Analysis of Lean Practices as a Continuous Improvement Program in the Manufacturing Industry

Ky Layfield

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**Bhaskaran Gopalakrishnan, Ph.D., P.E., Chair
Robert Creese, Ph.D., P.E.
Alan McKendall, Ph.D.**

Department of Industrial and Management Systems Engineering

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ABSTRACT

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The operation of the manufacturing industry is becoming customer driven. Products being produced are dependent on the needs of customers in a highly competitive environment. Manufacturing facilities across the United States must adapt to compete with other facilities around the world. In order to deliver high quality and low cost products that satisfy the desires of customers, manufacturers are adopting continuous improvement programs to systematically increase their performance.

Lean manufacturing is a widely pursued continuous improvement program but success is divided. In order to understand how lean manufacturing is being used, a study of its practice across industry was performed. The development of an assessment tool is described that is used to collect data from manufacturers on the use of lean methods. Information from real world manufacturing facilities was gathered using a questionnaire to examine the lean practices being used and the difficulty in doing so. Industry experts were interviewed to understand common challenges that companies face when implementing lean manufacturing practices in their facilities.

The results of the research suggest that the application of lean manufacturing practices is not appropriate for all but the ideology is. Adequate knowledge of lean manufacturing is limited across industry at operational and conceptual levels. Lean tools are improperly applied when sufficient expertise is unavailable and not developed. A manufacturer's management group has an influential effect on how lean manufacturing is implemented and its performance. A change in company culture is required when transforming from traditional manufacturing practices to lean manufacturing methods. Continuous improvement programs require continuous learning to maximize the advantages they present. It is seen that the application of lean manufacturing practices provides an opportunity for achieving a continual increase in performance however there lacks an established structure for how to apply these practices.

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Introduction

1.1 Lean Manufacturing Overview

Lean manufacturing is a management philosophy based on the Toyota Production Systems (TPS) [20]. An organization that practices lean manufacturing aims to create and maximize value for their customers through eliminating waste from their products or services. Customer value involves identifying what service or product characteristics and features customers are willing to pay for. Inversely, waste is anything that does not add value for the customer. A lean manufacturing operation continuously works toward adding value to processes and products that customers desire. The structure of lean manufacturing at its core is a type of continuous improvement program that companies use to become proactive in problem solving. Endlessly striving for improvement is why lean manufacturing should be viewed as a way of thinking instead of a physical state. There is not a defined end point to lean, therefore its progress and success is measured by overcoming challenges and increasing business performance [32].

1.2 History of Lean

The principles of lean are primarily derived from TPS which was initially developed in Japan by Sakichi Toyoda starting in 1918 while inventing the automated loom for the textile industry [33]. During the creation of the automated loom, Toyoda developed a function that would cause the loom to stop whenever a thread broke during operation allowing for immediate evaluation of the problem. This provoked the idea of creating production processes that would indicate when problems in its operation arrived forcing them to be immediately resolved before the operation could continue. The development of TPS spread to Toyoda’s son, Kiichrio, who used the philosophy in 1937 for the production of automobiles for Toyota Industries. Kiichiro ran into a multitude of quality complications and embarked on a detailed analysis of each step in the production process. Taiichi Ohno, an engineer at Toyota, was responsible for structuring the process of Kiichiro’s analysis into a system that Toyota would use to generate improvements for its manufacturing efforts by determining areas where resources were being wasted.

While the primary influence to lean was constructed from the work of Toyoda and Ohno, the concepts of continuous improvement and waste reduction have traces throughout industrial history back from work by Benjamin Franklin in "*The Way to Wealth*", Frank Gilbreth's motion studies, Fredrick Taylor's scientific management, Shigeo Shingo's operation analysis techniques, and Henry Ford's mass production system [22] [26] [45] [50].

Lean manufacturing was first defined by John Krafcik while working on the book, "*The Machine That Changed The World*" (Womack, Jones and Roos, 1990). The book was initially published in 1990, and was based on a 5 year long research project by the Massachusetts Institute of Technology that studied automobile manufacturing facilities in 14 countries including America, Japan, and parts of Europe. The findings of the study characterized what is now known as a "lean system" and explained how Toyota's value based production model helped them become one of the most successful manufacturers in the world. Leadership expert Steve Denning proclaimed, "Lean is a change in management paradigm that was as monumental as the shift from craft-style to mass production", [10]. Lean can be confusing to traditional manufacturers because it is commonly seen as an evolution in management approach. Lean Enterprise Institute founder James Womack has stated, "It's a fundamentally different system than traditional management for organizing and managing employees, suppliers, customer relationships, product development, production and the overall enterprise," [5]. Lean should be viewed as an independent business management model, not a method type that accompanies an existing management structure.

1.3 Foundation of Lean

Lean is often identified as being a collection of tools and methods that are used for problem solving. Identifying where value and waste exist in manufacturing processes, and then mapping the sequence of the value added tasks while eliminating wasteful tasks is the key in lean manufacturing. These tasks of identification and elimination are completed by using the tools and techniques which are referred to as the lean manufacturing "toolbox". This toolbox contains sophisticated systems for executing improvement initiatives. There is not a right or wrong tool to be used, but selection is based on the needs of the company to efficiently create value. With lean manufacturing involving a large scope of applications, management of companies often tend to focus on the tools themselves while losing sight of their purpose. While tools and techniques are useful, users must recognize where application is appropriate. The approach to the lean toolbox should follow the saying, “a tool is only as good as its user”, which references the need for understanding the motives and limitations before using a certain tool.

A company needs to understand their capability for accepting lean methods before the application of any tool to ensure sustainable success. The company must first consider its culture, including leadership’s ability to take accountability, become critical of their own practices, and teach employees to embrace the idea that every task can be improved. There are five fundamental components to lean methods that are required for successful implementation [4]; (1) reviewing the job environment and satisfaction where the mindset of employees are examined to evaluate their response to change, (2) motivating participation from all personnel to work towards a common goal, (3) demanding responsibility from leadership to drive the initiative by following through with its execution, often referred to as the most important component, (4) changing behavior patterns of personnel to focus the company’s culture towards sustaining success, and (5) insisting on the use of lean methods and tools to keep a consistent vision for how change will occur.

An integral feature of lean manufacturing is that it begins at the highest level of management with an overview of the system and then is broken down into smaller sub-systems. This form of management practice is called the “top-down” approach and is essential in implementing lean manufacturing methods. The approach requires a strong commitment from leadership to build trust in each level of a company’s employment hierarchy, which in turn ensures all employees share dedication to the initiative.

1.4 Lean Manufacturing Practice

There are five principles to the lean process that are cyclically repeated throughout its practice [25]. The first principle is identifying value at which an organization must recognize the value that customers desire in the products and services they provide. The second is creating a value stream map that dissects the production process into activities based on their ability to add value, while eliminating the activities that do not add value to the process. The third principle is to focus on the flow of production and ensure that it operates efficiently. The fourth principle is establishing a pull system where work upstream in the process is only performed when requested downstream by the customer. The fifth principle is to continually repeat the process until no waste exists and the value stream is optimized.

Lean manufacturing practice is continuous improvement that focuses on waste, but is often over-generalized and can be difficult to define. With a variety of management strategies, it is easy to confuse the applications. Similar continuous improvement methods to lean manufacturing include: Total Quality Management (TQM), Six Sigma, TPS, Theory of Constraints, Quality Circles, Just-In-Time (JIT) and Agile Manufacturing [5]. Individuals with limited technical knowledge of these methods commonly confuse their distinctions and use the terms interchangeably. It can be difficult to clearly categorize the continuous improvement methods because they can become derivative of each other as functions do overlap. In an attempt for consistency, organizations should establish a method to use and follow its terminology.

While many of these methods primarily share the same goals and can use the same tools, they are different based on their approach and thought process. For instance, JIT practices forced problem solving by focusing on throughput and inventory management, while Six Sigma desires to attain extraordinary process capability by reducing defects by using statistical methods. Although derived from TPS, which stresses assembly-line employee empowerment and education, the lean manufacturing approach drives improvement by understanding the customer’s needs. The goal of creating the perfect value stream through lean manufacturing is the same for all manufacturers; however the execution of the concepts is unique to each area of application, which can be independent between industries, companies and even facilities.

The elimination of waste in a manufacturing process's value streams is a core function to the lean ideology. Toyota's Taiichi Ohno identified the most common types of waste in the development of TPS [52]. These seven original wastes are: defects, inventory, motion, over-processing, over-production, transportation, and waiting. Although these are the most well-known, review of literature on lean manufacturing shows other types of waste exist such as under-utilized human capacity and accidents. There are also specific wastes that are dependent on the industry sector. Lean is a management philosophy which was born in a manufacturing environment, but has spread to nearly all business types. For example, lean wastes identified in a hospital would not be the same as those identified for a software developer or an accounting firm, all of which have their own version of applying lean methodology to their practices.

Once of the most prominent challenges in lean manufacturing is identifying waste. Luckily, there are tools and techniques that have been developed to help. The selection of which tools to use in identifying waste can become overwhelming depending on knowledge and previous experience in using lean manufacturing methods. Management's ability for understanding the company culture and possessing expertise in judgment are also factors in correctly selecting the proper tool. There are different levels of sophistication between various lean manufacturing methods, where some are just a continuation of other methods that can be expanded with the mastery of practice. A company's lean manufacturing toolbox is only as powerful as the user, thus strong understanding of the lean manufacturing philosophy allows for greater rewards. Organizations that strive to become "lean" tend to benefit from responsive production, higher quality, increased productivity, and greater customer satisfaction. The longer an organization practices lean methods, the more opportunities for improvement will present themselves

One of the tools that is commonly used for new organizations implementing lean manufacturing is "5S." Hiroyuki Hirano developed 5S as a method for organizing work spaces. The acronym 5S stands for the five pillars of the methodology *seiri*, *seiton*, *seiso*, *seiketsu*, and *shitsuke*. When translated from Japanese they mean s*ort*, s*et in order*, *shine*, s*tandardize*, and s*ustain*. Each pillar represents a stage in the cylindrical process that should be focused on [16]. Respectively they are: identifying items such as tools and equipment that are not needed for the work station tasks and removing them, organizing the remaining items so they are easily found, keeping the work station clean, creating a set of organizational procedures, and maintaining the routine.

Fundamentally, lean manufacturing operations use a ‘pull-based’ production system [16] [25]. Production systems can be either pull- or push-based. The difference between the two is that a pull-based system is reactive to customer demands, where the more traditional push-based system speculates customer demand [47]. With the push system, manufacturers produce products based on their capabilities. The work follows a schedule and is performed whether the demand is there or not. Products are pushed through process based on the input of the production system. The product moves to the next stage in the process once it has been completed in the previous stage. The issue in push systems is if the projected demand is incorrect, too many products are produced when demand does not meet expected levels, thereby creating excess inventory. If the demand is larger than expected, not enough products are produced and revenue is lost. This production system can waste resources by creating products that are not needed. A pull system creates minimal inventory because the only products produced are to meet customer demands that actually exist. The work is only performed when authorized. The products are pulled through the process stages based on the need from the output of the production system [47]. Once the output of the production system notifies that work needs performed, it is requested by the last stage in the process. Once the receiving process stage is ready for work, the preceding stage is alerted and it begins its work. The communication between stages in the process is managed by signals. These signals are called “kanbans”, which is translated from Japanese to signboard. A kanban can be a notecard, a series of lights, or anything that can notify when work needs to be performed [16] [47]. The use of kanbans in the pull production system allows for a higher level of communication and an increase in control of the work being performed, which limits any waste from being created.

A concern for lean manufacturing facilities attempting to optimize their production processes is bottleneck management. In order to meet any customer’s demand, a manufacturer needs to have a production system that is able to operate at its full capacity. A bottleneck is any process within the production system that limits its capacity or throughput. In order for the production of products to flow smoothly, capacity can be only be as large as the process with the smallest capacity. Typical lean manufacturing methods for eliminating or relieving the effects of a bottleneck include; increasing the bottleneck's capacity by purchasing new process equipment, restructuring the sequence of processes to avoid the bottleneck, and decreasing the lot size of products that arrive at the bottleneck [16]. The last method of reducing the lot size is commonly used when the purchase of new process equipment is infeasible and the sequence of processes cannot be altered to avoid the bottleneck. Ideally, a lean manufacturing facility produces products with lot sizes equal to one. When only one product moves between processes there is no work in process (WIP) inventory and the amount of defects can decrease by detecting errors before a large amount of products are processed, both of which being wastes in lean methodology. Reducing lot sizes to one is referred to as continuous or one-piece flow, where a discrete production process can behave like a continuous production process. A continuous production process is an ultimate lean manufacturing process, as it is achieved by becoming exemplarily balanced.

Another practice that is common for lean manufacturing is known as *poka-yoke*, which is Japanese for 'error proofing'. In poka-yoke, focus is placed on eliminating or reducing the chance for human error. This can be accomplished by designing work stations and tasks to become more limited or constrained where functions are only allowed to perform according to proper use. For reducing errors that are equipment or machine related, there are lean tools that focus on preventative maintenance. A structured program is put in place where regular maintenance and testing is performed on equipment to detect worn components or identify issues that may cause irregularities during operation. The goal of error proofing and preventative maintenance is to reduce defects and variability in the production process, all of which are seen as waste in lean manufacturing.

A few of the more frequent practices have been identified, but there is an endless amount of other tools and techniques that are used to execute continuous improvement initiatives using lean methods, with each following the same underlining theme. Lean manufacturing is about maximizing the production value of a company's products in terms of the customer. Every improvement initiative looks to eliminate wasted resources and increase the overall performance of the production process. When a company looks to pursue implementing lean manufacturing, it can easy be overcome by the possibilities. With a study of the most commonly used practices, a better understanding can be gained for not only what is being used, but why. Collecting information for how companies are applying lean concepts will help not only those who look to use lean manufacturing methods, but those that are currently practicing, allowing for comparisons to be drawn and an assessment of lean manufacturing in its current state, aiding in the establishment of structured practices.

1.5 Need for Research

The study of lean manufacturing practice helps individuals to understand how companies are pursuing continuous improvement initiatives based on the lean management philosophy in real world situations. It explores how the concepts of lean are being interpreted and applied in a practical setting rather than detailing an idealistic situation. Based on the information collected, conclusions can be drawn that help characterize lean manufacturing comprehension while identifying knowledge areas of strengths and deficiencies. Providing a measure for facilities that participate in the study educates those that are currently engaged in lean manufacturing along with those that are not, allowing them to compare their facility’s position to others that share similar goals for their products and services.

The research is valuable because it collects lean manufacturing application data from both lean and non-lean facilities in a real world setting which is then conferred with continuous improvement experts that specialize in the consultation of manufacturer business development. A viewpoint is provided that reviews both instruction and application of lean manufacturing practice, thus allowing an evaluation of effectiveness and direction in implementing lean methods.

More specifically, the research helps local-area manufacturing facilities by focusing the analysis on companies of similar industries located within a shared region, thus providing information that resonates stronger than a nationwide study. The research’s purpose becomes more intimate and personal by conducting a study that will have a direct impact on manufacturing operations throughout the area. As the state's flagship school and premier institution, West Virginia University is responsible for developing knowledge and technology that will benefit and promote the economic growth of West Virginia. In 2011, manufacturing in West Virginia accounted for 6.6% of its employment, ranking it 39th in the country [34]. The manufacturing sector also accounts for 56% of West Virginia's exports, illustrating its importance to the state's economic welfare. Therefore, it is essential that the university's manufacturing research be able to assist businesses across the state and surrounding areas in their efforts, thus creating a stronger relationship between the two that is beneficial for both.

The knowledge gained from this research provides information for manufacturing facilities to reference from when assessing their continuous improvement program and reviewing their lean manufacturing position, which leads to refined decision making for the practices they use by becoming better informed. The information also helps programs that educate the practice lean manufacturing and promote expertise in advanced manufacturing concepts such as West Virginia University and NIST Manufacturing Extension Partnership centers, which aids in directing future educational initiatives based on the needs of industry.

1.6 Research Objectives

The objectives of the research project were: (1) to develop a skip-logic assessment tool for the analysis of lean manufacturing practices being used in industry; (2) to verify the assessment tool as a feasible application that quantifies lean manufacturing practices with manufacturing experts; (3) to assess lean practices of facilities that currently utilize lean manufacturing and provide comparison information to allow them to improve their efforts; (4) to identify the challenges or difficulties in facilities who recognize lean manufacturing but do not pursue its practice and compare them to the difficulties experienced by lean practicing facilities; and (5) to verify the conclusions drawn from the questionnaire responses in interviews with lean manufacturing experts across industry.

1.7 Conclusions

Modern manufacturing efforts are highly influence by the lean philosophy. In order for the United States to produce goods that compete on a global scale, it must advance its knowledge and align operations to the level of world-class manufacturing facilities. In order to reach that level, the proper foundation must be laid that educates manufacturers in the appropriate execution of lean manufacturing practice. A new thought process is required as manufacturing shifts towards customer driven innovation, which creates challenges as the transition is being made.

Chapter 2

Review of Literature

A review of publications discussing the use of continuous improvement programs and implementing lean manufacturing practices in industry is discussed here. The application of lean is examined from performance, organizational structure, and philosophical positions. Key characteristics for success and failure of lean manufacturing practices are identified.

2.1 Continuous Improvement Programs

In a 2010 U.S. Census Bureau survey, over 30,000 manufacturing plants were questioned about their management practices in the largest scale study to investigate successful manufacturer management characteristics [6]. Results showed that manufacturing plants with a firmly structured management practice had a strong relationship to better performance. Regularly measuring performance and setting operational targets resulted in more productivity and profits. The survey questions used to analyze management practices were based on the principles of continuous monitoring, evaluation, and improvement found in lean manufacturing. The results show that over 18% of the survey participants engaged in more than three-fourths of practices listed in the study while 27% utilized less than half of the structured management practices.

U.S. manufacturers identified process improvement and customer-focused innovation as the two most important strategies in their organization's success over the next 5 years according to the 2011 Next Generation Manufacturing (NGM) Study performed by the Manufacturing Performance Institute [36]. The biennial national study also noted that manufacturers placed a greater emphasis on sustainability by nearly 25% between 2009 and 2011.

In a 2007 manufacturing census conducted by Industry Week (IW) magazine and the Manufacturing Performance Institute (MPI), 433 respondents were asked over 100 questions about their company's manufacturing metrics, management practices, and financial results [5]. Table 2.1 details findings from the study where over three-fourths of the respondents acknowledge their company applied continuous improvement programs to their business strategy, with nearly 70% deciding to embrace lean manufacturing as shown in Table 2.2. The application of continuous improvement was the most common strategic practice. Similarly, lean manufacturing was also the most widely used improvement method.

Table 2.1: 2007 IW/MPI manufacturing census strategic practices [5]

Rank	Strategic Practice	%
1	Continuous Improvement	76.9
2	Recycling / Reuse Program	56.1
3	Quality Certification	55.9
4	Customer Satisfaction Surveys	51.4
5	Value Stream Mapping	45.5
6	Kaizen Events / Blitzes	45.5
7	Environmental Management	43.6
8	Benchmarking	42.5
9	Supplier Management Program	36.1
10	Total Productive Maintenance	34.2
11	Energy Management	32.8
12	Quick Changeovers / SMEDs	29.3
13	Strategy / Policy Deployment	26.9
14	Open-Book Management	16.0
15	None of These	4.0

Table 2.2: Improvement methods used by census respondents [5]

Rank	Continuous Improvement Program	%
1	Lean Manufacturing	69.9
2	Total Quality Management	34.2
3	Six Sigma	29.0
4	Toyota Production System	17.0
5	Other	14.6
6	Theory of Constraints	14.4
7	None	11.6
8	Agile Manufacturing	6.4

In the same IW/MPI 2007 study, 17.8% respondents noted a major increase in productivity from the use of a continuous improvement program, 67.2% said there was some increase, while 12.4% saw no change and 2.7% reported a decrease.

A survey on the continuous improvement programs used in the Canadian food industry was conducted by Scott, Wilcock and Kanetkar (2008). Through the survey they hoped to identify significant motivational factors for implementing a continuous improvement program. Measured on a 3 point scale, 13 of the 15 motivational factors provided were statistically significant at a 5% level, with the exception of increasing speed to market for new products and increasing line item fill rate (LIFR). The most significant motivational factors for using continuous improvement programs were reducing the number of deviations, improving quality performance, and reducing the risk of product recalls [43].

2.2 Lean Manufacturing Practice

The practice of lean manufacturing in the United States is widely acknowledged and the Environmental Protection Agency (EPA) has created a Lean & Environment Toolkit for businesses that are looking to adopt the lean manufacturing philosophy. The EPA conducted numerous case studies for how lean manufacturing has been incorporated into a variety of organizations' business strategies and has provided reports on the benefits obtained and best practices used [8]. The EPA identified key findings in a summary of their studies: (1) "Lean produces an operational and cultural environment that is highly conductive to waste minimization and pollution prevention", (2) "Lean can be leveraged to produce even more environmental improvement", (3) "Some regulatory 'friction' can be encountered when applying lean to environmentally-sensitive processes", and (4) "Environmental agencies have a window of opportunity while companies are embarking on lean initiatives and investments – to collaborate with lean promoters to further improve the environmental benefits associated with lean".

Even though there are many organizations and businesses that aim to help ensure lean manufacturing success, many manufacturers still fail to achieve a lean transformation. A 2011 study was conducted on lean culture and leadership by Lawrence Miller who authored the books "*Lean Culture – A Leader's Guide*", "*The Team Guide to Continuous Improvement*" and "*Getting to Lean – Transformational Change Management*." Miller investigated factors that companies implementing lean methods felt were important to success, as well as how those factors performed within their organization. A total of 60 factors were provided, which companies ranked from highest importance for success to the most deficient in execution [31]. The top factors for each are listed in Table 2.3.

Table 2.3. Success and deficiency factors of manufacturer's implementing lean [31]

Rank	*Success Factors*	*Deficiency Factors*
1	Creating a sense of purpose	Managers have defined leader standard work
2	Instilling the spirit of teamwork by management	Most managers engage in disciplined problem solving
3	Promoting strong values	Managers are able to follow a disciplined problem solving model
4	Leaders that are effective in engaging team members	Every employee is a member of a team
5	Leaders creating employee empowerment	Managers can show a visual map of their processes

The prominent obstacles that prevent organizations from embracing lean methods or pursuing it further were studied by Bhasin (2011). The preventive reasons where based on organizational size in terms of employee numbers. Funding was the most prominent barrier for small organizations with less than 50 employees. In medium (50-250) and large ($\geq$ 250) organizations, supervisor skills were the largest challenge to sustaining a lean environment [3].

A case study was examined by Turesky and Connell (2010) to determine the factors that led to the derailment of a lean manufacturing initiative. The study determines that there are four phases that lay the groundwork for long-term success of lean projects: foundation, preparation, implementation, and sustainability for long-term improvements [49]. Derailment was identified to be caused by lack of accountability, ownership, and follow-up. In order to maintain sustainability, these factors must take priority.

Deflorin and Scherrer-Rathje (2011) examined lean manufacturing in the automotive industry for mass production, along with different challenges for craft producers attempting to apply lean methods. Their work concludes that the smaller craft producers have specific issues that pertain to lean methods, and that the initial process choices are an important factor to account for before implementing lean methods [9].

The relevance of relationship management was examined in 27 lean manufacturers by Panizzolo (1998). The full implementation of lean methods relies on the critical factor of external relationships rather than internal operations. The challenge then becomes integrating different organizations into value stream mapping [37]. Conclusions drawn indicate that the focus is required to be relationship management rather than operations management.

Facilities in India were examined to understand lean manufacturing practices' current status and impact on operations by Ghosh (2012). The research illustrates that lean manufacturing is a multi-dimensional construct in which 80% of survey participants have implemented some type of lean dimension at their facility [14]. The survey results were analyzed by a scorecard premise with the most commonly applied lean dimensions being monitoring supply performance, adding focus to customer needs, and implementing a pull system. The main drivers for lean implementation were first-pass correct output, reducing lead time, and increasing productivity.

Lean manufacturing performance in China was evaluated by Taj (2007) to explore how it has evolved from auto-manufacturing, and since been expanded across all industries. An assessment tool was created using a balanced scorecard approach. The study concludes that manufacturers apply lean methods to elevate practices based on inventory, team approach, processes, maintenance, layout/handling suppliers, setups, quality scheduling and control [46]. To monitor the performance of lean methods, companies cannot rely on accounting metrics alone. Lean methods are required to stay competitive, as they focus on operation performance and customer satisfaction.

Rahman, Laosirihongthong and Sohal (2010) studied the impact of which lean strategy a Thai company chooses to pursue in terms of its effect on operational performance. The study utilizes a survey that examines 13 lean strategies of 3 high level components of the lean construct throughout different organizations, just-in-time (JIT), waste minimization, and flow management. The results show that JIT has more significant impact on operational performance for large organizations (> 200 employees) than small (≤ 200) [39]. Small organizations saw waste minimization as a more significant impact compared to their larger counterparts. Both organizational sizes did not show much significance in flow management. In terms of ownership, all groups (Thai, foreign, and joint ventures) sought the importance of JIT, which had the highest significance on operational performance. Foreign owned companies displayed a higher significance for waste minimization and flow management than Thai and joint-owned operations.

Achanga et. al. (2005) researched the critical success factors for small manufacturing enterprises implementing lean manufacturing. The method used was a combination of reviewing literature material and interviewing essential personnel inside companies that implemented lean manufacturing by the Delphi method, and then analyzing information and responses across lean workshops and case studies. The research concluded that leadership, management, financial and organizational culture, corresponding skill, and expertise were the most important factors for successful implementation of lean manufacturing [1]. Lack of sufficient funding was a key concern for many small organizations because they cannot hire a management team experienced with lean methods. A sub-standard management team lacks the required leadership and planning skills to implement lean methods successfully.

Pettersen (2009) reviewed work focused on the definition of lean production, and presents issues that pertain on both conceptual and practical levels. In his analysis of literature, he finds large discrepancies between the authors' definition of lean production and the characteristics it possesses [38]. This presented difficulty for understanding lean methods on the conceptual level and within organizations attempting to implement it. As Hines et. al. (2004) states, lean is a moving target, and to define it only represents how it is characterized in that instance. Organizations must understand that differing opinions create various offerings to the processes [17]. Selection of the lean variants to be used should not be selected without review for which variant is best for the organization's requirements. Taking an unbiased approach to creating a lean continuous improvement program allows for the greatest chance of success.

2.3 Conclusions

There are many research efforts found in literature that attempt to quantify the practice of lean manufacturing and relate factors that lead to success or failure on its implementation. The context and scale of observation varies between studies making it difficult to determine significance of the results. There are common themes that are identified across the reviewed literature that highlight leadership, technical skills, and motivation as characteristics that have a significant effect on a facility's ability to transform towards the practice of lean methodology. Using this information gives foresight to be aware of when examining how facilities are employing lean manufacturing practices.

One of the most prominent challenges is defining lean by itself. There are many conflicting definitions and characterization of what lean manufacturing consists of. Lean manufacturing was first formally defined in 1990 but it is a philosophy that has evolved from ideals extending over the last century across various cultures and industries. For a modern manufacturer attempting to learn how to apply lean manufacturing concepts in their facility, the supply of information can be overwhelming. In the review of literature, there are many, yet differing, best practices identified but without an understanding of the context that the practices are being used their application can be unsuitable for some manufacturers. Without assistance, the implementation of lean manufacturing methods is susceptible to failure if following incorrect or deficient information. Therefore, concern is raise to provide proper and sufficient knowledge that will assist manufacturers in becoming successful. Information presented to manufactures on lean manufacturing practice should account for sensible validity, not just capability.

Chapter 3

Assessment of Lean Practices in Industry

3.1 Introduction

The purpose of this study was to work with companies that are operating throughout a variety of manufacturing sectors and assess their practice of lean manufacturing methods. While the concepts of lean manufacturing are developed and analyzed in an academic setting, application of the concepts can vary in practice. Therefore, the best way to understand how lean manufacturing is actually being applied in industry is to reach out to those facilities directly.

3.2 Assessment Approach

Many of the work found in the literature review attempts to determine facility factors and characteristics that influence the success or failure of lean manufacturing. There are a variety of approaches used to assess how lean manufacturing is being practiced, with case studies and questionnaires being the most common methods.

The benefits to the case study approach is that they provide very detailed information about the facilities practicing lean manufacturing and the challenges that are presented. However, the case studies are typically deficient in observations where the facilities studied are limited to a select few or at times only one. Case studies are also time dependent, where information collected is accumulated over multiple weeks or months, and even up to years. This requires a commitment from the facilities being observed to allow observers to intrude on regular functions and involve them in the company's operations. There is also a requirement for significant research funding so the researchers can travel between the facilities and conduct interviews with personnel or collect performance information.

The benefits to the questionnaire approach are that it reaches more facilities and provides a wider range on information across different regions, industries, and companies. There is not a significant intrusion on the operations at the facilities and the questionnaire can completed at the facility's convenience so time is not a prominent concern. Limitations of the questionnaire can include the information collected, since the responses gathered are from prescribed questions. The responses are closed ended which restricts study participants from elaborating on their experiences.

After reviewing the objectives of the research and discussion with the chair of the research committee, Dr. Gopalakrishnan, it was decided to develop a questionnaire that evaluates lean manufacturing practice. The use of a questionnaire provides an efficient method for collecting and managing data, and offers the potential for observations from diverse manufacturing facilities. Its application as an assessment tool challenges that the development of the questionnaire becomes an instrumental process and should best reflect the needs of the research that produces the highest quality data to be analyzed.

The approach of this study was to create a questionnaire encompassing the practice, application, and understanding of lean manufacturing. The questionnaire was sent to companies at the individual manufacturing plant level, specifically targeting the upper levels of management located at each facility.

3.2.1 Questionnaire Development

The questionnaire was created using an online document generating software, Google Docs®, which allowed for the use of an electronic storage service that could be shared easily. Google also provides free electronic storage for users developing websites, so the study could have a dedicated series of webpages to display the questionnaire and provide an intuitive user interface using Google Sites®. The questionnaire could be shared with anyone who had internet access as well as the website address. The structure of the questions consisted of multiple sections including: (1) demographics of respondents, (2) identification of the knowledge and practice of lean methods, (3) interpretation of lean application, (4) strategic direction of lean methods, (5) measurements of expertise and (6) difficulties for practicing lean. The question type would be multiple choice, closed ended, with pre-established answers to select from. The following subsections detail the development of the questionnaire, at which the completed questionnaire can be found in Appendix A.

3.2.1.1 Skip Logic Format

The questionnaire went through many revisions. The largest challenge was deciding the type and number of questions to be included. After review of similar types of studies in the literature review, it became clear that there was not an overwhelming direction to questionnaire structure. Many questionnaires were incredibly detailed, and subsequently required the respondent to spend a great amount of time to complete it. This was a concern during the questionnaire's development because the context of the study and excessive questioning being presented could possibly deter individuals from volunteering their time to complete it.

As mentioned in the research objectives, the participants of the study would include both manufacturing facilities that practice lean manufacturing and those that do not. Therefore, not all questions were appropriate for each participant's response, which required a situational approach. Using the participant's responses to dictate which question followed would allow for a simplified and shortened series of questions for the participants. Questions would not be presented to respondents who could potentially provide answers with little validity. For example, asking a participant who acknowledged little to no understanding of what lean manufacturing is to identify why it is difficult to implement would be irrelevant. Another benefit to using a situational questionnaire structure was the opportunity to include various levels of complexity in questioning. For those respondents who characterized themselves as knowledgeable about lean manufacturing and who were proficient in indicating which lean methods that they used, a more detailed series of questions could be presented which allowed for a higher quality response.

In order to create a questionnaire that involved a conditional format, a "skip logic" approach was used. In a skip logic questionnaire, the participant is directed through different paths of questions based on their previous responses. This forces the participants to follow the constraints created by the surveyor. Using this method, a questionnaire that contains 72 questions was reduced to presenting only a maximum of 20 questions, depending on the answers selected.

Using skip logic formatting led to a “leaner” questionnaire. Figure 3.1 displays a logic flow chart of the assessment tool created, presenting the numerous paths through the various sections of the questionnaire.

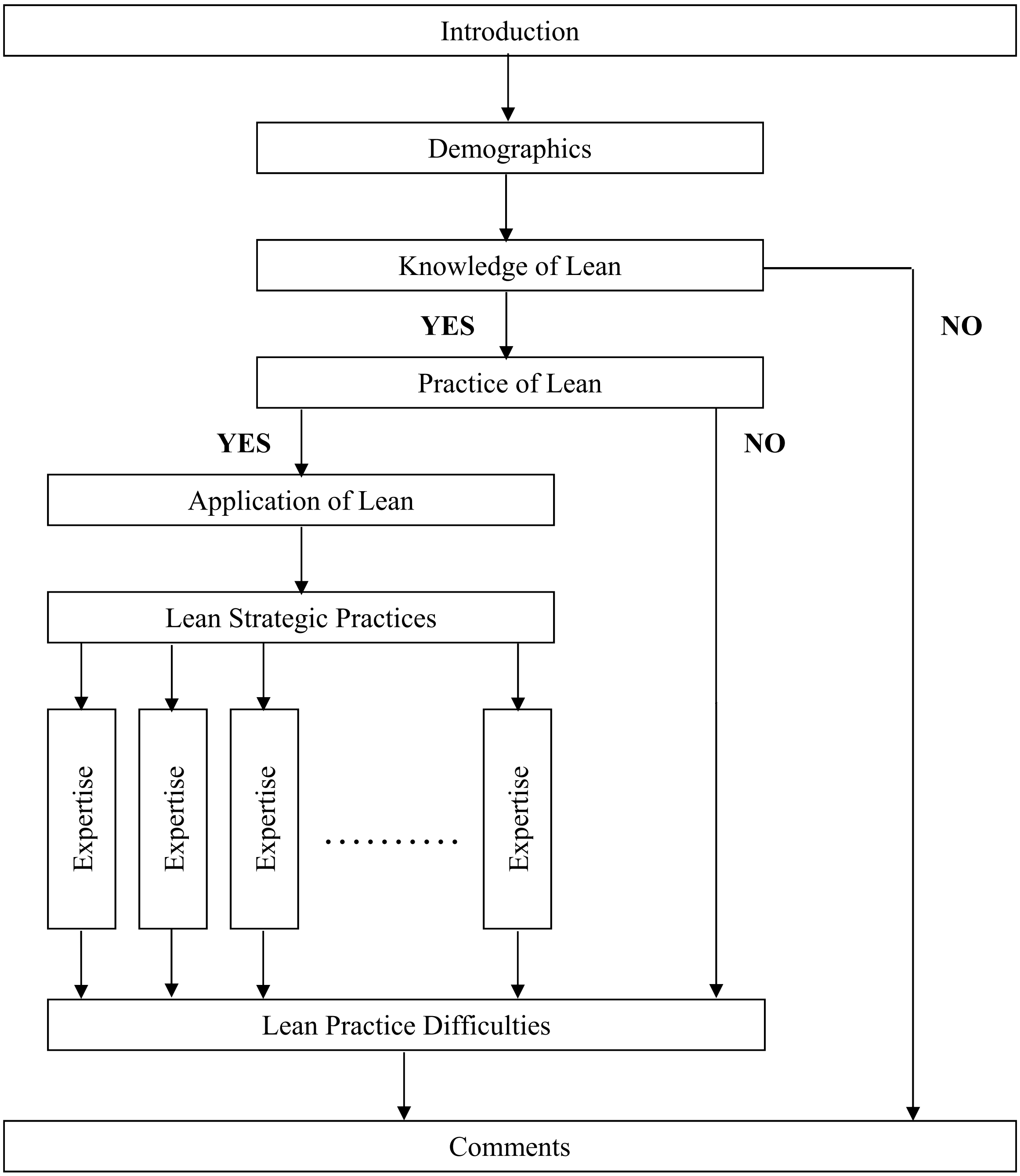

Figure 3.1 Skip-logic assessment tool flow chart

3.2.1.2 Demographics

In the demographic section of the questionnaire, the questions were developed to understand key information behind the participant regarding personal skills and experience, as well as their organization's business structure and characteristics.

The first set of questions was specific to the participant's employment status. In the initial question presented, the participant identified their employment position from a generic corporate hierarchy. The participant was then asked to indicate all departments they had roles in, as well as the duration of employment at their current position. The next pair of questions classified their manufacturing facility's industry sector by product type and size in terms of number of employees. Finally, the participant was asked to identify who had the ability to approve financial decisions for projects at their facility.

It is important to note that the final question was as close as the study would come to financial related information about the participant's company. Due to the sensitive nature of these types of questions, it was widely advised by industry experts from consulting organizations to avoid financial related information as it could deter participation even though the respondents were assured of confidentiality. Phrasing the question in terms of management approval allowed the questionnaire to gather information on the responsibility or authority for project approval in the case of implementing continuous improvement programs.

3.2.1.3 Lean Knowledge and Practice

The knowledge and practice sections were brief but an integral part of the questionnaire due to conditional formatting dictating the direction through the questionnaire. Initially, the participants were asked if they had knowledge or experience with lean manufacturing. If they did not then they were directed to the end of the survey due to the remaining questions requiring understanding of what lean manufacturing is. However, if they expressed that they had knowledge or experience with lean manufacturing they were asked if their facility participated in the use of lean methods.

For those participants that understood lean manufacturing but their facility did not participate in its practice, they were directed to a series of questions to try to understand the difficulty in implementing lean manufacturing at their facility. This sector of questions will be covered later on in the report. Likewise, those participants who knew of lean manufacturing and worked in facilities that practiced its methods, they were directed into the next section that focused on how lean manufacturing was being applied at their facility.

3.2.1.4 Lean Application

The application of lean manufacturing provided an overview of how the participants incorporated it into their operation. Participants were asked to indicate if the lean initiative was driven by the facility, or if it was part of a larger company movement across all production sites. Next, they were asked who was responsible for implementing and monitoring lean manufacturing based projects, whether it was a single individual, a specialized team, or all affected employees. Finally, participants specified the duration that their facility had used lean methods.

3.2.1.5 Lean Strategic Practices

The lean strategic practice section of the questionnaire involved technical related questions about the practices being used by facilities that implement lean manufacturing. Based on the research of Rahman, Laosirihongthong, and Sohal (2010) who identified 13 lean practices from the 22 manufacturing practices found in lean systems as determined by Shah and Ward (2003), the strategic approach for how companies practiced lean methods in the questionnaire was created [39] [44]. These practices are viewed as strategies due to the continuous nature of lean manufacturing, and which strategic practice a company decides to pursue has long term ramifications to the direction of their lean journey. The 15 strategic lean practices used in this study are provided in Table 3.1.

Table 3.1: Strategic lean practices

(1)	5S
(2)	Continuous / One-Piece Flow
(3)	Eliminate Waste
(4)	Error Proofing / Poka-yoke
(5)	New Process Equipment / Technology
(6)	Preventative Maintenance
(7)	Pull-Based Production / Kanban
(8)	Quick Changeover
(9)	Reduce Cycle Time
(10)	Reduce Inventory
(11)	Reduce Lot Size
(12)	Reduce Setup Time
(13)	Remove Bottlenecks
(14)	Single Supplier Focus
(15)	Other

Source: Adapted from Rahman, Laosirihongthong, and Sohal (2010)

Questionnaire participants were asked to indicate all practices that were being attempted at their facility, regardless of the level of implementation. Next, they were asked of those attempted, which were the most beneficial in reaching their company's lean manufacturing goals. The objective of each lean tool is specific to itself, however the collective use of multiple tools is driven by a single goal that all lean operations strive toward, the maximization of value. The idea was to identify which strategy has the largest impact to that underlying theme of value. The final two questions of the section focused on identifying which of the strategies listed presented the lowest and highest levels of difficulty for implementation at the participant's facility.

3.2.1.6 Exhibit of Expertise

To gauge the knowledge and understanding of lean methods, participants were asked about specific performance metrics and conceptual questions to determine their proficiency in the lean manufacturing practices they found to be the most beneficial to their facility, along with specifying the level of implementation for that strategy. The proficiency questions were only asked for one lean practice, the most beneficial, due to limiting the questions presented. It was assumed that the most beneficial practice a manufacturer applied in their facility would leave the strongest impression on them and allow them to reflect on the significant on that practice, which would produce a quality response. In some instances, manufacturers could identify several of the lean practices listed to being applied in their facility. To ask a few questions on each of the practices applied creates a much longer questionnaire and may lead to lower quality responses if participants would experience fatigue from excessive data collection. The aim of this section was to determine the participant's comprehension of basic principles for the different lean practices both meaningfully and efficiently. This allowed participants to demonstrate their aptitude in understanding lean manufacturing applications without the impression of the questions being an examination of intellect.

The selection of the performance metrics were based on knowledge accumulated from the literature review and textbook material [16]. The metrics chosen were intended to be some of the most common in terms of how they related to the strategic practice. For example, if the participant noted that reducing inventory was the most beneficial strategy, then a typical performance metric would be to monitor the percentage of work-in-process (WIP) in relation to the overall inventory. Having a high WIP percentage indicates problems in the process, so to declare inventory reduction as being the most beneficial strategy, but providing a poor metric directly linked to being one of Ohno's seven types of waste, doesn't demonstrate an expertise in lean methods.

Another example is selecting the use of a "single supplier focus" strategy with the performance metric being delivery performance. If a participant works towards using a single supplier, but the sole supplier's deliveries have a high percentage of being late, then that facility likely does not understand the purpose of using this strategy. Transportation, another one of Ohno's original wastes, is where no value can be added because the facility incurs additional costs of delays.

The proficiency questions were created on the basic concepts for each respective strategy. Misunderstanding a rudimentary element indicates a lack of proficiency. For example, in 5S, there is a five step process that uses a method called "red tagging" where items such as unnecessary tools or equipment for a work area are identified for removal. A participant that benefits the most in the practice of 5S should know where in the process red tags are used since it is a key part of that strategy. Similarly, a participant focused on using a Quick Changeover strategy should know each of the three components for the process, known as the "3-Ups". Therefore, each of the questions developed are derived from established material.

3.2.1.7 Difficulties for Implementing Lean

Finally, the survey closed with participants choosing a level of agreement with statements as to why implementing lean manufacturing as a continuous improvement program can be difficult. Referencing Figure 3.1, both lean practitioners and non-practitioners were required to participate in this section, allowing the ability to directly compare their reasoning. Reasons for implementation difficulty were researched throughout the literature review. The reasons that were selected for the questionnaire in the study were an adaptation of the work from Bhasin (2011) on prominent obstacles to lean practices. Table 3.2 lists each of the ten reasons provided in the study for why implementing lean practices is difficult at which participants rated their agreement on a standard 5 point Likert scale.

Table 3.2: Reasons of difficulty for the implementation of lean

(1)	*Lack of commitment from management*
(2)	*Lack of lean technical knowledge*
(3)	*Lack of understanding benefits to lean*
(4)	*Lean does not fit company culture*
(5)	*Management is resistant to change*
(6)	*Employees are resistant to change*
(7)	*Lean is a gimmick*
(8)	*Lean is not sustainable*
(9)	*High cost of investment*
(10)	*Previous failures of lean*

3.2.2 Participant Selections

One of the challenges with assessing the use of lean methods is determining quality feedback. A participant could claim expertise and vast implementation of lean methods at their facility, but the level of knowledge is subjective. By creating a series of proficiency questions that rely on knowledge of common lean metrics, a surveyor can gain a better understanding of the participants' knowledge and application of lean principles.

The initial targeted participants were all manufacturing facilities located in the state of West Virginia; however due to the limited number of facilities, the study was expanded to include participants from all manufacturers in the state of Pennsylvania as well. Pennsylvania was selected based on the high volume of manufacturers as well as their proximity to West Virginia University, which was used as a centralized location for the study. Including both states provided adequate potential participants and focused the analysis to a defined region, which eliminated factors that could have influenced the results if manufacturers were allowed participate from other surrounding states.

The West Virginia University Industrial Assessment Center (IAC) manufacturer database was used along with the Thomas Register of American Manufactures and the Manufacturers' News, Inc. 2012 West Virginia and Pennsylvania Manufacturers Registers and Directories to implore participants for completing the study's questionnaire. Introduction of the study and the website address for the questionnaire were electronically mailed to 327 manufacturing facilities with 51 ultimately participating. The questionnaire produced a 16% response rate that is comparable to similar studies of this type found in literature. The survey participants were allowed to respond under anonymity however Figures 3.2 and 3.3 show the locations of the manufacturing facilities contacted (327) as well as those that responded to the survey and identified themselves (38 of 51) to display the diversity in location of the respondents.

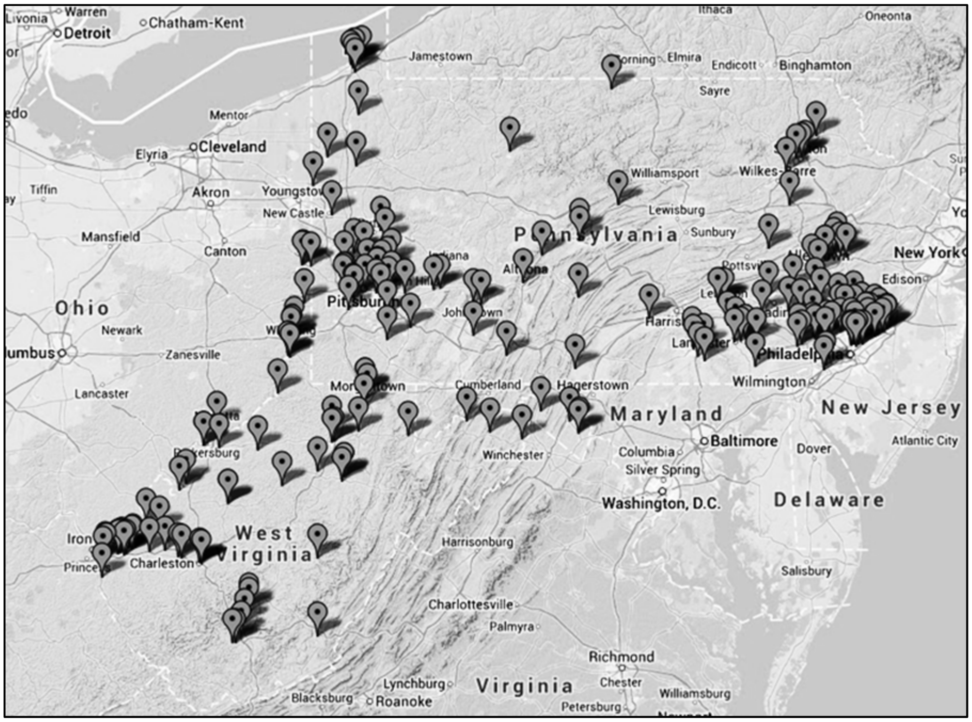

Figure 3.2: Map of contacted manufacturing facilities.

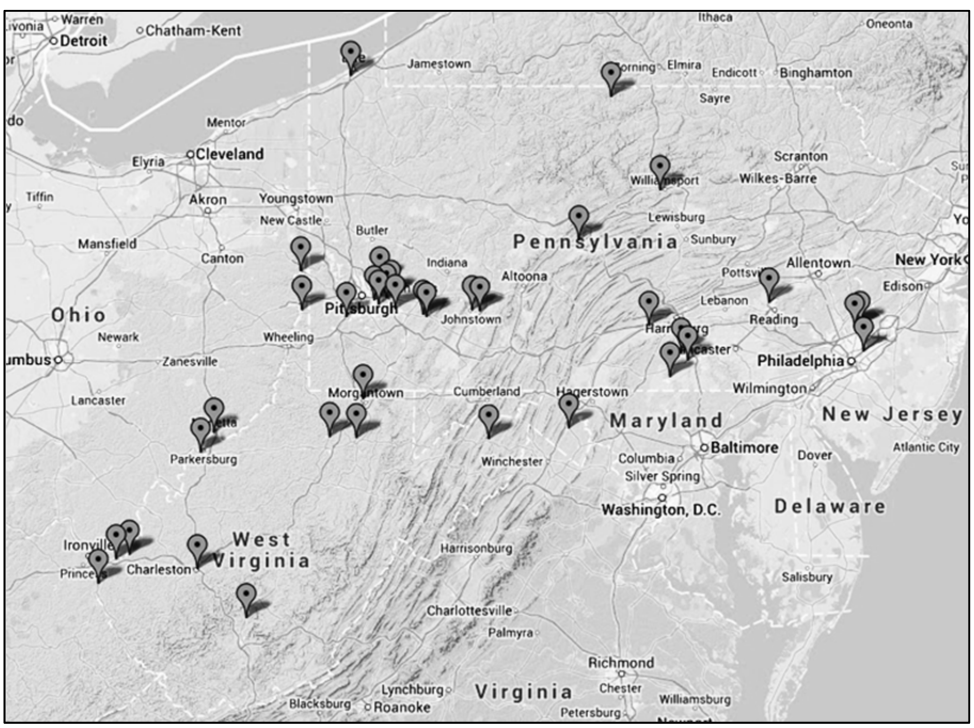

Figure 3.3: Map of identified participating manufacturing facilities.

3.2.3 Database Development

A Google-based website was created for the study and was used to distribute the questionnaire to potential participants while recording their responses once completed. The website automatically generated and stored all of the responses in a Google spreadsheet that could be exported in multiple file formats such as a Microsoft Excel® spreadsheet or csv file. Therefore the capacity of the data collection was the same as an Excel® spreadsheet file, 65,536 rows and 256 columns. As long as there were less than 256 inputted data values and 65,536 facility observations, the electronics storage provided by Google would be sufficient. Once converted into the appropriate format, the data could be managed and manipulated using whichever tools desired. For the analysis of the data collected, both Minitab 16 numerical analysis software and Microsoft Excel® 2013 were used to summarize the results and generate descriptive information.

3.3 Verification of the Assessment Tool

During the development of the assessment tool, there were many individuals that had a strong influence in its creation and the resulting design. Each of the individuals shared some form of expertise across areas that directly relate to the study including consulting manufacturing facilities in industry, analyzing manufacturing systems, instructing engineering courses, and leading research programs. The input of these experts help produce a robust method for evaluating the practice of lean manufacturing in facilities throughout industry.

The chair of the research committee, Dr. Bhaskaran Gopalakrishnan, who is also the Director of the Industrial Assessment Center at West Virginia University, has a considerable amount of experience conducting energy audits for assessing energy usage by manufacturers. His relationships with manufacturing facilities were also the basis for communicating with individuals across industry when seeking participants in the study. In the early stage of the development of the questionnaire, Dr. Gopalakrishnan helped align the focus of the research by explaining the need for an embracive assessment tool. Since the study was reaching out to manufacturing facilities of various industries and the individuals completing the questionnaire would possess different levels of knowledge in lean manufacturing practice, it needed to have ease of use and collect valid information from the responses. Collecting data that consisted primarily of performance metrics would not be appropriate as they are not universally applied and not necessarily measured regularly, if at all. If the information being requested in the questionnaire was not readily available then the participant would likely delay its completion, presenting the risk that the questionnaire be disregarded altogether. The discussions with Dr. Gopalakrishnan formed the idea of selective questioning based on the participant's knowledge and practice of lean manufacturing, which then expanded to applying the skip-logic approach. Using the skip-logic format for the questionnaire open the possibilities for selectively presenting questions that were applicable to certain participants, thus creating a highly efficient form of assessment.

Research committee member Dr. Alan McKendall provided key knowledge of lean manufacturing practice on both conceptual and operational levels. Dr. McKendall has expertise in consulting manufacturing companies in industry and instructing engineering courses that teach continuous improvement and lean manufacturing methods. One of the prominent pieces of information he provided during the development of the questionnaire was that even though lean manufacturing practices can be used across many production processes it does not mean that they necessarily should. Before manufacturers implement lean practices they should have an understanding of how lean manufacturing applies to their business. The manufacturer's production system, processes, and products all have an impact on whether lean manufacturing methods should be applied and, if so, which practices should be used. It is important to understand that lean manufacturing practices are not universally transferrable, leading the next key piece of information from Dr. McKendall based on observations where manufacturers will at times use lean tools without fully understanding why. This information had a large influence on the development of questionnaire and is the reason for the section that reviewed the participant's expertise in lean manufacturing by having them answer questions on their proficiency of lean manufacturing concepts relative to their practices. Collecting this information allows to assess how lean practices are being used in much wider context and provides a stronger evaluation of the questionnaire responses.

Dr. Robert Creese, also a member of the research committee, supplied one the most significant segment of literature used when developing the questionnaire based on his experiences with West Virginia University's Metalcasting Benchmarking Team. The technical report generated from benchmarking metalcasting processes across the United States provided a guideline for assessing industry practices. The report also included the questionnaires used in the assessments which supplied direction in structuring the lean manufacturing assessment tool. A very limited amount questionnaires were provided in the lean manufacturing literature, making it difficult to possess a baseline that could be reference from. Another influential response from Dr. Creese based on his experiences while critiquing the questionnaire was to avoid questions that requested financial information. Manufacturing facilities participating in the study would likely restrain from disclosing particulars about how funding is used and profitable information derived from their continuous improvement programs due to the sensitive nature of the information.

In the final revisions of the assessment tool that evaluated lean manufacturing practices in industry, West Virginia Manufacturing Extension Partnership's Mr. David Carrick, an industrial extension engineer, reviewed the questionnaire to assess its feasibility and credibility in completing the research objectives. Mr. Carrick works with manufacturing facilities on a consistent basis and provides services assessing manufacturers' business practices and instructing them on how to implement lean manufacturing methods. Upon his review, Mr. Carrick stated that questionnaire was well constructed, accessible, and covered important concepts and practices that are present in lean manufacturing. The main critique was to add commentary sections and additional description information in the questioning. The comment sections would allow for the participants to provide supplemental information and the description information would clarify what was being requested and limit participants from requiring further elaboration.

Finally, the questionnaire was critiqued by Mr. Tom Mahoney, the Director of Industrial Extension at West Virginia University and former President and Chief Executive Officer of the West Virginia Manufacturing Extension Partnership center, who is also an expert on consulting manufacturers on lean production. Mr. Mahoney was part of creating a survey that was sent to manufacturers across West Virginia in 2009 to assess the conditions they faced, and identify challenges and opportunities to improve their performance. Since his experiences share many similarities with this research, his participation provided an excellent opportunity for collecting valuable judgment. His comments were supportive of questionnaire's structure and agreed that the skip-logic approach provided the most efficient method for concise evaluation. The main concerns he raised was the ability of manufacturers to accurately depict their lean manufacturing practices. He had observed instances where manufactures were overzealous in proclaiming their lean practice in situations that were unjustified. Mr. Mahoney also recommended that "5S" be included in the lean manufacturing practices, as it commonly used as an introductory practice when implementing lean manufacturing methods.

3.4 Conclusions

The creation of the questionnaire was a labor intensive process. The end product was a culmination of learning about continuous improvement and lean manufacturing concepts and practices, applying knowledge obtained for coursework, reviewing literature on existing research, and interviewing individuals with experience and knowledge that shaped the assessment. These efforts are not to be understated, as it was required to produce the highest quality assessment tool which was the mainstay of the study.

A challenge that was not initially evident at the beginning of the research project was obtaining participants for the study. Accomplishing the task required skills of networking and communication that were originally trivialized. Managing the hundreds of lines of communication between phone calls and e-mails for each of the individuals contacted at the manufacturing facilities became more difficult than what could ever be expected. For the 6 week period where the questionnaires were being distributed and responses collected, it became nearly a full-time job for managing the information. In future studies it is recommended to place a larger emphasis on planning how communications will be handled. The experience provided an education on the importance of creating an efficient assessment tool that accounts for accessibility. It is imperative to be intuitive and attempt to anticipate how potential participants will preconceive the questionnaire when presented to them. The initial introduction is the main factor where individuals decide if they will participate in the study.

Once the contact information for a manufacturing facility was found, a phone call was placed to the facility in attempt to connect with the highest ranking management figure there, including but not limited to owners, presidents, vice presidents, plant managers, departmental managers, and engineers. Essentially, those willing to speak on behalf of the facility and were able to discuss their operation development on a strategic level were desired. One of more difficult challenges was reaching these individuals without a pre-established relationship. Generally, administrative assistants or customer service representatives would receive the initial phone call and then forwarding contact information and requests was relied on them. This occurrence would create the challenge of being connected with someone to speak to who understood lean manufacturing and could provide a cogitative conversation. Being direct and sincere in the request while stating the data collected was intended for research offered the highest chance in successfully gaining an individual's participation.

Chapter 4
Results

Each of the sections in this chapter cover the results of the study from the analysis of the questionnaire responses, a statistical analysis of the reasons that implementing lean manufacturing practices is difficult, interviews with continuous improvement experts verifying the results and discussing their experiences, and the identification of key findings.

4.1 Analysis of Questionnaire Responses

The following sub-sections present the data collected from questionnaire participants in a summarized form. Each sub-section represents a question set from the questionnaire broken down into a categorical grouping.

4.1.1 Demographics

The study participants identified their managerial employment position in Figure 4.1. The results show that both presidents and vice presidents were most likely to respond to the questionnaire, with equal representation. Surprisingly, more department managers than division managers responded. The smallest category of "other" consisted of respondents who identified as general managers or engineers.

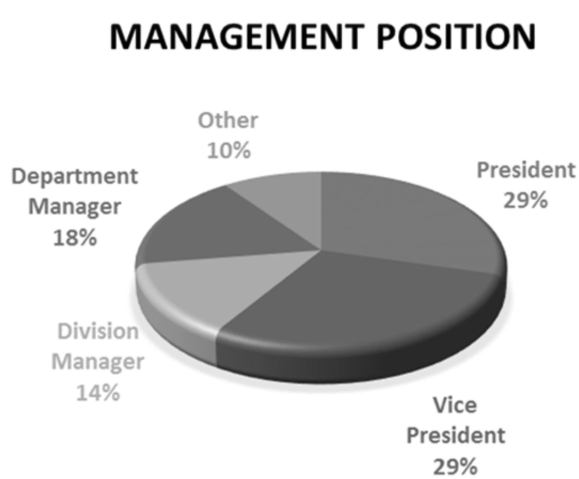

Figure 4.1. Participants by employment position

The participants identified all departments at their manufacturing facility which their roles and responsibilities reside. Nearly two-thirds of the respondents operated within manufacturing, operations and engineering departments. Less than half indicated responsibilities in human resources, marketing, research and development and finance departments. The smallest category was once again “other,” which included departments such as; sales, purchasing, shipping and information technology. Specific percentages for each department is displayed in Figure 4.2.

Figure 4.2. Participant responsibility by departments

Next, the manufacturing facilities were categorized based on industry sector. Generalized sectors were created to pool responses into similar categories rather than to use detailed industry codes like the U.S. Census Bureau North American Industry Classification System and Department of Labor’s Standard Industrial Classification so that the responses would not be diluted. Figure 4.3 displays each of the industrial sectors and the respective percentage of questionnaire participants. Computers & electronics and fabricated metals represented the largest amount of participants at 21% each, followed by the chemical industry with 14%. The industry sector diversity displays the unbiased view from any one dominant manufacturing sector for the facilities that participated in the study.

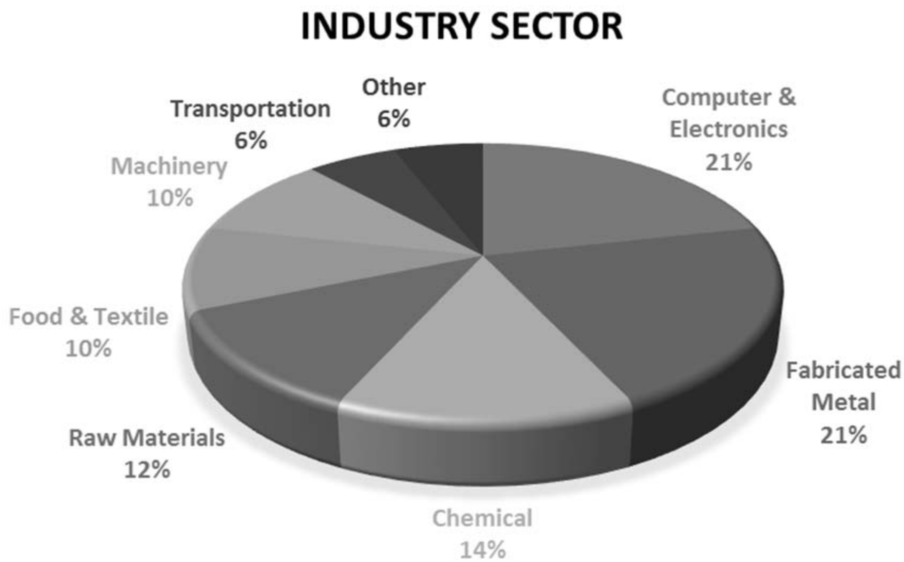

Figure 4.3. Industry sector of participating manufacturing facilities

Manufacturing facilities were separated based on their size according to the number of full-time employees working on site. Three groupings were used to characterize facilities as small, medium and large. 47% of the participants worked in a small manufacturing facility with less than 50 employees, while 39% of participants worked in facilities that had between 50 and 250 employees and 14% of the participants worked in large facilities with more than 250 employees.

Finally, participants indicated what levels of management had the ability to approve funding for projects at their facility. This information identifies the individuals that have the power to affect change at the facility through approving the implementation of a lean continuous improvement project. Recall that implementing lean methods requires a commitment from the top-level of management, and that the more management becomes involved, the chance for success increases. In 92% of situations, the company president has the ability to approve funding for facility projects. Special cases for financial approval involved board members in the case of family-owned businesses, chief executive officers, chief financial officers and strategic business units. All special cases were part of the "other" category. Each of the levels of management indicated in the questionnaire are represented in Figure 4.4.

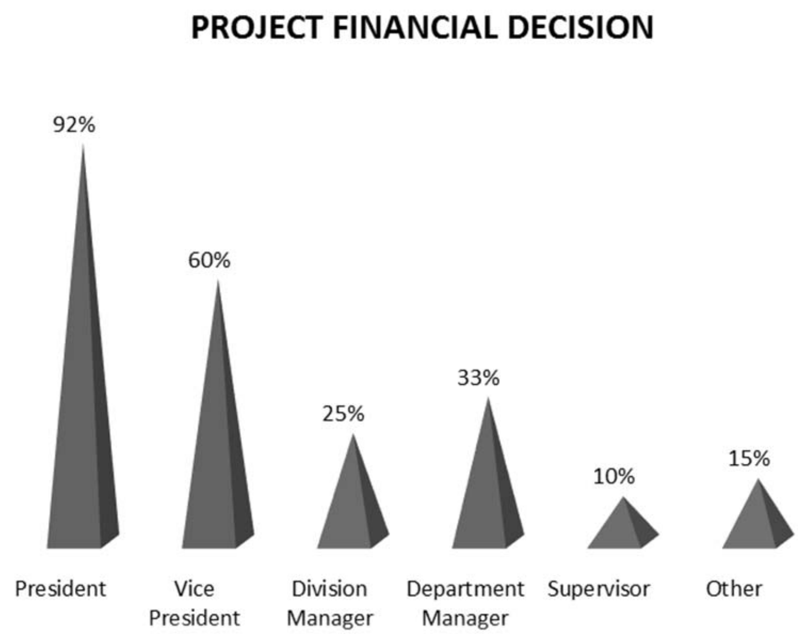

Figure 4.4. Management who approve financial decisions for facility projects

4.1.2 Lean Knowledge and Practice

Of the 51 total respondents to the survey, 42 acknowledged that they had a basic understanding of lean manufacturing, of which 34 noted that they currently were working in a manufacturing facility using lean methods as a continuous improvement program. This leads to 82% of participants possessing some extent of lean knowledge and 67% actively practicing in lean methods.

4.1.3 Lean Application

The lean practitioner survey participants were asked to indicate how long their facility had been practicing lean methods. 47% had been engaged from 0-5 years, 26% from 6-10 years, 18% from 11-15 years and 9% for more than 15 years. The results show a linear decrease in frequency as the amount of years increase. This is expected since the first documentation of lean was in 1990, only 23 years ago, therefore it took time for awareness of lean methods to spread. The results also display how the application of lean methods are growing across manufacturing facilities, almost doubling every 5 years.

Next, respondents of the lean practicing facilities described the initiative to implement lean methods were company driven for 62% of the cases, and the other 38% reported being facility driven. One of the main factors of success for implementing lean methods is commitment and leadership from the highest level of management. In the results, nearly two-thirds of facilities specified that they have the company pushing for lean methods to be implemented on the plant level. Therefore, companies have recognized the importance of organization-wide support and are using the top-down management approach.

Finally, the responsibility of implementing and monitoring the progress of lean projects at the facilities was shown to hold an individual manager accountable for 9% of the time, a specialized team 29% of the time, and all affected employees on 62% of occasions. These figures indicate lean practitioners understand that lean methods are a joint venture between management and employees. When the responsibility is shared, it allows for the employees to become empowered, and conversely an opportunity for management to work with the individuals who best possess the ability to detect where improvements can be made. The employees in many instances have the strongest understanding of production processes. Since they are the ones who will be affected by the changes, it makes them also valuable resources for monitoring the progress of lean projects. They can provide observational data for the management as they experience the effects of these changes on a daily basis.

4.1.4 Lean Strategies

The lean strategies that have been or currently are being practiced at the participating manufacturing facilities are listed in Figure 4.5 in order of frequency. Of the total number of manufacturing facilities implementing lean (n = 34), "eliminate waste" was the most practiced strategy with 88% of facilities engaging. Waste is any function of the production process that does not add value to the end product which the customer is willing to pay for. The method of eliminating the waste includes removing undesired tasks from the production process by mapping the value streams. The high level of practice indicates that participating manufacturing facilities recognized the cornerstone of lean manufacturing.

At the other end of the spectrum, the lean strategy 'single supplier focus' was the least used at only 15%. While the use of a single supplier presents benefits such as a strong relationship with high level of interaction between companies where customer needs can be better understood throughout the supply chain, it is also one of the most difficult to achieve. This difficulty is due to the manufacturing facility requiring an optimal supplier that can provide the materials for all products being produced, as well as establishing organizational trust between the two companies through openly sharing information. The manufacturing facility may use one supplier, but it is unlikely that the supplier only supplies one manufacturing facility. There are however drawbacks to a manufacturer limiting themselves to one supplier. A manufacturer can become dependent on the supplier and can experience significant operational issues if the supplier is out of materials or the quality becomes subpar. The manufacturer also reduces the chance for pricing discounts to be offered as multiple suppliers compete for their business.

It is important to note that the strategic practices applied can have an effect on each other's success. As new practices are implemented, they will affect the production system because parameters have changed. For example, reducing the setup times can increase productivity by reducing down time, which then can create new bottlenecks for processes than cannot handle the change in capacity. Another example includes purchasing new process equipment, which then requires new preventative maintenance measures to be developed. Every change to the system creates a response. Therefore, it is important to recognize that balance will always be chased while reiterating the definition of continuous improvement.

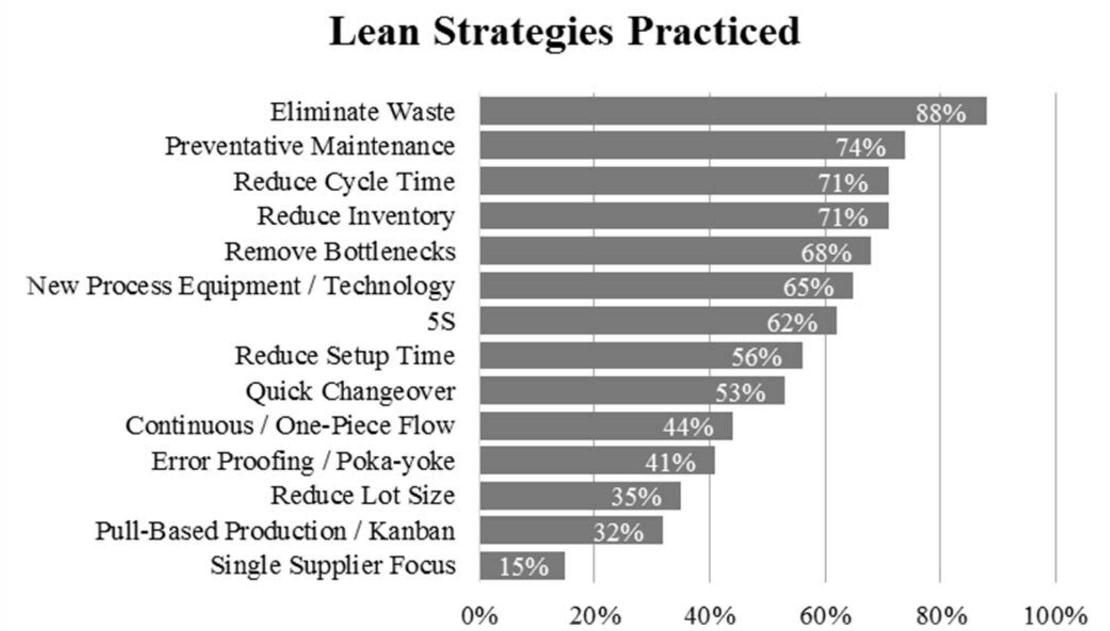

Figure 4.5. Strategies practiced by lean manufacturing facilities

Table 4.1 displays the leans strategies practiced throughout each industry. The computer and electronics industries were the most active in the practice of lean manufacturing methods, representing 29% of the participating facilities. Issues of overproduction and defective electronic components can be detrimental to a business because of the short product life cycles and limited ability for rework, so the high level of lean manufacturing practice is not surprising. Fabricated metal, raw materials and machinery industries were also well represented. Notably, there were no lean manufacturing facilities from the food and textile industries. Both of these industries typically use manufacturing processes with large batches which requires high levels of inventory, seen as a waste in lean manufacturing. Another challenge for these industries, especially for food, is the long lead times, which is also considered a waste in lean. Growing, producing, and harvesting food is a schedule dependent process where the products can have short shelf lives. Therefore, becoming responsive to customer demand is not a flexible as other industries.

Table 4.1. Frequency of lean strategic practices by industry

Lean Strategy	***Computer & Electronics*** (n = 10)	***Fabricated Metal*** (n = 6)	***Chemical*** (n = 4)	***Raw Materials*** (n = 6)	***Food & Textile*** (n = 0)	***Machinery*** (n = 5)	***Transportation*** (n = 3)	***Other*** (n = 3)	***Overall Practice*** (n = 34)
Eliminate Waste	100%	100%	50%	33%	0%	100%	67%	100%	88%
Preventative Maintenance	70%	83%	100%	50%	0%	40%	67%	67%	74%
Reduce Cycle Time	70%	83%	75%	50%	0%	40%	67%	67%	71%
Reduce Inventory	80%	83%	75%	50%	0%	40%	33%	67%	71%
Remove Bottlenecks	90%	67%	25%	33%	0%	60%	67%	67%	68%
New Process Equipment / Technology	50%	83%	100%	33%	0%	40%	100%	33%	65%
5S	80%	67%	25%	17%	0%	40%	100%	67%	62%
Reduce Setup Time	50%	100%	25%	50%	0%	20%	67%	33%	56%
Quick Changeover	50%	83%	25%	50%	0%	0%	100%	33%	53%
Continuous / One-Piece Flow	50%	83%	0%	0%	0%	20%	67%	67%	44%
Error Proofing / Poka-yoke	40%	67%	25%	17%	0%	20%	67%	67%	41%
Reduce Lot Size	30%	50%	25%	17%	0%	40%	33%	33%	35%
Pull-Based Production / Kanban	50%	33%	0%	0%	0%	60%	0%	33%	32%
Single Supplier Focus	30%	33%	0%	0%	0%	0%	0%	0%	15%
Percentage of Facilities by Industry	29%	18%	12%	18%	0%	15%	9%	9%	

The frequency of the lean strategic practices are segregated by their facility size in Table 4.2. Facilities with 50-250 employees provided more than half of the practices collected. Of the lean practicing manufacturing facilities, 11 had less than 50 employees, 18 had 50 to 250 employees and 5 had more than 250 employees.

Table 4.2. Frequency of lean strategic practices by facility size

	Number of Employees			
Lean Strategy	***< 50*** (n = 11)	***50 - 250*** (n = 18)	***> 250*** (n = 5)	***Overall Practice*** (n = 34)
Eliminate Waste	82%	94%	80%	88%
Preventative Maintenance	82%	61%	100%	74%
Reduce Cycle Time	64%	72%	80%	71%
Reduce Inventory	55%	72%	100%	71%
Remove Bottlenecks	36%	78%	100%	68%
New Process Equipment / Technology	45%	67%	100%	65%
5S	45%	67%	80%	62%
Reduce Setup Time	18%	67%	100%	56%
Quick Changeover	18%	67%	80%	53%
Continuous / One-Piece Flow	27%	44%	80%	44%
Error Proofing / Poka-yoke	18%	39%	100%	41%
Reduce Lot Size	18%	33%	80%	35%
Pull-Based Production / Kanban	27%	28%	60%	32%
Single Supplier Focus	0%	17%	40%	15%
Percentage of Facilities by Size	32%	53%	15%	

Table 4.3 provides the frequency of the lean practices by the duration a facility has practiced lean manufacturing. 16 of the lean manufacturing facilities had started its practice of lean manufacturing in the last 5 years, 9 had begun between 6 and 10 years ago, 6 between 11 and 15 years, and 3 have practice for a duration of longer than 15 years.

Table 4.3. Frequency of lean strategic practices by duration of practice

	Years Practicing Lean				
Lean Strategy	***0 - 5*** (n = 16)	***6 - 10*** (n = 9)	***11 – 15*** (n = 6)	***> 15*** (n = 3)	***Overall Practice*** (n = 34)
Eliminate Waste	94%	78%	83%	100%	88%
Preventative Maintenance	69%	78%	67%	100%	74%
Reduce Cycle Time	69%	67%	83%	67%	71%
Reduce Inventory	69%	56%	83%	100%	71%
Remove Bottlenecks	75%	67%	50%	67%	68%
New Process Equipment / Technology	63%	56%	67%	100%	65%
5S	81%	44%	67%	0%	62%
Reduce Setup Time	69%	22%	67%	67%	56%
Quick Changeover	69%	22%	67%	33%	53%
Continuous / One-Piece Flow	50%	44%	33%	33%	44%
Error Proofing / Poka-yoke	63%	11%	33%	33%	41%
Reduce Lot Size	38%	22%	50%	33%	35%
Pull-Based Production / Kanban	38%	22%	50%	0%	32%
Single Supplier Focus	19%	11%	17%	0%	15%
Percentage of Facilities by Duration	47%	26%	18%	9%	

Based on the strategies currently or previously implemented at their manufacturing facility, participants indicated one strategy that they felt was the most beneficial to their facility's performance in terms of operational and financial gains. The results in Figure 4.6 show that that most commonly used practiced was also viewed as the most beneficial, as "eliminate waste" accounted for 29% of the responses. The comparison of the lean strategies practiced to those that were the most beneficial show the "remove bottlenecks" and "5S" strategies take more prominence in terms of results. However, a more significant difference between practice and benefits is seen for the "pull-based production / kanban" strategy. Only 32% of participants had used pull-based production, yet of those, 9% felt it was the most beneficial lean strategy to their facility. That indicates that over a quarter of manufacturing facilities who had implemented that lean practice stated it had the largest effect of their facility's operational and financial performance gains.

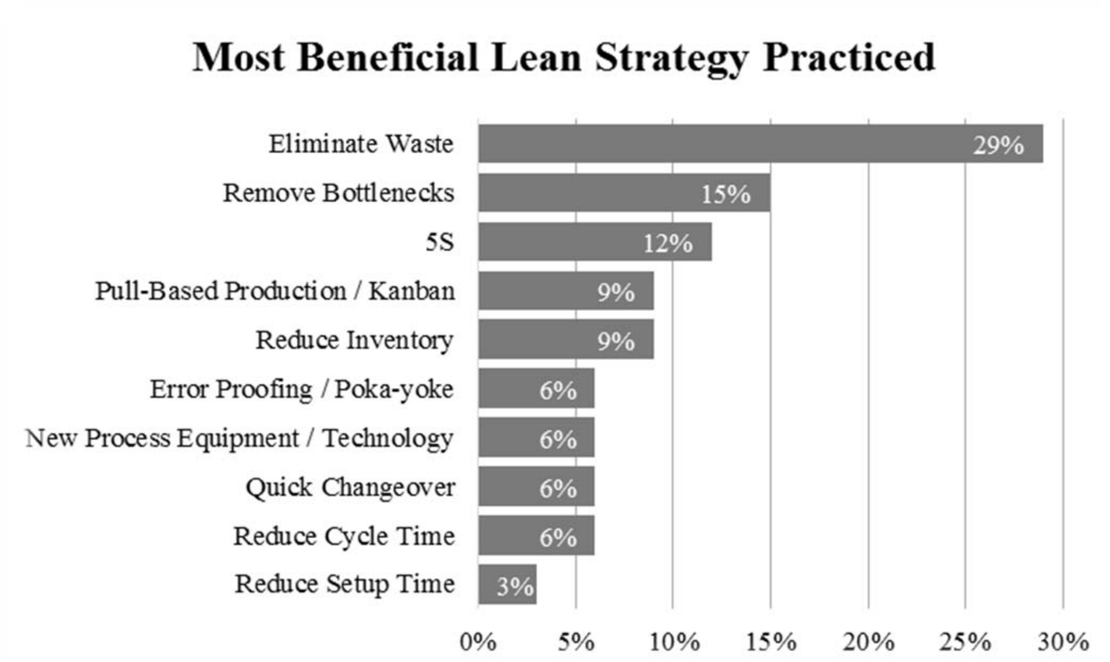

Figure 4.6. Most beneficial strategy practiced by lean manufacturing facilities

Participants indicated the strategic practice that would be the least difficult in implementing at their manufacturing facility in Figure 4.7. The practice selected did not need to previously or currently have been implemented at the facility. The practice 5S was viewed as the easiest lean strategy to implement by gathering 35% of the responses. The selection confirms the notion that 5S is the gateway for companies to begin the transformation to lean manufacturing. Implementing the 5S strategy sets up the change in culture required for structured continuous improvement. 5S allows for a visible and disciplined change where employees can recognize a lean manufacturing method in action that focuses on workspace organization and the elimination of non-essential equipment. The 5S strategy was practiced in only 62% of the participating facilities, which is unusual for a strategy described from the same survey participants to be the easiest to implement.

The second easiest lean strategy to implement was “eliminate waste”, which was also the most commonly practiced and beneficial strategy. 88% participating manufacturing facilities indicated using the “eliminate waste” strategy, therefore the evidence supports the understanding that it is easy to implement. “Preventative maintenance” and “reduce inventory” strategies also were indicated as low difficulty, as they were practiced in 74% and 71% of participating facilities, respectively.

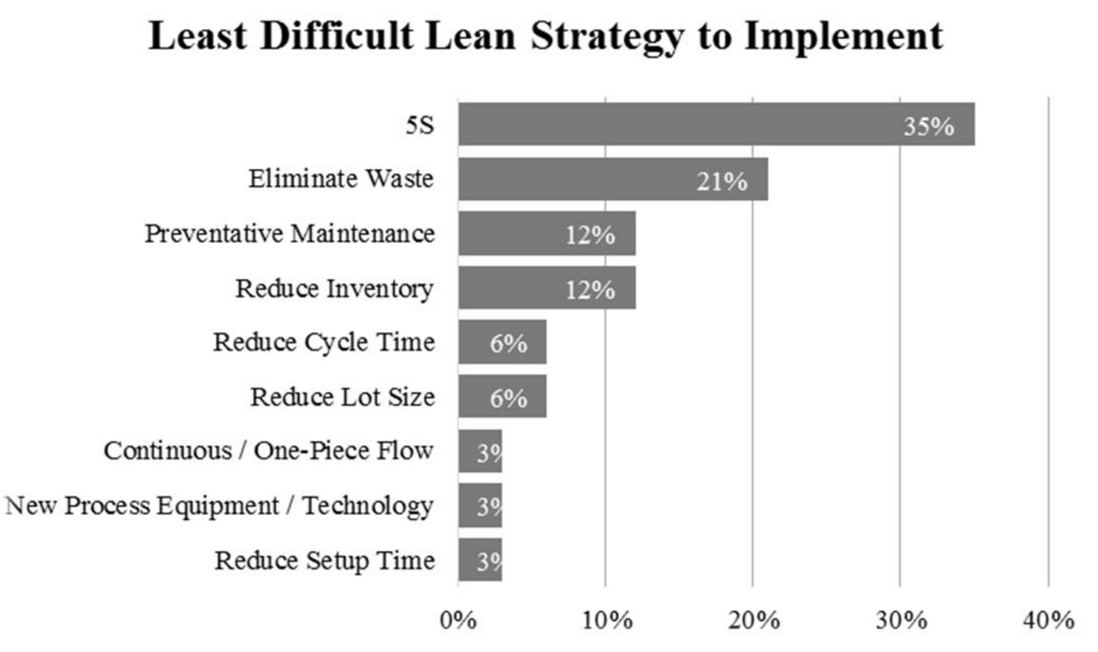

Figure 4.7. Least difficult lean strategic practice to implement

The most difficult lean strategies to implement are listed in Figure 4.8. 21% of participants identified the the “continuous / one-piece flow” strategic practice as the most difficult, while the “new process equipment / technology” and “remove bottlenecks” strategies followed with 18% and 15% of the total, respectively.

A notable observation was that 44% of participants indicated practicing the “continuous / one-piece flow” strategy, yet none identified it as the most beneficial lean strategy used. Practicing participants most likely did not expeience benefits due to the high level of difficulty in implementing this strategy, which reduces the chance for success. Choosing this strategy as the most difficult is appropriate, as continuous flow manufacturing can be considered the ultimate lean manufacturing practice as it eliminates or reduces the majority of Ohno’s seven original wastes. The “continuous / one-piece flow” strategy is an ideal state in which the production line is optimally balanced as units flow throughout work cells. The goal is to make a discrete production sequence improve its flow between processes by reducing the batch size to a single unit. A larger batch size causes the units to wait in a queue to be processed. Benefits to continuous flow manufacturing include work-in-progress being reduced to a single unit, higher quality and consistency due to sole focus being applied to the single unit, and the elimination of queues. These benefits relate to the elimination or reduction of the lean wastes such as defects, inventory, motion, and waiting. A large challenge in implementing continuous flow production is to create a cellular layout which includes all required equipment placed in sequence of operations inside work cells on the shop floor of the manufacturing facility. Each work cell is responsible for a specific series of production tasks. Other challenges include owning equipment with high reliabilty to prevent downtime, minimal variation in operation to limit deviation from quality specifications, and consistent process durations to avert delays. Using equipment that lacks all of these characteristics make implementing continuous flow production practically impossible.

The second most difficult lean strategic practice to implement was “new process equipment / technology” strategy, utilized by 65% of participants. Implementing the “new process equipment / technology” strategy involves purchasing modern equipment such as machines, controllers, and software that will help increase throughput and efficiency. Replacing outdated equipment with those that are more suitable to lean manufacturing’s pull-driven processes allows for greater flexibility in application. Consideration for upgrading equipment must take the machine capacities, user interfacing, and expense of the investment into account. There is also a learning curve for workers to become accustomed to the new equipment along with revisions or additions to maintenance programs. Modernizing production processes can become a time consuming and expensive investment that smaller facilities cannot afford.

The “remove bottlenecks” strategy was the third most difficult to implement yet it was practiced by 68% of participants. It also identified as the second most beneficial lean practice by 15% of the respondents. The removal of bottlenecks involves identifying processes in the production sequece that restricts throughput, and then relieving it by increasing that process’ capacity, adjusting its location in the production sequence, or scheduling throughput to match the bottleneck’s capacity. Other techniques for managing bottlenecks include maintaining full capacity operation of the bottleneck, or allowing other processes in the sequence to become idle. Identifying bottlenecks can become an endless search for production constraints. Once a bottleneck is identified and eliminated, it is not removed from the production sequence but rather relocated to a different process. The bottleneck becomes the process which has the lowest capacity, which means the flow of throughput will always experience restriction. There can also be multiple bottlenecks in the same production sequence which presents more difficulty in maintaining control.

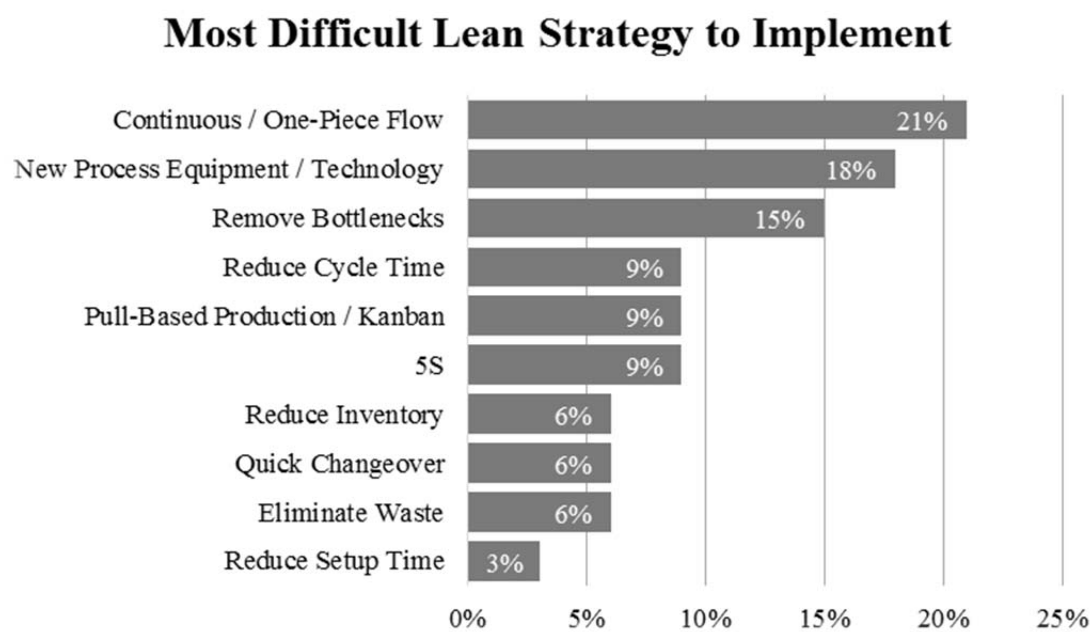

Figure 4.8. Most difficult lean strategic practice to implement

4.1.5 Implementation

Participants provided information on how the most beneficial lean practice at their facility was being implemented. The provided levels to select from included "limited" implementation where approximately 25% of the strategic goals were completed, "partial" implementation at 50% completion, "extensive" at 75%, and "full" with 100% of the implementation goals completed. It is important to note that the implementation percentage only indicates the specific level of implementation at the facility, not total completion. For example, 50% completion of the 5S strategy may indicate that the practice has been applied to shop floors and storage areas of the facility, but not to the shipping and office locations. Another example is if a company has been able to purchase 75% of the new process equipment required, but has yet to buy all the equipment that was originally planned. The practice of implementing lean strategies can be never ending, but specific implementation is finite.

Each of the participant's responses to the level of implementation of the most beneficial lean strategy practiced is listed in Table 4.4. The response frequency for each strategy is provided along with the corresponding implementation levels. The average level of implementation for each strategy is also provided. The results show that the majority of implementation for the most beneficial lean strategy is between 50% and 75%, also identified as "partial" and "extensive" implementation for 44% and 41% of responses, respectively. There was only one case where a strategy was fully implemented, which was a practice of "5S". The "error proofing / poka-yoke" and "new process equipment / technology" strategies had the highest average level of implementation, however the sample sizes are too small to draw significant conclusions from.

Table 4.4. Level of implementation for the most beneficial lean strategic practices

	Level of Implementation					
Most Beneficial Lean Strategy	***25%***	***50%***	***75%***	***100%***	***Average***	***n***
Error Proofing / Poka-yoke			2		75%	2
New Process Equipment / Technology			2		75%	2
Reduce Inventory		1	2		67%	3
5S		3		1	63%	4
Quick Changeover		1	1		63%	2
Eliminate Waste	2	3	5		58%	10
Pull-Based Production / Kanban		2	1		58%	3
Reduce Cycle Time		2			50%	2
Remove Bottlenecks	1	3	1		50%	5
Reduce Setup Time	1				25%	1
Percentage of Facilities	12%	44%	41%	3%		

4.1.6 Difficulties for Implementing Lean

Questionnaire participants who work in facilities that practice lean manufacturing and those that do not were all asked to assess their level of agreement for reasons that prevented or created difficulties in implementing lean practices at their facility. A 5 point Likert scale was used to measure the level of agreement with ratings of "Strongly Disagree", "Disagree", "Neutral", "Agree", and "Strongly Agree". In order to quantify the responses, each rating was assigned a numerical value to correlate so that a mean value could be used to summarize the general response from all questionnaire participants for each reason of difficulty provided. The numerical values for the ratings were as follows: "Strongly Disagree" = -2, "Disagree" = -1, "Neutral" = 0, "Agree" = 1, and "Strongly Agree" = 2. Therefore, the higher positive value average represents a stronger level of agreement and a higher negative value average represents a stronger level of disagreement between the range of +/- 2. The levels of agreement are provided for both practitioners and non-practitioners of lean methods in Table 4.5. There were 34 questionnaire participants that practice lean manufacturing and 8 that did not, however both groups identified themselves as knowledgeable about lean methods. The difference between averages of the agreement levels is also provided to compare the two groups on why implementing lean methods can be difficult for both facility types.

Table 4.5. Difficulties for implementing lean in both lean and non-lean practicing facilities

	Practitioners (n = 34)	***Non-Practitioners*** (n = 8)	
Reason of Difficulty for Implementing Lean	***μ***	***μ***	**Δ**
Employees are resistant to change	1.06	0.25	0.81
Lean does not fit company culture	-0.27	0.50	0.77
Management is resistant to change	-0.35	-1.00	0.65
Lack of understanding benefits to lean	0.09	0.63	0.54
Lack of commitment from management	-0.38	-0.88	0.49
Lean is not sustainable	-0.79	-0.38	0.42
High cost of investment	-0.35	0.00	0.35
Lean is a gimmick	-1.06	-0.75	0.31
Previous failures of lean	-0.50	-0.75	0.25
Lack of lean technical knowledge	0.44	0.50	0.06

The results show that lean practitioners felt that employee's resistance to change associated with implementing lean methods was the largest difficulty, with a mean agreement value of 1.06. There were only two other reasons that the lean practitioners agreed caused difficulty, which was the lack of the technical knowledge associated with lean (0.44) and the lack of understanding benefits to lean (0.09). Lean practitioners disagreed with the rest of the reasons provided. They most strongly disagreed with lean being seen as a gimmick (-1.06), while lean methods not being sustainable had the second highest level of disagreement (-0.79).

The non-practitioners indicated the highest level of agreement with the reason of lacking an understanding the benefits associated with practicing lean with the mean value of 0.63. Other reasons that were agreed with was that lean does not fit the company's culture (0.50), the lack of lean technical knowledge (0.50), and that employees were resistant to change (0.25). All remaining reasons were disagreed with exception for the high cost of implementing lean methods, which was neither agreed nor disagreed with. The strongest level of disagreement came with management being resistant to change (-1.00), followed by a lack of commitment to the execution of lean methods (-0.88), lean being a gimmick (-0.75), and previous failures of implementing lean acting as a deterrent (-0.75).

Comparing the lean practicing and non-practicing facilities indicates that the largest difference between the agreement means is "employees resistant to change". While both facility types agree that reason presents difficulty for implementing lean methods, lean practicing facilities indicated stronger agreement. Lean practitioners disagreed most strongly with non-practitioners on the point of lean methods fitting the company's culture. The practitioners felt that they were able to implement lean methods because it fit the company's culture, while non-practitioners described their cultures as not appropriate for implementing lean methods. All other reasons presented for difficulty in implementing lean methods between the facility types shared the same agreement or disagreement but varied in magnitude.

4.2 Statistical Analysis of Lean Implementation Difficulties

The following subsections use statistical methods to analyze the responses from manufacturing facilities regarding the challenges they face when implementing lean methods. Conclusions are drawn from responses that are statistically significant. The analysis compares the questionnaire participant's responses from both types of facilities, practicing and non-practicing.

4.2.1 Statistical Testing Method

In order to determine the significance of the participant's responses to the questionnaire, proper statistical test must be used that is appropriate for the data to draw a robust conclusion. The questionnaire data that was analyzed was the level of agreement to reasons as to why implementing lean methods in manufacturing facilities can be met with resistance. The responses were collected by the selection of an agreement rating on a 5 point Likert scale. Using the Likert scale for the questions produces data that is non-parametric and ordinal [2]. Non-parametric statistics do not follow a normal frequency distribution. Therefore, non-parametric data cannot use parametric parameters such as mean, variance, and standard deviation to represent its central tendency is statistical analysis[23].

There are four main data types; nominal, ordinal, interval, and ratio [2]. Nominal data has no form of ranking system for their categories. Examples of nominal data include gender or race. Attempting to perform statistical analysis is limited to frequency distributions. Ordinal data refers to that which has categories that follow a form of ranking that is not numerical, such as in the Likert scale measuring levels of agreement. Statistics to represent that data is limited to frequencies distributions, medians, and percentiles. Interval data has a numerically measurable ranking with an arbitrary zero value to reference from, such as temperature and dates. A scale can be defined with matching intervals between rankings. Ratio data has a numerically measurable ranking with an absolute zero value, such as length and velocity. Interval and ratio are the most commonly used forms of data.

For the Likert scale ordinal data, there is a form of ranking between categories. An example Likert scale follows this ranked structure; no agreement, slight agreement, partial agreement, some agreement, and strong agreement. Each rate increases the magnitude of agreement but the intervals between rates is not necessarily the same. The difference in magnitude between slight agreement and partial agreement cannot be accurately measured as the same difference in magnitude between some agreement and strong agreement. In order to determine if the central tendency of the responses collected from the questionnaire are statistically significant, a test needs to be performed. Since the data is ordinal, established tests determine the location of a population distribution using the median parameter. There are many tests that can be applied to non-parametric ordinal data, however each test has a different set of assumptions and objective. Common tests include; the Mann-Whitney U test, the Wilcoxon signed-ranks test, the sign test, and the Kruskal-Wallis test [13].

The objective for the study of lean manufacturing practice is determining if the questionnaire participant's responses are statistically significant through agreement or disagreement with the statement provided as to why implementing lean practices is difficult. A two-tailed test is required that will determine if the population median of the responses does not equal a hypothetical median value. If the median value is positive, then the participants agree with reason provided. If the median value is negative, then the participants disagree with the reason provided. Plotting the participant's responses across the Likert scale show that the single sample data does not follow any symmetrical population distribution. The assumptions for using the commonly used Mann-Whitney U, Wilcoxon signed-ranks, and Kruska-Wallis tests are violated as they require that the data follow a symmetric distribution. Therefore, the most appropriate test to use for the collected data is the sign test [40].

The 1-sample sign test is robust test that is comparable to the 1-sample t-test. Unlike the t-test which assumes a normal distribution, the sign test does not make assumptions of the population distribution in cases where the data can be non-symmetric. The sign test determines if a population's median is different than a hypothetical median. In the case of the study's Likert scale data, the test determines if the participant responses for difficulty in implementing lean methods differs from a "neutral" response where no agreement or disagreement is provided. As mentioned earlier in the report, the Likert scale was set to values of; "strongly disagree" = -2, "disagree" = -1, "neutral" = 0, "agree" = 1, and "strongly agree" = 2. The hypothetical population median ($\tilde{\mu}_0$) for the sign test was set to 0, which represents a neutral response. If the median of the population ($\tilde{\mu}$) of a sample size (n) does not significantly differ from the neutral response, for a level of confidence (α), then the conclusion drawn will indicate that the participants do not provide a significant level of agreement or disagreement with the reason provided. The hypothesis of the sign test is provided below where the hypothesis is rejected when the proportion of positive values from the population (x) are significantly less or greater than 1/2.

$$H_0: \quad \tilde{\mu} = \tilde{\mu}_0$$

$$H_1: \quad \tilde{\mu} \neq \tilde{\mu}_0$$

If $x < n/2$ and the computed P-value:

$$P = 2P\ (X \leq x\ when\ p = 1/2)$$

is less than or equal to α, or if $x \geq n/2$ and the computed P-value:

$$P = 2P\ (X \geq x\ when\ p = 1/2)$$

is less than or equal to α, then H_0 is rejected for H_1 [51].

4.2.2 Difficulties for Implementing Lean of Practitioners

The results determining if the median of the responses differed from the hypothetical median of the "neutral" agreement level through the sign test are displayed in Table 4.6. At a 95% confidence level, the reasons that lean manufacturing facilities agreed upon in presenting difficulty in the implementation of lean methods, by rejecting the hypothesis that the median of response population equaled a neutral value, included; (1) a lack of technical knowledge about lean methods and (2) employees are resistant to changes associated with lean manufacturing. Likewise, significant disagreement with reasons that present difficulty in implementing lean included; (1) management is not resistant to change that is needed for implementing lean methods, (2) lean manufacturing is not a gimmick business philosophy, and (3) lean manufacturing is able to be sustained for long-term practice.

Table 4.6. Sign test for median: facilities practicing lean

Sign test of median = 0.00000 versus not = 0.00000

	N	Below	Equal	Above	P	Median
Lack of Management Commitment	34	19	5	10	0.1360	-1.000
Lack of Technical Knowledge	34	8	6	20	0.0357	1.000
Lack of Understanding Benefits	34	14	4	16	0.8555	0.00000
Lean Does Not Fit Culture	34	17	6	11	0.3449	-0.5000
Management Resistant to Change	34	20	6	8	0.0357	-1.000
Employee Resistant to Change	34	3	3	28	0.0000	1.000
Lean is a Gimmick	34	26	5	3	0.0000	-1.000
Lean is Unsustainable	34	23	8	3	0.0001	-1.000
High Cost of Investment	34	17	8	9	0.1686	-0.5000
Previous Failures of Lean	34	18	8	8	0.0755	-1.000

4.2.3 Difficulties for Implementing Lean of Non-Practitioners

The results for the sign test to determine if the median of the responses differed from the hypothetical median of the neutral agreement level are displayed in Table 4.7. The reasons that participants agreed with have a positive median value, while the reasons they disagreed with have a negative median value. At a 95% confidence level, there were no response populations that rejected the null hypothesis where the non-lean manufacturing facilities agreed to reasons that present difficulty in implementing lean. The non-lean practicing questionnaire participants however did disagree with the following reasons, at a 95% confidence level where the null hypothesis could be rejected, that limited them from practicing lean manufacturing at their facilities; (1) management does has the commitment required to implement a continuous program such as lean, and (2) lean is not a gimmick business philosophy.

Table 4.7. Sign test for median: facilities not practicing lean

Sign test of median = 0.00000 versus not = 0.00000

	N	Below	Equal	Above	P	Median
Lack of Management Commitment	8	7	1	0	0.0156	-1.000
Lack of Technical Knowledge	8	1	1	6	0.1250	1.000
Lack of Understanding Benefits	8	1	2	5	0.2188	1.000
Lean Does Not Fit Culture	8	2	2	4	0.6875	0.5000
Management Resistant to Change	8	6	1	1	0.1250	-1.000
Employee Resistant to Change	8	3	1	4	1.0000	0.5000
Lean is a Gimmick	8	6	2	0	0.0313	-1.000
Lean is Unsustainable	8	3	5	0	0.2500	0.00000
High Cost of Investment	8	1	6	1	1.0000	0.00000
Previous Failures of Lean	8	5	3	0	0.0625	-1.000

4.3 Response from Continuous Improvement Experts

The National Institute for Standards and Technology operates a program called the "Hollings Manufacturing Extension Partnership" (MEP) that consists of a network of nonprofit, state university based firms [35]. The firms consist of technical experts that aim to help stimulate the success of small and mid-sized manufacturers across the United States. The objective of the government funded program is to help encourage economic growth across the manufacturing sector. Each state has at least one MEP center that provides advisory services to help surrounding companies in the region solve operational issues and promote business development.

After the results of the questionnaire were collected, the MEP centers located in West Virginia and Pennsylvania were contacted to interview each firm's continuous improvement expert regarding the findings of the study and to discuss their experiences with working with companies that have implemented lean manufacturing. In most instances, the center's continuous improvement representative was also its authority on lean manufacturing. Their roles at the center often required them to be knowledgeable not only of lean manufacturing but other continuous improvement programs, therefore identifying them as only experts in lean would be unjust. Since the questionnaire participants were manufacturing facilities from the same area that MEP centers attempt to connect with, the discussions were mutually beneficial to share information.

The MEP centers attract potential clients by offering their services to the targeted manufacturer audience through workshops, information sessions, and seminars. The majority of participants that come to the MEP center's continuous improvement events are mid-level managers who have some knowledge of a certain program or want to learn about methods they have seen another company use. A problem arises when the mid-level managers try to take lessons learned from the MEP event, such as the practice of lean manufacturing, and apply them in their facility. The mid-level managers are not able to successfully implement the lean methodology in their facility because they cannot effectively explain the purpose or practice well enough to convince upper management to support the initiative. Therefore, the MEP centers insist on connecting with the highest level of management for the company or facility before providing their services. Getting the person in charge of the manufacturing facility to believe in the practices of lean manufacturing ultimately has the higher chance for success.

According to Jim Marsilio, the director of business development at Catalyst Connection, companies that decide to partner with the MEP center generally have a high ranking manager that has experience working in a lean manufacturing facility previously and wants to implement it at their current facility. Russ Lawrence, the director of innovation at Innovative Manufacturers' Center (IMCPA), categorizes companies that seek the MEP center's help; those that have a problem and need someone else to fix it, and those that recognize that their business is inefficient and want to raise performance levels.

The first step the MEP centers take is assessing the current state of the manufacturing facility to determine if the company is ready for the required change in business philosophy and describing to the company which type of changes to expect. The MEP centers collect performance metrics on the facility's production processes to identify areas of waste and identify where immediate increases in performance can be obtained. Each facility is unique in which metrics are used based by MEP center's continuous improvement representative, but general information is collected on inventory levels, quality defects, lead times, throughput, and motion studies.

Estimation by Gerald Biser, director of the West Virginia Manufacturing Extension Partnership, the largest gains that facilities can expect from practicing lean manufacturing comes from reducing work in progress inventory in instances as much as 50% to 75%. Past experiences have seen companies reduce quality defects up to 75% and improve floor space utilization by reducing the required space by 50%. Other prominent improvements commonly seen are a reduction in lead times and increase of productivity by 25%.

Delaware Valley Industrial Research Center's (DVIRC) vice president of operations, Keith Ashlock, says one of the largest obstacles their experts experience when working with top-level managers to implement lean manufacturing is the ability to convince management that the projected performance gains from the MEP center's preliminary assessment are obtainable. Managers do not trust the information because they feel that it is not realistic to experience such large performance gains. The companies can potentially confuse the MEP center's intent with private consulting groups looking to profit from their services even though the MEP program is a government funded network of not-for-profit centers. Building trust between the company's management team and MEP representatives is a key component in the success of implementing lean manufacturing.

The success of implementing lean methods is primarily linked to the management team. Catalyst Connection's Jim Marsilio notes that successful companies who practice lean manufacturing based on their instruction are driven by a leader in the management team, deemed the "lean champion". The lean champion pushes the initiatives and keeps employees and the management team focused on execution. The lean champion is not typically chosen, but rather steps into the role. The lean champion may lead the lean manufacturing movement, but overall success hinges on the support and accountability of the top level of management.

DVIRC's Keith Ashlock believes that the companies can become successful in their practice of lean manufacturing depending on management trusting the provided guidance. A continuous improvement program is a strategic practice that consists of multiple long-term goals. The decisions made to reorganize a business's structure and functions in alignment with the beliefs in lean manufacturing can be hard to accept. It becomes easy for management to revert to previous practices when facing obstacles from the lean methodology being used. Companies do not necessarily look for the ideal solution to these obstacles, they only want an immediate solution. If reverting back to past practices offers resolution, it becomes matter of persistence for managers to continue to follow the lean methodology. The manager can either use a responsive solution based on traditional practice for which the obstacle may reoccur, or a proactive solution through lean manufacturing practices that offers a solution to eliminate the obstacle.

Russ Lawrence of IMCPA feels there is a disconnect between management and their understanding of the lean philosophy. He states that less than 5% of management interprets the application properly in companies that practice lean manufacturing or use continuous improvement programs. Managers think of lean tools as an option for their engineers to use in problem solving. If management cannot effectively communicate the purpose behind practicing lean manufacturing to their employees, then distrust in management can arise. When employees hear "lean", they think of it simply as a cost cutting measure. Lawrence believes that the most prominent factor in companies failing to implement lean manufacturing successfully is management not effectively explaining the purpose of lean methods to their employees due to a lack of understanding themselves. Employees need to know that the purpose behind a company adopting lean manufacturing is to empower their employees and involve them in the decision making process. When the employees become involved in the operations, the employees' needs can be recognized and the company can provide them with the necessary tools to satisfy those needs. If lean manufacturing is properly explained to employees, they will fully support the change.

By Northwest Pennsylvania Industrial Research Center's (NWIRC) lean specialist Craig Corsi's estimation, nearly 75% of companies fail at the implementation of lean methods. He states that the biggest issue the MEP center experiences when helping a company implement lean manufacturing is opening communication with the highest ranking manager. Since lean manufacturing requires the top-down management approach, success is driven by the highest ranking level of management. A challenge that NWIRC experiences is in approaching management when suggesting the use of lean manufacturing is the name itself. Managers associate the word "lean" with a condemnation. Ideas connected with trimming fat from their business are generated by typically being associated with eliminating jobs. Corsi states that people rarely understand the purpose of lean manufacturing. Therefore, NWIRC refers to a "continuous improvement program" as a vague term when introducing the methodology of lean manufacturing. The MEP center also enforces the belief that employees are a company's biggest asset. Lean methods are about maximizing a company's current resources, which can help retain and even increase their amount of employees. Employees become empowered and feel as if they are a part of something bigger than themselves in a lean manufacturing facility. The employees working directly on the processes are the company's best problem solvers, and failure to utilize them is a waste of a valuable resource.

Each MEP center representative that was interviewed offered valuable insight to understanding the factors for success and failure in companies that have attempted to implement lean manufacturing. The ultimate response was that management holds the responsibility for success and failures. They are the ones who must push and support the changes being made to their facility. The lack of a driving force from the head management position renders any efforts useless. Managers also need to apply effort in seeking an understanding for the purpose behind lean manufacturing. Employee knowledge is dependent on the extent of management knowledge. The entire company must undergo a change in their thought process. Practicing lean manufacturing places emphasis on preemptively problem solving. Lean manufacturing provides a structured program that a company can use to evaluate itself and monitor improvements being made. The following quote summarizes the fundamental barrier that companies must overcome before they can begin to implement lean manufacturing successfully.

"Manufacturing facilities are reactive, always putting out fires, where continuous improvement programs such as lean are proactive. It's counterintuitive." –Craig Corsi

4.4 Key Findings in Lean Manufacturing Practice

Evaluating the responses of the questionnaire from manufacturing facilities across industry and reviewing the conversations with lean manufacturing experts, there a five key findings that have been discovered. These findings encompass the practice of lean manufacturing in industry and are felt to be the core components that describe the challenges facilities face when attempting to implement lean methods. The five key findings from the study include: (1) the practice of lean manufacturing is better suited for certain industries and facilities while being dependent on the processes used and products being manufactured but the ideology of a lean system is universal; (2) lean manufacturing tools are misused due to a lack of both operational and conceptual knowledge; (3) failure of successfully implementing lean manufacturing methods is linked to misguided direction while attempting practice without a solid foundation of expertise; (4) a central point of leadership from management is required to drive the practice of lean manufacturing and concentrate the efforts of the continuous improvement program; and (5) there must be accountability from the top level of management to ensure that the commitment for change and the belief system for the practice of lean manufacturing is sustained.

4.5 Conclusions

Collecting information from both facilities that do and do not practice lean manufacturing provides a more balanced assessment rather than focusing on a singular type. Categorizing the two facility types is significant because it has a strong influence on how lean manufacturing is being viewed. It is also important to consider why facilities struggle with lean manufacturing practice from both the facilities themselves who applies the methods and the lean manufacturing experts that service them. Naturally, the manufacturing facilities will be defensive in their lean practice and the experts of lean will be critical of the facilities' application. When performing research that conducts an assessment between differing opinions, it is crucial to strive for balance and maintain impartiality to the results.

Chapter 5

Discussion

5.1 Findings from Manufacturing Facilities Responses

The following subsections elaborate on the prominent findings from the results of the questionnaire from the responses of participating manufacturing facilities and provide insight as to the significance of their understanding.

5.1.1 Lean Manufacturing Knowledge and Practice Commonality

From the results of the questionnaire, lean manufacturing is a widely recognized continuous improvement program where 82% of participants expressed knowledge of its practice. It is was also practiced by more than two-thirds of the study's participating manufacturing facilities, verifying that lean manufacturing is one of the most commonly practiced continuous improvement programs.

5.1.2 Lean Practice Applicability by Industry

The computer and electronic industries are highly active in lean manufacturing, supported by the results in Table 4.1. The majority of participating facilities were engaged in a large amount of the practices provided. The food and textile industries were not represented in the study as facilities that practice lean manufacturing. The conclusion that that practice of lean manufacturing can be dependent on the types of products a facility produces is drawn from this fact.

Lean is most commonly applied in facilities that utilize cellular production systems, where processes and machines are sequenced in a work cell with respect to producing a particular product type. Within each cell contains all the tools necessary to produce that product and ordered so the flow of products can move between one workstation to the next uninterrupted, therefore the process requires establishing standardization, where lean tools are the most effective. Other production systems, such as job shops and flow shops, make it more difficult to apply the lean tools. In job shops, there is a large variety of products being produced but in low volume. Typical job shop layouts group departments based on machine types, which is harder to standardize processes and create flow between tasks. In flow shops, there is a low variety of products being produced but in high volume. The process is already being optimized to the product being produced, therefore the flow is well-established and cost reductions would be more difficult to obtain because the product line is mature and typically has a long life cycle.

Lean methodology can be applied to nearly any industry, and the concepts can translate as well, however the actual tools being applied should be dictated by their purpose. Understanding the tools as to how they relate and execute the lean concepts is necessary because it is important not only to know how to use them, but why as well. Generalizations can be dangerous in lean manufacturing, and not every practice is appropriate even when it is possible to apply them.

5.1.3 Diverted Understanding of Lean Practices

The most widely used lean manufacturing practices included eliminating waste, preventative maintenance, reducing cycle time, and reducing inventory, all of which are practiced by at least 70% of participating manufacturing facilities. The most surprising deficiency in practice was the use of pull-based production and "kanbans" at only 32%. Only the use a single supplier was practiced less at 15%. More participants indicated that they practiced continuous flow manufacturing at 44% than the use of pull processes. This information is important as continuous flow is transitioned into facilities by implementing pull production processes. Continuous / one-piece flow eliminates WIP between operations. A push system creates WIP. Therefore, attempting to implement the continuous / one-piece flow practice in a push system is illogical. The limited practice of pull-based production and "kanbans" illustrates conflicting responses by the facilities that were eager to point out the practice of eliminating waste where they identified their values streams. If these facilities would have been monitoring their value streams they would have recognize the existence of inventory and queues in their push system. Establishing a pull system is one of the five principles in the lean manufacturing cycle used by facilities to become responsive to customer orders and prevent over-production [25]. There seems to be confusion on the understanding of the key concepts of lean manufacturing.

5.1.4 Accountability in Implementing Lean Practices

Throughout the report there has been an emphasis on the importance for the top level of management to be the main supporter for the implementation of lean practices. In determining what reasons created difficulty to implement lean strategic practices, the participating manufacturing facilities that practice lean methods primarily placed the blame on the employees being resistant to change. That action in reasoning directly contradicts the belief that the top level of management needs to be held accountable for successful lean implementation. Change starts from the top, and lack of execution reflects poor management. The knowledge of the employees is dependent on the manager. If the employees are resistant to the change it is because the purpose of practicing lean manufacturing has not been effectively communicated. The practice of lean methods allows for substantial intrinsic motivation for employees who are given the power of self-governance and problem solving [48]. Only when employees are subjected to excessive lean implementation practices does that motivation fade.

The same managers in lean practicing facilities significantly disagreed with the notion that management was resistant to change. One of the toughest things for a company to do is to evaluate itself because prejudice can exist in the assessment. A manager does not want admit poor performance even if it is true. Being subjective is an important asset to lean leadership because management is responsible for identifying their faults and correcting them [29].

5.1.5 Lack of Technical Knowledge in Lean Manufacturing

The lean practicing facilities stated that the lack of a technical understanding for lean manufacturing practices was a significant reason that causes resistance for implementing lean methods. Insufficient knowledge is a prominent issue, as the implementation of lean methods follows a disciplined structure, therefore companies are required to rely on the knowledge they are able to accumulate or hire aid from outside the company. For companies who attempt to undertake transforming their facilities based on existing staff members, it is easy to understand how difficulty can arise if the expertise is not there. For small enterprise businesses, the largest limiting factor for practicing lean methods is financially related, as they cannot afford personnel with the sole responsibility to focus on the continuous improvement program [1].

For the participating facilities that did not practice lean manufacturing, there was no significant agreement to any of the reasons provided that would prevent them from implementing lean methods. The highest level of agreement belonged to a lack of technical knowledge associated with the practice of lean manufacturing and understanding the benefits it provides. These companies may have a limited comprehension of lean manufacturing, but they also felt that its practice was not a gimmick. They noted that management was willing to commit to the practice of lean manufacturing methods, but there was uncertainty if success could be sustained. While there are many companies that have used lean manufacturing as a continuous improvement program, 47% of the study's participants have implemented it in the last 5 years and 73% in the last decade. The recent growth in practice illustrates how the knowledge of lean manufacturing is spreading.

5.1.6 Motivation for Practicing Lean Methods

The motivation for implementing lean manufacturing can be driven by competition in which a company attempts to mimic its competitors [19] [30]. Discussions with management at participating facilities commonly noted that their company had pushed for the implementation of lean manufacturing in many instances due to compete with competitors not only on a national level but also internationally where many facilities were already following the lean methodology. Pursuing lean manufacturing by following this approach can create problems if the companies only focus on how to use lean methods, rather than why. Understanding lean manufacturing does not come at just the execution level, but the conceptual level as well.

Inversely, there are also companies who believe lean manufacturing does not apply to them due to operational differences, thus suppressing motivation to further learn about lean manufacturing. Managers at participating facilities that did not practice lean manufacturing often described differences by comparing themselves to other facilities while referencing products, processes, and culture as deterrents. While these reasons my indeed have been valid for some cases, the general impression it created was that these facilities were satisfied with their current methods and did not desire to change or learn about alternative business models.

5.1.7 Defining Success in Lean Manufacturing

The use of lean manufacturing does not apply to all companies, as it depends on how improvements are valued. This is not to say that the concepts of lean cannot be applied to any company, as lean manufacturing has been successfully implemented in all production methods, but only that the practice requires a change in thinking and developing the proper culture for sustainable success. Lean methodology necessitates different management accounting for evaluating a company's improvements [41]. The use of traditional performance and cost metrics do not apply to lean manufacturing, as the practice of lean methods relies on many non-financial performance measures to track the effect of improvements on the company's profitability [12]. Companies that practice traditional manufacturing accounting can experience poor performance if they do not change their performance measurement approach when implementing lean methods [28].

5.2 Findings from Continuous Improvement Expert Interviews

The following subsections elaborate on the prominent findings derived from interviews with continuous improvement experts in the manufacturing industry and provide insight as to the significance of their understanding.

5.2.1 Leadership Expertise in Implementing Lean Practices

The overwhelming message from the continuous improvement experts is the same. If the foundation of lean manufacturing is not laid, there is nothing to build on for sustainability. In order for a company to become successful in the implementation of lean manufacturing as a continuous improvement program, they need to develop their own experts that will be able to direct the change. A piecemeal approach will lead to piecemeal results.

5.2.2 Lean Manufacturing Belief System

According to the experts, unsuccessful implementation of lean manufacturing is not just an issue of execution, it is a matter of difficulty in understanding concepts. To continuously improve is to accept that there are gains yet to be made without limitation for extent. One of the comments that resonated during the interviews with the MEP centers was the difficulty in convincing management that the purposed changes to their operation would provide a large increase in their performance. Skepticism is understandable, but that mindset is limiting. To become a lean manufacturing organization is to believe that improvements can always be made. A company culture has a strong effect on the success or failure during the implementation of lean methods because the process of transformation is endless and requires belief and dedication to the work being done. That challenge is not to be understated, and is something leadership must consider before embarking on the path of lean manufacturing.

5.3 Conclusions

The premise of lean manufacturing is often viewed as facile, which can cause those looking to implement it to be inert in their approach while attempting to understand the disciplined structure of lean methods. Practicing lean methods can be simple or complex depending on how much a company is willing to learn before attempting to implement them. The important part is that a company knows the reasoning behind pursuing lean methods. There will never be a quick fix to a company's problems because the difficulties will always be present. Lean manufacturing allows for a new approach to problem solving compared to traditional methods, where companies can become proactive and as their understanding of lean practices strengthens it will provide additional resolution skills. In the end, only those that truly understand the purpose and underlying thought behind the lean philosophy will become successful.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

(1) Lean manufacturing is a widely recognized and practiced business philosophy that companies use to increase their performance and relationships with their customers. It is difficult to find a manufacturing facility that is unaware of lean; however the extent of their knowledge does not mirror their awareness.

(2) The application of lean manufacturing practices is not readily appropriate for every company, but adopting the concept of focusing on the customer and reducing waste of resources to maximize the value of their products can be universally applied. Lean manufacturing faces criticism in many companies due to its low success rate which has promoted skepticism. When speaking to facilities that have failed at implementation, blame in placed on the methods. In instances where lean is criticized, it is at times described as aggressive cost cutting by the means of eliminating jobs and an overbearing form of management. When speaking to experts that offer lean consulting, blame is placed on the management team applying the methods. Failure it cited as a lack of capability or willingness to take the appropriate steps and learn the methodology. Each side's views may carry valid experiences in their reasoning, but it must be understood that both the application and instruction of lean is still developing. It will take trial and error to create a mature system that is better understood.

(3) There is a limited understanding of lean manufacturing across industry at conceptual and technical levels. Lean tools are commonly misused because individuals do not possess sufficient knowledge or skills for proper use. Ideally, lean manufacturing will develop into a structured system that has guidelines and well-established best practices. Lean needs an organization to create a process that manufacturers can use in their approach to applying tools in a structured format. As mentioned earlier in the report, the application of lean tools has been viewed as specific to an individual facility, however if commonalities between facilities can be determine then stronger guidance can be provided.

(4) The lack of accountability in lean manufacturing displays deficiency in leadership and direction. Management at lean manufacturing facilities feel that employees present the largest challenge in implementing lean practices because they are resistant to change. Management also feels that they are not resistant to change and are committed to ensuring the execution of lean practice. Change is difficult to accept regardless of employment position. If a company is currently successful it is less likely they will be willing to change their management model. For those companies facing difficulties, it becomes a struggle to stay on the current path and anticipate a better economic environment or consider making significant changes. Choosing to follow the lean philosophy requires commitment and accountability in its decision making. A belief has to be developed to push for change.

(5) Knowledge is invaluable and in order for manufacturers to compete for business worldwide, there has to be a desire to learn and grow as not to fall behind competitors who are doing so. Management at manufacturing facilities that do not practice lean manufacturing feel that a lack of technical knowledge is the limiting factor that prevents them from doing do. They do not discredit the practice of lean, only that their understanding is insufficient. Learning is essential to developing as a company. Lean can simple or complex, depending on the effort taken to understand it.

(6) Change is difficult but in an industry driven by demand it is necessary for manufactures to be flexible and have the ability to alter their practice by responding with modernized methods in order be successful. Continuous improvement experts from Hollings Manufacturing Extension Partnership centers identify management as the main factor for the success or failure of a company that is pursuing lean manufacturing. They feel that management does not take accountability for the practices and fails to understand the concepts of lean methods. Management that leads the change to lean manufacturing has the ability to alter a company's culture and provides the highest chance for success. Lean requires the promoting the growth of a company's employees and assisting them in doing so. Education and training are prominent expenses, but they are required for the sustainability of success.

(7) Continuous improvement programs require continuous learning. A lean manufacturing facility chases an unattainable target of perfect value with knowledge they cannot influence its direction but that they can change their ability to respond to it. Improvements can always be made, and the application of lean manufacturing practices provides a methodology for achieving them.

6.2 Future Work

Even the most sophisticated assessment can be improved since limitations and bias are always present. The research should be appraised in that same context by understanding its limitations and biases. Those conditions present in this study that should be accounted for include the sample size of the responses, the procedure for how data was collected, and the method of analysis. In order to improve the understanding of how lean manufacturing practice is being used in industry, future efforts can increase the capability of the study by exploring alternative methods. Areas for future work include:

1. Increase the distribution of the questionnaire to an expanded participant selection area, thus examining the lean manufacturing between different regions. Culture has been mentioned as important factor in the practice of continuous improvement programs, therefore it would be valuable to understand how the location of manufacturing facilities influences its experiences and perception of lean methods.

2. Extend the assessment tool to become more comprehensive by collecting additional information that relates to the practice of lean manufacturing. With the flexible construction of the questionnaire, the addition of supplemental questions based on the knowledge gained in the current study would not present considerable difficulty.

    - As mentioned in the development of the questionnaire, the study did not cover financial related data from the manufacturers. The impact of creating improvement projects and applying lean methods incurs an expense in hopes that the results would reduce operating costs and produce higher profitability. It would be of interest to examine the effect of investments in continuous improvement projects and the returns that they generated.

- Information on the participants' management positions were collected to understand who was participating in the study, however their responses were not analyzed in this respect. A worthwhile analysis would be to explore the differences in views of lean manufacturing between the employment hierarchies. For example, exploring the reason for applying the lean methodology in a facility and its difficulties between upper, middle, and low-level managers.

- For those manufacturers who are successful in the implementation of lean, it would be meaningful to research its ramifications across the supply chain. An area to review would the impact of push and pull systems throughout the supply chain and how balance is achieved. The premise of lean in a manufacturing facility initially focuses on the demand drivers, however the supply sources also have a direct impact on the flow of materials being processed and reaching the customer. Connecting the demand and supply flows and examining how lean affects that relationship is another topic for discussion that should be explored.

3. Conduct the study as an annual practice by repeatedly collecting similar data from the manufacturing facilities to evaluate the development of lean manufacturing and assess how it endures. The merit of this information is that it would provide a long-term evaluation, uncommon in existing literature.

4. Expand the reach of the study to collect data of associated continuous improvement practices. With the questionnaire following a skip-logic format, information can be collected from participants that do not practice lean manufacturing but may use other types of continuous improvement practices. The assessment tool is modular and presents the opportunity for infinite possibilities in how it can be used. There can be an endless number of unique flow paths through the questionnaire, only limited by their construction.

5. Utilize a different assessment approach by conducting case studies where researchers visits manufacturing facilities to coordinate on-site interviews and collect observations that are independent of facility personnel. Visiting manufacturing facilities that participated in the questionnaire and then performing an additional assessment would further validate the significance of the study.

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Appendix

A.1 Lean Manufacturing Practice Questionnaire

WestVirginiaUniversity

2013 West Virginia University Manufacturing Study

* Required

1. **What position do you currently hold in your company? ***

   Mark only one oval.

   - ( ) President
   - ( ) Vice President
   - ( ) Division Manager
   - ( ) Department Manager
   - ( ) Supervisor
   - ( ) Other: ____________________

2. **Which departments do your responsibilities reside? ***

   Check all that apply.

   - [ ] Engineering
   - [ ] Finance
   - [ ] Manufacturing
   - [ ] Marketing
   - [ ] Operations
   - [ ] Personnel / Human Resources
   - [ ] Research and Development
   - [ ] Other: ____________________

3. **How many years have you been in your current position? ***

   Mark only one oval per row.

	0 - 5	6 - 10	11 - 15	> 15
Number of Years	( )	( )	( )	( )

4. **In which industry sector is your facility's PRIMARY product?** *
Mark only one oval.

- ( ) Chemical
- ( ) Computer & Electronics
- ( ) Food & Textile
- ( ) Fabricated Metal
- ( ) Machinery
- ( ) Transportation
- ( ) Other: ____________________

5. **How many employees work at your facility?** *
Mark only one oval per row.

	< 50	50 - 250	> 250
Number of Employees	( )	( )	( )

6. **Who has the ability to approve financial decisions for projects at your facility?** *
Check all that apply.

- [ ] President
- [ ] Vice President
- [ ] Division Manager
- [ ] Department Manager
- [ ] Supervisor
- [ ] Other: ____________________

7. **Do you have any knowledge or experience with Lean Manufacturing?** *
Your knowledge or experience does NOT have to be extensive, only that you have a basic understanding or exposure to Lean.
Mark only one oval.

- ( ) Yes
- ( ) No *Skip to question 73.*

8. **Does your facility use any Lean methods?** *
This includes any projects or strategies working toward goals such as reducing waste, increasing ultilization, etc.
Mark only one oval.

- ( ) Yes
- ( ) No *Skip to question 72.*

9. **Is the use of Lean methods specific to your facility or is it a company-wide initiative?** *
Mark only one oval.

- ( ) Facility Initiative
- ( ) Company Initiative

10. **Who is responsible for implementing and monitoring Lean projects?** *
Mark only one oval.

- ( ) An Individual
- ( ) A Specialized Team
- ( ) All Affected Employees

11. **How long has your facility engaged in Lean?** *
Mark only one oval per row.

	0 - 5	6 - 10	11 - 15	> 15
Number of Years	( )	( )	( )	( )

12. **Which of the following Lean strategies have been implemented (partially or in full) at your facility?** *
Check all that apply.

- [ ] 5S
- [ ] Continuous / One-Piece Flow
- [ ] Eliminate Waste
- [ ] Error Proofing / Poka-yoke
- [ ] New Process Equipment / Technology
- [ ] Preventative Maintenance
- [ ] Pull-Based Production / Kanban
- [ ] Quick Changeover
- [ ] Reduce Cycle Time
- [ ] Reduce Inventory
- [ ] Reduce Lot Size
- [ ] Reduce Setup Time
- [ ] Remove Bottlenecks
- [ ] Single Supplier Focus
- [ ] N/A

13. **Which strategy has been the most beneficial to your facility's objectives?** *

Mark only one oval.

◯ 5S	*After question 15, skip to question 16*
◯ Continuous / One-Piece Flow	*After question 15, skip to question 20*
◯ Eliminate Waste	*After question 15, skip to question 24*
◯ Error Proofing / Poka-yoke	*After question 15, skip to question 28*
◯ New Process Equipment / Technology	*After question 15, skip to question 32*
◯ Preventative Maintenance	*After question 15, skip to question 36*
◯ Pull-Based Production / Kanban	*After question 15, skip to question 40*
◯ Quick Changeover	*After question 15, skip to question 44*
◯ Reduce Cycle Time	*After question 15, skip to question 48*
◯ Reduce Inventory	*After question 15, skip to question 52*
◯ Reduce Lot Size	*After question 15, skip to question 56*
◯ Reduce Setup Time	*After question 15, skip to question 60*
◯ Remove Bottlenecks	*After question 15, skip to question 64*
◯ Single Supplier Focus	*After question 15, skip to question 68*
◯ N/A	*After question 15, skip to question 72*

14. **Which strategy presents the lowest level of difficulty for implementation at your facility?** *

The strategy selected does NOT have to be used at your facility.

Mark only one oval.

◯ 5S
◯ Continuous / One-Piece Flow
◯ Eliminate Waste
◯ Error Proofing / Poka-yoke
◯ New Process Equipment / Technology
◯ Preventative Maintenance
◯ Pull-Based Production / Kanban
◯ Quick Changeover
◯ Reduce Cycle Time
◯ Reduce Inventory
◯ Reduce Lot Size
◯ Reduce Setup Time
◯ Remove Bottlenecks
◯ Single Supplier Focus
◯ N/A

15. **Which strategy presents the highest level of difficulty for implementation at your facility?** *

The strategy selected does NOT have to be used at your facility.

Mark only one oval.

- 5S
- Continuous / One-Piece Flow
- Eliminate Waste
- Error Proofing / Poka-yoke
- New Process Equipment / Technology
- Preventative Maintenance
- Pull-Based Production / Kanban
- Quick Changeover
- Reduce Cycle Time
- Reduce Inventory
- Reduce Lot Size
- Reduce Setup Time
- Remove Bottlenecks
- Single Supplier Focus
- N/A

Please skip to the next appropriate question based on your response for question 13.

5S

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

16. **What level or percentage of implementation for the 5S strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	⬭	⬭	⬭	⬭	⬭

17. **Red Tags are first used in which step?** *

Mark only one oval.

- ⬭ Sort
- ⬭ Set in Order
- ⬭ Shine
- ⬭ Standardize
- ⬭ Sustain

18. **Where is 5S performed?** *

Mark only one oval.

- ⬭ Areas that are messy
- ⬭ On the plant floor, maintenance, shipping and office areas
- ⬭ Only on the plant floor

19. **When is it best that 5S is performed?** *

Mark only one oval.

- ⬭ At the end of the day or before shutdown
- ⬭ Every day as part of a routine
- ⬭ Only when the plant is not busy

Skip to question 73.

Continuous / One-Piece Flow

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

20. **What level or percentage of implementation for the continuous / one-piece flow strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	⬭	⬭	⬭	⬭	⬭

21. **Which of the following is a benefit of cellular manufacturing?** *

Mark only one oval.

- ⬭ Management is more "hands-on" with the workers
- ⬭ Mass production becomes easier
- ⬭ Quality is less important
- ⬭ Workers become multi-skilled

22. **What is your Overall Equipment Effectiveness (OEE)?** *

Mark only one oval per row.

	< 50%	50 - 59%	60 - 69%	70 - 79%	80 - 89%	90 - 100%
OEE Rate	⬭	⬭	⬭	⬭	⬭	⬭

23. **What is the defect rate of your PRIMARY product?** *

Mark only one oval per row.

	< 0.1%	< 1%	< 5%	< 10%	> 10%	N/A
Defect Rate	⬭	⬭	⬭	⬭	⬭	⬭

Skip to question 72.

Eliminate Waste

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

24. **What level or percentage of implementation for the eliminate waste strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	◯	◯	◯	◯	◯

25. **What is the main reason why a business would want to reduce waste?** *

Mark only one oval.

- ◯ Improve Customer Service
- ◯ Increase Capacities
- ◯ Lower Costs
- ◯ Reduce Inventories

26. **Which of the following is NOT a Lean waste?** *

Mark only one oval.

- ◯ Defects
- ◯ Employees
- ◯ Inventory
- ◯ Transportation

27. **Does your facility have a program for monitoring its energy use?** *

Mark only one oval.

- ◯ Yes
- ◯ No

Skip to question 72.

Error Proofing / Poka-yoke

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

28. **What level or percentage of implementation for the error proofing / poka-yoke strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	⬭	⬭	⬭	⬭	⬭

29. **A chart that shows the number of defects that result from different causes would be used for:** *

Mark only one oval.

- ⬭ Benchmarking
- ⬭ Cause and Effect Diagrams
- ⬭ Control Charts
- ⬭ Flowcharts
- ⬭ Pareto Analysis

Please select the TRUE statement for the following:

30. **Poka-yoke:** *

Mark only one oval.

- ⬭ is a replacement for quality monitoring systems
- ⬭ can reduce or eliminate human error
- ⬭ cannot reduce process variance
- ⬭ is only used during source inspection

31. **Quality at the source involves:** *

Mark only one oval.

- ⬭ discarding defective items after production
- ⬭ identifying and correcting quality problems at the point of supply
- ⬭ inspecting products after they are produced
- ⬭ reworking defective products

Skip to question 72.

New Process Equipment / Technology

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

32. **What level or percentage of implementation for the new process equipment / technology strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	◯	◯	◯	◯	◯

33. **Approximately what percentage of your products have been added in the last year?** *

Mark only one oval per row.

	0%	25%	50%	75%	100%
New Product Percentage	◯	◯	◯	◯	◯

34. **Which of the following is related to determining equipment depreciation?** *

Mark only one oval.

- ◯ DMAIC
- ◯ LMC
- ◯ MACRS
- ◯ SMED
- ◯ SQCD

35. **Approximately how much annual training is provided to workers?** *

Mark only one oval per row.

	10 or less	20	30	40	50 or more
Annual Training Hours/Employee	◯	◯	◯	◯	◯

Skip to question 72.

Preventative Maintenance

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

36. **What level or percentage of implementation for the preventative maintenance strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	⬭	⬭	⬭	⬭	⬭

37. **When should preventative maintenance be performed?** *

Mark only one oval.

- A) During machine idle time
- B) During worker idle time
- C) Both A & B
- D) None of the above

38. **Minor repairs, upkeep, and cleaning are label as:** *

Mark only one oval.

- Corrective Maintenance
- Routine Maintenance
- Predictive Maintenance
- Preventative Maintenance

39. **Is it ever preferred to run a machine until failure without maintaining it?** *

Mark only one oval.

- Yes
- No

Skip to question 72.

Pull-Based Production / Kanban

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

40. **What level or percentage of implementation for the pull-based production / kanban strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	⬭	⬭	⬭	⬭	⬭

41. **A kanban card is used to notify:** *

Mark only one oval.

- ⬭ a machine has broken down
- ⬭ a machine is ready for scheduled maintenance
- ⬭ a worker is out of parts
- ⬭ work is authorized to replenish a downstream station
- ⬭ work is ready to be moved to the next station

42. **The inventory levels at my facility remain mostly constant.** *

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Level of Agreement	⬭	⬭	⬭	⬭	⬭

43. **What is your Overall Equipment Effectiveness (OEE)?** *

Mark only one oval per row.

	< 50%	50 - 59%	60 - 69%	70 - 79%	80 - 89%	90 - 100%
OEE Rate	⬭	⬭	⬭	⬭	⬭	⬭

Skip to question 72.

Quick Changeover

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

44. **What level or percentage of implementation for the quick changeover strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	⬭	⬭	⬭	⬭	⬭

45. **What of the following is NOT a component of a changeover process?** *

Mark only one oval.

- Cleaning
- Repair
- Setup
- Startup

46. **Which of the following is related to reducing changeover times?** *

Mark only one oval.

- MACRS
- JIT
- SMED
- Takt Time
- VMI

47. **Approximately how much annual training is provided to workers?** *

Mark only one oval per row.

	10 or less	20	30	40	50 or more
Annual Training Hours/Employee	⬭	⬭	⬭	⬭	⬭

Skip to question 72.

Reduce Cycle Time

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

48. **What level or percentage of implementation for the reduce cycle time strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	◯	◯	◯	◯	◯

49. **What is your Overall Equipment Effectiveness (OEE)?** *

Mark only one oval per row.

	< 50%	50 - 59%	60 - 69%	70 - 79%	80 - 89%	90 - 100%
OEE Rate	◯	◯	◯	◯	◯	◯

50. **TRUE OR FALSE: Reducing cycle time has a negative impact on quality.** *

Mark only one oval.

◯ TRUE
◯ FALSE

51. **Approximately how long does it take you to introduce a new product into the market?** *

Mark only one oval per row.

	1 or less	3	6	9	12 or more	N/A
Number of Months	◯	◯	◯	◯	◯	◯

Skip to question 72.

Reduce Inventory

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

52. **What level or percentage of implementation for the reduce inventory strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	⬭	⬭	⬭	⬭	⬭

53. **Since focusing on reducing your inventory, how much has it been reduced by?** *

Mark only one oval per row.

	0 - 20%	20 - 40%	40 - 60%	60 - 80%	80 - 100%
Inventory Reduction Percentage	⬭	⬭	⬭	⬭	⬭

54. **Approximately what percentage of your total inventory is Work In Progress (WIP)?** *

Mark only one oval per row.

	0 - 20%	20 - 40%	40 - 60%	60 - 80%	80 - 100%
WIP Inventory Percentage	⬭	⬭	⬭	⬭	⬭

55. **Please estimate how much floor space used for storing inventory has been reduced by:** *

Mark only one oval per row.

	0 - 20%	20 - 40%	40 - 60%	60 - 80%	80 - 100%
Floor Space Reduction Percentage	⬭	⬭	⬭	⬭	⬭

Skip to question 72.

Reduce Lot Size

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

56. **What level or percentage of implementation for the reduce lot size strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	◯	◯	◯	◯	◯

57. **What method do you primarily use to select a lot size?** *

Mark only one oval.

- ◯ Economic Order Quantity (EOQ)
- ◯ Least Unit Cost (LUC)
- ◯ Lot-for-Lot (L4L)
- ◯ Part Period Balancing (PPB)
- ◯ Periodic Order Quantities (POC)
- ◯ Other: ______________________

58. **Which of the following is NOT a benefit to smaller lot sizes?** *

Mark only one oval.

- ◯ Increased Flexibility
- ◯ Increased Setups
- ◯ Reduced Cycle Time
- ◯ Reduced Inventory
- ◯ Reduced Rework

59. **TRUE OR FALSE: Buffers, such as safety stock or longer lead times, allow for reducing variability in small lot production.** *

Mark only one oval.

- ◯ TRUE
- ◯ FALSE

Skip to question 72.

Reduce Setup Time

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

60. **What level or percentage of implementation for the reduce setup time strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	◯	◯	◯	◯	◯

61. **Since focusing on reducing setup times, have the number of defects during startup: increased, decreased, or stayed the same?** *

Mark only one oval.

- ◯ Increased
- ◯ Decreased
- ◯ Stayed the Same

62. **What has happened to the machine capacities?** *

Mark only one oval.

- ◯ Increased
- ◯ Decreased
- ◯ Stayed the Same

63. **Which of the following is related to reducing changeover times?** *

Mark only one oval.

- ◯ JIT
- ◯ MACRS
- ◯ SMED
- ◯ Takt Time
- ◯ VMI

Skip to question 72.

Remove Bottlenecks

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

64. **What level or percentage of implementation for the remove bottlenecks strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	◯	◯	◯	◯	◯

65. **Which of the following is related to detecting a bottleneck?** *

Mark only one oval.

- ◯ CPM
- ◯ JIT
- ◯ MRP
- ◯ TPS
- ◯ TQM

66. **Which is NOT a method for managing a bottleneck?** *

Mark only one oval.

- ◯ Change work sequences
- ◯ Increase lot sizes into the bottleneck
- ◯ Increase the bottleneck's capacity
- ◯ Reroute work away from the bottleneck

67. **TRUE OR FALSE: A bottleneck provides control of a production system.** *

Mark only one oval.

- ◯ TRUE
- ◯ FALSE

Skip to question 72.

Single Supplier Focus

Based on the selection of your Most Beneficial Lean Strategy, please answer the following questions. Use your best estimation for any you do not know.

68. **What level or percentage of implementation for the single supplier focus strategy has been completed?** *

Mark only one oval per row.

	None (0%)	Limited (25%)	Partial (50%)	Extensive (75%)	Full (100%)
Implementation Completed	⬭	⬭	⬭	⬭	⬭

69. **What is MOST important to you when selecting a supplier?** *

Mark only one oval.

- ⬭ Cost Competitiveness
- ⬭ Partner Relationship
- ⬭ Responsiveness to Demands

70. **What percentage of your supply deliveries are on time?** *

Mark only one oval per row.

	< 70%	70 - 79%	80 - 89%	90 - 100%
On-Time Delivery	⬭	⬭	⬭	⬭

71. **Do your suppliers monitor your inventory levels?** *

Mark only one oval.

- ⬭ No
- ⬭ Yes

Skip to question 72.

72. **State your level of agreement as to why implementing Lean methods at your facility can be difficult:** *

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Lack of Commitment from Management	⬭	⬭	⬭	⬭	⬭
Lack of Lean Technical Knowledge	⬭	⬭	⬭	⬭	⬭
Lack of Understanding Benefits	⬭	⬭	⬭	⬭	⬭
Does Not Fit the Company's Culture	⬭	⬭	⬭	⬭	⬭
Management Resistant to Change	⬭	⬭	⬭	⬭	⬭
Employees Resistant to Change	⬭	⬭	⬭	⬭	⬭
Lean is a Gimmick	⬭	⬭	⬭	⬭	⬭
Lean is Not Sustainable (AKA Quick Wins)	⬭	⬭	⬭	⬭	⬭
High Cost of Investment	⬭	⬭	⬭	⬭	⬭
Previous Failures of Lean	⬭	⬭	⬭	⬭	⬭

Questionnaire Completed

73. **First Name**

____

74. **Last Name**

____

75. **E-mail Address**

____

76. **Request for Summary of Results**
Check all that apply.

☐ I would like to be provided with the results of the study to be sent to the e-mail address that I have listed above.

77. **If you have any comments, please feel free to provide them below:**

____
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____