: high volume (more than 100,000 units per year), medium volume, or low volume (less than 20000 units per year). The literature discussed the effects of the volume produced in the organization. Jina et. al. (1997) mentioned that low volume organizations faced significant barriers in applying lean manufacturing. Jina et al. finding is supported in this study by using Kruskal-Wallis test (an extension of the Mann-Whitney test using non-parametric methods to test 2 or more populations). The test shows that there is a significance difference in the adoption of the lean principle based on the volume of production. Table 5-10 shows the average adoption for each lean principles and the Kruskal-Wallis test p-values. Table 5-10 shows that high volume production in organizations is more suited for applying lean practices. Abdulmalek and Rajgopal (2007) also found that high volume production is generally more adaptable to lean manufacturing implementation than low volume production in organizations, including the adopting of practices such as small lot production, JIT, and standardization.

Table 5-10: Effect of volume Produced on adoption of lean principles

Principles	High Volume (52)	Medium Volume (42)	Low Volume (43)	P- value
Value Specification	3.80	3.04	3.22	0.000
Respect of Humanity	3.57	3.26	3.32	0.159
Zero Defect	3.51	2.89	3.17	0.002
Flow	3.35	2.72	3.20	0.002
Pull	3.43	2.78	3.27	0.001
Continuous Improvement	3.32	2.78	3.18	0.024

5.5.5 Demand uncertainty

Survey respondents were asked to identify the level of demand uncertainty (ability to project customer demand). Thirty-three organizations exhibited high-level of uncertainty while 17 organizations indicated a medium level of uncertainty, and 86 organizations revealed a low level of uncertainty. No significant differences in lean principles adoption were identified based on the level of demand uncertainty as shown in Table 5-11.

Table 5-11: Effect of demand uncertainty on adoption of lean principles

Principles (number of organization)	High Level (33)	Medium Level (17)	Low Level (86)	P- value
Value Specification	3.40	3.32	3.37	0.982
Respect of Humanity	3.55	3.25	3.35	0.381
Zero Defect	3.36	3.04	3.18	0.471
Flow	3.26	2.99	3.05	0.469
Pull	3.26	2.96	3.17	0.476
Continuous Improvement	3.27	3.02	3.05	0.517

5.5.6 Process Flexibility and Raw materials

The respondents identified the level of the process flexibility in their organizations using three possible categories:

1- Flexible process: the organization can change the layout and the sequence of the process
2- Not Flexible process: the organization cannot change the sequence of the process
3- Mixed process

As shown in the Table 5-12, 39 organizations considered themselves to be flexible, 29 as not flexible and 68 had mixed process. A Kruskal-Wallis test was used to identify the impact of process flexibility on the level of lean implementation. The results show that there is a difference in level of implementation based on the flexibility of the process. The results revealed that higher amount of flexibility in the process led to a greater implementation of lean practices. Abdulmalek and Rajgopal (2007) also concluded that when processes are not flexible, it is difficult to implement some lean practices, such as small lot production. These practices include Kanban, Just in time, and other practices that require or lead to layout changes, such as cellular manufacturing.

Table 5-12: Effect of process flexibility on adoption of lean principles

Principles	Flexible (39)	Not Flexible (29)	Mixed (68)	P- value
Value Specification	3.57	3.40	3.26	0.250
Respect of Humanity	3.70	3.20	3.30	0.020
Zero Defect	3.51	2.99	3.15	0.042
Flow	3.46	2.72	3.09	0.006
Pull	3.49	2.88	3.14	0.011
Continuous Improvement	3.45	2.72	3.09	0.005

On the other hand, the result of the Mann-Whitney test in Table 5-13 showed that the variety of raw materials did not seem to impact the adoption of lean principles. However, Abdulmalek and Rajgopal (2007) found that low materials has a positive effects in adopting lean manufactring practicess. Some practices, such as supplier related practices (supplier development, Supplier Feedback and Relation, JIT delivery by supplier, supplier integration) are easier to adopt in organizations with low raw material variety, because the number of suppliers used are small. Minimization of the number of suppliers used by high raw material variety may be important to increase the adoption rate of lean supplier related practices.

In the result, the variety of raw materials does not affect the implemintation of five lean principle. However, minmization of suppliers is required in lean manufacturing to faciltate the Pull and Flow principles and to reduce varibility between raw materials, which is important in achieving zero defect principle.

Table 5-13: Effect of raw material on adoption of lean principles

Principles	High Variety (84)	Low Variety (53)	P- value
Value Specification	3.38	3.39	0.979
Respect of Humanity	3.52	3.19	0.038
Zero Defect	3.27	3.14	0.344
Flow	3.16	3.03	0.457
Pull	3.23	3.10	0.370
Continuous Improvement	3.19	2.96	0.183

5.5.7 Lean manufacturing adoption per sectors

In this section the data from Table 5-5 is classified according to different manufacturing sectors and the average is determined for each lean principle. The organizations were categorized using the sectors defined by the North American Industry Classification System (NAICS) (2012). Table 5-14 shows the sample sizes and the average implementation score for each principle by sector. A non-parametric test (Kruskal-Wallis) was conducted, and the p-values indicate that no significant differences in the lean practices implementation exist between the main sectors. The results suggest that it may be necessary to look at sectors using a lower level classification. For example, instead of using high-level sector such as food manufacturing, the researcher should use sub-sectors, such as Animal Food Manufacturing, Grain and Oilseed Milling, Fruit and Vegetable Preservation and Specialty Food Manufacturing. To test this hypothesis, the organizations from the transportation, equipment, appliance, and component manufacturing sectors were divided into three sub sectors: automobile manufacturing (include seven responses), motor vehicle parts manufacturing (21 responses), aerospace product and parts manufacturing (7 responses). Table 5-15 summarizes results from Kruskal-Wallis test by sub-sectors. The results revealed that there was a significant difference.

Table 5-14: sample sizes and the average implementation score per principle for each sector

	Value Specification	Respect of Humanity	Zero Defect	Flow	Pull	Continuous Improvement
Food & Beverage Manufacturing (N=6)	3.63	2.97	3.00	2.65	2.84	3.00
Wood Product Manufacturing (N=4)	3.13	3.34	3.44	3.52	3.67	2.86
Paper & Printing Manufacturing (N=8)	3.56	3.34	3.33	2.99	3.12	2.86
Petroleum and Coal Products Manufacturing(N=6)	2.75	3.31	2.70	2.88	2.78	2.86
Chemical Manufacturing (N=5)	2.75	3.05	2.63	1.85	2.13	1.93
Plastics and Rubber Products Manufacturing (N=7)	3.46	3.52	3.26	2.88	2.94	3.20
Primary Metal Manufacturing (N=11)	3.73	3.78	3.41	3.42	3.50	3.51
Fabricated Metal Product Manufacturing (N=18)	3.49	3.61	3.36	3.31	3.38	3.38
Machinery Manufacturing (N=20)	3.46	3.35	2.93	3.12	3.30	2.92
Computer and Electronic Product Manufacturing (N=15)	3.13	3.24	3.01	2.78	2.81	2.85
Electrical Equipment, Appliance, and Component Manufacturing (N=13)	3.15	3.15	3.02	3.04	3.11	2.93
Transportation Equipment Manufacturing (N=38)	3.72	3.60	3.53	3.16	3.32	3.27
Miscellaneous Manufacturing (N= 16)	3.22	3.26	3.12	2.87	2.94	2.71
P VALUE	0.157	0.368	0.222	0.149	0.103	0.191

Because there are 90 sub-sectors in the NAICS classification, it was not possible to test each sub-sector. As a result, it is strongly recommended to categorize the lean research according to organizational characteristics. Using organizational characteristics required an accurate definition for each characteristic related to lean, which is recommended in the future study.

Table 5-15: The effect of different transportation sub-sectors on the adoption of lean principles

	Automobile Manufacturing	**Aerospace Product and Parts Manufacturing**	**Motor Vehicle Parts Manufacturing**	**P-values (Kruskal-Wallis Test)**
Value Specification	4.30	3.32	3.58	0.068
Respect of Humanity	4.05	3.20	3.55	0.122
Zero Defect	4.33	2.94	3.47	0.008
Flow	4.11	2.70	3.16	0.004
Pull	4.19	2.80	3.20	0.004
Continuous Improvement	3.89	2.33	3.07	0.003

5.6 Balanced Scorecard Result:

Table 5-16 shows a lean scorecard based on the four scorecard perspectives for selected lean principles. Different combinations of financial and non-financial performance measures and the relationship between lean principles and the performance measures are identified. The performance measure was placed with the associated principle. The performance measures shown in Table 5-16 validate lean performance measures that have been selected for use by the lean companies.

Table 5-16: List of performance measures for lean manufacturing based on Balanced Scorecard

Perspective	Principle /Objective*	Performance measures	Practices
Financial	Cost reduction*	Manufacturing Cost per Unit Gross Annual Profit	
Customer	Value identification/Customer satisfaction*	Customer lead time Rate of customer returns Customer satisfaction index Percentage of defective products shipped to customer	Customer Relations Management Customer Requirements Analysis Quality Function Deployment (QFD) Supplier Integration
	Value identification/ Customer involvement*	Customer feedback on quality and delivery performance Active customer involvement Frequency of contact with customers Frequency of customers interaction with marketing department on current and future demand information	
Internal Process	Zero Defect/Waste elimination*	Finished Goods Inventory Raw Material Inventory Total Productive Floor Space WIP Inventory Transport time and distance traveled for each part Non Value Added Time	5s Andon Boards Supplier Development Supplier Feedback and Relation Poka Yoke Complementary Quality and Productivity Program Root Cause Analysis Visual Management System Statistical Process Control (SPC) Total Productive Maintenance Autonomation Lead Time Redaction Small Lot Sizes Value Stream Mapping Quality Circle Self-directed Teams Employee Improvement Customer Requirements Analysis
	Zero defect	Scrap and Rework Costs Percentage of defective parts adjusted by Production line workers Percentage of inspection carried out by autonomous defect control Percentage of manufacturing process under statistical control First Pass Yield Percentage of people involved in stopping the Line due to problems Percentage of information continuously displayed in dedicated Space, in the production flow Time perspective in the information Percentage of procedures for which standard work instruction have been developed The frequency with which information is given to employees Frequency of preventive maintenance Percentage of unscheduled downtime	
	Flow	Takt Calculations Products are classified into groups with similar processing and routing requirements Our factory layout groups different machines together to produce families of products Throughput Time or Manufacturing Lead Time Setup Time Reduction in the Level of Work Load Variability Batch Size Number of mixed models in a line	Line Balancing Focused Factory Cellular Manufacturing Group Technology Autonomation Lead Time Redaction Value Stream Mapping Single-Minute Exchange of Dies (SMED) U-shaped Cells JIT delivery by suppliers Takt time JIT Production and Delivery Setup Reduction Small Lot Sizes Mixed Model Production
	Pull	Number of Kanbans Number of S.O.Ps and Regulation (Standardization) The number of stages in the material flow that use pull(backward requests) in relation to the total number of stages in the material flow Frequency of Production is pulled by the shipment of finished goods Frequency of production at stations is pulled by the current demand of the next station	Kanbans Standard Work Value Stream Mapping Supplier Integration
	Integration of suppliers*	The frequency with which suppliers' technicians visit the company Number of years a supplier is associated with your organization Supplier delivery lead time Percentage on time delivery Factory disruption (supplier prevent any quality issue (material purges, stop ships, line sorts…)	Supplier Reduction Information sharing with supplier Long tram relation contract JIT delivery by suppliers Supplier development

Perspective	Principle /Objective*	Performance measures	Practices
		Average number of suppliers for the most important process/production components	
Internal Process	Continuous improvement	Percentage of implemented suggestions per employee Number of kaizen events Percentage of capacity increment of current facilities The number of separate supervisory level in the organization The number of hierarchical levels in the manufacturing organization Time to market for new products Number of new Technology Development per year/Month	Top Management Commitment Long-term Philosophy Genchi Genbutsu Nemawashi Concurrent Engineering Design for Manufacturability New process or equipment technologies
Learning and Growth	Respect of humanity	Percentage of employees working In teams Ratio of indirect labour to direct labour Number and percentage of tasks performed by team Labour Productivity Amount (in hours) of training given to newly employed personnel Employee Turnover rate Percentage of implemented suggestions per employee	Pay for Skill and Performance Safety Improvement Multifunctional Teams Employee Training and Growth Employee Involvement Quality Circles Self-directed Teams Employee Improvement

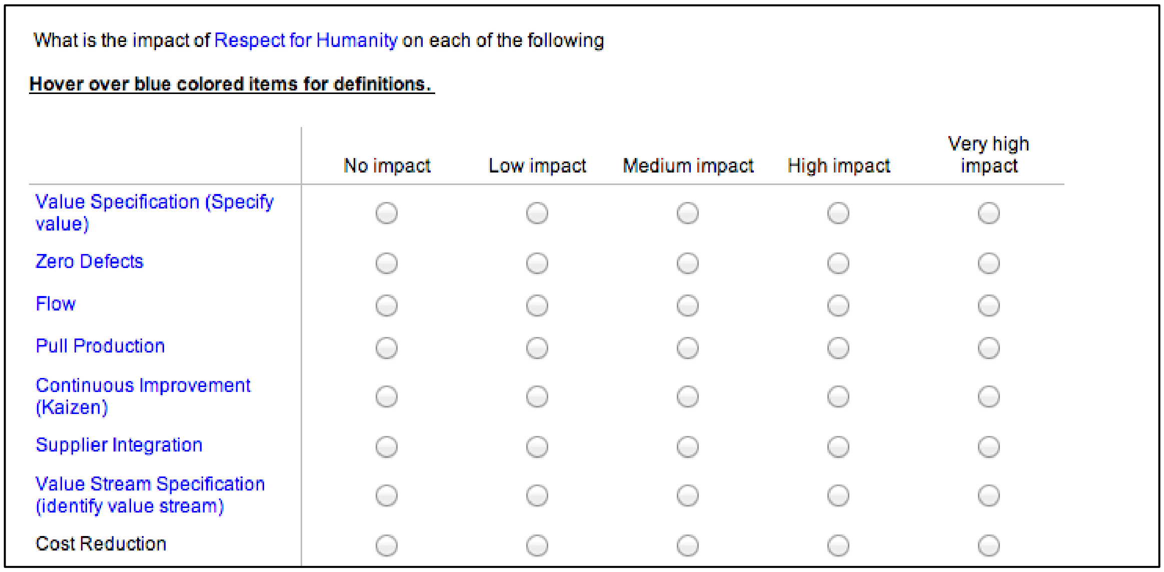
5.7 Framework for constructing a strategy map by the Decision Making Trial Laboratory (DEMATEL)

The strategy map is a visual tool used to link between performance measurement system (balanced scorecard) and strategy. The balanced scorecard (Table 5-16) was used to construct the items (lean principles, practices, and performance measures) in the strategy map. The next step was to determine the causal relationship between lean principles in the strategy map. Therefore, the DEMATEL technique was used to identify causal relationships between the lean principles.

A survey was created to understand direct relations between lean principles. The survey was divided into two parts. The first part included demographic information (Organizational characteristics, and Sectors). The second part included DEMATEL questions. All questions were in the following form ”What is the impact of ‘X principle’ on each of the following”, Figure 5-8 shows an example of the survey structure. The responders specify the direct influence by a selecting one of the following answers:

- No impact (0 score)
- Low impact (1 score)
- Medium impact (2 score)
- High impact (3 score)
- Very high impact (4 score)

The survey was designed using Qualtrics (Web-based survey software) and electronically distributed to different organizations in United States. The participants could respond online by using a web link provided in the email. To ensure uniform understanding of terms used, the purpose of the study and definitions of terms were provided. Industrial engineers, process engineers, lean engineers and manufacturing engineers were the target recipients of the mailed survey. A total of 198 experts started the survey, 134 completed the survey. The survey was designed to allow use of data provided in incomplete surveys.



What is the impact of Respect for Humanity on each of the following

Hover over blue colored items for definitions.

	No impact	Low impact	Medium impact	High impact	Very high impact
Value Specification (Specify value)	○	○	○	○	○
Zero Defects	○	○	○	○	○
Flow	○	○	○	○	○
Pull Production	○	○	○	○	○
Continuous Improvement (Kaizen)	○	○	○	○	○
Supplier Integration	○	○	○	○	○
Value Stream Specification (identify value stream)	○	○	○	○	○
Cost Reduction	○	○	○	○	○

Figure 5-8: Example of DEMATEL questions

The survey was designed to allow an analysis of causal relationships using the DEMTAL technique, and to subsequently construct a strategy map from their data. The procedure is summarized next:

Step 1

Calculate the average matrix (A). The average matrix is obtained directly from the survey (Figure 5-8) using an integer scale ranging from 0 to 4 (Table 5-17). Respondents were asked to indicate the direct influence among elements, according to their own judgment. A higher score means stronger direct influence. Each element in the matrix is derived from the mean of the same elements in the different direct matrices of the group respondents.

$A = [\, a_{ij} \,]$, a_{ij} represent the response of the impact of i(row) to j (column)

Table 5-17: Average matrix (A)

	Specify value	Respect of humanity	Zero Defect	Flow	Pull	Continuous improvement	Supplier Integration	Value Stream Identification	Cost Reduction	Sum
Specify value	0.00	2.46	3.22	2.61	2.32	2.79	2.30	2.57	3.25	21.53
Respect of humanity	2.28	0.00	2.81	2.40	2.12	2.79	1.95	2.37	2.72	19.44
Zero Defect	2.95	2.37	0.00	2.63	2.28	2.90	2.36	2.56	2.99	21.03
Flow	2.50	2.24	2.72	0.00	2.66	2.82	2.32	2.56	2.81	20.62
Pull	2.20	1.93	2.40	2.85	0.00	2.62	2.22	2.36	2.59	19.17
Continuous improvement	2.77	2.56	3.05	2.80	2.51	0.00	2.38	2.76	3.16	21.99
Supplier Integration	2.28	1.75	2.54	2.48	2.45	2.41	0.00	2.17	2.72	18.81
Value Stream Identification	2.80	2.12	2.61	2.78	2.53	2.75	2.26	0.00	2.77	20.62
Cost Reduction	2.64	2.04	2.69	2.48	2.30	2.91	2.40	2.49	0.00	19.95
Sum	20.42	17.48	22.04	21.03	19.17	21.99	18.19	19.83	23.02	

Step 2: Calculate the normalized initial direct rotation matrix (D) (Table 5-18)

Let $s = \max\left(\max_{1\le i\le n} \sum_{j=1}^{n} a_{ij}, \max_{1\le j\le n} \sum_{i=1}^{n} a_{ij} \right)$ (1)

Then $D = \frac{A}{s}$ (2)

In our example s = Max(23.02, 21.99) which is 23.02 (23.02 represents the maximum number between the summation). Then calculate D using equation 2.

Table 5-18: Normalized initial direct rotation matrix

	Specify value	Respect of humanity	Zero Defect	Flow	Pull	Continuous improvement	Supplier Integration	Value Stream Identification	Cost Reduction
Specify value	0.00	0.11	0.14	0.11	0.10	0.12	0.10	0.11	0.14
Respect of humanity	0.10	0.00	0.12	0.10	0.09	0.12	0.08	0.10	0.12
Zero Defect	0.13	0.10	0.00	0.11	0.10	0.13	0.10	0.11	0.13
Flow	0.11	0.10	0.12	0.00	0.12	0.12	0.10	0.11	0.12
Pull	0.10	0.08	0.10	0.12	0.00	0.11	0.10	0.10	0.11
Continuous improvement	0.12	0.11	0.13	0.12	0.11	0.00	0.10	0.12	0.14
Supplier Integration	0.10	0.08	0.11	0.11	0.11	0.10	0.00	0.09	0.12
Value Stream Identification	0.12	0.09	0.11	0.12	0.11	0.12	0.10	0.00	0.12
Cost Reduction	0.11	0.09	0.12	0.11	0.10	0.13	0.10	0.11	0.00

Step 3: Compute the total relation matrix (T) (Table 5-19), by using equation 3, in which I is the identity matrix.

$T = D(I-D)^{-1}$ *(3)*

In our example, D calculated in the previous step. Calculating T from Equation 3.

Table 5-19: The total relation matrix

	Specify value	Respect of humanity	Zero Defect	Flow	Pull	Continuous improvement	Supplier Integration	Value Stream Identification	Cost Reduction	Sum
Specify value	0.82	0.81	1.00	0.94	0.86	0.98	0.83	0.90	1.04	8.19
Respect of humanity	0.84	0.65	0.91	0.86	0.79	0.91	0.75	0.82	0.94	7.48
Zero Defect	0.92	0.79	0.86	0.93	0.85	0.97	0.82	0.88	1.01	8.02
Flow	0.89	0.77	0.95	0.81	0.85	0.95	0.80	0.87	0.99	7.87
Pull	0.83	0.72	0.88	0.87	0.70	0.89	0.75	0.81	0.92	7.37
Continuous improvement	0.94	0.83	1.01	0.96	0.89	0.89	0.85	0.92	1.05	8.34
Supplier Integration	0.82	0.70	0.87	0.84	0.78	0.87	0.65	0.79	0.91	7.24
Value Stream Identification	0.90	0.77	0.95	0.92	0.84	0.95	0.80	0.77	0.99	7.88
Cost Reduction	0.87	0.75	0.92	0.88	0.81	0.93	0.78	0.84	0.85	7.65
Sum	7.83	6.79	8.36	8.01	7.37	8.35	7.04	7.61	8.70	

Step 4: Analyze the results of influences and relationships (Table 5-20).

$D = [d_i]_{n\times1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1}$, which is the summation of rows.

$R = [r]_{n\times1} = \left(\sum_{i=1}^{n} t_{ij}\right)'_{1\times n}$, which is the summation of columns.

Table 5-20: Results of the (D+ R) (relation) and (D+R) (influence)

Lean Principles/ Objective	Rate of the effect on other principle (D)	Rate of the effect from other principle (R)	Total effects rate (D+R)	Net effect on system (D-R)
Specify value	8.191	7.828	16.019	0.362
Respect of humanity	7.476	6.793	14.269	0.683
Zero Defect	8.021	8.356	16.377	-0.335
Flow	7.872	8.006	15.879	-0.134
Pull	7.370	7.365	14.735	0.005
Continuous improvement	8.340	8.345	16.685	-0.005
Supplier Integration	7.238	7.038	14.276	0.200
Value Stream Identification	7.880	7.612	15.492	0.268
Cost Reduction	7.652	8.696	16.348	-1.044

5.8 Strategy map discussion and results

Table 5-20 indicates the values of (D+R, D-R) which are used for lean principles to determine the central factor (highest value of D+R), main cause factor (highest value of D-R) and the main effect factor (lowest value of D-R). The value of (D+R) indicates the strength of influence of both dispatch and receipt, the highest value of (D+R) represents the central factor (The central factor indicates the most relationship with other principles), based on Table 5-20, Continuous improvement is the central factor (Continuous improvement) is considered as a connector between the basics and the output of the lean project. Ignoring continuous improvement will reduce the benefits of lean manufacturing. It is important to mention that, the continuous improvement principle is related to each practice in lean manufacturing (Mirdad & Eseonu, 2014). Top management must support this philosophy, demonstrate willingness to incur initial costs of change, and continuously improve all practices (Womack, Jones, & Roos, 1990b). Top management must also understand that there is no ideal state in lean manufacturing.

The value of (D-R) indicates the intensity of influence, the highest value of D-R has greatest influence on the other principles it is called the “main cause factor.” Table 5-20 shows that Respect of humanity principle is the main cause factor. Consequently, the decision maker must give the highest priority to main cause factor “Respect of humanity” and must make sure the Respect of Humanity principle is completely satisfied before diving into other activity. It can also imply that, the respect of humanity principle represents the basics or the infrastructure of the lean projects. Neglecting this principle would lead to build on the weak basics that in the end translates to failure implementation.

On the other hand, the lowest value of D-R represents the main affecting factors among the other principles. Table 5-20 shows that “ Cost Reduction” objectives is the main affecting factor, which is mean the objective “ Cost Reduction” receive the strongest influence from the other principles.

The strategy map in Figure 5-9 was crated based on the results of the DEMATEL matrix. The regular lines represent the strong relationship, while the bold lines represent the strongest relationship. The direction of influence can be identified by the direction of the arrow. The causal relationship in the strategy map showed that it is impossible to completely separate lean principles from each other. This explains previous statements by Bhasin & Burcher, (2006); Liker & Kaisha (2004); Sánchez & Pérez (2001), which suggest the implementation of all or most of the lean practices to ensure successful implementation.

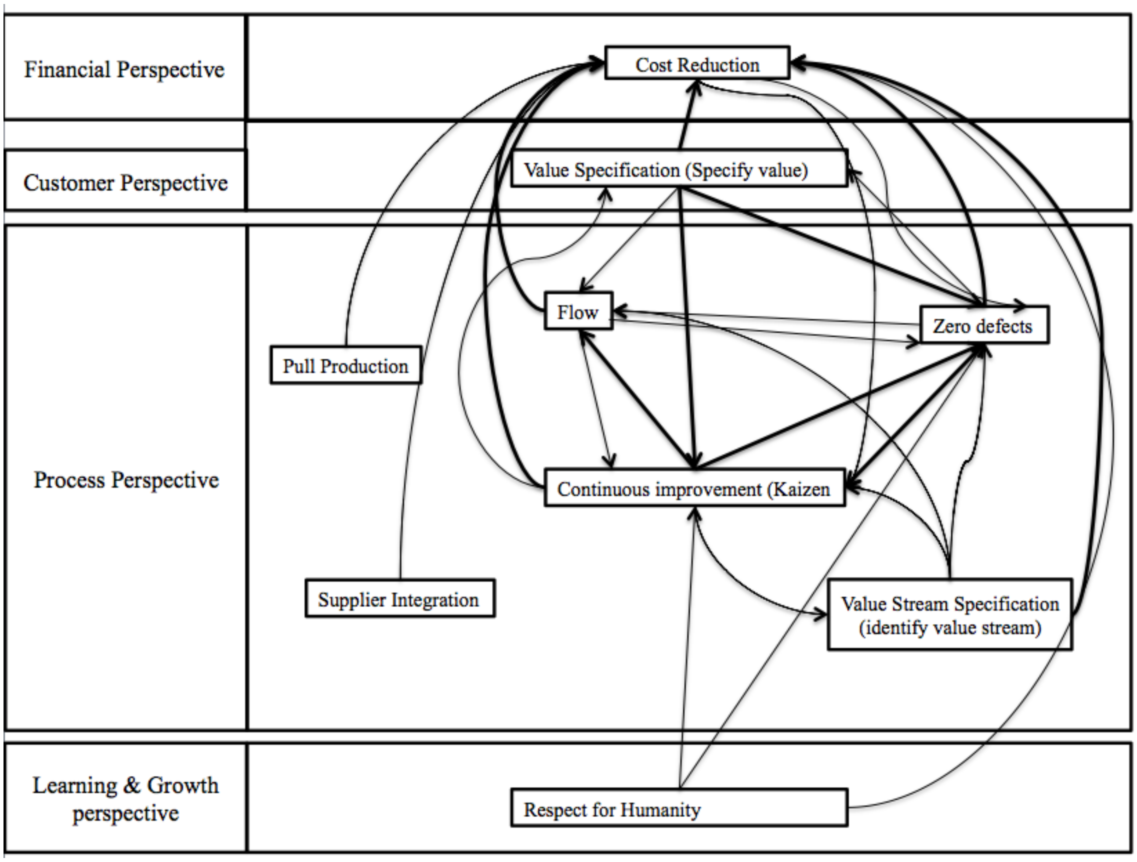


Figure 5-9: Lean strategy map

As shown in the strategy map, continuous improvement receives and dispatches the highest number of the arrows. This corresponds to DEMATEL result, indicating Continuous improvement as central factor. Table 5-21 summarizes the strategy map by showing the total number of dispatches and received arrows for each principle. Continuous improvement principle dispatched to 6 principles and received from 8 principles (14 relationship as total), which indicates the importance of Continuous improvement in the lean manufacturing environment.

Table 5-21: The total number of dispatches and received arrows for each principle

Principles	Dispatching to	Total	Receiving from	Total
Specify value (SP)	ZD, F, P, CI, VS, CR	6	ZD, F, CI, VS, CR	5
Respect of humanity (RH)	ZD, F, CI, CR	4		0
Zero Defect (ZD)	SP, F, CI, VS, CR	5	SV, RH, F, P, CI, SI, VS, CR	8
Flow (F)	SP, ZD, CI, VS, CR	5	SV, RH, ZD, P, CI, VS, CR	7
Pull (P)	ZD,F, CI, CR	4	SV, CI	2
Continuous improvement (CI)	SP, ZD, F, P, VS, CR	6	SV, RH, ZD, F, P , SI, VS, CR	8
Supplier Integration (SI)	ZD, CI, CR	3		0
Value Stream Identification (VS)	SV, ZD, F, P, CI, CR	5	SV, ZD, F, CI	4
Cost Reduction (CR)	SV, ZD, F, CI	4	SV, RH, ZD, F, P, CI, SI, VS	8

On the other hand, Respect of humanity principles and Supplier integration are not influenced by any other principles (no received arrows). Thus, respect of humanity and supplier integration are leading factors. However, the main affecting factor "Cost Reduction" is the most lagging indicators (depends on 8 other principles) that means to achieve cost reduction objective, many other indicators must be achieved. As a result, the Financial performance measures (such as manufacturing cost per units or Gross profit which is represents cost reduction objective in this study) are not suitable in early stages of lean implementation project because it is depends on other indicators. This finding validates the statement by Ahlström (1998), which states that it is not logical to use performance measures that are based on traditional management accounting system, in the early stage of implementing lean manufacturing. This is because productivity decreases in early stage and sole reliance on traditional measures will indicate failed lean implementation without allowing for organization change. The profit and loss indicators are as a result of long connected processes that need longer time to have valid indicators.

While, implementing lean key information is required about what happened in the current situation of the event (Taj, 2008). Consequently, the intermediate indicators (non-financial performance measures) are required to measure the performance in the entire stages (Sánchez & Pérez, 2001), Which is in this study is presented by Respect of humanity performance measures and Supplier integration performance measures (Appendix 5).

5.9 Comparing the lean strategy map between Academics and Practitioners.

The previous strategy map showed the lean strategy map based on 134 practitioners from different industries in United States. The same analysis was conducted based on 49 lean experts from different universities. The study was conducted before identifying the lean principles in this study. Therefore, in addition to the lean principles (Value Identification, Respect of Humanity, Zero Defects, Flow, Pull and Continuous Improvement) important lean constructs were added to the analysis. Table 5-22 includes the results of the (D+R) and (D-R). As shown, the highest value of (D+R) "central factor" is Continuous Improvement. While, the highest value of (D-R) "main cause factors" is respectively referred to as Employee Training and Growth, Identify value stream, Multifunctional Teams, Supplier Integration, and Employee involvement. The results obtained from the academics experts validate the results obtained by the practitioners. It is important to remind the reader about the practices Employee Training and Growth, Multifunctional Teams, and Employee involvement as represented in the respect of humanity principle in the practitioners case (Appendix 5).

Table 5-22: Results of the (D+R) (relation) and (D+R) (influence) based on academics lean expert.

Lean Principles/ Objective	Rate of the effect on other principle (D)	Rate of the effect from other Principle (R)	Total effects rate (D+R)	Net effect on system (D-R)
Genchi Genbutsu	0.493553113	0.999941887	1.493495	-0.506388774
Setup Reduction	1.235739415	1.71744476	2.953184175	-0.481705345
Standard Work	0.570182194	0.988612538	1.558794732	-0.418430344
Flow	1.44178904	1.770294075	3.212083115	-0.328505034
Long-term philosophy	1.451163967	1.488248964	2.93941293	-0.037084997
Workload Leveling (heijunka)	0.642804979	0.675793009	1.318597988	-0.032988029
Decentralized Responsibilities	1.13923548	1.076783734	2.216019215	0.062451746
Use only reliable, thoroughly tested technology that serves your people & processes	1.445553786	1.356233573	2.801787359	0.089320212
Zero defects	1.524003801	1.407983336	2.931987137	0.116020465
Value Specification (Specify value)	1.429325516	1.295405659	2.724731175	0.133919857
Continuous improvement (Kaizen)	2.189030629	1.985845206	4.174875835	0.203185423
JIT Production and Delivery	1.11464465	0.877698185	1.992342834	0.236946465
Pull Production	1.582075207	1.315730806	2.897806013	0.266344401
Employee Involvement	2.095636463	1.821477713	3.917114176	0.27415875
Supplier Integration	1.488713779	1.159205765	2.647919543	0.329508014
Multifunctional teams	1.678884119	1.319546539	2.998430658	0.359337579
Value Stream Specification (identify value stream)	1.526712182	1.062287217	2.588999399	0.464424966
Employee Training and Growth	2.022658565	1.438402416	3.461060981	0.584256149

The strategy map for significant organizational characteristics:

In the previous sections, the study shows that there is a significant effect on the lean practices implementation based on different organizational characteristics. In this section, the researcher tries to investigate if there is any impact of the organizational characteristics in the direction (systematic implementation process) to implement the lean manufacturing (i.e. strategy map) by investigating the previous hypothesis.

The data obtained from the survey (table 5-19) were categorized to the most significant organizational characteristics were considered in this analysis, which are:

- The level of manufacturing in terms of volume produced (high, medium, or low)
- The level of process flexibility (flexible, not flexible, or mixed)

Additionally, to make sure that each group represents the characteristics properly, fifteen samples from each group is the minimum number of responses to consider the group in the study. Therefore, four groups are considered, high variety and flexible (16 responses), high variety and mixed flexibility (29 responses), medium variety and mixed flexibility (15 responses), and low variety and flexible (22).

The data in Table 5-19 was categorized into the four groups. Then a Kruskal-Wallis test was conducted to investigate. Table 5-23 shows that there was insufficient evidence to reject the null hypothesis (The p-values in the table are always greater than .05). Consequently, the direction (systematic implementation process) for implementing lean manufacturing (i.e. strategy map) for different organizational characteristics is almost similar (not identical). As a result, the principle-based strategy map in Figure 5-9 could be generalized as general strategy map for lean implementation project.

Table 5-23: P-values based on Kruskal-Wallis test to investigate the difference between different strategy maps

	Identify value	Respect of Humanity	Zero Defect	Flow	Pull	Continuous improvement	Supplier integration	Value Stream	Cost Reduction
Identify value		0.358	0.261	0.181	0.261	0.708	0.448	0.689	0.239
Respect of Humanity	0.639		0.252	0.458	0.298	0.161	0.171	0.632	0.013
Zero Defect	0.62	0.588		0.349	0.949	0.58	0.166	0.808	0.897
Flow	0.389	0.536	0.997		0.939	0.595	0.195	0.667	0.429
Pull	0.59	0.715	0.965	1		0.607	0.269	0.624	0.366
Continuous improvement	0.172	0.993	0.261	0.548	0.876		0.44	0.933	0.202
Supplier integration	0.631	0.703	0.922	0.972	0.478	0.317		0.832	0.829
Value Stream	0.552	0.882	0.552	0.994	0.302	0.958	0.104		0.591
Cost Reduction	0.511	0.715	0.339	0.817	0.826	0.576	0.143	0.548	

This conclusion was validated using the DEMATEL techniques on the four groups (high variety and flexible, high variety and mixed flexibility medium variety and mixed flexibility, and low variety and flexibility) and lead to the same conclusion obtained from the non-grouped data (Table 5-24). The central factor is Continuous Improvement principle, and the main cause factor is Respect of Humanity.

Table 5-24: DEMATEL results of various strategy map configurations

Characteristics	Main factor	Cause Factor
High – Flex (N=16)	Specify value Zero Defect	Respect of humanity
High- Mixed (N=29)	Continuous improvement Value Stream Identification	Specify value
Med- Mixed (N=15)	Continuous improvement Zero Defect	Respect of humanity
Low- Mixed (N=22)	Continuous improvement Zero Defect	Supplier Integration

It is important to mention that, each organization has a unique strategy map to implement lean manufacturing, which depends on the culture, policies and system

(Anvari et al., 2011). Therefore, the suggested strategy map is only a general guidance to give the logical path to implement lean manufacturing principles.

5.10 Conclusion

In this study, the researchers based the result only on the organizations that formally implemented lean manufacturing. It is interesting to find that almost all the manufacturing sectors are adapting lean manufacturing formally. The level of lean adoption differs from one sector to another based on the organizational characteristics. In this study, we examined the level of the lean adoption based on different organizational characteristics and found that the ideal organizational characteristics for adapting the lean manufacturing practices are:

- Large organizational size (more than 500 employees)
- High environment competitive
- High-Medium volume production level
- Flexible process (The organization can change the layout and the sequence of the process).

Lean implementation is affected by the organizational characteristics but not hinder the implementation. Consequently, the organization must consider the organizational characteristics in selecting the lean practices. The result is supported by Crute, Ward, Brown, and Graves (2003). They conclude different characteristics, such as "volume level " are not considered as obstacles to implementation of lean manufacturing.

The study suggested a checklist to ensure that selected performance measures are useful to the organization. This should be followed by another checklist to evaluate the effectiveness of the performance measurement system. In addition, the study also provides lean balanced scorecard that is validated by the practitioners from different manufacturing sectors. The suggested balance scorecard could help the organization/scholars to compare or adopt items (principles, practices, and performance measures) in lean manufacturing projects.

Additionally, a lean strategy map was created to identify the logical link between lean principles. The strategy map was constructed by using the validated balanced scorecard. Subsequently, the causal link between the lean principles by using DEMATEL techniques instead of using the rule of thump to define the relationship between the principles. The results of the analysis help in different way:

- The organizations are usually restricted by limited time and resources. The strategy map help organizations by focusing on the most important factors, (Respect of Humanity principle as cause factor and Continuous Improvement principle are central factor) to achieve the objective effectively and efficiently.
- The different logical path in the strategy map indicates the strategy map to get improvement.
- The main effects factor “Cost Reduction” is a lagging indicator, which indicates that to achieve cost reduction, other indicators must be achieved. This finding validates that financial performance measures are not suitable for lean projects.
- The principal “Respect of Humanity” represents cause factor. Therefore, the organization must focus on applying practices such as improving employee training, high multifunctional teams, in turn to ensure success lean implementation.

Moreover, the study suggests a general strategy map for implementing lean manufacturing that works for different organizational characteristics. It is important to differentiate between the previous and the current results about the lean practices adoption. The study concludes that the general strategy map for implementing the lean manufacturing "principles" is the same even if the organizational characteristics are different. However, there is a difference in implementing lean "practices" based on the organizational characteristics. Consequently, the organization must be meticulous about lean practices selection which is affected by different organizational characteristics.

6 Conclusions and Future Work

6.1 Summary

Since the introduction of lean manufacturing by Toyota and publication of Womack and Jones, organizations have realized sizeable gains through lean process improvement. The spread of lean practices across organizations and industries – from manufacturing to healthcare and construction – requires adjustments of the lean process and, in the case of construction engineering, modification of the traditional lean paradigm (stationary product versus the traditional mobile product). Consequently, only 10% or less of organizations are successful with their lean implementation (Gupta & Kundra, 2012). Previous studies show that this unsatisfactory result for lean manufacturing implementation is often due to selecting inappropriate lean strategies, using the wrong tool to solve the problem, sole reliance on financial measures and consequent performance measures, and an overall lack of synchronization between lean goals and actual practices. Given the challenges with adopting lean and synchronizing strategy beyond financial measures, this paper attempted to resolve the confusion surrounding lean implementation by providing a systematic, clear description of the effective and efficient routes to facilitate lean implementation that helps different sectors adapt appropriate lean strategy.

The development of the study includes: (a) a Literature review of lean principal, lean practice, performance measures and performance measurement system; (b) an investigating of lean principle to integrate the literature with a survey of lean experts; (c) creation of a lean conceptual map that integrates lean principles with lean practices and performance measures; (d) incorporation of the lean balanced scorecard as a performance measurement system based on validated performance measures obtained through a survey of different manufacturing sectors in the United States; (e) identification of causal relationship between lean principles using Decision Making Trial Evaluation Laboratory method (DEMATEL), to construct an industry-specific strategy map with information from a survey of lean manufacturing companies in the United States (f) an investigating of the difference between the strategy maps constructed for each sectors, and the cause and the central factors for each lean sector; and (g) a suggestion of an effective lean strategy for each sector. These results identify a path for management to better invest resources in the aspects of lean implementation that are acute need of improvement, by focusing on the most salient and central lean objectives. Such as tool could result in more effective and efficient lean implementation.

6.2 Conclusions

The challenges and difficulties that occur during the implementation of lean manufacturing often result in a high levels of failed lean projects. This study provides tools to address the underlying causes of lean implementation failure. The first outcome of this study is to resolve the confusion surrounding lean implementation by providing a clear conceptual map that connects lean principles and practices to financial and non-financial performance measures. This first study demonstrated the high levels of confusion among lean experts, who differed on lean nomenclature and associated definitions. Looking at the high percentage of failure in implementing lean manufacturing, this study validated aforementioned conceptual confusion in the literature on lean manufacturing philosophy. Confusion in the literature was one of the major causes of lean implementation failure. This study provides a conceptual map, which relates lean principles with associated practices and reinforcing performance measures. The conceptual map helps potential adopters select suitable practices to solve lean problems. In addition, the lean conceptual map encourages the implementation of lean manufacturing as integrated system, as opposed to the current ad hoc, opinion based, selection of tools.

The second objective was to examine the level of the lean adoption based on different organizational characteristics. The study identified the ideal organizational characteristics for adapting lean manufacturing practices, which are:

- Large organizational size (more than 500 employees)
- High environment competitive
- High-Medium volume production level
- Flexible process (The organization can change the layout and the sequence of the process).

However, there are some barriers that reduce the adoption of lean practices based on different organizational characteristics. Consequently, the organization must consider the organizational characteristics in selecting the lean practices.

The third objective of this study was to identify suitable measures for a performance measurement system based on the balanced scorecard. In turn to achieve the previous objective, the study suggested a checklist to ensure that selected performance measures are useful to the organization. This should be followed by another checklist to evaluate the effectiveness of the performance measurement system. In addition, the study also provides lean balanced scorecard that is validated by the practitioners from different manufacturing sectors. The suggested balance scorecard could help the organization/scholars to compare or adopt items (principles, practices, and performance measures) in lean manufacturing projects.

The last objective is to create a lean strategy map for each significant organizational characteristic and suggest the cause factor and the central factor for implementing lean manufacturing. This study suggested a lean strategy map to identify the logical link between lean principles. The strategy map is constructed by using the validated balanced scorecard. The DEMATEL techniques were used to investigate the causal links in the strategy map, instead of using the rule of thump to define the relationship between the principles. The results of the analysis helps in the following ways:

1. Organizations are restricted by time and other resource limitations. The strategy map developed here can help organizations manage resources effectively by identifying the most important factors for lean implementation.
    a. Based on the study, “Respect of Humanity” principle is the *cause factor*. This implies that respect for humanity is the first lean principle to be adopted if a company seeks to be successful.
    b. Continuous Improvement principle is the *central factor*. This implies that a continuous improvement mindset is required for sustained and successful lean implementation.
2. Provides clear, stepwise descriptions of the strategy required for lean

improvements.

a. The strategy map depicts the *main effects* factor "Cost Reduction" as a lagging indicator, which pictorially directs an organization to focus on the cause and central factors – underlying drivers of success – before evaluating cost reduction. This finding validates that financial performance measures are not suitable stand-alone metrics for lean projects.

b. The "Respect of Humanity" principle represents the most cause factors. Therefore, the organization must focus on applying practices such as improving employee training, high multifunctional teams, in order to ensure successful lean implementation.

Finally, the study suggests a general strategy map for implementing lean manufacturing that works for different organizational characteristics. This study supports the notion that lean is more dependent on organizational culture than on the type or extent of tools applied. Respect for humanity and associated employee empowerment can lead to citizenship behavior, which would support continuous improvement efforts. The following section outlines avenues for extending this work.

6.3 Future Research Opportunities

The literature shows the lean manufacturing could be integrated with other successful programs such as lean six sigma (Franco, Marins, & Silva; Timans, Antony, Ahaus, & van Solingen, 2011); total quality management (Cua, McKone, & Schroeder, 2001; Ho, 2010a, 2010b) ; theory of constraint (Nave, 2002); or International

Organization for Standardization "ISO" (Marash, Berman, & Flynn, 2004). The abundance of different improvement programs can lead to confusion among lean adopters about the appropriate program for an organization. Consequently, we conducted work to integrate the conceptual map in this study with other programs.

This study introduced a conceptual map for lean nomenclature-principles, practices, and performance measures, to resolve a source of confusion facing lean adopters. The information in the conceptual map was categorized using the DEMATEL method, to develop a strategy maps for lean implementation. Since its inception, lean has been adopted in several sectors, such as construction and healthcare. These sectors have seen resulting gains. Future work will expand the strategy map beyond the current focus on manufacturing, to include other industries.

The conceptual map helps lean researchers develop a standardized nomenclature to avoid confusion in future research. However, it is strongly recommended to convert the theoretical part in this study to a tangible product that can be used to help practitioners apply the output of this study (conceptual map, balanced scorecard, and strategy map) in the actual environment. A suggested solution is to create web-based tool that support the practitioners by providing a systematic implementation process that integrates the lean performance measure with lean strategy in order to avoid lean failures. Additionally, the tools could be used as educational tools to improve understanding of lean manufacturing concepts. The website could also be integrated with any simulation activity such as TIME WISE clock assembly game or lampshade game simulation(Ozelkan & Galambosi, 2009)

In this study, the organizational characteristics were identified from the literature. Most of those characteristics do not have accurate definitions related to lean manufacturing. For example, the definition of large and small organizations is different from study to other study, which could to misunderstanding results. So, it is strongly recommended to define each significant characteristic in relation to lean. This approach will help organizations identify organizational characteristics and adopt suitable lean practices.

6.4 Weaknesses and Improvement Opportunities

This study is based on responses from 49 lean manufacturing experts based on their experiences conducting research in lean process improvement. While the authors attempted to increase the size and the variety of the sample through a completion prize, future studies might take steps to increase survey responses. In addition, in order to determine the best practices for each significant organizational characteristic, the sample size for each group must be increased to significantly represent the group.

The results of this study are based on the literature and surveys, like all other surveys, responses are limited by human subjectivity. Therefore, empirical and case studies are recommended to support and validate the result of this research.

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8 Appendices

8.1 Appendix 1: Lean practices list

Element	Author																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq
Total productive mainenance (TPM)	1	2	3	4	5	6	7	8		10		12	13		15	16	17	18	19	20		22	18
Cellular manufacturing	1	2		4	5		7	8		10					15	16		18	19		21	22	13
Kaizen (Continous improvement) (Perfection)	1	2				6		8		10	11	12	13	0	15				19	20		22	13
Set up time reduction	1	2	3	4	5		7	8	9				13			16	17		19		21		13
Kanban system	1		3	4		6	7	8			11				15		17		19		21	22	12
Pull production (JIT production) (Pull system of meterial control)	1	2		4	5	6	7				11	12	13		15			18	19				12
Work standardisation	1	2				6	7	8				12	13	0		16			19			22	11
Small lot production (lot size reductions)	1	2			5		7	8	9	10					15	16			19				10
Single-minute exchange of dies (SMED)	1	2				6	7			10	11				15					20		22	9
Pokayoke or mistake proofing or defect prevention	1	2			5	6	7			10						16				20		22	9
Housekeeping (5S)	1	2			5			8			11		13	0						20		22	9
flow lines	1				5			8		10		12	13	0	15					20			9
Quality circles (operator involvment)	1	2	3	4		6		8									17					22	8
Total quality management and control (TQM)	1		3					8		10					15	16	17		19				8
Multifunctional training (skills training)	1	2		4	5			8											19	20		22	8
Cycle time and lead time reduction	1				5	6			9						15	16						22	7
Layout change or U-shaped cell	1			4		6		8					13	0					19				7
Workload or line balancing (uniform workload)	1		3	4			7										17			20		22	7
Focused factory production	1		3	4				8		10					15		17						7

Element	Author																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq
Visual control of the shop floor (visual management ofproduction control)	1				5	6		8					13							20		22	7
One-piece flow	1					6							13	0						20		22	6
Statistical process control (control chart)(SPC)	1	2				6				10											21	22	6
Just-in-Time delivery (from suppliers and within workstations)	1			4	5		7									16			19				6
Value stream mapping	1	2				6			9		11									20			6
Multiskilled workforce	1		3	4	5			8									17						6
Cross functional teamworking	1									10			13	0	15	16							6
worker involvement in continous quality improvement programmes (quality improvement teams)	1				5								13	0				18			21		6
Design for manufacturing	1	2			5		7									16							5
Production smoothing or load levelling (heijunka)	1				5	6							13						19				5
Long-term supplier relationship	1	2		4	5											16							5
Manufactring flexibility (product customization)	1	2			5							12				16							5
process capability	1				5					10					15							22	5
Quality certification (suppliers and manufacturers) (supplier qyuality level)	1			4	5														19				4
Takttime or takt calculations	1					6			9													22	4
Mixed model manufacturing/ scheduling (production scheduling)	1				5											16			19				4
jidoka (autonomation)(stop the line)	1					6							13	0									4
Team concept (self directed teams)	1	2						8							15								4

Element	Author																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq
Top management commitment and leadership	1	2											13	0									4
JIT	1		3												15							22	4
JIT purchasing	1	2		4													17						4
Work teams	1			4									13	0									4
dependable suppliers	1			4			7											18					4
commercial actions to stabilize demand (demand stablization)	1				5							12				16							4
Group technology	1		3														17						3
Supplier involvement in design (Supplier involvment)	1				5																	22	3
Information sharing with suppliers	1				5											16							3
Sole sourcing or supplier reduction	1				5		7																3
Andon (warning lights)	1																		19	20			3
New process or equipment technologies	1				5										15								3
Inventory management	1	2					7																3
reengineering setups	1			4														18					3
product and process quality improvement (use 7 tools of quality control into line)	1			4			7																3
quality and process management	1			4					9														3
quality improvement efforts	1			4														18					3
Customer involvement	1			4	5																		3
innovative performance appraisal and performance related pay systems	1				5											16							3
parts standardization	1				5											16							3
multifunctional design teams (design for manufacture)	1				5																21		3

Element	Author																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq
Fexibility on meeting customer requirements (customer req analysis)	1				5											16							3
service-enhanced product (service to enhance value)	1				5											16							3
Deming wheel , Shewhart cycle (plan-do-check-act)	1					6																22	3
Familiarity with complementary quality and productivity program(six sigma , theory of constraints, TS16949)	1					6																22	3
bottleneck constrain removal (production smoothing)	1									10					15								3
visibility and information exchange													13	0									2
supplier evaluation/ rating																16						22	2
WIP reduction	1						7																2
Successive checking (check list) (check sheet)	1																					22	2
Computer Integrated Manufacturing (CAD/CAM/CAE)(Robot/Fms)	1																		19				2
Synchronisation	1				5																		2
Concurrent engineering	1															16							2
Standardised containers	1																		19				2
Supplier training and development	1				5																		2
Safety improvement programmes	1														15								2
Product and process simplification	1																		19				2
Employee empowennent (learning , innovation)	1	2																					2

Element	Author																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq
Employee participation	1	2																					2
Rewards and recognition (foramal reword system)	1															16							2
Suggestion schemes	1			4																			2
Job rotation or nexible job responsibilities	1				5																		2
Automated transport	1	2																					2
information technology	1	2																					2
Compossite inventory Index	1	2																					2
Co-operative Index(CII)	1	2																					2
employee commitment	1	2																					2
manufactring strategy	1	2																					2
planing oriented	1	2																					2
Joint effort	1	2																					2
Automated Guided Vehicles	1	2																					2
multi skilled worker	1	2																					2
ISO 9000	1	2																					2
JIT scheduling	1			4																			2
level scheduling	1			4																			2
daily schedule adherence	1			4																			2
stable cycle schedules	1			4																			2
market-paced final assembly	1			4																			2
schedule flexibility	1			4																			2
setup reduction plans	1			4																			2
analysis, and feedback	1			4																			2
problem solving groups	1			4																			2
shop floor problem solving	1			4																			2
mulyifunctional employee	1			4																			2
Job rotation.	1			4																			2
Integrated supplier	1						7																2
under capacity scheduling	1				5																		2

Element	Author																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq
overlapped production	1				5																		2
few level management	1				5																		2
team decision making	1				5																		2
product modularization	1				5																		2
mushroom concept	1				5																		2
phase overlapping	1				5																		2
open orders	1				5																		2
reliable and prompt deliveries	1				5																		2
capability and competence of sales network	1				5																		2
early information on customer needs	1				5																		2
4W2H (what, when,where,why ,how and how much)	1					6																	2
Supplier management	1							8															2
maintenance optimiation	1									10													2
Quality at the source												12											1
Lean performance metrics													13										1
visual management of quality control													13										1
value identification																16							1
shop floor orgnaization																16							1
Work delegation																16							1
employee evaluation																16							1
pull flow control																16							1
operator responsibility for quality																					21		1
5W1H																						22	1
ABC meterial handling																						22	1
Activity analysis																						22	1
Analysis of variance																						22	1
benchmarking																						22	1
box plot																						2	1

Element	Author																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq
																						2	
cell audit																						22	1
cell team work plan																						22	1
company chart																						22	1
cost benefit analysis																						22	1
cost of quality																						22	1
cycle time flowchart																						22	1
defect map																						22	1
employee recognition																						22	1
energy audit																						22	1
exit criteria and entery criteria																						22	1
events log																						22	1
facility layout diagram																						22	1
failure mode and effect analysis (FMEA)																						22	1
Fault tree analysis																						22	1
fishbone diagram																						22	1
five whys																						22	1
forecasting																						22	1
histogram																						22	1
hoshin planning (hoshin kanri) (policy deployment)																						22	1
HR assessments																						22	1
job design and description																						22	1
Lean accounting (ABC)																						22	1
cell workload analysis																						22	1
linking diagram																						22	1
MRP/ MPS																						22	1
multivariable chart																						22	1
multi process handling																						22	1
operating rule																						22	1
equipment effectiveness(OEE)																						22	1
Pareto charts																						2	1

Element	Author																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq
																						2	
point of use storage (POUS)																						22	1
P/Q analysis																						22	1
potential problem analysis																						22	1
prioritztion matrix																						22	1
problem boards																						22	1
process analysis																						22	1
process flow chart																						22	1
process mapping																						22	1
program evaluation and review technique (PERT)																						22	1
quality chart																						22	1
Quick response manufactring																						22	1
resorce histogram																						22	1
resource rquirements matrix																						22	1
right sized equipment																						22	1
routing analysis																						22	1
service cell agreements																						22	1
shewhart PDCA cycle																						22	1
shop floor metrics																						22	1
six sigma																						22	1
SWOT analysis																						22	1
Target cost management																						22	1
Task analysis																						22	1
time audit																						22	1
Time study sheet																						22	1
Top down flow chart																						22	1
tree diagram																						22	1
value non value added cycle time chart																						22	1
variance analysis																						22	1
voice of customer																						22	1
why/how charting																						22	1

Element	Author																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq
work content matrix																						22	1
workable work																						22	1
Yield chart																						22	1
Process sharing	1																						1
Flat organisation structure	1																						1
Defects at source (self-inspection)	1																						1
Rolling production plans	1																						1
Use of EDI with suppliers	1																						1
Maintain spare capacity	1																						1
Use of multiple small machimes	1																						1
Commonisation and standardisation of pans	1																						1
Supplier proximity	1																						1
Use of problem solving tools	1																						1
Elimination of buffers	1																						1
Storage space reduction	1																						1
Automation	1																						1
Long term employment	1																						1
Job enlargement or Nagara system	1																						1
Communication between employees	1																						1

1(Anand & Kodali, 2009)
2(Deshmukh et al., 2010)
3(White et al., 1999)
4(Olsen, 2004)
5(Panizzolo, 1998)
6(Fliedner & Mathieson, 2009)
7(Black, 2007)
8(A. M. N. Rose et al., 2011)
9(Sahoo, Singh, Shankar, & Tiwari, 2007)
10(Shah, Chandrasekaran, & Linderman, 2008)
11(Worley & Doolen, 2006)
12(Jon et al., 2000)
13(Saurin, Marodin, & Ribeiro, 2011)
14(GUPTA & KUNDRA, 2012)
15(Shah & Ward, 2003)
16(T. L. Doolen & Hacker, 2005)
17(Rosemary R. Fullerton et al., 2003)

18(Koufteros, Vonderembse, & Doll, 1998)
19(Sakakibara et al., 1993)
20(Mejabi, 2003)
21(Lewis, 2000)
22(Pavnaskar et al., 2003)

8.2 Appendix 2: List of the performance measures and their appearance in references

Performance Measures	Author																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FR EQ
Setup time	1	2	3		5	6		8		10		12			15	16	17	18		20	21	22	23		25	26		28					33	20
Scrap and rework costs	1	2	3		5		7				11	12					17		19	20			23		25	26					31		33	15
Finished goods inventory	1			4	5	6		8	9	10			13				17									26		28		30		32	33	14
Supplier or delivery lead time	1	2						8						14	15	16		18		20	21	22		24				28	29				33	14
Percentage on time delivery	1			4				8		10	11	12	13	14											25	26			29	30		32		13
Throughput time or manufacturing lead time	1			4	5				9	10							17						23	24	25	26				30	31			12
Percentage of defective parts adjusted by production line workers	1	2	3				7	8			11		13												25				29			32		10
Labour productivity	1			4	5				9										19					24					29		31			8
WIP inventory	1			4													17						23			26		28		30		32		8
The number of stages in the material flow that uses pull(backward requests) in relation to the total number of stages in the material flow			3							10					15	16					21			24	25						31			8
Frequency of preventive maintenance	1												13		15			18				22			25	26								7
Manufacturing cost per unit	1			4	5				9										19						25					30				7
Number of kanbans	1														15	16					21	22						28		30				7
Number of suggestions per employee per year	1	2	3												15	16					21								29					7
Percentage of unscheduled downtime	1	2	3					8					13				17																33	7
Health and seafty per employee :(Accidents,Absenteeism,Labour Turnover)				4						10	11		13														27			30			33	7

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
percentage of personal (employee) are active members of formal work teams, quality teams, or problem solving teams													13		15	16		18			21		23						29					7
Amount (in hours) of training given to newly employed personnel	1		3													16					21							28					33	6
Manufacturing cycle time	1			4			7	8											19							26								6
Percentage of employees working in team	1	2	3														17										27	28						6
Raw material inventory	1			4	5												17									26				30				6
Value of WIP in relation to sales	1	2	3				7																	24			27							6
Number of people dedicated primarily to quality control		2	3												15	16					21				25									6
Quality rating				4				8	9	10	11																	28						6
Employee turnover rate	1			4							11		13																				33	5
Gross annual profit	1			4																							27					32	33	5
Improved equipment efficiency (OEE)	1			4	5		7			10																								5
Improved time-based competitiveness	1		3		5	6							13																					5
Level of integration between suppliers delivery and the company's production information	1	2																18			21												33	5
Percent of employees cross trained to perform three or more jobs	1		3										13														27						33	5
Percentage of inspection carried out by autonomous defect control	1	2	3												15	16																		5
Percentage of manufacturing process under statistical	1												13			16					21				25									5

Performance Measures	Author																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
control																																		
Number of time and distance part are transported		2	3			6							13										23											5
Material waiting time (WIP time)					5								13				17								25					30				5
Factory disruption (supplier prevent any quality issue (material purges, stop ships,line sorts…)														14	15			18		20					25									5
Average distance between the supplier and manufacturer	1											12				16					21													4
Average number of suppliers for the most important parts	1	2														16					21													4
Customer lead time	1	2																	19							26								4
First pass yield	1						7												19							26								4
Labour utilisation	1							8					13																29					4
Number of suggestions made to suppliers	1	2														16					21													4
Number of suppliers	1												13												25				29					4
Percentage of parts delivered just in time between sections in the production line	1	2	3																					24										4
Rate of customer returns	1										11																	28				32		4
Time to market for new products	1			4																						26						32		4
Total productive floor space	1							8					13																			32		4
Warranty cost	1										11														25	26								4
Percentage of employee rotating tasks within the company		2	3															18										28						4

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FR EQ
Customer satisfaction index				4							11														25							32		4
Line efficiency					5						11									20										30				4
Falut analysis (supplier meets established timeline for falut analysis of defective parts														14	15	16					21													4
Adherence to schedule	1										11												23											3
Batch size	1	2																					23											3
Equipment utilisation	1												13							20														3
Frequency of the deliveries	1																								25				29					3
Increase in productivity	1						7	8																										3
Increased flexibility	1									10			13																					3
Length of product runs	1		3																						25									3
Non value added time	1				5																									30				3
Number of certified suppliers	1					6							13																					3
Number of total parts in bill of materials	1			4																					25									3
Percentage of people involving in stopping the line due to problems	1		3										13																					3
Percentage of preventive maintenance over total maintenance	1	2													15																			3
Production capacity	1																													30	31			3
Ratio of indirect labour to direct labour	1		3					8																										3
Total sales	1																								25							32		3
Percentage of implmented suggestions		2	3																									28						3

Performance Measures	Author																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FR EQ
Percentage of team leaders that have been elected by their own team co-workers		2																					23					28						3
The frequency with which suppliers' technicians vist the company		2														16					21													3
Time perspective in the information			3		5																						27							3
new technology decelopment				4									13									22												3
culture change										10	11																27							3
number of kaizen events												12													25						31			3
What is the overall inventory turnover, including finished goods, WIP and purchased/raw material													13							20			23											3
PPM (ratio of defective parts due to supplier to total parts received from supplier, multiplied by 1000000)														14									23						29					3
cost reductions % (supplier achieves reductions in unit cost of product or service in current quarter as compared with previous quarter)														14		16					21													3
Shop floor employees are involved in designing process and tools that focus on improvement															15	16								24										3
Employees work on set-up improvement															15	16					21													3
We use fishbone type diagrams to identify causes of quality problems															15	16					21													3
We conduct process capability studies															15	16					21													3
We maintain our equipment regularly															15	16						22												3
Products are classified into groups with similar processing requirements															15	16					21													3

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
Products are classified into groups with similar routing requirements															15	16					21													3
Our factory layout groups different machines together to produce families of products															15													28	29					3
Equipment is grouped to produce families of products															15	16					21													3
Families of products determine our factory layout															15	16					21													3
Our customer give us feedback on quality and delivary performance																16					21				25									3
Our customer are actively invoved in current and future product offering																16					21										31			3
Container size	1	2																																2
Cost of poor quality	1			4																														2
Increase in production volume	1				5																													2
Number of awards and rewards provided for workers	1																								25									2
Number of employees	1																															32		2
Number of inventory rotations	1	2																																2
Number of mixed models in a line	1																									26								2
Number of sole sourcing suppliers	1																																33	2
Number of teams	1		3																															2
Number of years a supplier is associated with the manufacturer	1																				21													2
Percentage of common or standardised parts	1	2																																2
Percentage of parts co-designed with	1	2																																2

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
suppliers																																		
Percentage of parts delivered directly to the point of use from supplier without incoming inspection or storage systems	1												13																					2
Percentage of procedures which are written or recorded or documented in the company	1	2																																2
Percentage of production equipment that is computer integrated or automated	1	2																																2
PPM defective products shipped to customer	1																									26								2
Reduced inventory investment	1																														31			2
Reduction in direct labour	1							8																										2
Reduction in number of workers/employees	1					6																												2
Takt time	1				5																													2
Utilisation of capacity	1																													30				2
Value added time	1		3																															2
Number and percentage of tasks performed by teams		2	3																															2
The frequency with which information is given to employee		2	3																															2
Number of informative top management meeting with employee		2																															33	2
Number of different functional areas employee are trained in			3															18																2
Customer retention rate				4																									29					2

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
Service quality				4																										30				2
Quality of professional/technical development				4																					25									2
increases in capacity in current facilities								8			11																							2
Employee behavior									9		11																							2
use of lean based performance measurements										10	11																							2
proportion of overtime worked											11																			30				2
Max demand-minimum demand (ratio of diference between the maximum annual demand and the minimum annual demand divided by the maximum annual demand)												12											23											2
supplier flexibility % (customer ability to adjust ship date of pequisitioned supplies (either forward or back) upon request														14									23											2
Root cause/ corrective action (supplier meets the establishedtimeline for root cause problem solving and corrective action required														14	15																			2
response for quotes (supplier meets established response time for requests for quotes)														14									23											2
purchase order confirmation time														14												26								2
Standard set-ups are developed for new processes															15												27							2
Our employees are trained to reduce set-up time/Set up time reduction															15	16																		2
We use design of experiments (i.e., Taguchi methods)															15										25									2

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
We receive the correct type of parts from suppliers															15																		33	2
Products with design or processing similarities are produced together															15	16																		2
Products that share similar design or processing requirements are grouped into families of products															15							22												2
We have a formal supplier certification program																16					21													2
We evalute suppliers on the basis of total cost and not per unit price																16					21													2
We frequently are in close contact with our customers																16					21													2
Our customer are directly invoved in current and future product offering																16					21													2
our customers frequently share current and future demand information with marketing department																16					21													2
Production is pulled by the shipment of finishied goods																16					21													2
production at staions is pulled by the current demand of the next station																16															31			2
We have low set up times of equipment in our plant/Set up time reduction																16					21													2
Extensive use of statistical techniques to reduce process variance																16					21													2
worker flexbility																	17										27							2
Increase in revenue	1																																	1
Level of housekeeping	1																																	1

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
Number of new products introduced	1																																	1
Number of shifts	1																																	1
Overtime	1																																	1
Penalties due to short quantity	1																																	1
Percent of products accepted as good without inspection	1																																	1
Production rate	1																																	1
Reduced product cost or price	1																																	1
Reduced purchase cost	1																																	1
Reduction in indirect labour	1																																	1
Reduction in overall plant investment	1																																	1
Time spent on engineering changes	1																																	1
Use of visual management or aids	1																																	1
Saving or benefits from suggestion		2																																1
Average frequency of task rotation		2																																1
the frequency with which company's suppliers are visited by technicians		2																																1
percentage of documents interchanged with suppliers through EDI(electronic data interchange) or Intranets		2																																1
Number of decisions employee may accomplish without supervisory control		2																																1
Formal suggestion scheme			3																															1
No explict organization			3																															1
Workers identify defective parts, but do not stop the line			3																															1
Quality control department identify defective parts and informs production management			3																															1

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
Defective parts are sent back to the worker responsible for the defect to adjust it			3																															1
Adjusment deparment adjusts defective parts			3																															1
Processes are controlled through measuring inside the process			3																															1
Measuring is done after each process			3																															1
Measuring is done only after product is complete			3																															1
Sequential just in time possible			3																															1
Type specific deliveries just in time possible			3																															1
Percentage of the annual requirement value that is scheduled thrugh a pull system			3																															1
Team leadership rotates among team members			3																															1
supervisory tasks performed by the team			3																															1
separate supervisory level in the orgnaizatiopn			3																															1
Percentage of employee being able to accept responsibility for team leadership			3																															1
The number of hierarchical levels in the manufacturing orgnization			3																															1
Number of functional areas that are the responsibility of the teams			3																															1
The number of different indirect tasks performed by the team			3																															1

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
Percentage of information continuously displayed in dedicated space, in the production flow, discussed in the meating			3																															1
Number of areas contained in the information given to employees			3																															1
Number of different measure used to assess the performance of the teams			3																															1
rate of return on capital employed				4																														1
Current ratio				4																														1
market share by product group				4																														1
Responsiveness(customer defined)				4																														1
Quality to market for new product				4																														1
Quality of new product development and project management process				4																														1
defects of critical products/components				4																														1
space productivity				4																														1
Stock turnover				4																														1
Employee perception surveys				4																														1
Retention of top employee				4																														1
Quality of leadership development				4																														1
Depth and quality of strategic planing				4																														1
Anticipating future change				4																														1
new market development				4																														1
Percentage sales from new products				4																														1
Material handling time					5																													1
Return on assets improvement of more than 100%								8																										1

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
cost od equipment									9																									1
cost of employee training									9																									1
administrative cost									9																									1
% on time production											11																							1
batches(% of adjusted)											11																							1
Activity(standard hours produced / budgeted std hrs)											11																							1
the overall apperance of the plant													13																					1
What portion of machine operators have had formal training in rapid setup techniques?													13																					1
What is the ratio of inventory turnover to industry average													13																					1
How many large scale machines or single process areas are in the pant through which 50 percent or more of different products must pass													13																					1
Excluding new installtions and construction projects, what percentage of maintenance hours is unplanned, unexpected, or emergency?													13																					1
Does equipment breakdowns limit or interrupt production?													13																					1
What portion of the plant space is orgnaized by function or process type?													13																					1
On average, how ofen, in months, are items put up for resourcing?													13																					1
What is portion of raw materials and purchased parts is delivered more than once per week?													13																					1

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
To what extent are managers and worker measured andjudged on setup performance?													13																					1
Cost reduction proposals														14																				1
cost reduction implementations														14																				1
Financial statements (supplier provides quarterly financial statements, providing cost analysis of goods/ service currently provided														14																				1
EOL certification data														14																				1
Shop floor employees are involved in improvement effort															15																			1
Tools for set-up are conveniently located															15																			1
Employees redesign or reconfigure equipment to shorten set-up time															15																			1
Employees redesign jigs or fixtures to shorten set-up time /Set up time reduction															15																			1
We use special tools to shorten set-up															15																			1
We aim for a process design which prevents employee errors															15																			1
There is a separate shift, or part of a shift, reserved for preventive maintenance activities															15																			1
Records of routine maintenance are kept															15																			1
Our suppliers accommodate our needs															15																			1

Performance Measures	Author																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
We receive parts from suppliers that meet our specifications															15																			1
We receive the correct number of parts from suppliers															15																			1
A coding classification is used to group parts into families															15																			1
We have corporate level of communication on important issues with key supplier																16																		1
Our key supplier mannage our inventory																16																		1
We post equipment maintenance records on shop floor for active sharing with employee																16																		1
move times																	17																	1
cutomer response time																	17																	1
accounting simplification																	17																	1
firm proftability																	17																	1
Inspections																	17																	1
Task identity (the worker can do the whole work rather than simple task)																											27							1
Autonomy (the jobholder can excercice choice and discretion on their work)																											27							1
feedcabck (the extent to which the job itself (as opposed to other) people provides jobholder with information on their performance)																											27							1
job related strain (measuring aspects of anxiety, depression and diffculties in coping with everday problems)																											27							1

Performance Measures	Author																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	FREQ
due date measures(lost sales, shortage of final product , past due demand)																														30				1
formal training program for management																																	33	1
management support JIT implementation																																	33	1
used unionized workers																																	33	1
reduction in the level of work load variability																																	33	1

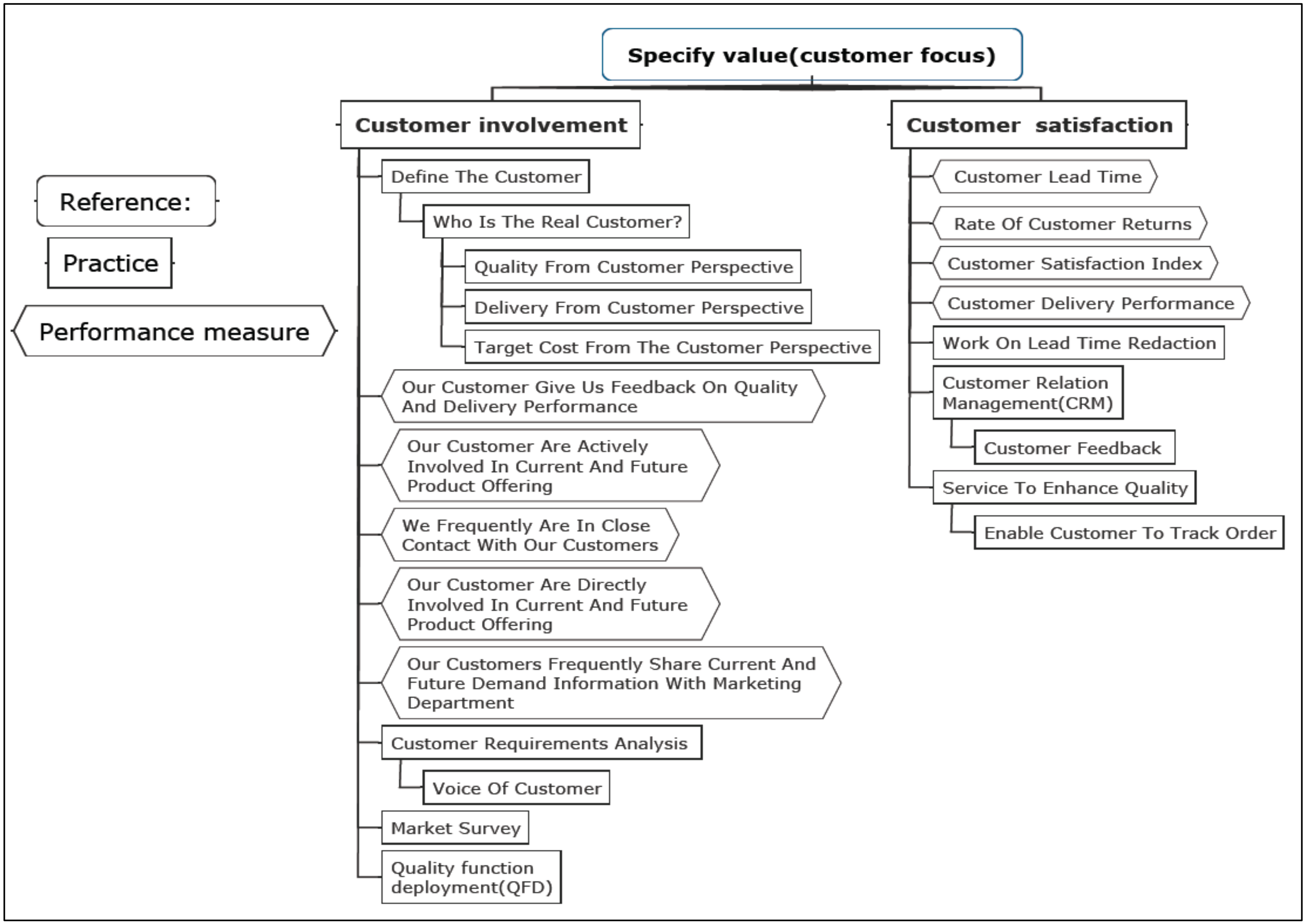
(1) (Anand & Kodali, 2008) (2) (Sánchez & Pérez, 2001) (3)(C. Karlsson & Ahlström, 1996) (4)(Bhasin, 2008) (5)(Mejabi, 2003) (6)(Detty & Yingling, 2000) (7)(Brown et al., 2006) (8)(Pavnaskar et al., 2003) (9)(White et al., 1999) (10)(Cumbo et al., 2006) (11)(Abdel-Maksoud et al., 2005) (12)(Srinivasaraghavan & Allada, 2005) (13)(Taj, 2005) (14)(T. Doolen, Traxler, & McBride, 2006) (15)(Koufteros et al., 1998) (16)(Shah & Ward, 2007) (17)(R. R. Fullerton & McWatters, 2001) (18)(Sakakibara et al., 1993) (19)(Shah & Ward, 2003) (20)(Upton, 1998) (21)(Hofer, Eroglu, & Rossiter Hofer, 2012) (22)(Rosemary R. Fullerton et al., 2003) (23) (Jina et al., 1997) (24)(Dong, 1995) (25)(Koh, Sim, & Killough, 2004) (26)(Christiansen, Berry, Bruun, & Ward, 2003) (27)(Mehta & Shah, 2005) (28)(Kojima & Kaplinsky, 2004) (29)(Oliver, Delbridge, & Barton, 2002) (30)(CHU & SHIH, 1992) (31)(Crute et al., 2003) (32)(Lewis, 2000) (33)(Wafa & Yasin, 1998)

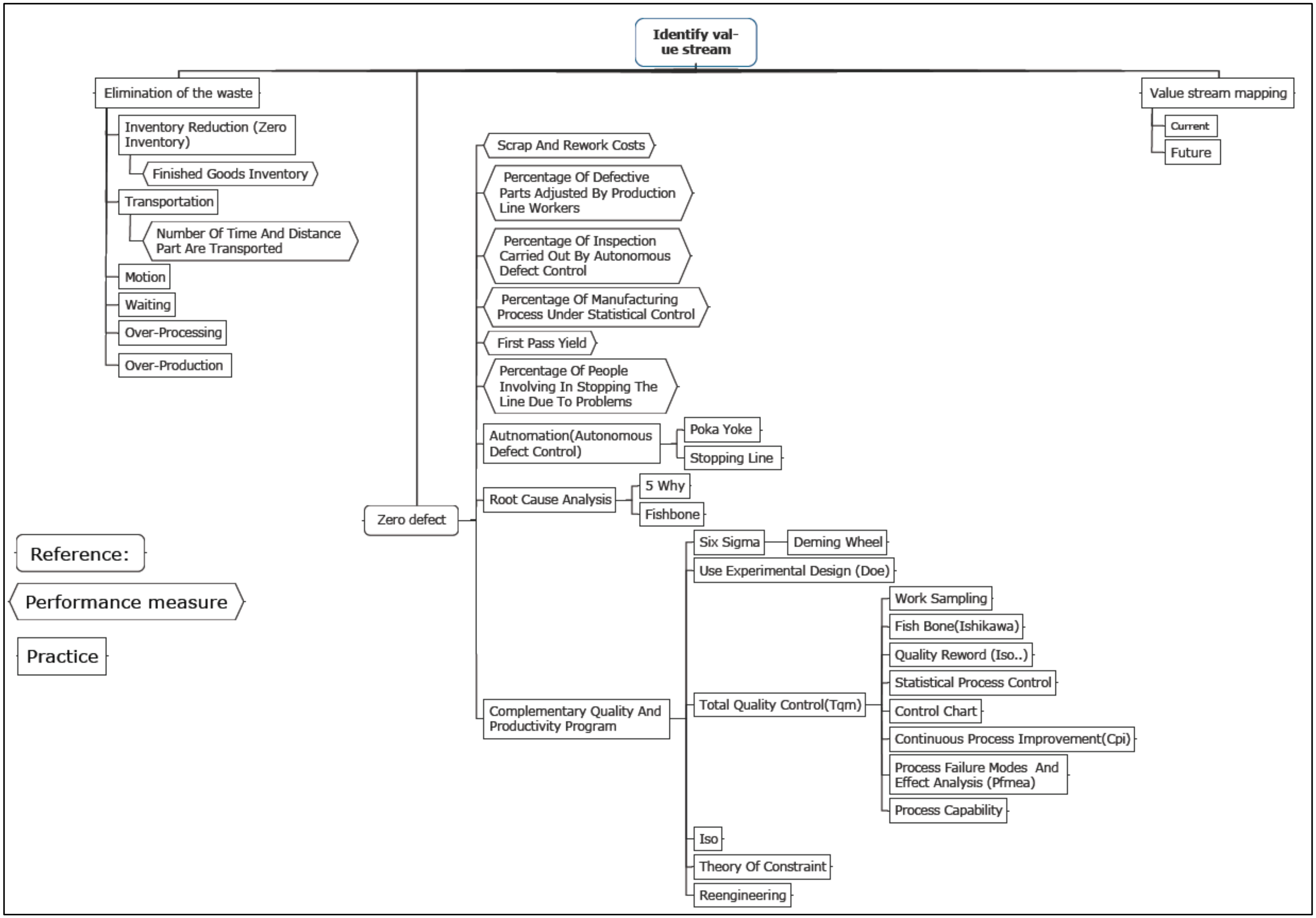
8.3 Appendix 3: An evaluation of balanced scorecard using the performance measurement checklist

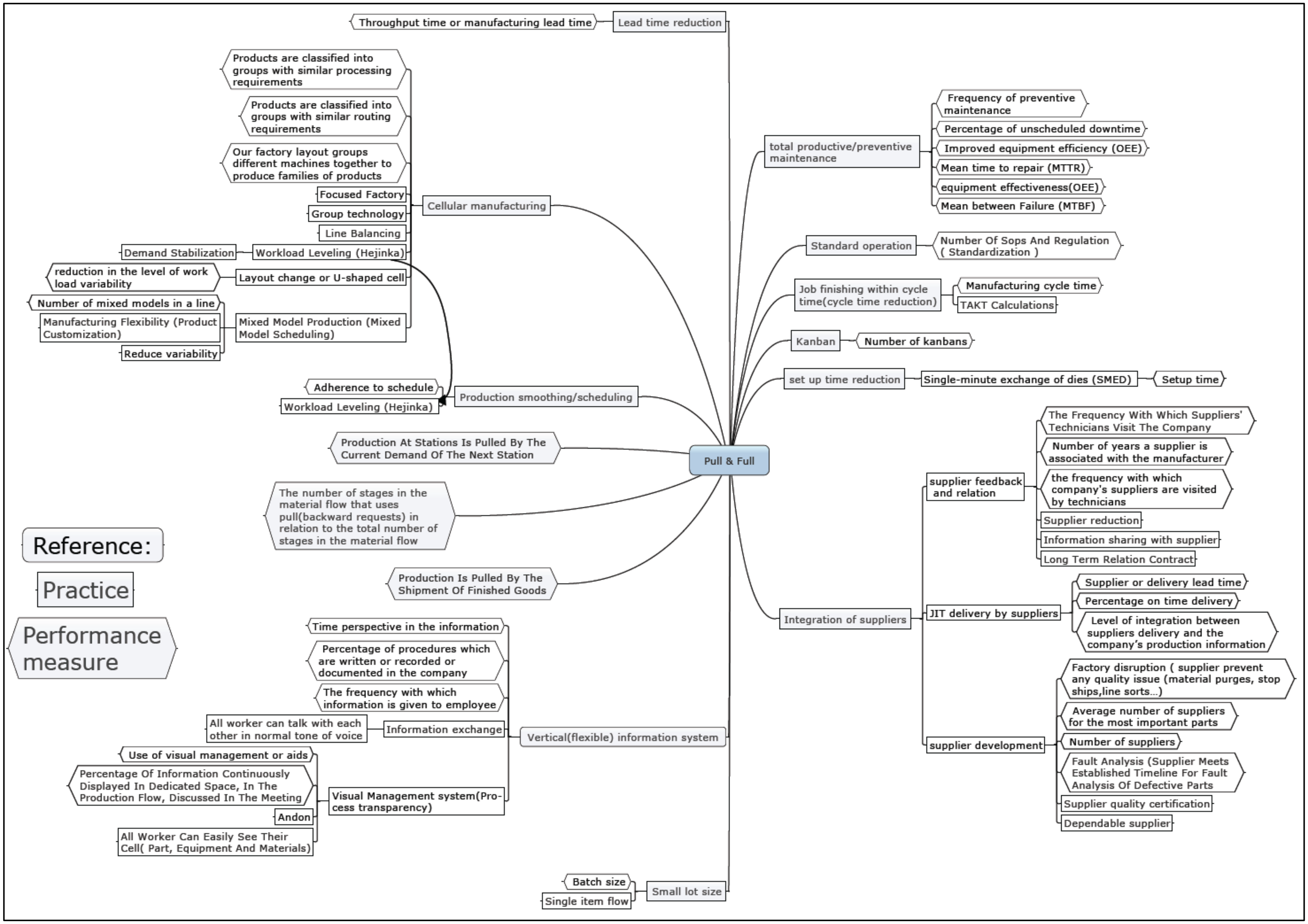
	YES/NO	Notes	Reference
Support organization strategy			
The performance measures are derived from the company's objectives	Yes		(R. S. Kaplan & Norton, 2004),
Translate the strategic objective into tactical and operational objective to the lower level of the company	Somehow	The balanced scorecard is designed to provide manager an overall view, so it is not applicable to operations level.	(Ghalayini, Noble, & Crowe, 1997)
The performance measurement system is consistence with strategic objective at each level	Yes	The balanced scorecard aligns the objectives on the four important perspectives contain nearly in all organization.	(R. S. Kaplan & Norton, 2004),
Balance between different performance measures:			
Balance between: short and long term results	Yes	The balanced scorecard links the objectives and measures so the short-term actions lead to long-term actions.	(R. S. Kaplan & Norton, 2004),
Various organizational level (global and local performance)	Yes		(R. S. Kaplan & Norton, 1993; Mohamed, 2003)
Between financial & non-financial	Yes		(R. S. Kaplan & Norton, 1993; Mohamed, 2003)
Between tangible & intangible assets			(R. S. Kaplan & Norton, 1993; Mohamed, 2003)
The measure vary between location- one measure is not suitable for all departments or sites	Yes		(R. S. Kaplan & Norton, 2004),
Cover various perspectives:			
Customer	Yes		(R. S. Kaplan & Norton, 2004),
Shareholder	Somehow	The balanced scorecard does not assess shareholder contribution. However, the balanced scorecard answer the question how does we look to our shareholder.	(Smith, 1998)
Competitor	No	The balanced scorecard does not consider the competitive perspective at all.	(A. Neely et al., 2005)
Internal Process	Yes		(R. S. Kaplan & Norton, 2004),
External Process	Yes		(R. S. Kaplan & Norton, 2004),
Suppliers	Yes		(R. S. Kaplan & Norton, 2004),
Innovation and future	Somehow	There are no specific operational measures are provided to assess future prospect. However, the balanced scorecard cover the innovation perspective	(Bhasin, 2008)
Learning and Growth	Yes		(R. S. Kaplan &

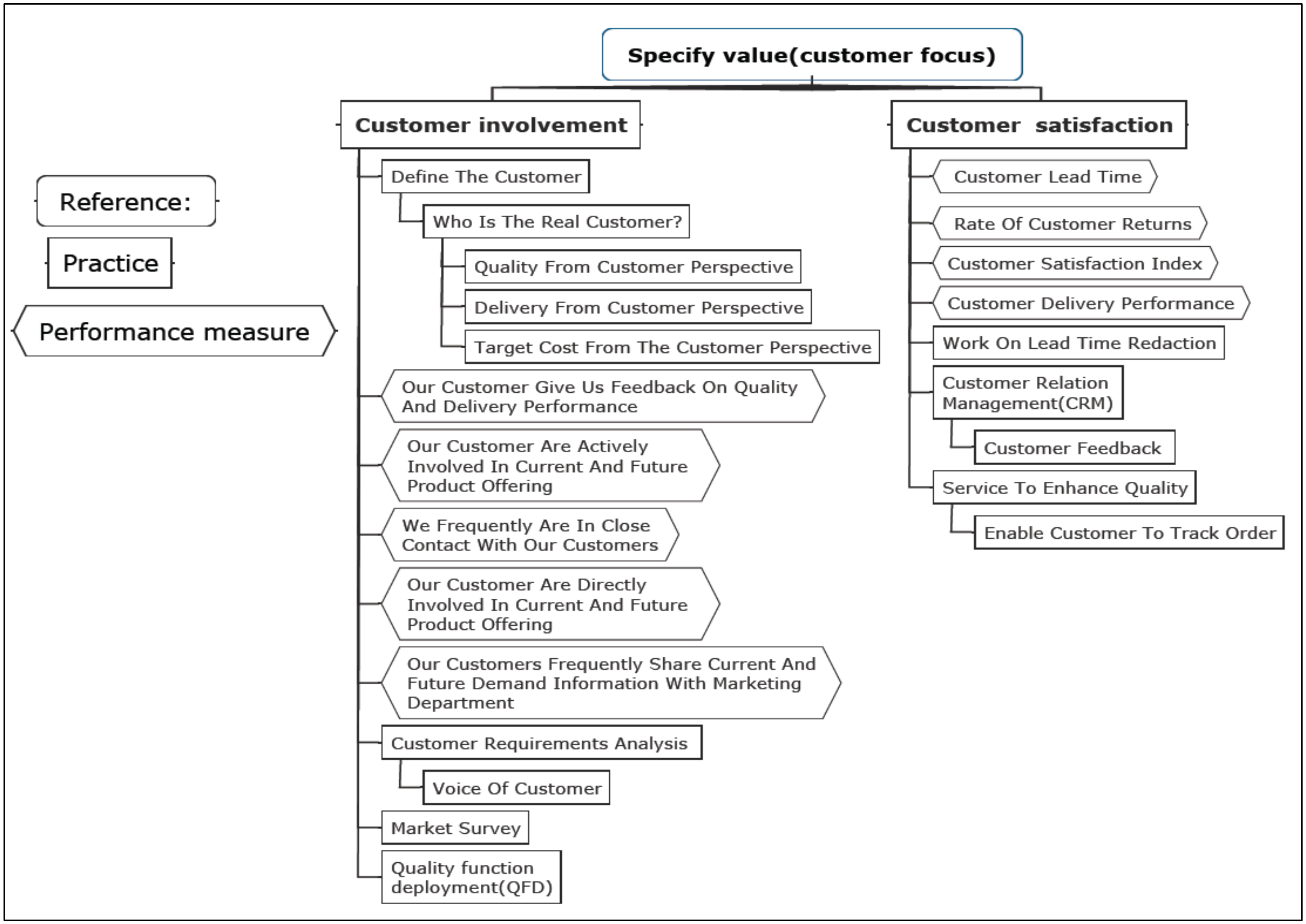
			Norton, 2004),
Cover different types of performance:			
Cost [1]	Yes		(R. S. Kaplan & Norton, 2004),
Quality [2]	Yes		(R. S. Kaplan & Norton, 2004),
Delivery [3]	Yes		(R. S. Kaplan & Norton, 2004),
Flexibility [4]	Yes		(R. S. Kaplan & Norton, 2004),
Dependability	Yes		(R. S. Kaplan & Norton, 2004),
Should provide fast and accurate feedback			
Have limited number of performance measures	Yes	The balanced scorecard minimize overload by limiting number of measures.	Stefan Tangen, 2004)
Information easily accessible	Yes	An IT balanced scorecard is recommended to achieve these requirement	(Bhasin, 2008)
Give important information, at the right time, to the right person	Yes		(Bhasin, 2008)
Timely and comprehensive information to provide critical decision	Yes		(Bhasin, 2008)
Translate the information into organizational knowledge and useful strategy	Yes	The balanced scorecard help to translate firm strategy and mission into tool that helps to plan and communicate the strategy with performance measures to facilitate achieving the objectives and narrowing the gab between mission and strategy with operational performance measures	(Hsuan-Lien Chu, Chen-Chin Wang, & Yu-Tzu Dai, 2009; Robert S. Kaplan & Norton, 2001a)
Real time accurate information	Yes		(R. S. Kaplan & Norton, 2004),
Diagnose the problem for the current situation	Yes	Balanced scorecards have been regarded as a means of integration between lagging and leading indicators.	(R. S. Kaplan & Norton, 1993)
Support continuous improvement			
Stimulate continuous improvement rather than simply monitor	Somehow	The balanced scorecard is mainly designed to monitoring rather than an improvement tool. However, it becomes a management system to implement strategy.	(Ghalayini et al., 1997), (Umayal Karpagam & Suganthi, 2012)
Easy to update (flexible)	Yes	An IT balanced scorecard is recommended to achieve this requirement	(Bhasin, 2008)
Guard against sub-optimization			
The measures are not contrary the corporate goal	Yes	The balanced scorecard forces managers to consider all measures and evaluate whether improvement in one area may have been achieved at the expense of another.	(Stefan Tangen, 2004)
Measures improvement in one area does not lead to deterioration in another	Yes		(Stefan Tangen, 2004)

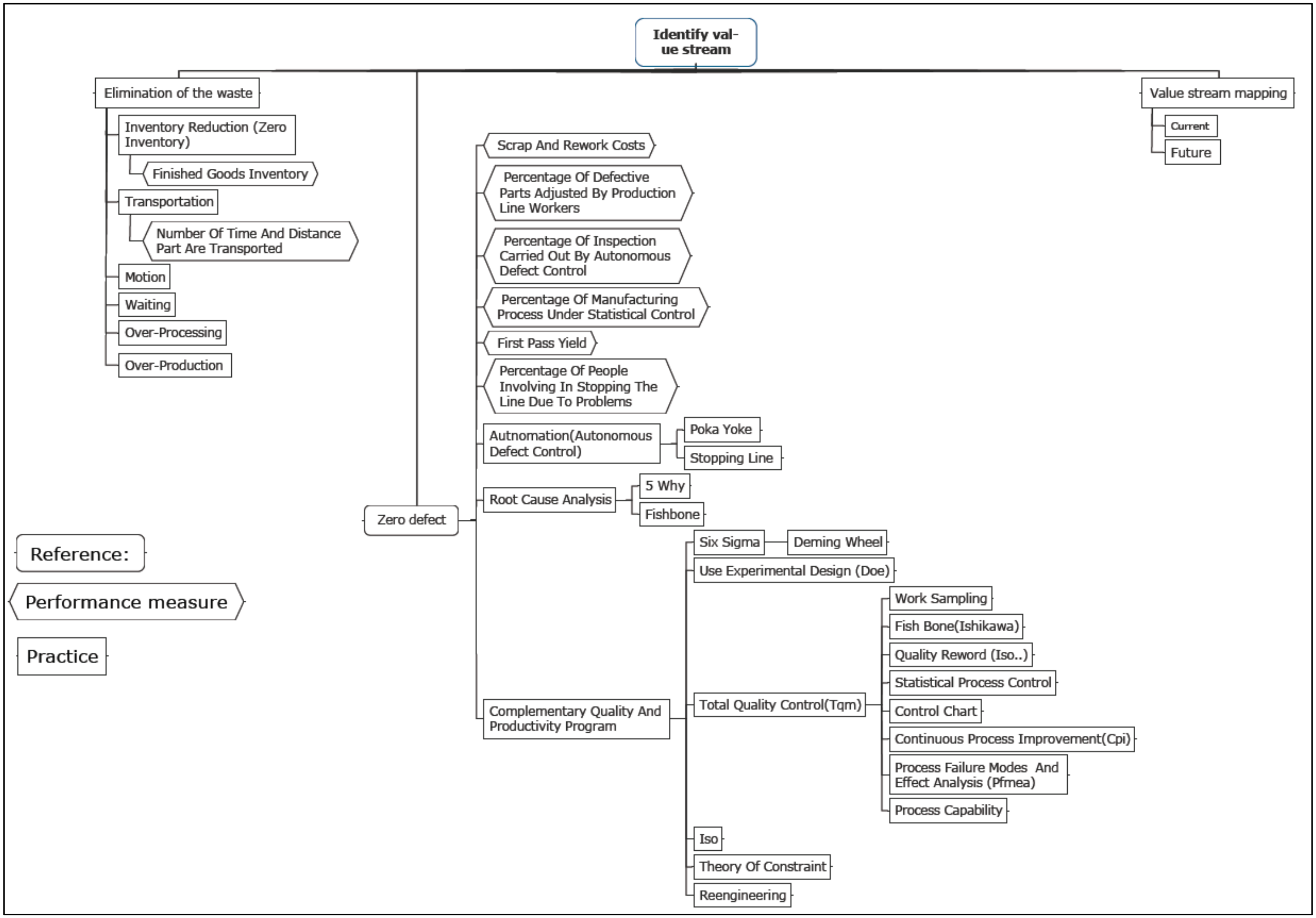
8.4 Appendix 4: Lean conceptual map based on the literature



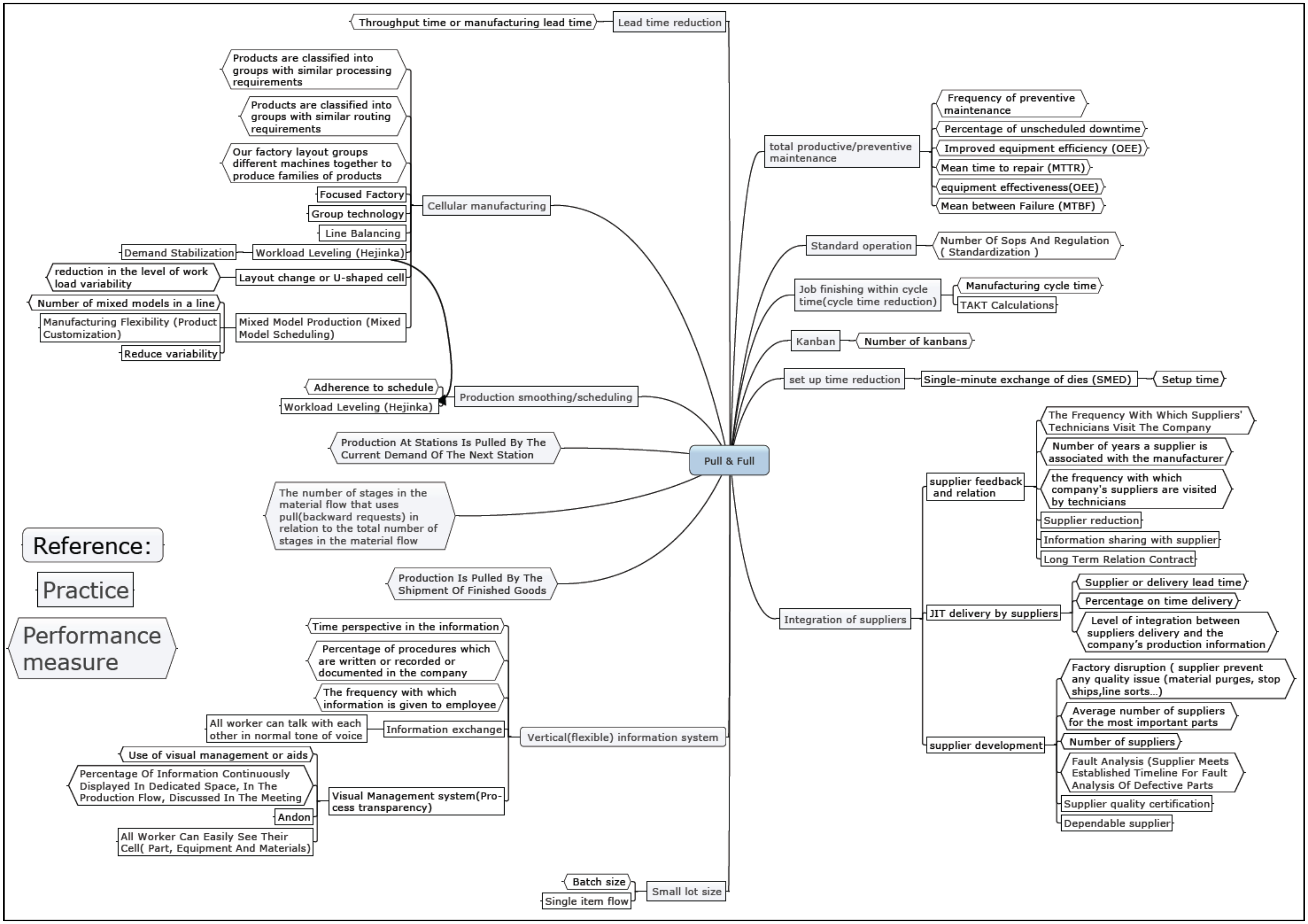

Identify value stream
Elimination of the waste
Inventory Reduction (Zero Inventory)
Finished Goods Inventory
Transportation
Number Of Time And Distance Part Are Transported
Motion
Waiting
Over-Processing
Over-Production
Zero defect
Scrap And Rework Costs
Percentage Of Defective Parts Adjusted By Production Line Workers
Percentage Of Inspection Carried Out By Autonomous Defect Control
Percentage Of Manufacturing Process Under Statistical Control
First Pass Yield
Percentage Of People Involving In Stopping The Line Due To Problems
Autnomation(Autonomous Defect Control)
Poka Yoke
Stopping Line
Root Cause Analysis
5 Why
Fishbone
Complementary Quality And Productivity Program
Six Sigma
Deming Wheel
Use Experimental Design (Doe)
Total Quality Control(Tqm)
Work Sampling
Fish Bone(Ishikawa)
Quality Reword (Iso..)
Statistical Process Control
Control Chart
Continuous Process Improvement(Cpi)
Process Failure Modes And Effect Analysis (Pfmea)
Process Capability
Iso
Theory Of Constraint
Reengineering
Value stream mapping
Current
Future
Reference:
Performance measure
Practice


Pull & Full
Lead time reduction
Throughput time or manufacturing lead time
Cellular manufacturing
Products are classified into groups with similar processing requirements
Products are classified into groups with similar routing requirements
Our factory layout groups different machines together to produce families of products
Focused Factory
Group technology
Line Balancing
Workload Leveling (Hejinka)
Demand Stabilization
Layout change or U-shaped cell
reduction in the level of work load variability
Mixed Model Production (Mixed Model Scheduling)
Number of mixed models in a line
Manufacturing Flexibility (Product Customization)
Reduce variability
Production smoothing/scheduling
Adherence to schedule
Workload Leveling (Hejinka)
Production At Stations Is Pulled By The Current Demand Of The Next Station
The number of stages in the material flow that uses pull(backward requests) in relation to the total number of stages in the material flow
Production Is Pulled By The Shipment Of Finished Goods
Vertical(flexible) information system
Time perspective in the information
Percentage of procedures which are written or recorded or documented in the company
The frequency with which information is given to employee
Information exchange
All worker can talk with each other in normal tone of voice
Visual Management system(Process transparency)
Use of visual management or aids
Percentage Of Information Continuously Displayed In Dedicated Space, In The Production Flow, Discussed In The Meeting
Andon
All Worker Can Easily See Their Cell(Part, Equipment And Materials)
Small lot size
Batch size
Single item flow
total productive/preventive maintenance
Frequency of preventive maintenance
Percentage of unscheduled downtime
Improved equipment efficiency (OEE)
Mean time to repair (MTTR)
equipment effectiveness(OEE)
Mean between Failure (MTBF)
Standard operation
Number Of Sops And Regulation (Standardization)
Job finishing within cycle time(cycle time reduction)
Manufacturing cycle time
TAKT Calculations
Kanban
Number of kanbans
set up time reduction
Single-minute exchange of dies (SMED)
Setup time
Integration of suppliers
supplier feedback and relation
The Frequency With Which Suppliers' Technicians Visit The Company
Number of years a supplier is associated with the manufacturer
the frequency with which company's suppliers are visited by technicians
Supplier reduction
Information sharing with supplier
Long Term Relation Contract
JIT delivery by suppliers
Supplier or delivery lead time
Percentage on time delivery
Level of integration between suppliers delivery and the company's production information
supplier development
Factory disruption (supplier prevent any quality issue (material purges, stop ships,line sorts…)
Average number of suppliers for the most important parts
Number of suppliers
Fault Analysis (Supplier Meets Established Timeline For Fault Analysis Of Defective Parts
Supplier quality certification
Dependable supplier
Reference:
Practice
Performance measure


Specify value(customer focus)
Customer involvement
Customer satisfaction
Reference:
Practice
Performance measure
Define The Customer
Who Is The Real Customer?
Quality From Customer Perspective
Delivery From Customer Perspective
Target Cost From The Customer Perspective
Our Customer Give Us Feedback On Quality And Delivery Performance
Our Customer Are Actively Involved In Current And Future Product Offering
We Frequently Are In Close Contact With Our Customers
Our Customer Are Directly Involved In Current And Future Product Offering
Our Customers Frequently Share Current And Future Demand Information With Marketing Department
Customer Requirements Analysis
Voice Of Customer
Market Survey
Quality function deployment(QFD)
Customer Lead Time
Rate Of Customer Returns
Customer Satisfaction Index
Customer Delivery Performance
Work On Lead Time Redaction
Customer Relation Management(CRM)
Customer Feedback
Service To Enhance Quality
Enable Customer To Track Order



Identify value stream
Elimination of the waste
Inventory Reduction (Zero Inventory)
Finished Goods Inventory
Transportation
Number Of Time And Distance Part Are Transported
Motion
Waiting
Over-Processing
Over-Production
Value stream mapping
Current
Future
Zero defect
Scrap And Rework Costs
Percentage Of Defective Parts Adjusted By Production Line Workers
Percentage Of Inspection Carried Out By Autonomous Defect Control
Percentage Of Manufacturing Process Under Statistical Control
First Pass Yield
Percentage Of People Involving In Stopping The Line Due To Problems
Autnomation(Autonomous Defect Control)
Poka Yoke
Stopping Line
Root Cause Analysis
5 Why
Fishbone
Complementary Quality And Productivity Program
Six Sigma
Deming Wheel
Use Experimental Design (Doe)
Total Quality Control(Tqm)
Work Sampling
Fish Bone(Ishikawa)
Quality Reword (Iso..)
Statistical Process Control
Control Chart
Continuous Process Improvement(Cpi)
Process Failure Modes And Effect Analysis (Pfmea)
Process Capability
Iso
Theory Of Constraint
Reengineering
Reference:
Performance measure
Practice


Pull & Full
Lead time reduction
Throughput time or manufacturing lead time
Cellular manufacturing
Products are classified into groups with similar processing requirements
Products are classified into groups with similar routing requirements
Our factory layout groups different machines together to produce families of products
Focused Factory
Group technology
Line Balancing
Workload Leveling (Hejinka)
Demand Stabilization
Layout change or U-shaped cell
reduction in the level of work load variability
Mixed Model Production (Mixed Model Scheduling)
Number of mixed models in a line
Manufacturing Flexibility (Product Customization)
Reduce variability
Production smoothing/scheduling
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Production At Stations Is Pulled By The Current Demand Of The Next Station
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Visual Management system(Process transparency)
Use of visual management or aids
Percentage Of Information Continuously Displayed In Dedicated Space, In The Production Flow, Discussed In The Meeting
Andon
All Worker Can Easily See Their Cell(Part, Equipment And Materials)
Small lot size
Batch size
Single item flow
total productive/preventive maintenance
Frequency of preventive maintenance
Percentage of unscheduled downtime
Improved equipment efficiency (OEE)
Mean time to repair (MTTR)
equipment effectiveness(OEE)
Mean between Failure (MTBF)
Standard operation
Number Of Sops And Regulation (Standardization)
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Setup time
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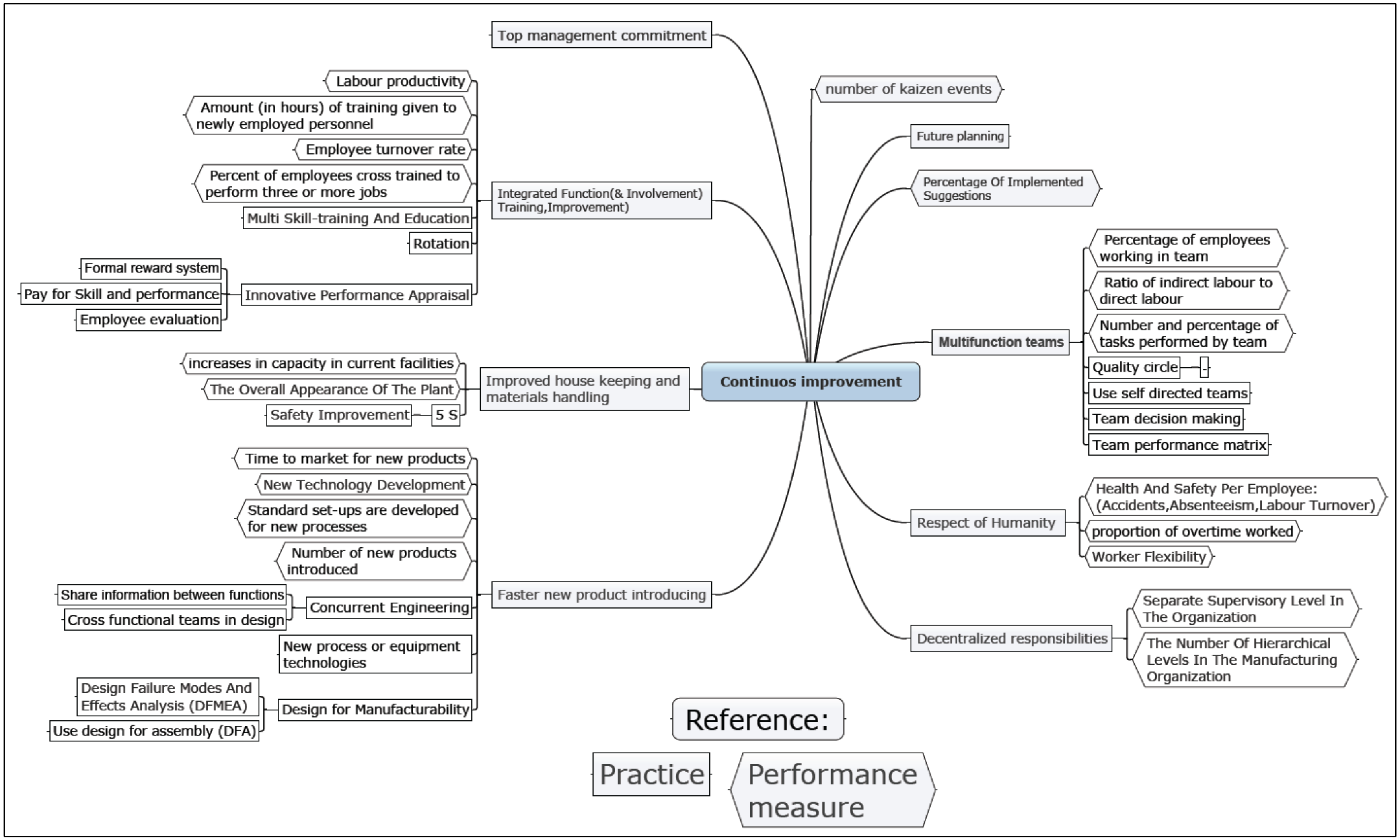
Information sharing with supplier
Long Term Relation Contract
JIT delivery by suppliers
Supplier or delivery lead time
Percentage on time delivery
Level of integration between suppliers delivery and the company's production information
supplier development
Factory disruption (supplier prevent any quality issue (material purges, stop ships,line sorts...)
Average number of suppliers for the most important parts
Number of suppliers
Fault Analysis (Supplier Meets Established Timeline For Fault Analysis Of Defective Parts
Supplier quality certification
Dependable supplier
Reference:
Practice
Performance measure


Continuos improvement
Top management commitment
Integrated Function(& Involvement) Training,Improvement)
Labour productivity
Amount (in hours) of training given to newly employed personnel
Employee turnover rate
Percent of employees cross trained to perform three or more jobs
Multi Skill-training And Education
Rotation
Innovative Performance Appraisal
Formal reward system
Pay for Skill and performance
Employee evaluation
Improved house keeping and materials handling
increases in capacity in current facilities
The Overall Appearance Of The Plant
Safety Improvement
5 S
Faster new product introducing
Time to market for new products
New Technology Development
Standard set-ups are developed for new processes
Number of new products introduced
Concurrent Engineering
Share information between functions
Cross functional teams in design
New process or equipment technologies
Design for Manufacturability
Design Failure Modes And Effects Analysis (DFMEA)
Use design for assembly (DFA)
number of kaizen events
Future planning
Percentage Of Implemented Suggestions
Multifunction teams
Percentage of employees working in team
Ratio of indirect labour to direct labour
Number and percentage of tasks performed by team
Quality circle
Use self directed teams
Team decision making
Team performance matrix
Respect of Humanity
Health And Safety Per Employee: (Accidents,Absenteeism,Labour Turnover)
proportion of overtime worked
Worker Flexibility
Decentralized responsibilities
Separate Supervisory Level In The Organization
The Number Of Hierarchical Levels In The Manufacturing Organization
Reference:
Practice
Performance measure

8.5 Appendix 5: Validated Practices and performance measures

Principle (Average)	Practices	Average out of 5	% of implementation	Performance Measures	Average out of 5
Specify Value	Customer Relations Management	3.21	64.23%	Customer lead time	4.10
	Customer Requirements Analysis	3.55	71.09%	Rate of customer returns	3.96
	Quality Function Deployment (QFD)	3.39	67.70%	Customer satisfaction index	3.69
	Supplier Integration	3.36	67.21%	Percentage of defective products shipped to customer	4.16
				Customer feedback on quality and delivery performance	4.11
				Active customer involvement	3.73
				Frequently of contact with customers	3.96
				Frequently of customers interaction with marketing department on current and future demand information	3.56
Respect of Humanity	Pay for Skill and Performance Safety Improvement	3.14	62.84%	Percentage of employees working In teams	3.16
	Safety Improvement	4.11	82.11%	Ratio of indirect labour to direct labour	3.35
	Multifunctional Teams	3.67	73.43%	Number and percentage of tasks performed by team	2.87
	Employee Training and Growth	3.46	69.10%	Labour Productivity	3.90
	Employee Involvement	3.53	70.60%	Amount (in hours) of training given to newly employed personnel	3.15
	Quality Circles	2.85	57.01%	Employee Turnover rate	3.12
	Self-directed Teams	3.05	61.04%	Percentage of implemented suggestions per employee	2.68
	Employee Improvement	3.32	66.32%		
Zero Defect	5s	3.91	78.17%	Scrap and rework costs	3.79
				Percentage of defective parts adjusted by Production line workers	3.05
	Andon Boards	2.82	56.34%	Percentage of inspection carried out by autonomous defect control	2.65
	Supplier Development	3.04	60.78%	Percentage of manufacturing process under statistical control	2.85
	Supplier Feedback and Relation	3.27	65.35%	First Pass Yield	3.50
	Poka Yoke	3.20	63.97%	Percentage of people involved in stopping the Line due to problems	2.85
	Complementary Quality and Productivity Program	3.15	62.90%	Percentage of information continuously displayed in dedicated Space, in the production flow	2.89
	Root Cause Analysis	3.79	75.73%	Time perspective in the information	2.71
	Visual Management System	3.62	72.46%	Percentage of procedures for which standard work instruction have been developed	3.54
	Statistical Process Control (SPC)	3.05	60.92%	The frequency with which information is given to employees	3.28
	Total Productive Maintenance	3.15	62.90%	Frequency of preventive maintenance	3.37
	Autonomation	2.65	52.92%	Percentage of unscheduled downtime	3.22
	Lead Time Redaction	3.15	62.92%	Finished Goods Inventory	3.88
	Small Lot Sizes	3.43	68.62%	Raw Material Inventory	3.93

Principle (Average)	Practices	Average out of 5	% of implementation	Performance Measures	Average out of 5
	Value Stream Mapping	3.57	71.45%	Total Productive Floor Space	3.06
	Quality Circle	2.73	54.62%	WIP Inventory	3.63
	Self-directed Teams	2.86	57.25%	Transport time and distance traveled for each part	2.74
	Employee Improvement	3.19	63.88%	Non Value Added Tme	3.05
	Customer Requirements Analysis	3.36	67.18%		
Flow	Line Balancing	3.40	68.00%	Takt Calculations	3.29
	Focused Factory	2.99	59.84%	Products are classified into groups with similar processing and routing requirements	3.47
	Cellular Manufacturing	3.37	67.42%	Our factory layout groups different machines together to produce families of products	3.35
	Group Technology	2.87	57.42%	Throughput Time or Manufacturing Lead Time	3.59
	Autonomation	2.58	51.68%	Setup Time	3.29
	Lead Time Redaction	3.16	63.11%	Reduction in the Level of Work Load Variability	3.00
	Value Stream Mapping	3.44	68.80%	Batch Size	3.16
				Number of mixed models in a line	2.98
Pull	Kanbans	3.32	66.35%	Number of Kanbans	2.86
	Standard Work	3.65	72.96%	Number of S.O.Ps and Regulation (Standardization)	3.44
	Value Stream Mapping	3.46	69.12%	The number of stages in the material flow that use pull(backward requests) in relation to the total number of stages in the material flow	2.54
	Supplier Integration	2.94	58.73%	Frequency of Production is pulled by the shipment of finished goods	2.63
				Frequency of production at stations is pulled by the current demand of the next station	2.75
Flow & Pull	Single-Minute Exchange of Dies (SMED)	2.49	49.84%		
	U-shaped Cells	2.95	59.05%		
	JIT delivery by suppliers	2.86	57.14%		
	Takt time	3.32	66.35%		
	JIT Production and Delivery	3.20	64.00%		
	Setup Reduction	3.38	67.68%		
	Small Lot Sizes	3.38	67.62%		
	Mixed Model Production	3.21	64.29%		
Continuous Improvement	Top Management Commitment	3.69	73.71%	Percentage of implemented suggestions per employee	2.63
	Long-term Philosophy	3.58	71.61%	Number of kaizen events	2.93
	Genchi Genbutsu	2.86	57.26%	Percentage of capacity increment of of current facilities	2.88
	Nemawashi	2.52	50.41%	The number of separate supervisory level in the organization	2.50
	Concurrent Engineering	2.81	56.23%	The number of hierarchical levels in the manufacturing organization	2.53
	Design for Manufacturability	3.12	62.40%	Time to market for new products	2.93
	New process or equipment technologies	3.12	62.44%	Number of new Technology Development per year/Month	2.46
Supplier Integration				The frequency with which suppliers' technicians visit the company	2.41
				Number of years a supplier is associated with your organization	2.81
				Supplier delivery lead time	3.43
				Percentage on time delivery	3.67
				Factory disruption (supplier prevent any quality issue (material purges, stop ships, line	3.22

Principle (Average)	Practices	Average out of 5	% of implementation	Performance Measures	Average out of 5
				sorts…)	
				Average number of suppliers for the most important process/production components	2.88
Cost Reduction				Manufacturing Cost per Unit	4.18
				Gross Annual Profit	4.43

8.6 Appendix 6: Definitions for the most important terms related to lean

Terminology	Definition	Citation
Value Stream Specification (identify value stream)	Identify activities that, when performed correctly, satisfy customer “wants” (activities that provide value)"	(Womack et al., 1990b)
Pull Production	Material is moved within the plant, or from the supplier, only when the next process in line needs the material processing	(Womack et al., 1990b)
Continuous improvement (Kaizen)	Generate, test , and implement process refinements in an ongoing drive for perfection.	(Womack et al., 1990b)
Supplier Integration	Provide regular feedback to suppliers about their performance, develop suppliers so they can be more involved in the production process of the focal firm and ensures that suppliers deliver the right quantity at the right time in the right place.	(Karlsson & Ahlström, 1996)
Value Specification (Specify value)	Identify what customers want (and/or are willing to financially support)	(Womack et al., 1990b)
Flow	Create continuous, interruption-free work process across value adding activities.	(Womack et al., 1990b)
Multifunctional teams	All workers are able to carry out all cell operations (i.e. cross-training is fully implemented).	(Karlsson & Ahlström, 1996)
Zero defects	Fault free product/service from beginning to end. Each person is responsible for quality assurance.	(Karlsson & Ahlström, 1996)
JIT Production and Delivery	Produce exactly what customer wants, when it is needed	(Karlsson & Ahlström, 1996)
Employee Training and Growth	Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.	(Liker & Kaisha, 2004)

Terminology	Definition	Citation
Visual Management System	Use visual graphs, charts that aid lean implementation and maintenance in the plant.	(Abdulmalek, Rajgopal, & Needy, 2006)
Decentralized Responsibilities	Responsibility and authority are shared across all levels of the organization	(Karlsson & Ahlström, 1996)
Vertical Information system	Provide timely information continuously and directly to all stakeholders and employee in the production line.	(Karlsson & Ahlström, 1996)
Respect for Humanity	Reflect respect for and sensitivity to morale, not making people do wasteful work, real team work, mentoring to develop skillful people, humanizing the work and environment, safe and clean environment, and philosophical integrity among management team.	("Principles of Lean Thinking: Tools & Techniques for Advanced Manufacturing," 2004)
Setup Reduction	Reduce the time and costs involved in changing tooling, layout, etc.	(R. E. White, Pearson, & Wilson, 1999)
Statistical Process Control (SPC)	Involves the implementation of the statistical tool (like control charts) that monitors process in order to identify improvement opportunities.	(Case, 2004)
Total Productive Maintenance	Ensure that machines will be able to operate at the maximum efficiency, at any time that they are needed producing the products of ultimate quality.	(Abdulmalek, Rajgopal, & Needy, 2006)
Employee Involvement	Create an environment that allow the workers to improve the process, develop solution and plan.	(Nicholas, 2011)
Long-term philosophy	Base your management decisions on a long-term strategy.	(Liker & Kaisha, 2004)
Workload Leveling	Stabilize and smooth the	(Abdulmalek, Rajgopal, & Needy, 2006)

Terminology	Definition	Citation
	production workload (level schedule). A process designed to keep the production level as constant as possible from day to day.	
Standard Work	Ensures that each job is organized and is carried out in a consistent and effective manner.	(Case, 2004)
Use only reliable, thoroughly tested technology that serves your people & processes	Use technology to support people, not to replace people. and support the process, not conflict with your culture or that might disrupt stability, reliability, and predictability.	(Liker & Kaisha, 2004)
Genchi Genbutsu	Go and see for yourself to thoroughly understand the situation.	(Liker & Kaisha, 2004)
Nemawashi	Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly.	(Liker & Kaisha, 2004)
Quality Circle	Formation of a group of workers to address work related problem.	(Case, 2004)
Self-directed teams	A group of workers who combine different skills and talents to work without the usual managerial supervision toward a common purpose or goal	(Shah & Ward, 2007)
Pay For Skill And Performance	Reward systems that seek to replace traditional reward systems to system that demand for more a knowledgeable, more highly skilled, and more flexible work force increases.	(Nicholas, 2011)
5s	a methodology for achieving a clean , orderly workplace. 5S is an abbreviation for sort, straighten, sweep, standardize, and sustain	(Case, 2004)

Terminology	Definition	Citation
Concurrent Engineering	a work methodology based on the parallelization of tasks (i.e. performing tasks concurrently). It refers to an approach used in product development in which design engineering, manufacturing engineering and other engineering functions are synchronized to reduce the time required to bring a new product to the market.	(Nicholas, 2011)
Design For Manufacturability	is the general engineering art of designing products in such a way that they are easy to manufacture.	(Nicholas, 2011)
Andon Boards	A system of flashing lights used to indicate production status in one or more work centers	(Nicholas, 2011)
Small lot sizes	Produce in small lots so as to keep the production process continuously moving.	(Abdulmalek, Rajgopal, & Needy, 2006)
Single-Minute Exchange Of Dies (SMED)	The ability to perform any setup activity in a minute or less of machine or process downtime.	(Abdulmalek, Rajgopal, & Needy, 2006)
Mixed Model Production	Assembles multiple product versions, intermixed on the same line and without changeovers.	(Nicholas, 2011)
U-shaped Cell	"Product-oriented cell layouts that allow an operator(s) to produce and transfer parts one piece, or one small lot, at a time.	(Nicholas, 2011)
Line Balancing	A synchronization process to ensure uniform flow rates across all workstations.	(Abdulmalek, Rajgopal, & Needy, 2006)
Group Technology	Improve the scheduling efficiencies by grouping similar (geometry, function, or production process) parts to minimize duplication, effort, and the	(Nicholas, 2011)

Terminology	Definition	Citation
	number of problem solving events.	
Focused Factory	A simplified factory with fewer processes, products, geared toward low-cost, high throughput operations.	(R. E. White et al., 1999)
Cellular Manufacturing	A manufacturing method whereby machines are arranged in a sequence/loop that maximizes product flow	(Abdulmalek, Rajgopal, & Needy, 2006)
Supplier Development	Involve suppliers in planning, and execution of process improvement and daily initiatives, to improve their ability to meet improved flow standards.	(Case, 2004)
JIT Delivery By Suppliers	Ensures that suppliers deliver the right quantity at the right time in the right place.	(Olsen, 2004)
Supplier Feedback And Relation	Provide regular feedback to suppliers about their performance.	(Olsen, 2004)
Autonomation	"The automatic shut-down of a process, line or machine in the event that a defect is detected.	(Abdulmalek, Rajgopal, & Needy, 2006)
Poka Yoke	Mistake-proofing, or designing systems in such a way that the right way is the only way.	(Case, 2004)
Customer Requirements Analysis	Identify customer needs through tools such as interviews and quality function deployment, then converting them to design or manufacturing requirements	(Fung, Popplewell, & Xie, 1998)
Customer Relation Management	is a model for managing a company's interactions with current and future customers. It involves using technology to organize, automate, and synchronize sales, marketing, customer service, and technical support.	(Nicholas, 2011)

Terminology	Definition	Citation
Lead Time Redaction	Reduce the delay between the initiation and execution of a process.	(Nicholas, 2011)
Kanbans	A card or sheet used to authorize production or movement of an item.	(Abdulmalek, Rajgopal, & Needy, 2006)
Takt time	"The rate of customer demand.	(Nicholas, 2011)
Top management commitment	Lean is a journey, not a destination. Top management support for this philosophy and willingness to incur initial costs of change.	(Womack et al., 1990b)
Value stream mapping	A technique used to map the entire value stream in an effort to identify value added vs. non-value added processes.	(Abdulmalek, Rajgopal, & Needy, 2006)
Employee Improvement	multi-skill training and education.	(Olsen, 2004)
Root cause analysis	A method of problem solving that tries to identify the underlying problems that hinder effective operations.	(Nicholas, 2011)