AN ABSTRACT OF THE DISSERTATION OF

Woraruthai Choothian for the degree of Doctor of Philosophy in Industrial Engineering presented on November 24, 2014.

Title: A Study of the Application of Lean Practices to New Product Development Processes.

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The application of lean to new product development (NPD) processes has been claimed to generate positive impact on NPD performance. There are very few empirical studies, however, on how organizations should apply lean practices or on the exact nature of the impact of lean on NPD performance. To further understand how the application of lean can improve NPD performance, additional empirical studies are needed. This research was designed to gain a better understanding of how organizations can apply lean to improve NPD processes. The objectives of this research were (1) to identify common practices used to apply lean to NPD processes, (2) to identify performance indicators used to evaluate NPD process performance and the impact of applying lean on NPD process performance improvement, (3) to identify challenges faced by organizations in applying lean to NPD, (4) to study whether or not there was a relationship between the number of practices used and NPD process performance, and (5) to study whether or not there was a relationship between years of experience with lean and NPD process performance.

Eight hypotheses were developed to support the research objectives. An internet survey was created to collect data to test the eight hypotheses. Fifty-eight organizations

completed the survey. Of the 58 responding organizations, only 27 had applied lean to NPD. Following analyses of the data, five findings, related to the research objectives, are of particular note. First, the results indicated that all fourteen practices included on the survey were useful in applying lean to NPD. Since the practices included on the survey were a mix of lean and more traditional continuous improvement practices, these findings suggest that organizations can use a variety of practices, and are not limited to only lean practices, when applying lean principles to NPD.

Second, the research results also suggest that organizations can use a wide range of performance indicators to evaluate NPD process performance after implementing lean. The results also confirmed that the application of lean practices generally produced positive impacts on NPD process performance, as measured by time, cost, and quality performance indicators.

Third, all six challenges proposed in this research were experienced by the organizations included in this study during their lean implementations in NPD. The lack of management commitment and support and unsupportive organizational culture were two challenges that were identified as barriers to applying lean in NPD.

Fourth, the results indicated that there was no relationship between the number of practices used and NPD process performance, as measured by time, cost, and quality performance indicators. Although organizations made an effort to use a variety of practices to support all lean principles, NPD performance improvement does not appear to increase as the number of practices used increased.

Fifth, there was an inverse relationship between years of experience with lean and NPD process performance, as measured by time, cost, and quality performance indicators.

Two explanations have been suggested to explain this unexpected finding. First, it is possible that as organizational experience with lean increases, organizational leaders expect greater improvement than actually realized. Second, it is possible that since participating organizations had limited lean knowledge, organizations were less effective in these lean implementations.

A Study of the Application of Lean Practices to New Product Development Processes

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

Woraruthai Choothian, Author

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A Study of the Application of Lean Practices to New Product Development Processes

1 Introduction

1.1 Research Objectives

The desired outcomes of this research were five-fold. First, the research identified common practices used when organizations apply lean to the new product development (NPD) process. Second, the research identified performance indicators used to evaluate NPD process performance and the impact of applying lean on NPD process performance improvement, as measured by time, cost, and quality. Third, the research identified challenges faced by organizations when applying lean to NPD processes. Fourth, the research studied whether or not there was a relationship between the number of practices used by organizations and NPD process performance as measured by time, cost, and quality performance indicators. Finally, the research studied whether or not there was a relationship between the years of experience with lean and NPD process performance as measured by time, cost, and quality performance indicators.

1.2 Research Variables and Hypotheses

The variables of interest for this research included practice use frequency, perceived usefulness of practices, performance indicator use frequency, perceived NPD process performance improvement, challenge frequency, perceived lean barriers, number of practices used, and years of experience with lean. The research hypotheses tested in this study are summarized in Table l.1. The first two hypotheses were used to investigate practices used by organizations and practices used in applying lean in NPD processes. The third and fourth hypotheses were used to identify performance indicators used to assess NPD process performance improvement after applying lean and to understand the impact of lean on NPD process performance, as measured by time, cost, and quality. The fifth and sixth hypotheses were used to characterize the challenges faced by organizations and perceived lean barriers in NPD processes. The seventh hypothesis was used to study the relationship between the number of practices used by organizations and NPD process performance, as measured by time, cost, and quality performance indicators. Similarly, the eighth hypothesis was used to understand the relationship between years of experience with lean and NPD process performance. There is evidence from previous research to support each of the hypothesized relationships. Previous research findings supporting these hypotheses are reviewed briefly in the following sections.

Table 1.1 Research Hypotheses

Hypotheses
$H1_0$: There is no difference in the frequency at which a specific practice is applied in NPD processes.
$H2_0$: There is no difference in the perceived usefulness of specific lean practices in NPD processes.
$H3_0$: There is no difference in the frequency at which a performance indicator is used to measure the impact of the application of practices used in implementing lean in NPD processes.
$H4_0$: There is no difference in the perceived performance improvement in NPD processes after implementing lean as measured by time, cost, and quality performance indicators.
$H5_0$: There is no difference in the frequency at which a specific challenge is faced by organizations when implementing lean to NPD processes.
$H6_0$: There is no difference in the extent to which a particular challenge is perceived to be a barrier to lean implementation in NPD processes.
$H7a_0$: There is no relationship between the number of practices used by organizations and NPD process performance, as measured by time performance indicators. $H7b_0$: There is no relationship between the number of practices used by organizations and NPD process performance, as measured by cost performance indicators. $H7c_0$: There is no relationship between the number of practices used by organizations and NPD process performance, as measured by quality performance indicators.
$H8a_0$: There is no relationship between the years of experience with lean and NPD process performance, as measured by time performance indicators. $H8b_0$: There is no relationship between the years of experience with lean and NPD process performance, as measured by cost performance indicators. $H8c_0$: There is no relationship between the years of experience with lean and NPD process performance, as measured by quality performance indicators.

1.2.1 Practices Used to Apply Lean to NPD Processes

Haque and James-Moore (2004) suggest that when improving NPD processes by applying lean, organizations use the five lean principles, including customer specification, value stream identification, flow improvement, pull creation, and continuous improvement, to identify issues found in NPD processes and select proper practices to solve those issues. Lean practices associated with minimizing waste and maximizing flow are most frequently mentioned in the literature. A variety of practices have been identified as being useful in improving NPD processes. Oppenheim (2004), for example, proposed using value stream mapping and Kanbans to eliminate waste and improve flow in NPD processes. Reinertsen (2009) proposed using queue management and stand-up meetings to improve flow in NPD processes. Mascitelli (2011) proposed Kaizen events and gap analysis to eliminate waste and improve flow in NPD processes. For this research, two types of practices were studied: traditional lean practices and other improvement practices. Traditional lean practices are tools and techniques that were originally developed and used within the Toyota Production System framework or "lean." Other improvement practices, such as those used in project management and marketing, were also included in the study. Previous researchers and practitioners have suggested that such practices can be used to implement lean principles in NPD processes.

1.2.2 Performance Indicators and the Impact of Lean on NPD Process Performance Improvement

The application of lean to NPD has been studied by researchers and practitioners for two decades. Most practitioners suggest that organizations will benefit from applying lean to NPD processes. The impact of lean on NPD process performance improvement is important to justifying the efforts required to implement lean. In the improvement cycle, organizations set targets to motivate employees and use performance indicators to assess businesses and processes after improvement (Michel, 1995). Some examples of the potential impact and effect of lean on NPD processes have been identified in the practitioner and research literature. Improvements documented in the literature include shortened total time for NPD processes and reduced product development costs (Anand & Kodali, 2008; Haque & James-Moore, 2004; Liker & Morgan, 2011; Reinertsen, 2009). There are limited empirical studies that have focused on the impact of lean on NPD process performance. However, the studies that have been undertaken provide evidence for a positive impact of lean on NPD process performance (Anand & Kodali, 2008; Haque & Moore, 2004). One purpose of this research was to identify performance indicators used by organizations to measure the impact of lean on NPD processes. From the literature, there are three main performance perspectives that organizations can use to measure NPD process performance improvement: time, cost, and quality.

1.2.3 Challenges Faced by Organizations

Organizations likely face challenges when implementing lean in NPD processes. Many of the challenges result from the need for transformational change (Marker, 2006). There are many changes and adaptations required in a transition to lean. Many organizations have been unable to successfully navigate this transformational change. Lean implementation also requires collaboration and effort from all stakeholders, employees, and departments (Dombrowski, Mielke, & Engel, 2012). Collaboration between many employees and departments can make a lean transition more challenging. Knowing challenges that may occur during a lean transformation can be helpful by enabling top management to develop contingency plans prior to the implementation.

1.2.4 The Number of Practices Used and NPD Process Performance

Organizations are more likely to successfully implement lean if they apply all five lean principles and if they use different practices to address each principle (Shah & Ward, 2003). In a lean implementation, organizations should select proper lean practices to match with situations or issues found in processes (Malmbrandt & Åhlström, 2013). Most practices used in a lean implementation are related to a particular lean principle. At the beginning of a lean implementation, organizations use a few practices. Moving forward in a lean implementation, organizations are more likely to adopt additional practices to realize additional improvement (Bhasin, 2012b). Research suggests that organizations should not apply only a couple of principles to processes (Bhasin, 2012b; Liker & Morgan, 2011). Organizations should apply all five lean principles, as a lean system, to achieve improvement. Thus, if organizations use more practices, it is implied that more lean principles are applied, and organizations are more likely to see performance improvement.

1.2.5 Years of Experience with Lean and NPD Process Performance

Studies of Total Quality Management (TQM) by Powell (1995) and Taylor and Wright (2003), showed that TQM adoption time affects the level of performance improvement. Organizations require sufficient time to adapt and integrate new approaches in their processes. Organizations that have implemented TQM for a longer time can adapt and adjust the TQM implementation to better suit their processes and to achieve greater process performance improvement. Similar to TQM, lean is an improvement method. Thus, it is possible that the number of years of experience with lean may be associated with the level of NPD process performance improvement. Researchers suggest that in the implementation of lean, organizations will see a positive impact from lean, but may not see major changes initially after implementing lean (Bhasin, 2011). However, in the long term, organizations can potentially see significant changes in processes and process performance improvement.

1.3 Research Context

New product development (NPD) is an important strategic function in many organizations. A new product means products that has never produced by a company and will be sold for new targeted customers (Crawford and Bennedetto, 2008). New products can result from breakthrough innovation, product repositioning, or cost reduction activities (Crawford & Benedetto, 2008). Organizations launch new products to markets to grow and sustain their revenue and position in the market (Griffin, 1997). Without new products, organizations may fail to penetrate new markets and may ultimately lose market share. Thus, NPD is an important activity from a competitive perspective. Cooper (2000) found that U.S. firms generated 50% of sales revenues and 40% of total profits from new products. Although organizations gained more profits on new products, research by Barczak, Griffin, and Kahn (2009) found that just over half (59%) of new products introduced by U.S. organizations are actually successful. This success rate has remained unchanged since the mid-1990s. The continued failure of many new products implies that there are still opportunities to improve NPD processes.

Researchers and practitioners have studied and published success factors for organizations to consider in improving NPD. NPD processes, as summarized by previous researchers, consist of four phases: idea generation, concept selection, development, and launch (Crawford & Benedetto, 2008; Ulrich & Eppinger, 2000). NPD processes begin with generating ideas, followed by initial screening, and so on until products launch. Before beginning activities in one phase, the previous phase must be initiated.

This research studied improvement in NPD processes by applying an Industrial Engineering perspective. Industrial Engineering (IE) is focused on deploying concepts, tools, and techniques to increase effectiveness and efficiency of production processes and organizational operations. Lean, one set of IE tools and techniques, has been widely applied to production processes and in other organizational functions, including new product development. Based on previous research on lean, the application of lean to NPD processes has the potential to improve NPD process performance.

Lean, used first in Japanese manufacturing organizations, has been well-known since the publication of *The Machine that Changed the World* (Womack, Jones, & Roos, 1990). The fundamental objectives of lean production are to minimize wastes and to maximize flows (Tapping, Luyster, & Shucker, 2002). Lean has been deployed and implemented in many different manufacturing organizations. More recently, lean practices have spread to other industrial sectors, including health care and information technology. Lean practices have also spread to other functional processes in manufacturing organizations, including NPD. Researchers and practitioners have suggested that organizations can improve NPD processes by applying lean practices (Haque & James-Moore, 2004; Mascitelli, 2011; Reinertsen & Shaeffer, 2005; Schulze & Stormer, 2012). The application of lean practices to NPD processes can streamline NPD by shortening time to market, by reducing NPD costs, and improving new product quality. Before discussing the application of lean to NPD processes, two terms must be defined, “lean principles” and “lean practices.” Lean principles refer to the five lean concepts developed by Womack and Jones (1996) and include customer specification, value stream identification, flow improvement, pull creation, and continuous improvement. The five lean principles are fundamental rules to guide organizations in selecting and using lean practices. “Lean practices,” on the other hand, refer to tools and techniques used to enable the application of lean principles to a particular activity or process.

Researchers and practitioners use the term “lean product development” to refer to the application of lean in NPD. Researchers and practitioners have studied “lean” in NPD processes using a variety of approaches. There are three main approaches used to apply lean in NPD: design for lean production, the Toyota Product Development System (TPDS), and lean principles in product development (2007). Design for lean production is focused on designing new products to support a lean production environment (Radeka & Sutton, 2007). TPDS is focused on the approach that Toyota has used to develop quality new products, as well as making the product development process faster and cheaper (Radeka & Sutton, 2007). Lean principles in product development are focused on applying lean thinking, including the five lean principles, to NPD processes (Radeka & Sutton, 2007).

Researchers and practitioners have proposed frameworks that organizations can use in applying lean to NPD processes. One framework, proposed by Haque and James-Moore (2004), suggests that organizations improve NPD processes by using the five lean principles to identify issues found in NPD processes and to select proper practices to solve those issues. Another framework was proposed by Oppenheim (2004) and is called the

Lean Product Development Flow. The framework defines deliverables, success factors, and performance measures for applying lean principles.

In addition to Haque and James-Moore (2004) and Oppenheim (2004), other researchers and practitioners have proposed similar frameworks, including Anand and Kodali (2008), Reinertsen (2009) and Mascitelli (2011). These researchers and practitioners also recommend that organizations use the five lean principles and lean practices, as well as practices from project management and marketing, to create lean NPD processes. In particular, lean practices associated with minimizing waste and maximizing flow are frequently mentioned in the literature (Tapping et al., 2002; Womack & Jones, 1996).

Previous research has shown that lean can improve NPD processes. However, only a few empirical studies have tested the usefulness of practices when applied to NPD processes and in NPD process performance improvement. Additionally, few studies have looked at identifying the challenges faced by organizations and the extent to which challenges become barriers to lean implementation. Haque and James-Moore (2004) and Anand and Kodali (2008), for example, used case studies to validate the impact of lean on NPD processes. To further understand how the application of lean can improve NPD performance, additional empirical studies are needed. This research was designed to gain a better understanding of how organizations can apply lean to improve NPD processes.

1.4 Research Approach

An internet survey was designed to collect data used to test eight hypotheses focused on practiced used to apply lean in NPD processes, performance indicators used, the impact of lean on NPD processes measured by time, cost and quality, a relationship between the number of practices used and NPD process performance improvement, and a relationship between the years of experience with lean and NPD process performance improvement. The survey developed for this study included five sections. Targeted participants for completing the survey included CEOs, managers, supervisors, engineers, marketing specialists, and other employees who had NPD process experience and who worked in the targeted organizations. The targeted organizations for this research were manufacturing, product-producing organizations from the industrial equipment, aerospace manufacturing, and electronic manufacturing sectors. A variety of statistical analyses were used to test the eight hypotheses, due to the type and structure of the data.

2 Literature Review

This chapter describes previous research findings on the product development process, lean principles, the application of lean to NPD processes, practices used in applying lean to NPD processes, NPD performance indicators, and challenges faced by organizations in applying lean. The chapter begins by identifying NPD processes and lean principles. The next section clarifies the application of lean to NPD processes. Next, practices used in applying lean to NPD processes are discussed. Finally, NPD performance indicators and challenges in applying lean are discussed.

2.1 New Product Development Processes

New product development (NPD) processes include a diverse set of activities. NPD processes are different depending on the type of product, industry, and organization size. This review will focus on only NPD processes related to tangible products. From previous research, there are four phases in the NPD process: idea generation, concept selection, development, and launch. See Figure 2.1. The details of each of the four phases are discussed next.

Figure 2.1 New Product Development Process

2.1.1 Idea Generation Phase

The idea generation phase is used to generate alternative ideas for new products that can possibly generate profits or improve the market position of an organization (Cooper & Kleinschmidt, 1986; Schilling & Hill, 1998; Ulrich & Eppinger, 2000; Unger & Eppinger, 2011; Veryzer, 1998). Within the idea generation phase, many activities are undertaken, including scoping ideas, screening ideas, and project screening (Cooper & Kleinschmidt, 1986; Rochford & Rudelius, 1997; Unger & Eppinger, 2011). Most activities in the idea generation phase are related to strategic planning and data collection (Crawford & Di Benedetto, 2006).

The number of ideas generated in the idea generation phase can be large, and ideas for new products are typically widely variable (Crawford & Benedetto, 2008; Kuczmarski, 2000). Organizations can reduce the number of new product ideas to pursue using market research (Cooper & Kleinschmidt, 1986; Kono & Lynn, 2007; Rochford & Rudelius, 1997). The results of market research can help organizations in identifying opportunities for developing new products to maintain or penetrate the market. Market research also provides additional information regarding the needs of customers in the targeted market (Kono & Lynn, 2007; Schilling & Hill, 1998). In addition to market information and customer needs, organizations should also develop new product ideas that align with the goals and the strategies of the organization (Cooper & Kleinschmidt, 1986; Rochford & Rudelius, 1997).

After generating new product ideas, organizations screen potential ideas to develop new product concepts. New product concepts should result in clear descriptions that can be understood across an organization (Kuczmarski, 2000). New product concepts should be created by expanding initial ideas to more detailed descriptions, in which all contributions can be clearly understood (Kuczmarski, 2000). Although new product concepts can be difficult to explain in terms of exact dimensions or features at this phase, potential product functions, needed resources, and the target market can be scoped (Veryzer, 1998). At the end of the idea generation phase, organizations may have multiple new product concepts that can potentially be explored and developed into new products. Because of limited resources, organizations cannot follow through on all new product concepts. Selecting suitable new product concepts is important. The activities associated with this second phase are discussed next.

2.1.2 Concept Selection Phase

Concept selection is the second of four phases in the NPD process. Concept selection is used to evaluate and select new product concepts (Crawford & Benedetto, 2008; Rosenau, Griffin, Castellion, & Anchuetz, 1996; Veryzer, 1998). Veryzer (1998) mentions that it is necessary to do more research about new products and make new product concepts clearer before making decisions on whether or not new product concepts should be worked on or rejected at the end of this concept selection phase.

In the concept selection phase, organizations estimate the financial impact of new products and complete additional market research to use in the evaluation of new product concepts (Cooper & Kleinschmidt, 1986; Rochford & Rudelius, 1997; Rosenau et al., 1996). After gathering additional information, organizations should be able to assess new product concepts from the idea generation phase and select new product concepts that can result in the highest profit and those that are responsive to the market. To estimate the financial impact, organizations forecast the profits that would result from an investment in a particular new product concept (Rochford & Rudelius, 1997; Rosenau et al., 1996). If the result is positive, organizations can invest in that new product. Organizations also use the results of market research to assess the competitive position of the new product and how well the new product will penetrate the market (Cooper & Kleinschmidt, 1986; Schilling & Hill, 1998). Although the selection of concepts is based on market research and financial impact, organizations should also consider organizational objectives in the evaluation (Crawford & Benedetto, 2008).

In the concept evaluation process, organizations should include people from different functions, especially those in technical roles in the organization, including engineers and technicians working on NPD teams or experts in organizations who understand product design and/or production processes (Cooper & Kleinschmidt, 1986; Crawford & Benedetto, 2008). In addition, users should be involved to help assess the potential of new product concepts (Crawford & Benedetto, 2008). Integrating the views of both technical personnel and users can provide a balanced set of perspectives to evaluate and select product concepts.

At the end of this process, organizations have finalized new product concepts that can be invested in and can move forward to the development phase. Organizations should create a plan for developing new products in the third phase, the development phase (Kuczmarski, 2000). The activities that organizations undertake to move from new product concept to new product development are described next.

2.1.3 Development Phase

The development phase includes further developing new products and preparing production processes and resources to support new products. Developing new products is the translation from concept to actual products (Kono & Lynn, 2007; Kuczmarski, 2000; Rochford & Rudelius, 1997; Ulrich & Eppinger, 2000; Unger & Eppinger, 2011). Ulrich and Eppinger (2000) state that designing new products consists of system-level design, detail design, and testing and refinement.

Developing new products requires many trials and tests to demonstrate the performance and quality of newly developed products (Ulrich & Eppinger, 2000; Unger & Eppinger, 2011; Veryzer, 1998). In different organizations or different industries, there are particular approaches for evaluating prototypes. One approach common to most industries is to test new product prototypes against customer needs and requirements (Kuczmarski, 2000; Rosenau et al., 1996; Ulrich & Eppinger, 2000; Unger & Eppinger, 2011). Varyzer (1998) suggests that organizations test prototypes with customers by asking potential customers to try products and to provide feedback. From the customer feedback, organizations have additional information related to product specifications and applications, which can be used to improve the final prototype, prior to launching a new product. During new product development, organizations must also consider production process design (Coletta, 2012).

In preparing production processes and resources, organizations must design and test production processes. Organizations can investigate tools and workforce capacity. Organizations must also contact existing suppliers to determine if the suppliers have the capacity and ability to produce parts for new products. If the existing suppliers cannot handle new parts, organizations have to explore new suppliers to support the new product. (Crawford & Benedetto, 2008; Kuczmarski, 2000; Rochford & Rudelius, 1997; Ulrich & Eppinger, 2000; Unger & Eppinger, 2011). While developing new products and preparing for production, organizations should consider market planning to ensure the success of the product in the market during the launch phase. At the end of the development phase, organizations must finalize the product design, develop a production plan, and identify a market plan. The next section discusses the activities that organizations must perform in the fourth and final phase, the launch phase.

2.1.4 Launch Phase

In the launch phase, prototypes for new products are prepared for commercialization (Kuczmarski, 2000; Rosenau et al., 1996; Schilling & Hill, 1998; Unger & Eppinger, 2011). During the launch phase, the capacity of production may increase from pilot production levels (Cooper & Kleinschmidt, 1986; Ulrich & Eppinger, 2000). Ramping up capacity may result in production problems, such as not having proper quality control processes or insufficient resources. Organizations need to find and resolve such problems before demand increases (Crawford & Benedetto, 2008; Veryzer, 1998). Training workers is also often a requirement of launch for the production of new products because of new techniques and standards, as well as the need for higher productivity (Ulrich & Eppinger, 2000).

During the development phase, new products are tested before launch to the market. To ensure that new products provide what customers want, organizations must gather marketing data and customer feedback (Cooper & Kleinschmidt, 1986; Crawford & Benedetto, 2008; Rosenau et al., 1996). Feedback from customers also helps organizations identify issues with new products. This information can be used to help organizations improve the product and also to improve the NPD process.

NPD processes include many activities, and require the involvement of different job functions. Previous studies have identified that lean can increase NPD process performance. The main components of a lean implementation are lean principles and lean practices. One must first understand lean principles and then select the right lean practices to implement lean in NPD processes. The next section provides an overview of lean principles.

2.2 Lean Principles

After *The Machine that Changed the World* was published in 1990, organizations around the world realized how Toyota was able to ascend to the top tier in the automobile market (Womack, Jones, & Roos, 1990). This encouraged organizations, especially within the automotive industry, to improve production processes and product development processes to be more competitive. Since that time, many organizations have used Toyota Production System (TPS) methods to try to improve performance. TPS is also known as lean production and has been studied and applied in a variety of industries. Many authors have tried to clarify the key concepts of TPS. In *Lean Thinking*, Womack and Jones (1996) simplify the lean principles used by Toyota and formulate them as five guidelines from which organizations can select and apply to improve themselves. Cusumano and Noeoka (2005) define the term of "lean" as a thinking system that can help organizations improve processes to save costs, time, and resources. While researchers and practitioners use different terms and definitions, the core principles of TPS or lean production remain the same and are focused on eliminating wastes and improving the flow of materials through processes. Womack and Jones (1996) defined five lean principles: customer specification, value stream identification, flow improvement, pull creation, and continuous improvement. The five lean principles are presented in Figure 2.2 and the details of each principle are explained next.

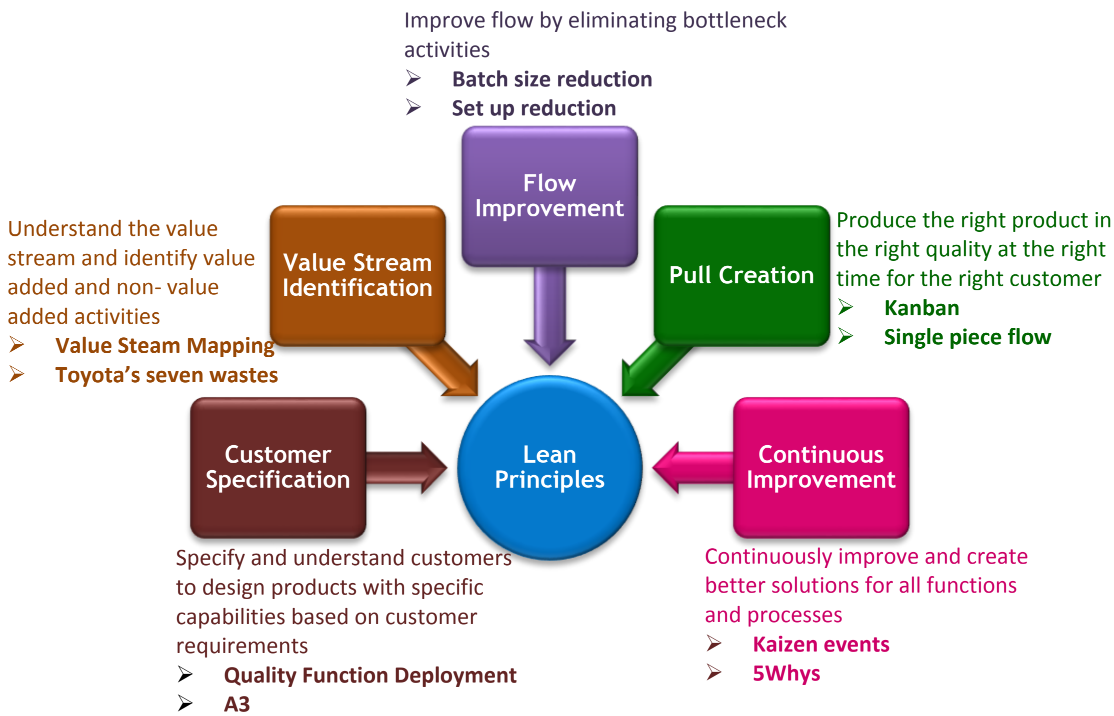


Figure 2.2 Lean Principles

2.2.1 Customer Specification

Organizations must specify and understand their customers. When organizations know their customers, they know what customers want and can provide products with capabilities based on customer requirements (Haque & James-Moore, 2004; Qudrat-Ullah, Seong, & Mills, 2012; Womack & Jones, 1996). There are two types of the customers: internal customers and external customers (Ryan & Reik, 2010). Internal customers are people working in downstream processes who are involved in the production process. In

NPD processes, internal customers can be people from departments in the organization including production process owners, procurement specialists, as well as top management, who support and invest in NPD projects. External customers are end users or people who buy the final product. In the NPD process, many organizations try to develop and produce new products for customers without fully considering what the customers want. If customers buy products and the products do not meet customers' true needs, the product will not be successful. After identifying customers, organizations must identify the value stream for new products, as discussed next.

2.2.2 Value Stream Identification

A value stream includes all activities that produce a product or service from the raw materials to customer payment (Carreira & Trudell, 2006). By understanding the value stream, organizations can identify value added and non-value added activities related to producing products or services (Haque & James-Moore, 2004). Value added activities are activities that are performed and add content to the final product or service (Nicholas, 2010; Womack & Jones, 1996). Non-value added activities are activities that do not create content or value to a product or service. Some non-value added activities may be necessary and cannot be eliminated from a process (Nicholas, 2010; Womack & Jones, 1996). Organizations have to understand the value in product and service delivery and be able to identify value added and non-value added activities.

The value created from a process has to be examined from the customer perspective (Nicholas, 2010; Womack & Jones, 1996; Zidel, 2006). Using customer perspective and value stream identification principles, organizations can define activities that do not respond to customer requirements or do not add value to products or services. Those activities are called waste (Haque & James-Moore, 2004; Tapping et al., 2002). Organizations should eliminate all wastes from the value stream. After wastes are eliminated, organizations must next improve process flows to ensure that products and services are delivered on time. The improvement of flow is discussed next.

2.2.3 Flow Improvement

After wasteful activities have been eliminated from processes, organizations next need to improve the flow of the remaining activities in the value stream (Morgan & Liker, 2006; Oppenheim, 2004; Tapping et al., 2002; Womack & Jones, 1996). Organizations improve flow by removing bottlenecks. To eliminate bottleneck activities, organizations must identify bottlenecks by using work-in-process levels or cycle times (Qudrat-Ullah et al., 2012).

There are many approaches to improving flow. Allocating resources to activities can help balance processes. When all activities have the same production rate, bottleneck activities are also eliminated. One-piece flow is another recommended approach for flow improvement (Nicholas, 2010). However, some processes such as product change-overs and machine set-ups can have long cycle times. In these cases, organizations must adjust batch sizes to optimize flows and to produce products at a rate to supply downstream processes or customer demand (Ryan & Reik, 2010).

2.2.4 Pull Creation

The fourth principle is pull. Organizations have to produce the right product in the right quantity at the right time for the right customers, as in the TPS's just-in-time system (Carreira & Trudell, 2006; Haque & James-Moore, 2004; Tapping et al., 2002; Womack & Jones, 1996). To create a just-in-time system and pull production, processes must be controlled by customers (Carreira & Trudell, 2006). Customers should trigger production processes. When customers do not order products, production processes should not produce products. Similarly, within the production system, upstream activities should not generate work without receiving a downstream request (Haque & James-Moore, 2004; Qudrat-Ullah et al., 2012; Womack & Jones, 1996). This approach results in lower inventory levels for the organization.

Communication between upstream and downstream processes is critical. Kanban, a system created by Toyota, can help organizations control material and product inventory levels in a pull system. Kanban systems create effective communications between downstream and upstream processes using Kanban cards to signal when processes should produce and to signal the number of products to produce (Morgan & Liker, 2006; Qudrat-Ullah et al., 2012; Worley & Doolen, 2006). Creating pull production requires collaboration between people in the organization, customers, and suppliers. Since lean principles drive change in processes, continuous improvement is also critical to creating a lean organization. The fifth lean principle, continuous improvement, is discussed next.

2.2.5 Continuous Improvement

Products, production processes, and technologies may change, especially in an era when products and technology have shorter life cycles. Organizations need to change processes and improve existing activities or processes to be more effective. Eliminating wastes to reduce excessive costs and improving flow are part of continuous improvement (Carreira & Trudell, 2006; Haque & James-Moore, 2004). Lean requires everyone in an organization to contribute to improvements (Morgan & Liker, 2006; Oppenheim, 2004; Womack & Jones, 1996). One continuous improvement approach, called Kaizen events, places employees in small groups to identify issues and to suggest improvements or solutions (Qudrat-Ullah et al., 2012; Santos, Wysk, & Torres, 2006). Kaizen events enable organizations to adopt effective solutions, in particular, because employees understand the details of specific tasks better than supervisors or managers (Nicholas, 2010). Making contributions to improvement can also increase employee morale.

In summary, organizations should use the five lean principles to guide lean implementations. Previous studies have found that most organizations failed in implementing lean because organizations focused on using lean practices without understanding lean principles or because the organization implemented only one or two lean principles (Liker, 2004; Yadav, Nepal, Goel, Jain, & Mohanty, 2010). The successful organizations in implementing lean applied all principles and used different practices to respond to each principle (Shah & Ward, 2003). Researchers and practitioners have tried to expand lean to other functional areas, including NPD processes. A review of the application of lean in NPD processes is presented next.

2.3 The Application of Lean in New Product Development Processes

Lean has been implemented in NPD in some organizations over the past 10 – 20 years. There are many different terms used to refer to the implementation of lean in NPD processes. Some researchers and practitioners use the term "lean product development." There are three main approaches used to apply lean in NPD: design for lean production, the Toyota Product Development System, and lean principles in product development (Radeka & Sutton, 2007).

The first approach is designed for lean production. Design for lean production is focused on designing new products to support a production environment (Radeka & Sutton, 2007). New products are expected to have lower production costs and be easier to assemble. Under this approach, new products should not require major changes to existing production processes and would not include components that existing suppliers cannot produce (Radeka & Sutton, 2007).

The second approach is the Toyota Product Development System (TPDS). TPDS captures the way that Toyota has approached developing quality new products, as well as improving product development processes to be faster and cheaper. *The Machine that Changed the World* provided an overview of the product development system used by Toyota (Womack et al., 1990). Organizations have tried to duplicate processes used by Toyota. Morgan and Liker (2006) were the first researchers to deeply study and document the details of NPD processes at Toyota. Morgan (2002) spent 1,000 hours interviewing Toyota employees, as well as Toyota stakeholders in Japan, to determine the practices underlying Toyota's achievements. From the study, Morgan and Liker (2006) summarized 13 principles of TPDS:

1) Establish customer-defined value to separate value added from waste.
2) Front-load the product development process to thoroughly explore alternative solutions, while there is maximum design space.
3) Create a level product development process flow.
4) Utilize rigorous standardization to reduce variation and create flexibility and predictable outcomes.

5) Develop a chief engineer system, which assigns a leader to manage a new product development team from project start to finish.
6) Organize to balance functional expertise and cross-functional integration.
7) Develop technical competences for all engineers.
8) Fully integrate suppliers into the product development system.
9) Build in learning and continuous improvement.
10) Build a culture to support excellence and relentless improvement.
11) Adapt technologies to fit your people and process.
12) Align your organization through simple visual communication.
13) Use powerful practices for standardization and organizational learning.

The third approach for applying lean to NPD is lean principles in product development. The lean principles in product development approach is focused on how to apply lean thinking, which includes the five lean principles, to the NPD processes (Radeka & Sutton, 2007). This approach originated from the success of the implementation of lean principles in the production process. A key element of this approach is to eliminate wastes and to improve flow in NPD processes. Previous studies of this approach have focused on developing frameworks for organizations to use in applying the five lean principles to NPD processes. A summary of three published studies using this approach is provided next.

2.3.1 Studies of Lean Principles Applied to Product Development

The first study was conducted by Haque and Moore (2004). Haque and Moore proposed a framework for applying the five lean principles to the NPD process. The product or outcomes of the NPD processes are defined as knowledge or information. Haque and Moore defined each lean principle to use in NPD processes as follows:

1) Value specification: NPD teams must know who the internal customers and external end users are, as well as the expectations of the customer. Thus, NPD teams should have good relationships with their customers and suppliers.
2) Value stream identification: NPD teams must identify the value stream of current NPD processes and eliminate non-value added activities from processes associated with NPD. The value stream map should include information across the entire organization. The value stream map for a new product should also include information flows across NPD processes or information that can be used to create standards for each process.
3) Flow improvement: NPD teams must improve the flow of information in the NPD process and develop flow by paying attention to the workload rate needed for upstream and downstream activities. NPD teams should also focus on reducing delays in NPD processes, as well as improving knowledge and information flow.
4) Pull creation: NPD teams must control and manage information flow to support downstream activities and customer needs.
5) Pursue perfection or continuous improvement: NPD teams must continuously identify and eliminate waste from NPD processes. To enable continuous improvement, top management and managers should motivate NPD teams to keep pursuing the application of lean in NPD processes.

The second study used a similar approach and was conducted by Oppenheim (2004). Oppenheim proposed a framework called Lean Product Development Flow. This Lean Product Development Flow framework is similar to the framework proposed by

Haque and Moore (2004), but includes deliverables, success factors, and some measures used to evaluate the lean implementation in NPD processes.

1) Value specification: NPD teams identify all customers and stakeholders and develop new products that satisfy all customers' and stakeholders' requirements. NPD teams eliminate wastes from the NPD process and deliver new products in shorter times and with lower costs. After implementing value specification, NPD teams can use the throughout time of NPD processes to evaluate success in the implementation of the value specification principle.
2) Value stream identification: NPD teams use value stream mapping to define the current state of NPD processes and suggest a more effective future state. The future state should have shorter takt times. To measure performance improvement, savings from waste in terms of both money and time values, can be used.
3) Flow improvement: Organizations allocate all resources to support the desired future state and to meet targeted takt times. NPD teams also identify and eliminate uncertainties that can cause activity delays. After completely implementing the proposed future state. NPD teams can use the completion time of the value stream to evaluate the improvement of NPD processes.
4) Pull creation: NPD teams and people who work on activities associated with NPD processes should know who will receive the output of each activity, understand the needs of downstream activities or processes and understand when downstream activities or processes need specific outputs.

5) Pursue perfection or continuous improvement: The implementation of lean principles to NPD processes requires effort. Effective leadership is important. Training NPD teams and people who are involved in the NPD processes can help support lean implementation.

The third study was conducted by Reinertsen (2005, 2009). Reinertsen emphasized improving flow in NPD processes to make them more efficient. Because the flow of information in the NPD process is critical, improving information flow can shorten NPD time. Although the application of lean to NPD processes is different from manufacturing, some lean practices can be used in NPD. For example, organizations can reduce batch sizes to improve the flow of information in NPD processes. Organizations have to manage information between upstream and downstream activities by increasing communications among people who work in NPD processes. Organizations can ask engineers who work on drawings to constantly communicate to production department or suppliers. When finished with the design of parts for a new product, engineers should propose that design to the production department or suppliers. Production staff and suppliers can provide feedback to engineers part by part. A feedback loop between production staff, suppliers, and engineers is shorter and faster. Engineers can redesign a problem part right after production staff and supplier reviews instead of waiting until completing the entire new product design. Such a process will reduce major changes to new product designs, at the end of development process.

Since lean principles originated from Toyota, TPDS and lean principles in product development are similar. Three recently published studies have proposed frameworks for implementing lean in NPD processes. Those studies were conducted by Ward (2007), Welo

(2011), and Mascitelli (2011). Each framework focuses on eliminating wastes and improving flow in NPD processes and on adopting lean manufacturing concepts, such as Toyota Seven Wastes, to NPD processes.

Ward (2007) identified four elements for applying lean to NPD. The first element is knowing the customer and identifying NPD value streams. The second element is using set-based concurrent engineering to create new product alternatives at the beginning of the NPD process. The third element is promoting an entrepreneur design system to determine NPD project leaders who know the entire NPD process and NPD value streams. The fourth element includes: cadence, flow, and pull. Cadence is used to create standardized NPD processes that specify resource loads and reduce chaos in NPD processes. Flow is focused on making knowledge available when needed. Pull is focused on engaging people involved in NPD processes to respond directly to the needs of customers.

Welo (2011) proposed a model for implementing lean in the NPD process. The model consists of six components: define customer values; promote lean as the organization's culture; integrate resource planning and management, portfolio management, and organizational management; implement standardization; add knowledge from organizational learning to the NPD value stream; and continually improve across all functions in an organization.

Mascitelli (2011) proposed a framework that incorporates Toyota's methods, five lean principles, and project management practices to approach the product development process. This work suggests different practices to implement in different NPD activities, such as using QFD to translate customer requirements to design requirements. In addition to lean, Mascitelli proposed the use of project management practices, decision-making practices, and other practices that can help improve flow in development projects and make development projects successful by delivering new products on time and within budget. Previous studies have shown the possibility of applying lean to NPD processes. The next section illustrates the application of lean to NPD processes.

2.3.2 Lean Applied to NPD

Lean principles can be applied to NPD processes. Customer specification refers to designs that provide customers with new products that satisfy customer needs, at the right price, and at the right time. NPD teams have to know who the customers are. Both internal and external customers must be specified. Knowing the customer makes NPD teams better understand needs and requirements.

Value stream identification refers to activities from idea generation to launch that focus on creating value for customers and eliminating non-value added activities and wastes from the NPD process. In the NPD process, information, data, and knowledge are often as important as the physical products. In the value stream of NPD processes, all information, data, and knowledge must be identified.

Flow improvement refers to driving tasks and activities in the NPD process to proceed without stoppages or defects. NPD teams and all stakeholders who are involved in NPD processes should know who works on downstream activities and process. The transition time between processes and activities and communications between processes and activities should be minimized.

Pull creation refers to performing activities only when a downstream customer signals a need. People who work in upstream activities or processes should observe and understand the cycle time and workload of downstream activities or processes. Thus, the transition of information, data, and knowledge between activities or processes will flow without bottlenecks and with minimal work in process.

Continuous improvement refers to improving the customer value, value stream, flow, and pull in NPD processes, continuously and relentlessly. Continuous improvement requires support from top management. The morale of NPD teams is very important to sustaining improvements in NPD processes.

NPD processes must adjust activities or strategies to deliver a particular new product. To transfer lean principles to NPD processes, a variety of practices, such as design practices, traditional lean, and project management practices have been used successfully. The next section presents some alternative practices that can be applied as a part of efforts to create lean NPD processes.

2.4 Practices Used in Applying Lean to NPD Processes

There are practices and methods that researchers and practitioners have suggested to improve the NPD process when implementing lean. Some practices are used in lean production and other practices are applicable practices that can be used in applying lean to NPD processes. The next section describes the application of lean practices to implement lean to NPD processes. Practices are categorized using the five lean principles: customer specification, value stream identification, flow improvement, pull creation, and continuous improvement.

2.4.1 Practices Used in Customer Specification

Practices used in customer specification can help organizations determine who the customer is and what customers need from new products. Examples of applicable practices used to specify customer needs in NPD processes include gap analysis and quality function deployment. The details of each practice are discussed next.

Differentiator practices, such as gap analysis, are commonly used in marketing research and can be used to find gaps in the market (Mascitelli, 2011). Organizations can use gap analysis to determine pricing and features that customers want to see in new products. In the idea generation phase of a NPD process, organizations encourage NPD teams to generate as many ideas as possible. NPD teams can use the features of new products to generate new product ideas that respond to customers in a market. Another practice that can be used to translate customer needs to new product features is quality function deployment.

Quality function deployment (QFD) is a practice used to convert customer needs into key features of new products in to a table (Delano, Parnell, Smith, & Vance, 2000; Mascitelli, 2011). NPD teams can use QFD to specify important features for new products, based on customer requirements. NPD teams can use the defined features to guide and generate ideas to integrate into new product concepts. Using QFD in the idea generation phase can reduce the time wasted on screening and selecting ideas. The next section describes practices used to identify the NPD process value stream and to eliminate waste from NPD processes.

2.4.2 Practices Used in Value Stream Identification

Practices used in value stream identification are aimed at assisting organizations and NPD teams in identifying the value stream for NPD processes. Examples of applicable practices used to identify the NPD value stream include value stream mapping, Toyota seven wastes, A3, product families, production process preparation (3P), and standard work. The details of each of these practices are discussed next.

Value stream mapping (VSM) is generally used to identify the value stream for production processes and to identify opportunities to improve flow. The literature on lean product development suggests that VSM can be used for the same purpose when applied to the new product development process rather than to the production process (Anand & Kodali, 2008; Radeka & Sutton, 2007). VSM is used to identify non-value added activities or wastes that are created through hand-offs or delays in NPD processes. In a case study by Anand and Kodali (2008), a current state analysis of a NPD process in an organization showed that only 1.85% of the working time in this particular NPD process created value. After creating a current state map, a future state map can be developed to specify a less wasteful value stream. Wastes are obstacles to creating value. Techniques for identifying wastes and waste elimination are discussed next.

Eliminating wastes removes non-value added activities and all sources of waste from the NPD value stream. There are many practices that can help organizations in identifying and eliminating wastes. The following are examples of practices used to eliminate wastes in NPD processes. Toyota's seven wastes is a classification system that can help NPD teams identify waste (Morgan & Liker, 2006). The seven wastes are overproduction, transportation, motion, waiting, defects, over-processing, and inventory. NPD teams can also use Toyota's seven wastes to ensure that they have identified all possible wastes in a particular set of NPD processes. Using Toyota's Seven Wastes helps ensure that teams can more quickly and comprehensively identify activities and steps in a NPD processes that do not add value. NPD teams can list all the activities currently undertaken in a NPD process and then divide these activities into two categories: non-value added and value added activities (Ryan & Reik, 2010). After identifying wastes, eliminating wastes from NPD processes is necessary.

A3 is a communication practice used to identify problems and solutions in a concise format, i.e. on one A3-sized sheet of paper (Sobek, Liker, & Ward, 1998). An A3 report includes important information related to a particular improvement effort. An A3 report has to be clear and simple for everyone to understand. NPD teams can design an A3 template that can be used to resolve problems and to identify methods to solve those problems (Mascitelli, 2011; Sobek et al., 1998). Another opportunity for using A3 in NPD is creating new product concept reports. Organizations can create an A3 template and ask NPD teams to present key details related to development activities using this A3 template, rather than creating a lengthy report (Mascitelli, 2011). This approach enables all new product concepts to be presented in the same format. This may reduce the time that managers spend on reviewing reports and allows managers to more efficiently compare concepts. Leaders and managers can more easily locate key information related to proposed concepts and more quickly screen competing concepts.

The use of product families can also save time during the development phase (Morgan & Liker, 2006; Sobek et al., 1998) During the development phase, NPD teams focus on designing prototypes, testing, and planning production. Delays in the development phase directly affect the time it takes to launch a product. Controlling the schedule during development is very important, especially for new products that must undergo significant testing. If new products have common parts or production processes with existing products, i.e. are part of a product family, NPD teams can more quickly adjust existing product drawings and production processes leading to shorten time for development activities.

The production preparation process (3P) practice was originally developed and tested by Toyota for product development. 3P consists of three steps: brainstorming designs, developing and testing design mock-ups, and evaluating design options (Coletta, 2012; Farris, Van Aken, Letens, Ellis, & Boyland, 2007). The main concept underlying the 3P process is collaboration between those working on the design and those working on the production process to create product design alternatives based on customer requirements. With the collaboration, the communication employees from both functions is more effective. Exchanging information and providing feedback between functions is quicker. This collaboration ensures that the production process and design are compatible and when the production starts, new products are manufacturable.

Standard work is a practice that can be used to eliminate waste due to errors in the production process (Hoppmann, Rebentisch, Dombrowski, & Zahn, 2011). Standard work can be applied to specific NPD activities, product drawings, and machine development. Standard work allows individuals to complete a specific procedure correctly even if they have never attempted a procedure before. The more details have been standardized, the fewer errors that will occur. Standard work procedures should be created and maintained by the people or departments that use them; otherwise, standard work is useless because it does not correspond with actual practice (Sobek et al., 1998). The next section describes practices used to help organizations in improving flow.

2.4.3 Practices Used to Improve Flow

Flow improvement refers to efforts to improve activities that are bottlenecks or activities that impede the flow of product or information through processes. Examples of applicable practices used to improve flow in NPD processes are value stream mapping, queue management, batch size reduction, visual management and 5S. The details of each of these practices are provided next.

Value stream mapping (VSM) visualizes the material and information flow of the entire process (Tapping et al., 2002). VSM helps in efforts to identify activities that affect flow, result in delays, and that are unnecessary. If an information loop or activities that block the flow appear in the VSM, NPD teams can eliminate steps from the process or reorganize the steps within the process to make it more effective. VSM can be used to identify the flow of work in the NPD process and to assist NPD teams in managing sequence information. This mapping can make it easier, for example, to determine whether or not specific information is in the right place when it is needed.

Queue management can be used to improve flow in NPD by prioritizing activities in NPD processes to effectively utilize the limited resources (Reinertsen, 2005). If an activity has too many queues, backlogs can develop, because the utilization of resources is higher than the capacity available. Such backlogs will prompt a review of the utilization of resources and can help identify when resources need to be re-allocated. Queue management is a technique used to balance the capacity of people with demands and to provide services in the most efficient way (Reinertsen, 2005). New product development teams can use queue management techniques to balance resource assignments (such as engineers and machines) at any phase of the new product development process. Most assignments in the

NPD process are dependent on results from preceeding activities. If NPD teams cannot manage queues of assignments, they may be unable to complete and deliver assignments on time to the next activity in the process.

Frequently sending information back and forth between upstream activities and downstream activities can be improved by applying batch reduction techniques (Ward, 2007). Those handling downstream activity or phases can start working on assigned tasks early and send feedback or acknowledge problems to those working upstream. For example, many new products contain multiple parts. If part drawings can be released as they are completed, rather than in a single batch, this would allow those in production or suppliers to start working on a production plan sooner (Ward, 2007).

Visual management is another practice that can be applied to the NPD process. Visual project boards are a practice that can be used to present the progress or status of NPD processes for each new product (Mascitelli, 2011). Visual project boards can contain information related to the current status of a NPD process, as well as plans and assignments for each member of a NPD team. Visual project boards can be very valuable if NPD project teams update information on the board in real time. If this is done, the board can be used by NPD team members and managers to identify when bottlenecks or resource issues may be compromising the performance of the NPD team.

5S is a system that helps organizations organize the workplace. New product development teams can use 5S concepts to remove clutter from key work areas and to organize data collected in developing new products. Applying 5S can help NPD teams eliminate time spent on finding data or making information exchanges within the team

(Deshpande, Filson, Salem, & Miller, 2012). The next section describes practices used to help organizations in creating pull in NPD processes.

2.4.4 Practices Used to Create Pull

Pulling value by customers is defined as performing activities only when a downstream customer signals a need. Knowing upstream activities or processes, understanding the cycle time and workload of downstream activities or processes, and knowing what resources are available is important to ensuring that activities are completed on time and when needed by downstream processes. NPD processes involve the transfer of data and information. To create pull, organizations should make NPD-related information in NPD processes visible so that upstream and downstream processes can track the progress of each other's processes (Ward, 2007). Visual project boards, visual management practices, are not only used to improve flow in NPD processes, but can also be used to create pull. Another example of applicable practices used to create pull in NPD processes is the stand-up meeting.

Stand-up meetings, which are quickly organized meetings that bring together team members, as needed, are a practice that can be used to support the pull principle in NPD (Mascitelli, 2011). Stand-up meetings can be used to provide status updates to team members. Team members share problems, ask for support, or provide follow-up information on progress. NPD teams that hold frequent stand-up meetings can more rapidly identify and address emerging problems. Stand-up meetings can help NPD teams manage resources on a daily basis and respond rapidly to problems and changes in the project (Reinertsen & Shaeffer, 2005). The next section describes practices used to help organizations in applying the continuous improvement principle to NPD processes.

2.4.5 Practices Used to Create Continuous Improvement

Organizations must continuously improve and create better solutions for all functions, production steps, and products. Lean requires everyone in an organization to contribute to improvement. Continuous improvement activities can create collaborations within organizations required to make progress in the journey of eliminating waste by identifying customers and value streams and by creating flow and pull.

Lean organizations often use Kaizen events to bring together employees from various departments to work on improving production processes. The objective of a Kaizen event is to apply lean principles to improve key work processes. The same practices used in previous four principles can also be used to improve the NPD process. Practices used to identify root causes for problems, such as the fishbone diagram and five why's, can be applied to the continuous improvement of NPD processes in the same way that they are applied to production processes (Anand & Kodali, 2008; Mascitelli, 2011; Morgan & Liker, 2006)

Most of the practices that researchers and practitioners recommend are related to the effective utilization of information in the NPD process. When categorizing practices in reference to the related principles, most practices identified in the literature as being relevant to the NPD process are linked to eliminating waste and improving flow as shown in Table 2.1. This implies that these two principles are very compatible with the improvement of the NPD process. In applying lean principles to NPD processes, many practices can be used to assist organizations to creating more efficient and effective NPD processes. Practices presented in Table 2.1 include traditional lean practices, as well as other improvement practices often applied by organizations when implementing lean in NPD processes.

Liker and Morgan (2011) contend that organizations should focus on the fundamentals of each lean principle, rather than the practices. If organizations pay attention only to the task of integrating specific practices into the NPD process without knowing how those practices can help address a specific lean principle, those practices will not create value for the organization. On the other hand, if organizations understand lean principles, they will find it easy to select appropriate practices.

Some practices can be used for implementing multiple principles, while other practices primarily support a single principle. Previous research has found that the number of practices used by an organization can impact the success of a lean implementation. Organizations that apply many practices are more likely to successfully implement lean because, in applying many practices, organizations typically address all five lean principles simultaneously (Powell, 1995; Taylor & Wright, 2003).

After applying lean to the NPD processes through various lean and improvement practices, organizations need to assess the impact on NPD process performance. There is no specific performance measurement system to evaluate NPD process performance. The next section identifies performance indicators that can be used to assess the extent of improvement in NPD processes after applying lean.

Table 2.1 Summary of Practices Used in NPD Processes Organized by Lean Principles

Practices	Applicable to Lean Principles					Traditional Lean Practices
	Customer Specification	Value stream Identification	Flow Improvement	Pull Creation	Continuous Improvement	
3P		++				Yes
5S			++			Yes
5whys	+	+	+	+	++	Yes
A3	++	++	++	++	++	Yes
Batch size reduction			++			Yes
Fishbone diagram	+	+	+	+	++	Yes
Gap analysis	++					No
Kaizen events					++	Yes
Product Families		++				Yes
Quality function deployment	++					No
Queue management			++	+		No
Stand-up meeting				++		No
Standard Work		++				Yes
Toyota's seven wastes		++				Yes
Value stream mapping		++	++			Yes
Visual Management			++	++		Yes

++ = High impact
+ = Low impact

2.5 New Product Development Process Performance Indicators

Organizations use performance measurement to evaluate outcomes of processes and to determine opportunities for process improvement (Farris, Van Aken, & Letens, 2013). In the performance measurement process, indicators are used to assess the efficiency and effectiveness of a process (Neely, Gregory, & Platts, 2005). The performance measurement literature recommends that multiple performance indicators should be used and that performance indicators consider different perspectives (Kaplan & Norton, 1993; Neely et al., 2005). A balanced scorecard, for example, is a performance measurement framework that focuses on four perspectives: financial, customer, internal business process, and innovation and learning (Kaplan & Norton, 1993). In another framework, Neely, Gregory, and Platts (2005) proposed four core performance indicators to apply in organizations: quality, time, flexibility, and cost. Performance measurement frameworks are not necessarily applicable to all organizations. Rather, organizations must modify or adapt performance indicators for the unique aspects of the organization, and businesses must use performance indicators that fit with the organization's needs (Driva, Pawar, & Menon, 2000).

Organizations implement lean to improve process performance (Bhasin, 2012b). Performance measurement concepts are applied to understand improvement resulting from the application of lean to NPD processes. Researchers and practitioners have claimed that applying lean to the NPD process can result in shorter NPD process times and reduced costs (Haque & Moore, 2004; Mascitelli, 2011; Oppenheim, 2004; Ward, 2007). However, there are few studies that define performance indicators to assess improvement in NPD processes after organizations apply lean. To identify a large set of possible performance indicators that could be used to assess NPD processes performance after lean is applied, the new product development and new product development project literature was reviewed.

In the new product development literature, organizations use performance measurement to evaluate the effectiveness of NPD processes (Loch, Stein, & Terwiesch, 1996). There are three main dimensions of performance indicators commonly used to assess the success of NPD processes and projects: time, cost, and quality (Griffin & Page, 1996; Iamratanakul, Patanakul, & Milosevic, 2008; Meredith & Mantel, 2008). Time, cost, and quality are multiple dimension indicators and consistent within the frameworks created by Kaplan and Norton (1993) and Newly, Gregory, and Plattes (2005). Thus, performance indicators, used to assess NPD process performance can be divided into indicators related to time, indicators related to cost, and indicators related to quality. A summary of time, cost, and quality performance indicators is presented in Figure 2.3. The details of performance indicators for each of these three dimensions are described in the next section.

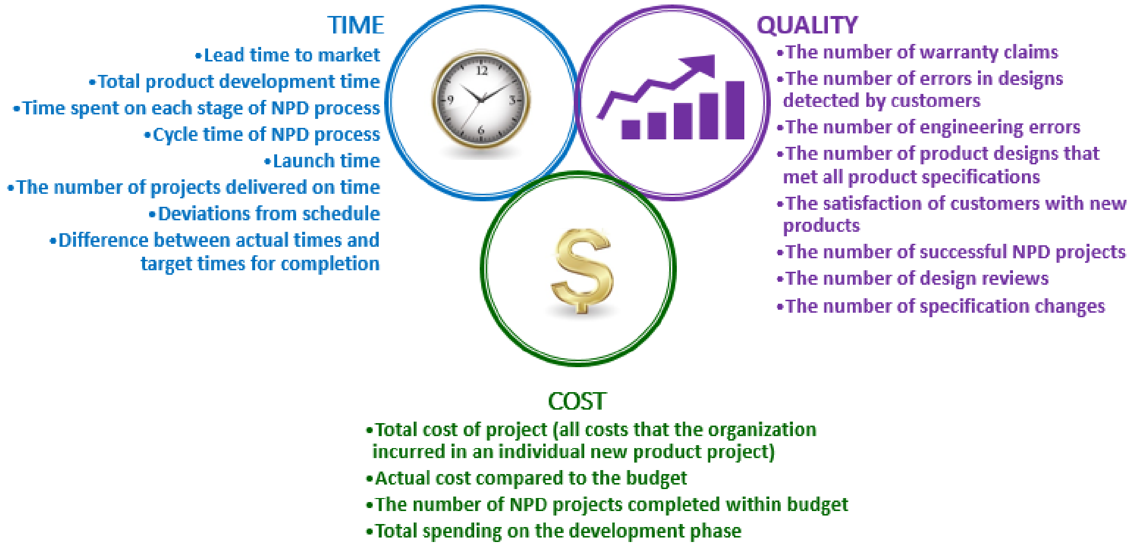


Figure 2.3 Time, Cost, and Quality Performance Indicators

2.5.1 Time Performance Indicators

Time is one measurement dimension that is critical to the NPD process (Iamratanakul et al., 2008; Loch et al., 1996; Pawar & Driva, 1999). Time-to-market is very important, and success in time based measurement is often correlated with new product success (Pawar & Driva, 1999). Applying lean to the NPD process has been shown to have a positive relationship with market performance of new products (Yang, Hong, & Modi, 2011). For example, Toyota reduced the cycle time of the NPD process by one year and retained existing customers and won new customers by launching new products faster (Bowonder, Dambal, Kumar, & Shirodkar, 2010). In a second, well-known example, Intel was able to retain customers by releasing the quad-core processor earlier than its competitor, AMD (Bowonder, Dambal, Kumar, & Shirodkar, 2010). If a project team develops new products more quickly than its competitors, new products are launched to the market ahead of the competition. For organizations, this can result in higher product sales, better market share, or better market position (Schilling & Hill, 1998). If organizations can shorten the NPD process, they can release new products more quickly than competitors and will see greater benefit from the new product.

NPD project delivery time is also important. When delays occur in NPD projects, project costs are likely to exceed budgets, and such projects often require additional resources (Carlin, 2010). If additional resources are allocated, the organization spends more on the project. The shorter the NPD process, the more the organization can benefit from the launch of a new product. However, organizations must also pay attention to the quality of new products. Organizations must not deliver low-quality products to customers, as a mechanism for reducing NPD process time (Smith, 1999). The speed of the NPD process also has an inverse relationship with the costs of NPD projects (Langerak & Hultink, 2006). Thus, organizations must consider both time and cost performance when improving NPD processes. Time performance indicators have identified by Driva et al. (2000), Leswith and O'Dwyer (2009), Loch et al. (1996), Manion and Cherion (2009), Oppenheim (2004), and Park (2010). Such indicators could be used to assess time performance improvements in NPD processes after applying lean and are summarized in Table 2.2.

Table 2.2 Time Performance Indicators Used in Assessing NPD Process Performance

Time Performance Indicators	References
1) Lead time to market	Driva et al, 2000; Ledwith & O'Dwyer, 2009; Manion & Cherion, 2009
2) Total product development time	Driva et al, 2000 Oppenheim, 2004
3) Time spent on each stage of NPD process	Driva et al, 2000
4) Cycle time of NPD process	Page, 1993; Oppenheim, 2004
5) Launch time	Griffin & Page, 1996
6) The number of projects delivered on time	Driva et al, 2000; Ledwith & O'Dwyer, 2009; Park, 2010
7) Deviations from schedule	Loch et al., 1996
8) Difference between actual times and target times for completion	Loch et al., 1996

2.5.2 Cost Performance Indicators

Cost is often a top priority for organizations. NPD requires a significant investment by organizations. Organizations expect to realize profits after increased spending on NPD projects. Project costs have a direct impact on the financial performance of organizations. Organizations with the lowest cost NPD process will be able to offer lower prices (Brown & Eisenhardt, 1995). If the cost of a new product project is very high, it will likely drive the cost associated with the final product. As a result, the selling price of a new product may be higher than expected and could potentially have a negative impact on reception of the new product in the market. Organizations must control costs throughout the NPD process and keep NPD costs within budget to protect the product's profit margin. Thus, the cost of the new product project can be used as an indicator to quantify NPD process improvement (Driva et al., 2000; Salter & Torbett, 2003). Cost performance indicators, proposed by Driva et al. (2000), Leswith and O'Dwyer (2009), Loch et al. (1996), Manion and Cherion (2009), Giffin and Page (1996), Park (2010), and Hart et al. (2003) can potentially be used to assess the improvement of NPD processes after applying lean and are summarized in Table 2.3.

Table 2.3 Cost Performance Indicators Used in Assessing NPD Process Performance

Cost Performance Indicators	References
1) Total cost of project (all costs that the organization incurred in an individual new product project)	Driva et al, 2000; Ledwith & O'Dwyer, 2009; Manion & Cherion, 2009
2) Actual cost compared to the budget	Ledwith & O'Dwyer, 2009
3) The number of NPD projects completed within budget	Hart et al., 2003
4) Total spending on the development phase	Griffin & Page, 1996

2.5.3 Quality Performance indicators

Quality is the third dimension for measuring NPD process performance. An input to the new product development process is the full set of customer requirements. The new NPD process translates customer requirements into a new product. If a NPD process is of high quality, it should be able to create new products that meet customers' expectations. Therefore, compliance to customer requirements is one NPD quality measurement (Cedergren, Wall, & Norström, 2010; Driva et al., 2000; Haque & Moore, 2004).

Another measurement used to capture NPD process quality is how well resources are managed in NPD processes. Organizations must manage and support each new product project to be successful by providing adequate resources (Cooper & Kleinschmidt, 2007). Organizations that have a robust NPD process typically review and revise new product designs less frequently (Loch et al., 1996). Research has suggested that good NPD processes should also be flexible to support changes or new requirements from customers

(Sobek et al., 1998). Quality performance indicators, proposed by Driva et al. (2000), Leswith and O'Dwyer (2009), Loch et al. (1996), Manion and Cherion (2009), Salter and Torbett (2003), Haque and Moore (2004), and Park (2010) can possibly be used to assess the improvement of NPD processes after applying lean and are summarized in Table 2.4.

Table 2.4 Quality Performance Indicators Used in Assessing NPD Process Performance

Quality Performance Indicators	**References**
1) The number of warranty claims	Haque & Moore, 2004
2) The number of errors in designs detected by customers	Driva et al., 2000
3) The number of engineering errors	Salter & Torbett, 2003
4) The number of product designs that met all product specifications	Driva et al. 2000; Manion & Cherion, 2009
5) The satisfaction of customers with new products	Driva et al, 2000; Griffin & Page, 1996; Ledwith & O'Dwyer, 2009; Manion & Cherion, 2009
6) The number of successful NPD projects	Driva et al., 2000
7) The number of design reviews	Park, 2010
8) The frequency of specification changes	Loch, et al., 1996

Assessing NPD process performance is important to determine whether or not the implementation of lean has positively impacted on NPD processes. The impact of lean is not only dependent on organizational efforts, but also on whether or not the organization faces challenges when implementing lean. In a lean implementation, organizations or functional areas face different challenges and different levels of difficulties. If organizations are aware of potential challenges, they can develop contingency plan to respond to such challenges. The next section discusses some common challenges faced by organizations during NPD lean implementations.

2.6 Challenges Faced by Organizations in Applying Lean

Positive results from implementing lean should serve to motivate organizations to apply lean methods. Many organizations, however, are not successful in implementing lean. In fact, some estimates indicate that only ten percent of organizations have effectively implemented lean (Marker, 2006). Six common challenges faced by organizations in applying lean are summarized in Figure 2.4 and each challenge identified within the literature, is presented next.

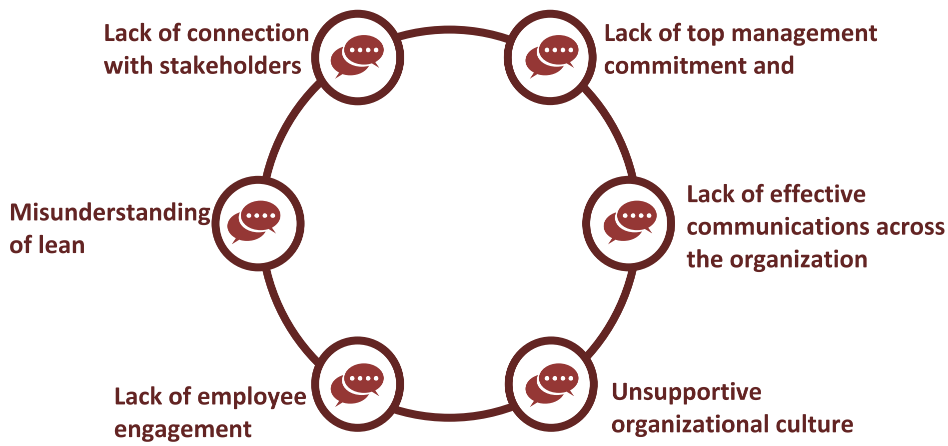


Figure 2.4 Challenges Faced by Organizations in Applying Lean

2.6.1 Lack of Top Management Commitment and Support

Top management plays an important role in the implementation of lean. Without top management commitment, it is difficult for operational managers and employees to be successful in a lean implementation (Bhasin, 2012a). Top management must provide sufficient resources to implement lean, such as allocating funds for lean training (Sarhan & Fox, 2013; Scherrer-Rathje, Boyle, & Deflorin, 2009). During the lean transition, employees may have heavier workloads due to the fact that they must complete both routine work and lean implementation tasks or projects, simultaneously (Grove, Meredith, MacIntyre, Angelis, & Neailey, 2010). Top management can authorize employees to spend more time on lean implementation activities and balance employee workloads. In addition, top management should be involved in all stages of a lean transition and implementation (Scherrer-Rathje et al., 2009). An unclear vision and plan for lean implementation is another issue faced by organizations implementing lean (Karlsson & Åhlström, 1996). To address this issue, top management should provide strategies, goals, and long and short term plans for the lean implementation (Crute, Ward, Brown, & Graves, 2003; Lucey, Bateman, & Hines, 2005). Clear strategies and plans can help employees at all levels set specific goals to implementing lean.

2.6.2 Lack of Effective Communications across Organizations

Poor communications are one of the biggest challenges faced by organizations working on implementing lean. Ineffective communication can lead to misunderstandings between top management and operational level employees (Lucey et al., 2005; Scherrer-Rathje et al., 2009; Worley & Doolen, 2006). Top management might provide plans to implement lean, but if they do not inform operational employees of these plans, employees may be unable to support the lean implementation plan. Ineffective communication can also negatively affect learning (Worley & Doolen, 2006). Organizations should create channels for effective communication in order to convey the need for the lean implementation, to convey lean knowledge, and to receive feedback from operational employees. The lack of effective cross-organizational communication channels can also affect the sharing of lean knowledge between departments (Grove et al., 2010). Communication acknowledging the achievements of teams or departments within organizations can play an important role in motivating all employees to fully commit to lean (Scherrer-Rathje et al., 2009).

2.6.3 Unsupportive Organizational Culture for Change

Lean implementation is a long process. Organizations must invest substantial resources to create a plan for the lean adoption. When organizations are not interested in improvement, they often lack the motivation needed to overcome obstacles that result from the lean implementation. Organizational cultures that do not encourage employees to keep learning new skills or to explore new techniques to improve the workplace can also be problematic. Organizations that resist change will also struggle with a lean implementation (Crute et al., 2003). Successful lean implementations require involvement from everyone in the organization. If people in an organization resist changes, then the lean implementation is less likely to be successful (Sarhan & Fox, 2013). Conflicts in organizations are another barrier to a successful lean implementation. Conflicts prevent collaboration and make communication difficult. As a result, organizations that have high levels of conflicts are typically unsuccessful in implementing lean (Sarhan & Fox, 2013).

2.6.4 Lack of Employee Engagement

If employees do not commit to the lean implementation, organizations cannot reap the benefits of lean (Lucey, Bateman, & Hines, 2004; Lucey et al., 2005). Employee engagement in lean implementation is very important (Crute et al., 2003). Some employees believe that a lean implementation will result in layoffs, due to cost reductions and work changes (Scherrer-Rathje et al., 2009). Such a belief can prevent employees from becoming involved in lean implementation activities.

A study by Gomez (2013) showed that positive results can serve to motivate employees to commit to lean and to be more accepting of changes to work processes. Without the acknowledgement of positive results from lean, employees can resist lean implementation activities. Another challenge is that employees are not always given sufficient time to be involved with lean implementation activities (Lucey et al., 2004). Previous research has also shown that if employees do not have sufficient lean knowledge or training, they are more likely to be less motivated and to be less involved in a lean implementation (Bhasin, 2012a).

2.6.5 Misunderstanding of Lean

Misunderstanding lean is another barrier to success (Sarhan & Fox, 2013). Organizations must determine their own approach to implement lean, rather than attempting to replicate the methods used by other organizations (Crute et al., 2003; Sarhan & Fox, 2013). Many organizations use lean practices without knowing lean principles, or think that the lean implementation is the use of lean practices. To implement lean, organizations have to make sure everyone in the organization, from top management to operational employees, understands lean. It requires not only an understanding of how to use lean practices, but also an understanding of lean principles (Grove et al., 2010). For non-manufacturing organizations, such as healthcare or construction organizations, understanding lean principles is even more important because the lean practices that first originated from manufacturing may not be well-suited for other functional areas (Sarhan & Fox, 2013). Thus, organizations have to understand lean principles and then select the most appropriate lean practices to apply within their organization.

2.6.6 Lack of Connection with Stakeholders

Organizations should ensure that all stakeholders, including contractors and suppliers, understand lean implementation plans and the new processes that will be used (Sarhan & Fox, 2013). Organizations may successfully set up new processes to apply lean principles, but suppliers or contractors may not understand how to support and contribute to these processes. This can result in a disconnect between organizations and stakeholders (Grove et al., 2010). Organizations should engage stakeholders in lean improvement activities and provide training for stakeholders to minimize this disconnect.

2.7 Summary

This chapter provided an overview of NPD processes, lean principles, and the application of lean in NPD processes. Different approaches for applying lean to NPD processes were also presented. The practices applicable to NPD processes were also summarized and organized using the five lean principles. Performance indicators that can be used to evaluate NPD process performance after organizations apply lean were described using three different dimensions: time, cost, and quality. Some potential challenges faced by organizations when applying lean to NPD processes as outlined in the literature were identified. There is no single method for successfully applying lean to NPD processes. However, this review of literature has provided a foundation for understanding the relationship between lean, NPD processes, and NPD process performance. To gain a better understanding of the applicability of lean to NPD processes, additional study is clearly needed. This research was undertaken to address this gap in understanding. A description of the methods used for this study is provided next.

3 Research Methodology

This chapter describes the research methodology used to test the eight hypotheses developed for this study. This chapter begins with identifying and operationalizing the research variables. The next sections describe the survey used to collect data for the research. Data collection details for this study are discussed next. The final section describes the analyses used to test the hypotheses.

3.1 Variables and Terms

This section describes the variables and terms used in this research. Table 3.1a and 3.1b present the variables for each of the eight research hypotheses. The variables used in this research included practice use frequency, perceived usefulness of practices, performance indicator use frequency, perceived NPD process performance improvement, challenge frequency, perceived lean barriers, number of practices used, and years of experience with lean. Additional terms used in this research included practices, performance indicators, and challenges. The definitions of these variables and terms are summarized next.

Table 3.1 Hypotheses, Variables, and Analysis Methods

Hypotheses	Variables	Analysis Method	Model
$H1_0$: There is no difference in the frequency at which a specific practice is applied in NPD processes.	Practice use frequency	Chi – square (χ^2) Goodness-Of-Fit-Test	$H1_0: \pi_{P1} = \pi_{P2} = \cdots = \pi_{P14}$
$H2_0$: There is no difference in the perceived usefulness of specific lean practices in NPD processes.	Perceived usefulness of practice	Kruskal-Wallis test	$H2_0: \bar{R}_{P1.} = \bar{R}_{P2.} = \cdots = \bar{R}_{P14.}$
$H3_0$: There is no difference in the frequency at which a performance indicator is used to measure the impact of the application of practices used in implementing lean in NPD processes.	Performance indicator use frequency	Chi – square (χ^2) Goodness-Of-Fit-Test	$H3_0: \pi_{M1} = \pi_{M2} = \cdots = \pi_{M20}$
$H4_0$: There is no difference in the perceived performance improvement in NPD processes after implementing lean, as measured by time, cost, and quality performance indicators.	Perceived NPD process performance improvement	Kruskal-Wallis test	$H4_0: \bar{R}_{time.} = \bar{R}_{cost.} = \bar{R}_{quality.}$
$H5_0$: There is no difference in the frequency at which a specific challenge is faced by organizations when implementing lean to NPD processes.	Challenge frequency	Chi – square (χ^2) Goodness-Of-Fit-Test	$H5_0: \pi_{C1} = \pi_{C2} = \cdots = \pi_{C6}$
$H6_0$: There is no difference in the extent to which a particular challenge is perceived to be a barrier to lean implementation in NPD processes.	Perceived lean barriers	Kruskal-Wallis test	$H6_0: \bar{R}_{C1.} = \bar{R}_{C2.} = \cdots = \bar{R}_{C6.}$

Table 3.1 Hypotheses, Variables, and Analysis Methods (Continued)

Hypotheses	Independent Variables	Dependent Variables	Analysis Method	Model
$H7a_0$: There is no relationship between the number of practices used by organizations and NPD process performance, as measured by time performance indicators.	Number of practices used	Perceived NPD process performance improvement, as measured by time performance indicators	Linear regression	$H7a_0: \beta_{7a} = 0$
$H7b_0$: There is no relationship between the number of practices used by organizations and NPD process performance, as measured by cost performance indicators.	Number of practices used	Perceived NPD process performance improvement, as measured by cost performance indicators	Linear regression	$H7b_0: \beta_{7b} = 0$
$H7c_0$: There is no relationship between the number of practices used by organizations and NPD process performance, as measured by quality performance indicators.	Number of practices used	Perceived NPD process performance improvement, as measured by quality performance indicators	Linear regression	$H7c_0: \beta_{7c} = 0$
$H8a_0$: There is no relationship between the years of experience with lean and NPD process performance, as measured by time performance indicators.	Years of experience with lean	Perceived NPD process performance improvement, as measured by time performance indicators	Linear regression	$H8a_0: \beta_{8a} = 0$
$H8b_0$: There is no relationship between the years of experience with lean and NPD process performance, as measured by cost performance indicators.	Years of experience with lean	Perceived NPD process performance improvement, as measured by cost performance indicators	Linear regression	$H8b_0: \beta_{8b} = 0$
$H8c_0$: There is no relationship	Years of experience with lean	Perceived NPD process performance improvement, as measured by quality performance indicators	Linear regression	$H8c_0: \beta_{8c} = 0$

3.1.1 Variables

Practice use frequency was defined as the total number of organizations that used a particular practice.

Perceived usefulness of practices was defined as the average usefulness rating for a particular practice, used by organizations to apply lean to NPD processes.

Performance indicator use frequency was defined as the total number of organizations that used a particular performance indicator to evaluate the impact of lean on NPD process performance.

Perceived NPD process performance improvement was defined as the average extent to which NPD process performance improved in organizations after applying lean.

Challenge frequency was defined as the total number of organizations that faced a particular challenge, during efforts to implement lean in NPD processes.

Perceived lean barriers was defined as the average rating of the extent to which a particular challenge was a barrier to lean implementation efforts.

Number of practices used was defined as the total number of practices used by an organization to apply lean to NPD processes.

Years of experience with lean was defined as the number of years that an organization had applied lean to NPD processes.

3.1.2 Terms

Practices were defined as tools and techniques used to apply lean principles to NPD processes. There are two types of practices used to apply lean to NPD processes: traditional lean practices and other improvement practices. Traditional lean practices are tools and techniques that were originally created and used in the Toyota Production

System. Other improvement practices, used in project management or marketing, were also included as previous researchers and practitioners have suggested such practices can be used to implement lean in NPD processes.

Performance indicators were defined as measures used to evaluate the impact of lean on NPD process performance. Performance indicators were categorized using three perspectives: time, cost, and quality.

Challenges were defined as circumstances that obstructed organizations in efforts to apply lean to NPD processes.

To collect data and measure all variables, a survey was developed. The next section provides details on the survey used in this research. The structure of each section of the survey, survey items, and survey questions are also described.

3.2 Survey

An internet survey was designed and used for this study. Internet surveys can be deployed, and data can be collected in a short time and at low cost (de Leeuw, Hox, & Dillman, 2008). Internet surveys can incorporate complex items; however, the survey must be short and should not include too many items, because the display on some computer monitors and some internet browsers make longer surveys difficult to read (de Leeuw et al., 2008). The survey developed for this study included five sections. The five sections were focused on lean use, practices used to apply lean to NPD processes, performance indicators used to evaluate NPD process performance, challenges faced by organizations, and participant and organizational information. The details of each section are described next.

3.2.1 Lean Use

The first section of the survey, as seen in Figure 3.1, was used to identify organizations that had applied lean to NPD processes. The first question was used to determine whether or not an organization had implemented any lean practices in the organization. As some organizations may not have applied lean to NPD processes or to any activities associated with NPD, a second question was used to identify those organizations that had applied lean specifically to NPD processes. Participants were also asked to indicate how long the organization had been applying lean, in general, and to NPD. The number of years that organizations had been applying lean provides an indication of the organization's maturity. After completing this section, organizations that indicated that they had applied lean to NPD processes were asked to complete the remaining sections of the survey. For those organizations that indicated that they had not applied lean to NPD processes, they were asked to complete a modified version of Section 2 and Section 5 of the survey.

Section 1 Lean Use

Has your organization implemented lean?

- Yes
- No

Approximately, how long has your organization been involved in implementing lean?

Less than 1 year	5 to 6 years
1 to 2 years	6 to 7 years
2 to 3 years	7 to 8 years
3 to 4 years	8 to 9 years
4 to 5 years	More than 9 years

Has your organization implemented lean in new product development processes?

- Yes
- No

Approximately, how long has your organization been involved in implementing lean in new product development processes?

Less than 1 year	5 to 6 years
1 to 2 years	6 to 7 years
2 to 3 years	7 to 8 years
3 to 4 years	8 to 9 years
4 to 5 years	More than 9 years

Figure 3.1 Snapshot of Survey Section 1

3.2.2 Practices Used to Apply Lean to NPD processes

The second section of the survey focused on collecting data on practices, both lean and other improvement practices, used by organizations. This section included two sections: a section for organizations that had applied lean in NPD processes and another section for organizations that had not applied lean in NPD processes.

Section 2, created for organizations that indicated that they had applied lean to NPD processes, was used to test Hypothesis 1 and Hypothesis 2. A list of fourteen possible practices, suggested in the research and practitioner literature, was provided to participants. In this section of the survey, definitions were also provided for each practice. If participants were unclear about the definition of a particular practice, the participant was instructed to click on the practice name to review the definition. The fourteen practices, along with definitions included in the survey, are summarized in Table 3.2. The structure of this section of the survey is presented in Figure 3.2. To complete this section of the survey, participants first determined whether or not the organization had applied a specific practice when applying lean to NPD processes. If the organization used other practices in implementing lean in NPD processes, participants were given an opportunity to add additional practices to the survey. To evaluate the level of usefulness of each practice, participants were also asked to rate the extent to which a particular practice was useful. A seven-point Likert scale, with responses ranging from 1 (not at all) to 7 (to a very large extent), was used for rating the perceived usefulness of each practice.

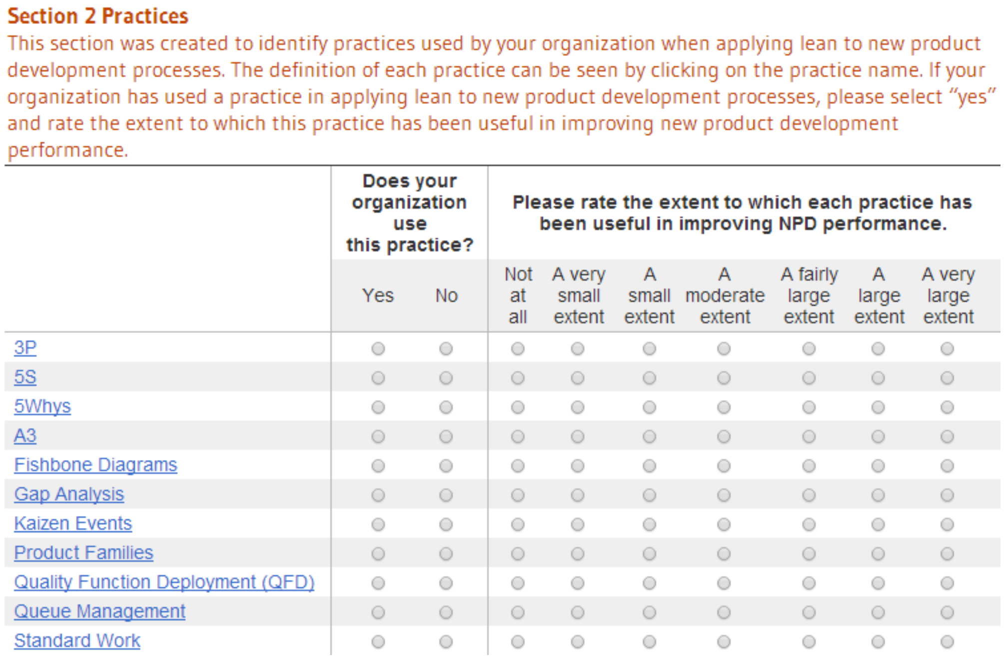
Section 2 was designed for organizations that indicated they had not applied lean to NPD processes. The data collected from these organizations was used for post-hoc analysis. Although these organizations indicated that they were not using lean practices to improve NPD processes, it is possible that they were applying improvement practices included in this study without identifying these practices as part of lean. In this section, a list of fourteen possible practices along with definitions, used in section 2.1, was provided to participants. The structure of this section of the survey is presented in Figure 3.3. To complete this alternate section 2, participants first determined whether or not the organization used a particular practice to improve NPD processes. If the organization used other practices in NPD process improvement, participants were given an opportunity to add additional practices to the survey. To evaluate the level of usefulness of each practice, participants were also asked to rate the extent to which a particular practice was useful. A seven-point Likert scale, with responses ranging from 1 (not at all) to 7 (to a very large extent), was used for rating the perceived usefulness of each practice.

Table 3.2 Practice List and Definitions

Code	Practices	Definition
P1	**3P**	3P is a process for designing products and production processes, implemented by Toyota to ensure that new products meet quality and cost objectives. 3P consists of three steps: brainstorming designs, developing and testing design mock-ups, and evaluating design options. The main concept underlying the 3P process is collaboration between those working on the design and those working on the production process. People from both functions exchange information and provide each other feedback to ensure that the production process and design are compatible.
P2	**5S**	5S is a system that helps organizations organize the workplace. 5S consists of Sort, Set in order, Shine, Standardize, and Sustain. Since new product development processes are concerned with information, new product development teams can apply 5S to both the physical workplace and to the organization's information.
P3	**5Whys**	5Whys is a problem-solving practice used to identify root causes for problems by asking "why" five times. 5Whys requires brainstorming by everyone associated with a particular problem domain. New product development teams can use 5Whys to resolve problems at any point in the new product development process.
P4	**A3**	A3 is a communication practice used to identify problems and solutions in a concise format i.e., on one A3-sized page. An A3 report contains important information related to a particular case, graphs, and figures in a standard format. An A3 report is designed to be clear and simple to make problems and solutions understandable. New product development teams can use A3 to resolve problems at any point in the new product development process.
P6	**Gap Analysis**	Gap analysis is a practice used to identify market gaps and to determine whether a particular new product is different enough from other products in the market to satisfy customer demand. New product development teams can use gap analysis to more effectively scope new product ideas.
P5	**Fishbone Diagrams**	A fishbone diagram is a problem-solving practice used to determine the root cause of problems. The head of the fishbone diagram is the effect: the bones (typically six) in the fishbone diagram are the generic cause behind every effect. New product development teams can use fishbone diagrams to identify causes for problems encountered at any phase of the new product development process.
P7	**Kaizen Events**	Kaizen events bring employees from various functions together to examine a problem, propose solutions, and implement changes in particular areas. New product development teams can use Kaizen events for a variety of purposes, including identifying new product features and improving existing new product development processes.
P8	**Product Families**	Product families are used to organize and group products that share common parts. New product development teams can use the concept of product families to identify opportunities for common part usage and for reuse of drawings from existing products to reduce design times.

Table 3.2 Practice List and Definitions (continued)

Code	Practices	Definition
P9	**Quality Function Deployment (QFD)**	QFD is a practice used to identify product specifications. New product development teams can use QFD to convert customer requirements into new product features and parts. To apply QFD, new product development teams create a matrix that includes new product design and customer requirement attributes. New product development teams score the significance of each product design item on each customer requirement. The product design items that have higher scores are chosen. New product development teams can select those highest scoring features to incorporate into new product designs.
P10	**Queue Management**	Queue management is a technique used to balance the capacity of people with demand and to provide services in the most efficient way. New product development teams can use queue management to balance resources (such as engineers and machines) with assignments at any phase of the new product development process.
P11	**Standard Work**	Standard work provides an establish method and sequence for all processes or activities. New product development teams can apply the concept of standard work to any process in any phase of the new product development cycle, including product concept evaluation and prototype testing, to reduce errors.
P12	**Stand-up meeting**	A stand-up meeting is a short and casual meeting to provide status updates to team members. In new product development, new product development teams can use stand-up meetings as a practice to pull information or work process information from each team member. Team members also share problems, ask for support, or provide follow-up information on progress related to new product development activities.
P13	**Value Steam Mapping (VSM)**	VSM is a practice used to sketch the material and information flow of processes. New product development teams can use VSM to identify activities that effect flow, result in delays, and that are unnecessary and to identify opportunities for improvement to the new product development process.
P14	**Visual Management**	Visual management is a technique used to control and manage the flow in production processes by using visual signals. New product development teams can use visual management to create a visual project board of the overall work flow and to effectively communicate information related to the status of new product development team activities.

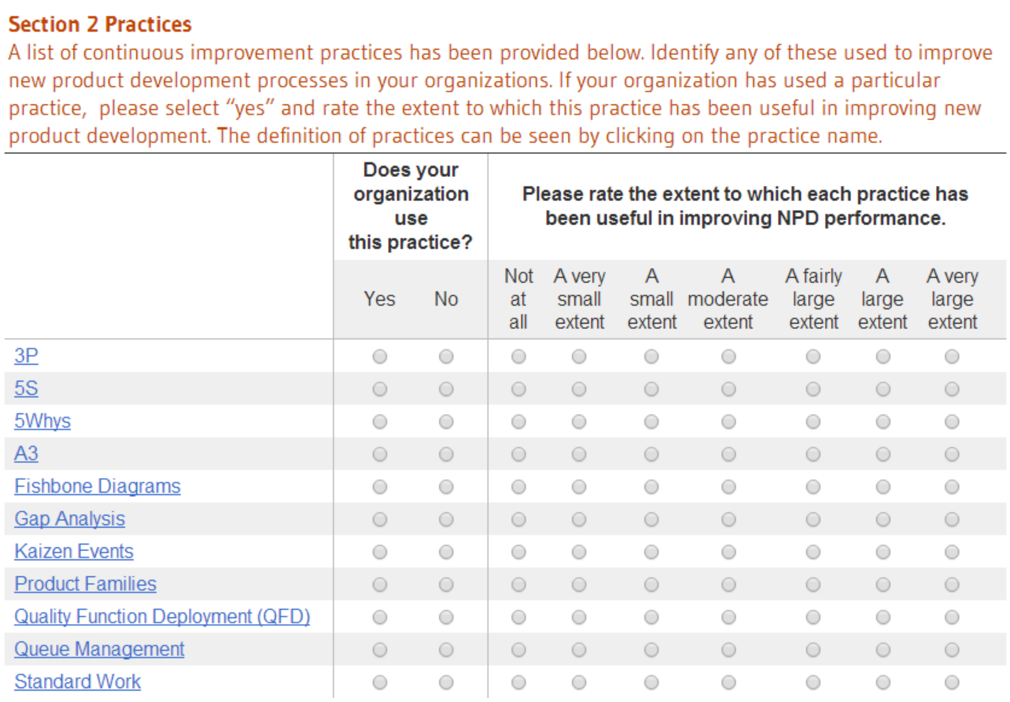


Section 2 Practices

This section was created to identify practices used by your organization when applying lean to new product development processes. The definition of each practice can be seen by clicking on the practice name. If your organization has used a practice in applying lean to new product development processes, please select "yes" and rate the extent to which this practice has been useful in improving new product development performance.

	Does your organization use this practice?		Please rate the extent to which each practice has been useful in improving NPD performance.						
	Yes	No	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
3P									
5S									
5Whys									
A3									
Fishbone Diagrams									
Gap Analysis									
Kaizen Events									
Product Families									
Quality Function Deployment (QFD)									
Queue Management									
Standard Work									

Figure 3.2 Snapshot of Survey Section 2 for Organizations that Indicated that They Had Applied Lean to NPD Processes



Section 2 Practices

A list of continuous improvement practices has been provided below. Identify any of these used to improve new product development processes in your organizations. If your organization has used a particular practice, please select "yes" and rate the extent to which this practice has been useful in improving new product development. The definition of practices can be seen by clicking on the practice name.

	Does your organization use this practice?		Please rate the extent to which each practice has been useful in improving NPD performance.						
	Yes	No	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
3P									
5S									
5Whys									
A3									
Fishbone Diagrams									
Gap Analysis									
Kaizen Events									
Product Families									
Quality Function Deployment (QFD)									
Queue Management									
Standard Work									

Figure 3.3 Snapshot of Survey Section 2 for Organizations that Indicated that They Had Not Applied Lean to NPD Processes

3.2.3 Performance Indicators Used to Evaluate NPD Process Performance

The third section of the survey consisted of a list of performance indicators, potentially used by organizations, to evaluate the impact of lean on NPD process performance. A list of twenty performance indicators, based on the literature, were used. The performance indicators included in the survey are summarized in Table 3.3. The structure of this section of the survey is presented in Figure 3.4. Participants indicated whether or not a particular performance indicator was used by their organization. Participants could also add additional performance indicators, not provided, but used by their organization. Participants were asked to rate the extent to which lean has resulted in NPD process performance improvement, based on a particular performance indicator. A seven-point Likert scale, with responses ranging from 1 (not at all) to 7 (to a very large extent), was used. At the end of this section, participants were also asked to evaluate how much NPD processes had improved as measured by overall time, cost, and quality performance indicators as shown in Figure 3.5. A seven-point Likert scale, with responses ranging from 1 (not at all) to 7 (very large improvement), was used.

Table 3.3 Performance Indicators Used in Evaluating the Impact of Lean on NPD Process Performance

Code	**Performance Indicators**
M1	Lead time to market
M2	Total product development time
M3	Time spent on each stage of NPD process
M4	Cycle time of NPD process
M5	Launch time
M6	The number of projects delivered on time
M7	Deviations from schedule
M8	Difference between actual times and target times for completion
M9	Total cost of project (all costs that the organization incurred in an individual new product project)
M10	Actual cost compared to the budget
M11	The number of NPD projects completed within budget
M12	Total spending on the development phase
M13	The number of warranty claims
M14	The number of errors in designs detected by customers
M15	The number of engineering errors
M16	The number of product designs that met all product specifications
M17	The satisfaction of customers with new products
M18	The number of successful NPD projects
M19	The number of design reviews
M20	The number of specification changes

Section 3 Performance Indicators

This section lists performance indicators used by some organizations to evaluate new product development process performance. If your organization has used a particular performance indicator to evaluate new product development process performance, please select "yes" and rate the extent to which performance has improved, as a result of your lean implementation.

	Does your organization use this perfromance indicator?		Please rate the extent to which NPD process performance has improved in this area, as a result of applying lean						
	Yes	No	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
Lead time to market	○	○	○	○	○	○	○	○	○
Total product development time	○	○	○	○	○	○	○	○	○
Time spent on each stage of new product development process	○	○	○	○	○	○	○	○	○
Cycle time of the new product development process	○	○	○	○	○	○	○	○	○
Launch time	○	○	○	○	○	○	○	○	○
The number of project delivered on time	○	○	○	○	○	○	○	○	○
Deviations from schedule	○	○	○	○	○	○	○	○	○
Difference between actual times and target times for completion	○	○	○	○	○	○	○	○	○
Total cost of project (all costs that the organization incurred in an individual new product development project)	○	○	○	○	○	○	○	○	○
Actual cost compared to the budget	○	○	○	○	○	○	○	○	○

Figure 3.4 Snapshot of Survey Section 3: Performance Indicators

Overall, since implementing lean in your new product development processes, how much have you seen new product development process performance improve, as measured by time performance indicators?

Not at all	Very small improvement Small	Small improvement	Moderate improvement	Fairly large improvement	Large improvement	Very large improvement	Not applicable
○	○	○	○	○	○	○	○

Overall, since implementing lean in your new product development processes, how much have you seen new product development process performance improve, as measured by cost performance indicators?

Not at all	Very small improvement Small	Small improvement	Moderate improvement	Fairly large improvement	Large improvement	Very large improvement	Not applicable
○	○	○	○	○	○	○	○

Overall, since implementing lean in your new product development processes, how much have you seen new product development process performance improve, as measured by quality performance indicators?

Not at all	Very small improvement Small	Small improvement	Moderate improvement	Fairly large improvement	Large improvement	Very large improvement	Not applicable
○	○	○	○	○	○	○	○

Figure 3.5 Snapshot of Survey Section 3: Overall Performance

3.2.4 Challenges Faced by Organizations

The fourth section of the survey included a list of six potential challenges faced by organizations when applying lean to NPD processes. The list of challenges included on the survey was based on a review of the literature on lean implementation and is summarized in Table 3.4. In this section, definitions were also provided for each challenge. If participants were unclear about the definition of a particular challenge, participants were instructed to click on the challenge name to review the definition. The items included in this section of the survey are presented in Figure 3.6. Participants were also given the opportunity to add additional challenges. Participants were asked to rate the extent to which a particular challenge was a barrier to the implementation of lean in NPD processes. A seven-point Likert scale, with responses ranging from 1 (not at all) to 7 (to a very large extent), was used in this section.

Table 3.4 Challenges Faced by Organizations

Code	Challenges	Definition
C1	Lack of top management commitment and support	• Top management does not support lean implementation and does not provide strategies, goals, and/or long and short term plans for lean implementation. • Top management does not provide sufficient resources to implement lean in new product development processes. • Top management does not help employees balance workload during the lean implementation.
C2	Lack of effective communications across the organization	• The organization does not have a good mechanism to communicate to employees, in all levels and functions associated with new product development, about the lean implementation. • The organization does not have an established system to exchange lean knowledge between departments, functions, or facilities. • The organization does not collect feedback from employees, especially operational level employees, to determine issues and to help employees solve problems during implementing
C3	Unsupportive organizational culture for change	• The organization does not have good collaboration between departments, functions, and/or facilities. • The organization experiences conflicts between departments, functions, and/or facilities. • The organization has many employees who resist change, including changes in job tasks or changes in processes.
C4	Lack of employee engagement	• Employees do not have sufficient training or knowledge to implement lean in new product development processes. • Employees do not perceive value from implementing lean in new product development processes. • Employees do not have adequate time to contribute to lean implementation activities due to other job responsibilities. • Employees believe that lean implementation will lead to job insecurity, resulting from cost reductions and process redesign.
C5	Misunderstanding of lean	• Organizations only focus on using practices, without understanding lean principles. • Organizations are unaware of lean principles. • Organizations use lean approaches without knowing what lean means.
C6	Lack of connection with stakeholders	• The organization has not informed stakeholders about lean implementation activities. • The organization does not provide sufficient information about lean and does not transfer lean knowledge to stakeholders. • The organization does not provide lean training for stakeholders. • The organization does not encourage stakeholders to be involved in lean implementation activities.

Section 4 Challenges

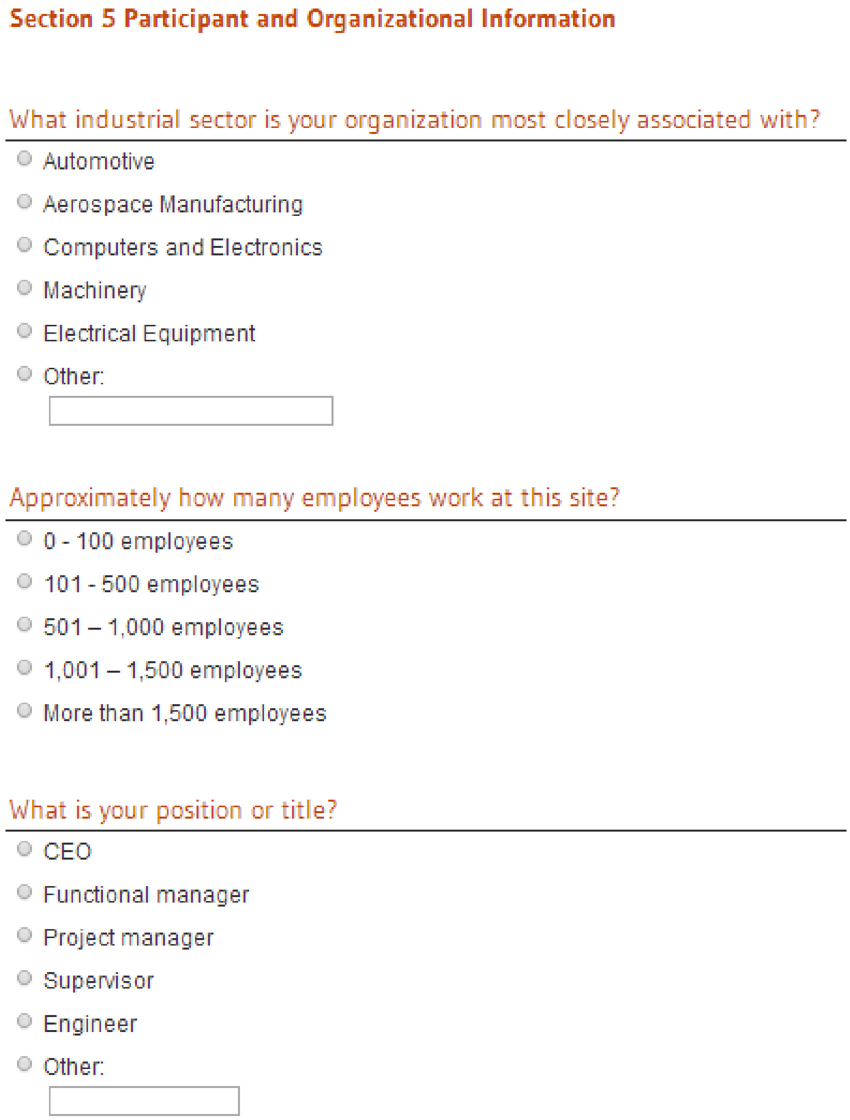
This section lists challenges faced by some organizations when applying lean to new product development processes. If your organization has faced a particular challenge when applying lean to new product development processes, please select "yes" and rate the extent to which a particular challenge has been a barrier to lean implementation. The definition of each challenge can be seen by clicking on the practice name.

	Does your organization face this challenge?		**Please rate the extent to which each challenge has been a barrier to lean implementation.**						
	Yes	No	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
Lack of top management commitment and support	○	○	○	○	○	○	○	○	○
Lack of effective communications across the organization	○	○	○	○	○	○	○	○	○
Unsupportive organizational culture for change	○	○	○	○	○	○	○	○	○
Lack of employee engagement	○	○	○	○	○	○	○	○	○
Misunderstanding of lean	○	○	○	○	○	○	○	○	○
Lack of connection with stakeholders	○	○	○	○	○	○	○	○	○

Figure 3.6 Snapshot of Survey Section 4

3.2.5 Participant and Organizational Information

The fifth section was used to collect participant and organizational information. Participants were asked to provide general organizational information, such as the type of industry and the number of employees at the facility in which a participant worked. Participants were also asked to provide their position or title. The structure of this section is presented in Figure 3.7.



Section 5 Participant and Organizational Information

What industrial sector is your organization most closely associated with?

- Automotive
- Aerospace Manufacturing
- Computers and Electronics
- Machinery
- Electrical Equipment
- Other:

Approximately how many employees work at this site?

- 0 - 100 employees
- 101 - 500 employees
- 501 – 1,000 employees
- 1,001 – 1,500 employees
- More than 1,500 employees

What is your position or title?

- CEO
- Functional manager
- Project manager
- Supervisor
- Engineer
- Other:

Figure 3.7 Snapshot of Survey Section 5

3.3 Survey Approval

The survey and a detailed protocol for participant identification and survey administration were submitted to Oregon State University's Institutional Review Board (IRB). The IRB reviewed the materials to ensure that individuals asked to complete the survey understood their rights. The survey was estimated to take no longer than 20 minutes to complete. Participants did not sign consent forms to help ensure that information collected would not be directly linked to a particular participant. The approved IRB materials included the protocol, the survey, the cover letter, and the recruitment letter. The research protocol is included in Appendix A. Qualtrics, an internet survey product, was approved and used as the data collection mechanism. The survey was opened for a period of two months.

3.4 Data Collection

This research used a survey to collect data. Dillman, Smyth, and Christain (2009) suggest that when using a survey, researchers should minimize risks that can lead to survey administration errors. This section discusses how the data were collected and steps taken to minimize survey administration errors. First, four common errors in survey administration are presented. Second, recommendations for how to select and sample survey participants is discussed. Third, details related to survey distribution are presented.

3.4.1 Survey Administration Errors

A successful survey depends on the development of methods to administer the survey. However, poorly planned survey administration can lead to errors. Errors that can occur in survey administration include coverage error, sampling error, measurement error, and non-response errors (de Leeuw et al., 2008). Each of these four survey administration errors is described next, and steps taken to minimize each error in this research are presented.

Coverage error occurs when the list of targeted participations does not match the sample frame of the population. There are two common coverage errors that can occur:

under-coverage and over-coverage. Under-coverage occurs when all targeted participants are not included in the list. Over-coverage occurs when targeted participants appear on the list more than once because of duplicated information, such as two e-mail addresses. Internet surveys require participants who have access to the internet. If some targeted participants do not have access to the internet, these participants are not covered in the research. Browsers can also impact the appearance of internet surveys. Some browsers do not support certain styles of internet surveys. This can lead coverage errors as participants who are unable to open the survey website cannot participate.

To minimize coverage error in this research, the list of targeted participants was checked and duplicated participants were eliminated from the list. All targeted participants in the list had e-mails as the contact information. This implied that the targeted participants had access to the internet. To minimize unreadable surveys, Qualtrics, a website used to collect survey data, was selected. Qualtrics supports most browsers, including Mozilla Firefox, Google Chrome, Apple Safari, and Internet Explorer. These browsers are commonly used and run on both IOS and Window operating systems. The use of Qualtrics was intended to minimize browser/survey compatibility issues.

The second error, sampling error, occurs when a sample of the population of interest is used, instead of targeting the entire population. A probabilistic sample is determined based on desired significance levels. To minimize sampling error, a sufficiently large sample size should be used. This research used a statistical method for determining the appropriate sampling size. The details of the analysis used to determine sample size are discussed in section 3.4.2.

The third error, nonresponse error, results from the failure to collect information from all targeted participants. There are two main causes of nonresponse error. The first source of nonresponse occurs when researchers fail to contract all participants. The second source occurs when participants refuse or forget to respond to the survey or to items on the survey. To minimize contact error, the researcher sent two e-mails to participants. The first e-mail was sent to recruited participants asking them to contribute to this research and complete the survey. The second e-mail was sent two weeks after the first e-mail was sent, and was used to remind participants, who did not complete the survey, as well as to those who might have missed the initial request e-mail. The details of the survey distribution process is summarized in section 3.4.3. To minimize nonresponse due to incomplete surveys, survey items were designed to make it easy for participants to respond to all items. Critical items on the survey required participants to provide a response. If participants missed any critical items, a message appeared on the survey page, and participants could not move to the next survey section until responding to these critical items.

The fourth error, measurement error, is caused by items in the survey that lead participants to provide the wrong answer. When directions and/or survey items are not clear, participants can unintentionally choose responses that do not correctly reflect their experiences. Writing clear questions and directions can minimize measurement error. To minimize measurement errors, the survey used in this research was reviewed by the researcher and the major professors multiple times. The words used in survey items were selected to maximize understanding. Definitions for technical terms used in the survey were also provided to participants. Participants were able to click on terms and see definitions. All questions in the surveys were structured to maintain a simple structure and to utilize the same response scale. No items required reverse scoring. The survey used a consistent item structure and layout to allow participants to easily navigate items.

3.4.2 Survey Targeted Participants

Since NPD processes for tangible products, such automobiles and computers, are different from NPD process for non-tangible products, such as service products or software products, this research focused on studying the application of lean in NPD processes only for organizations producing tangible products. Targeted organizations of this research should have experience in applying lean to NPD processes. However, it was difficult to identify which organizations had implemented lean in NPD. To create the list of targeted organizations, previous research was used to identify industrial sectors.

Hoppmann (2009) used a survey to study lean in NPD. The results showed that the majority of organizations applying lean in NPD processes were in the automotive industry (44%); others were in electronic manufacturing industries (15%), industrial equipment (14%), and aerospace manufacturing (10%). Organizations in automotive manufacturing, industrial equipment, aerospace manufacturing, and electronic manufacturing sectors are more likely to have experience with lean. Thus, the targeted organizations for this research were manufacturing organizations from automotive manufacturing, aerospace manufacturing, industrial equipment, and electronic manufacturing organizations that produced tangible products. Semiconductor and computer equipment manufacturing organizations were also added to the list of targeted organizations, because some organizations in this industry had a long history of lean implementations in manufacturing processes. It was possible that these organizations might start implementing lean in NPD processes as well.

Targeted participants for completing the survey included CEOs, managers, supervisors, engineers, marketing specialists, and other employees who had NPD process experience and who worked in the targeted organizations. Three sources were used to find targeted participants and information contact. The first source was a business research organization, which provided information on organizations from the targeted organizations as well as contact information. The business research organizations used in this research were Data.com and Hoovers.com. Both Data.com and Hoovers.com generated a list of targeted participants, including the name of the organization, a participant name, a participant title, and an e-mail address. Eight hundred contacts were generated by Data.com and fifty were contacts generated by Hoovers.com. Computers, electronics, and manufacturing (only automotive, boat, and aerospace products) were used as keywords to identify organizations. Engineering and research were used to refine the job function of targeted participants. After a list were generated, people who had a job position in project development, research and development, engineering, and product functions were selected and added to the targeted participants. If any targeted organizations had multiple people included, only one contact would be added to the participant list. From 850 contacts purchased from Data.com and Hoovers.com, the final list of targeted participants included 780 contacts from different 780 organizations.

The second source of targeted participants was the American Society for Engineering Management (ASEM). ASEM is a society that includes members from industry and academia, who work in area of the engineering management or closely associated areas, such as industrial engineering. ASEM members often work in product development or research and development functions or closely related functions.

Approximately 550 ASEM members were contacted with an invitation to complete the survey.

Targeted participants were also identified using LinkedIn.com, a business-oriented social networking service. Approximately 100 targeted participants from different organizations were selected on LinkedIn based on having job titles related to new product development or employment in the targeted organizations. Participants from these different sources were contacted using different protocols. The details of participant recruitment and survey distribution the survey are described next.

3.4.3 Survey Distribution

Four methods were utilized to distribute the survey. The four methods are summarized in Figure 3.8. The first method was on email survey. An initial e-mail was sent to 780 targeted participants from the final list created by Data.com and Hoover.com. This e-mail included the survey recruitment message, shown in Appendix B, explaining the objectives of the research with a request to participate by completing the survey, an explanation of how to complete the survey, and a link to the Internet survey. Within the Internet survey, participants viewed a cover letter, which included the research objective, details on the researcher and the major professor, and the researcher's contact information. This contact information enabled respondents to receive prompt answers to any questions, as well as IRB contact information. After the cover page, participants were asked to respond to the complete set of survey items. Participants could discontinue participation at any time. At the conclusion of the survey, a thank-you message was displayed. Two weeks after getting an initial email, a reminder email was sent to targeted participants who had not responded. Second and third reminder emails were sent to participants who did not complete the survey after the first reminder email was sent out at two weeks and four weeks, respectively. Even after three reminders, the participant response rates were very low. Other methods, including physical mailings were considered in an effort to increase the number of survey responses. Phone calls were used due to the high costs associated with completing a paper mailing process.

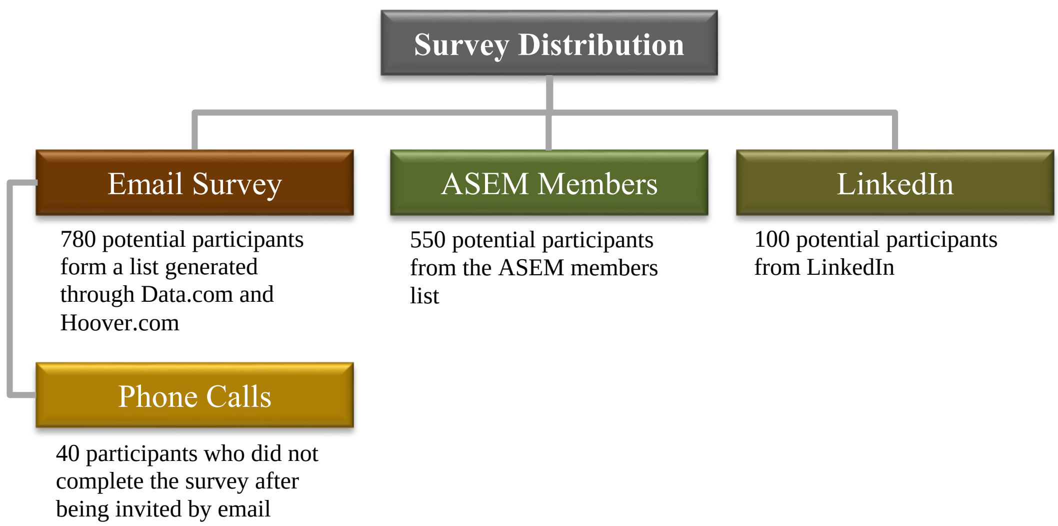


Figure 3.8 Survey Distribution

The second method, making phone calls, was utilized to contact targeted participants. Forty targeted participants who did not complete the survey using the email survey method were selected from the final list generated by Data.com and Hoover.com. A script, shown in Appendix B, was used to recruit these participants. The script was approved by the IRB. The researcher called targeted participants and left a message, using the script to ask if they would be willing to complete the survey. If targeted participants were interested in completing the survey, they could contact the researcher with details on how they would they prefer to complete the survey. Targeted participants had two options.

The first option was to complete the internet survey. Targeted participants could ask the researcher to send the survey link to a preferred email address. The second option was to request the researcher send a hard copy of the survey to the targeted participant's physical mailing address. After calling all 40 targeted participants, no participants responded. The main reason for low response could be the researcher was unknown to the targeted participants. Two additional approaches were used to try to increase the number of participants and are described next.

The third method, the ASEM member list, was used next. A request email was sent to the ASEM office manager to ask if it would be possible to post or send the survey recruitment message to all ASEM members, who worked or had experience in new product development and could respond to the survey. The ASEM office manager forwarded the survey recruitment email to all 550 ASEM members.

The fourth method used to distribute survey was LinkedIn.com. The researcher used the message function, provided by LinkedIn.com, to contact people who were connected to the researcher. The survey recruitment message, including the objectives of the research with a request to participate by completing the survey, information on how to complete the survey, and a link to the internet survey, were sent to 100 individual participants using this approach.

All information collected from participants using the four survey distribution methods was temporarily stored in Qualtrics. The Internet survey was open from May through September 2014. After the survey closed, collected data were downloaded and stored by the researcher and the major professors on a university server. Information was deleted from the Qualtrics survey site at this time.

3.4.4 Response Rates

Data collection was a challenge for this research. Targeted participants had to have work experience related to new product development. Not every organization in the targeted industries had a new product development department or a research and development department. Thus, the number of participants was limited. The total number of targeted participants who were asked to complete the survey was 1,430. There were 120 participants who opened the survey, but only 58 participants completed all or portions of the survey. The overall response rate of the survey was 3.5%. Although the overall response rate was low, a sufficient number of responses was secured to test the research hypotheses. The next section discusses the details and statistical tools used to analyze the survey data.

3.5 Research Analysis

Eight hypotheses were developed and tested. Different statistical analyses were used to test the hypotheses, due to the type and structure of the data. Table 3.1 summarizes the eight research hypotheses and the statistical tests used. Three analyses, chi-square (χ^2) goodness-of-fit, Kruskal-Wallis, and linear regression (least-squares) were performed to test the eight defined research hypotheses. The details of the statistical analyses are described next.

3.5.1 Chi-square (χ^2) Goodness-Of-Fit Analysis

Chi-square (χ^2) goodness-of-fit was performed to test Hypothesis 1, Hypothesis 3, and Hypothesis 5. Chi-square goodness-of-fit is a single-sample, nonparametric test used to determine whether the distribution of collected counts matches an expected distribution of counts (Elliott & Woodward, 2007; Fisher & Van Belle, 1993). n_i is the number of collected counts of outcome i, where i = 1,…, k. π_i is the probability that outcome (i) occurs. n is the total number of collected counts. π_i^0 is the expected probability that outcome (i) can occur. If the expected probabilities of every outcome (i) are equal, the null hypothesis is presented as shown in Equation 3.1.

$$H_0: \pi_1 = \pi_2 = \cdots = \pi_k = \pi_i^o \tag{3.1}$$

The expected value of n_i, $E(n_i)$, is determined by $E(n_i) = n\pi_i^o$. The value of outcome (n_i) is equal to $n\pi_i$. The resulting test for the chi-square (χ^2) goodness-of-fit is presented in Equation 3.2.

$$\chi^2 = \sum_{i=1}^{k}\left(\frac{(n\pi_i - n\pi_i^o)^2}{n\pi_i^o}\right) = \sum_{i=1}^{k}\left(\frac{(n_i - n\pi_i^o)^2}{n\pi_i^o}\right) \tag{3.2}$$

The chi-square (χ^2) distribution is well-approximated if there are at least five expected values, $n\pi_i^0$. At a significance level (α), the null hypothesis (H_o) is rejected if $\chi^2 \geq \chi^2_{1-\alpha,k-1}$, where $\chi^2_{1-\alpha,k-1}$ is the 1 – α significance level for a χ^2 random variable, with k – 1 degrees of freedom.

3.5.2 Kruskal – Wallis Analysis

Kruskal-Wallis tests were performed to test Hypothesis 2, Hypothesis 4, and Hypothesis 6. Kruskal-Wallis is a nonparametric method used to test if there is a difference between groups. Kruskal-Wallis is equivalent to a one-way ANOVA, but uses the ranks of data to calculate the test statistic (Fisher & Van Belle, 1993). Collected data are assigned ranks according to their position or rank. The average rank from collected data are then calculated for each group. Let R_{ij} be the rank of collected data j in group i. k is the number of ranks in group i, and g is the total number of groups. $\bar{R}_{i.}$ is the average ranks from collected data in group i. The average ranks are calculated by using Equation 3.3. Let n be the total number of ranks and n_i be the number of ranks in group i. $\bar{R}_{..}$ is the grand mean of the ranks and is calculated by using Equation 3.4.

$$\bar{R}_{i.} = \frac{\sum_{j=1}^{k} R_{ij}}{k} \tag{3.3}$$

$$\bar{R}_{..} = \frac{\sum R_{ij}}{n} = \frac{\sum_{i=1}^{n} n_i}{n} = \frac{(n+1)}{2} \tag{3.4}$$

The null hypothesis is there is no difference between average ranks between groups and can be identified as specified in Equation 3.5.

$$H_0: \bar{R}_{1.} = \bar{R}_{2.} = \cdots = \bar{R}_{i.} \tag{3.5}$$

The Kruskal-Wallis test statistic can be calculated as show in Equation 3.6.

$$T_{KW} = (n-1)\frac{\sum_{i=1}^{g} n_i(\bar{R}_{i.} - \bar{R}_{..})^2}{\sum_{i=1}^{g}\sum_{j=1}^{n_i}(R_{ij} - \bar{R}_{..})^2} \tag{3.6}$$

The distribution of the Kruskal-Wallis statistic approaches a chi-square distribution with i – 1 degree of freedom. Large values of T_{KW} imply that average ranks for groups differ, and the null hypothesis is rejected. At a significance level (α), the null hypothesis (H_o) is rejected if $T_{KW} \geq \chi^2_{1-\alpha,i-1}$, where $\chi^2_{1-\alpha,i-1}$ is the 1 – α significance level for a χ^2 random variable with i – 1 degrees of freedom.

3.5.3 Linear Regression Analysis

Linear regression was performed to test Hypotheses $7_{a\text{-}c}$ and Hypotheses $8_{a\text{-}c}$. Linear regression is used to determine whether or not there is a relationship between two variables. The regression line, calculated from collected data, is used to describe the relationship between an independent variable (X) and a dependent variable (Y) (Fisher & Van Belle, 1993). In linear regression, a data set is summarized using a straight line (Elliott & Woodward, 2007). For this research, the method of least squares was used to find the linear regression line that best fit the data. The regression line has the form presented in Equation 3.7, where α is the y-intercept, β is the slope, and ε is an error term, with a zero mean and constant variance.

$$Y = \alpha + \beta X + \varepsilon \tag{3.7}$$

To characterize the relationship between a dependent variable and an independent variable, the slope of a regression line (β) is studied using a statistical test. If the slope is zero, there is no linear relationship between the dependent variable and the independent variable. The null hypothesis is identified as specified in Equation 3.8.

$$H_0: \beta = 0 \tag{3.8}$$

β is also called the regression coefficient. The sign associated with the regression coefficient (β) indicates whether the independent variable (X) and the dependent variable (Y) have a positive or negative relationship. If the regression coefficient has a positive sign, the independent variable and the dependent variable change in the same direction.

3.5.4 Hierarchical Cluster Analysis

Hierarchical cluster analysis is a method that uses distances, representing dissimilarity of data, to create clusters of data (Burns & Burns, 2008). Hierarchical cluster analysis is useful for clustering a data set that has less than a few hundred data points and can be used for categorical and variable data (IBM, 2011; Norušis, 2011). Hierarchical cluster analysis is agglomerative, grouping cases by the most similar first and after these case are grouped, they cannot be separated or used to compare to other case individually (Norušis, 2011).

The approach that is effective and recommended is Ward's method (Burns & Burns, 2008). Ward's method uses the squared Euclidean distance (d^2), the sum of the squares of the differences between cases to group cases in a cluster (Norušis, 2011). If there are n dimensions used to identify clusters, the squared Euclidean distance between case p and q of all dimensions can be calculated by Equation 3.9.

$$d^2(p,q) = (p_1 - q_1)^2 + (p_2 - q_2)^2 + \cdots + (p_n - q_n)^2 \quad (3.9)$$

This research used SPSS to generate the results of hierarchical cluster analysis. SPSS creates a proximity matrix that is used to identify which cases should be firstly combined. An example of a proximity matrix is presented in Table 3.5. The results of the hierarchical cluster analysis are presented in an agglomeration schedule table, shown in Table 3.7, and a dendrogram, shown in Figure 3.9.

After calculating the squared Euclidean distances, SPSS summarizes squared Euclidean distances between cases in a proximity matrix. The two cases that produce the smallest squared Euclidean distance are combined first. For example, in Table 3.5, C2 and C4 produce a squared Euclidean distance of 0.00, which is the smallest distance. Thus, cases C2 and C4 are grouped, as shown in the agglomeration schedule table. When cases are combined into a group and used to compare with other cases or other combined groups, Ward’s method uses the mean of dimensions used to calculate the squared Euclidean distance. In Table 3.6, for example, case p and case q were combined in the previous stage. To compare combined case p and q to case t, the mean of Dimension 1 of Case p and Case q (4) and the mean of Dimension 2 of case p and q (4.5) are used to calculate the squared Euclidean distance. The squared Euclidean distance between combined group of Case p and Case q and Case t is calculated by

$$d^2(p\&q,t) = (4-6)^2 + (4.5-7)^2 = 8.2$$

Table 3.5 An Example of a Proximity Matrix

Case	Squared Euclidean Distance					
	1:C1	2:C2	3:C3	4:C4	5:C5	6:C6
1:C1	.000	.348	.044	.372	.640	.144
2:C2	.348	.000	.640	.000	.044	.044
3:C3	.044	.640	.000	.672	1.020	.348
4:C4	.372	.000	.672	.000	.036	.053
5:C5	.640	.044	1.020	.036	.000	.176
6:C6	.144	.044	.348	.053	.176	.000

Table 3.6 An Example of Means of Dimensions Used in Ward's Method

Dimension	**Combined Group of Case p and Case q**			**Case t**
	p	**q**	**Mean**	
1	3	5	**4**	**6**
2	4	5	**4.5**	**7**

An agglomeration schedule table is a numerical summary of the cluster results and includes five columns (IBM, 2011; Norušis, 2011). The first column is *Stage*. The Stage column shows the number of stages used to combine cases by comparing squared Euclidean distances. Stage 1 combines two cases that produce the least squared Euclidean distance. Hierarchical cluster analysis keeps comparing and grouping cases until the final stage, in which all cases are combined into one cluster. The total number of stages is calculated by the number of cases – 1.

The second and third columns are *Cluster Combined*. The Cluster Combined column shows the number of individual cases that are combined at each stage, based on squared Euclidean distances. The fourth column is *Coefficients*. The coefficient resulting from Ward's method, which is included in the agglomeration schedule table, is the within-group sum of squares at each stage, which can calculated by Equation 3.10.

$$Within - group\ sum\ of\ squares = \sum_{i=1}^{n}(y_i - \bar{y})^2 \qquad (3.10)$$

For Ward's method, a larger coefficient indicates that a cluster in that stage is more heterogeneous. Hierarchical cluster analysis uses differences in the coefficients determined by Ward's method, to identify the number of clusters. The number of clusters is identified by counting the number of stages, from the last stage to the stage in which a coefficient is dramatically changed. In Table 3.7, for example, the largest gap (0.111 – 0.764) occurs between adjacent coefficients from Stage 4 (0.111) and the coefficient at Stage 5 (0.764). The count from the last stage (Stage 5) up to Stage 4 is two. Thus, the suggested number of clusters in this example is two.

The fifth and sixth columns are S*tage Cluster First Appears*. The Stage Cluster First Appears column shows the stage number at which cases are combined for the first time. For example, as shown in Table 3.7, at Stage 3, the value 1 in cluster 1 of the Stage Cluster First Appears column signifies that Case 2 used in Stage 3 in cluster 1 of the Cluster Combined column first appeared in Stage 1 and combined with Case 4 in cluster 1 of the Cluster Combined column first appeared in Stage 1. It means that Case 2 in Stage 3 represents a combined group of Case 2 and Case 4.

The fifth and sixth columns are *Next Stage*. The Next Stage column represents the stage at which the combined cases will appear. For example, in Table 3.7, at Stage 3, the 4 in the Next Stage column indicates that case 2 and case 5 were combined at Stage 3, and this combined set of cases (2 and 5) will appear at Stage 4.

Table 3.7 An Example of An Agglomeration Schedule Table

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	2	4	.000	0	0	3
2	1	3	.022	0	0	5
3	2	5	.049	1	0	4
4	2	6	.111	3	0	5
5	1	2	.764	2	4	0

The dendrogram is a graphical summary of hierarchical cluster analysis results (Burns & Burns, 2008; IBM, 2011; Norušis, 2011). The vertical axis of a dendrogram presents the cases used in the hierarchical cluster analysis. The horizontal axis represents the distances between cases, from 1-25. 1 represents the most similarity and larger numbers imply lower similarity. Actual distances between cases are calculated and rescaled to a 25-point scale (Norušis, 2011). Although actual distances between cases are not shown in the dendrogram, the rescaled distances in a dendrogram represent the ratio of actual distances and can be used to identify the numbers of clusters (Norušis, 2011). The distances between cases calculated by Ward's method are rescaled from the squared Euclidean distance to the 25-point scale.

To identify the possible number of clusters, the distance from one the linkage point to the next linkage point is used. The longest distance between linkage points or vertical lines determines the number of clusters. By counting the number of intersecting horizontal lines, the number of clusters can be determined. For example, in Figure 3.9, D1, D2, and D3 are distances between linkage points. The largest gap in this dendrogram is D1 and is about 22 units. Two horizontal lines span the D1 distance and indicate that there are two possible clusters. When the gap distances between linkage points in a dendrogram are very similar, the number of clusters will be determined by the results of both the agglomeration schedule table and the dendrogram (Burns & Burns, 2008).

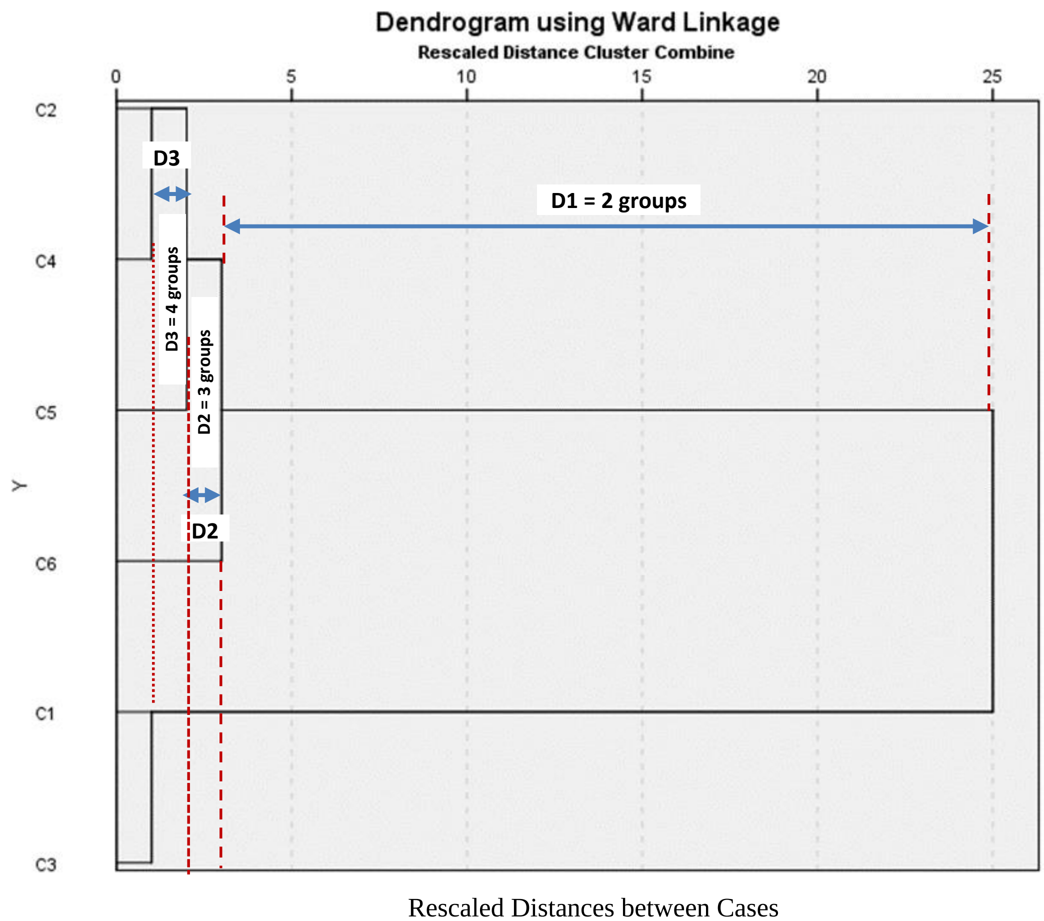


Figure 3.9 An example of a dendrogram

Chapter 3 summarizes the variables and hypotheses, the survey used to collect data, the data collection plan, and the analyses. Variables and terms used in this research are identified. The survey details are described, as well as data collection details. A survey distribution plan was developed to minimize administration errors and is described. Finally, the analysis tools are discussed and explanations of each analysis are provided.

4 Results

This chapter summarizes the results of statistical analyses of data collected from the survey. This chapter includes three sections. The first section is a summary of participant and organizational information. This section summarizes survey responses, organizational and participant information, and lean use. The second section provides the results of statistical analyses used to test the eight research hypotheses. The third section provides details of post-hoc analyses performed to investigate differences in practices used by organizations that applied lean to NPD processes and organizations that did not implement lean in NPD processes.

4.1 Survey Response Summary

A total of 1,034 targeted participants were contacted to participate in the survey. A total of 58 participants completed the entire survey or some portion of the survey. Since not every section in the survey was completed by all participants, the number of responses for each section of the survey varies. Table 4.1 summarizes the number of responses for each section of the survey. The number of responses used to test each hypothesis were different, due to partially completed surveys.

Table 4.1 Number of Responses in Each Section of the Survey

Survey Section	Number of responses (% of total responses)
1. Lean use	58 (100%)
2. Practices used to apply lean to NPD processes	
2.1 Practices used by organizations which implemented lean in NPD processes.	27 (47%)
2.2 Practices used by organizations, not implementing lean in NPD processes	27 (47%)
3. Performance indicators used to evaluate NPD process performance	
3.1 Performance indicators used by organizations	20 (34%)
3.2 Overall NPD process improvement, measured by time, cost, and quality indicators.	21 (36%)
4. Challenges faced by organizations	20 (34%)
5. Participant and organizational information	39 (67%)

4.1.1 Organizational and Participant Information

In Survey Section 5, participants were asked to identify the industrial sector of their organizations, numbers of employees, and their position. Thirty-nine participants provided organizational and participant information. The summary of industrial sectors of participating organizations is presented in Figure 4.1. The highest response rates, by sector were electrical equipment, computers and electronics, and automotive manufacturing. Other industrial sectors participating in this survey included semiconductor and power system manufacturers.

Participant positions and organizational size are summarized in Figure 4.3 and Figure 4.2, respectively. The number of employees varied from less than 100 employees to 5,000. Participant positions included CEO, manager, engineer, and others. The highest number of participants identified as manager and engineer.

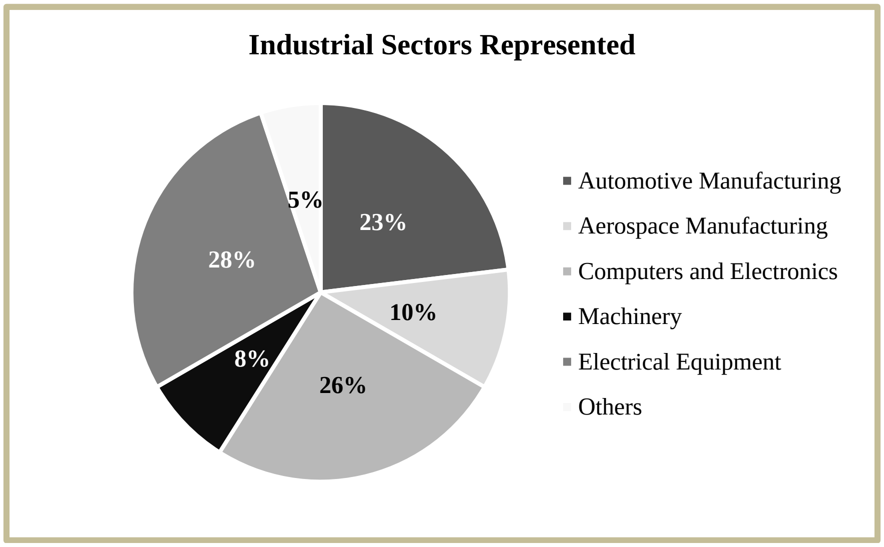


Figure 4.1 Industrial Sector Representation

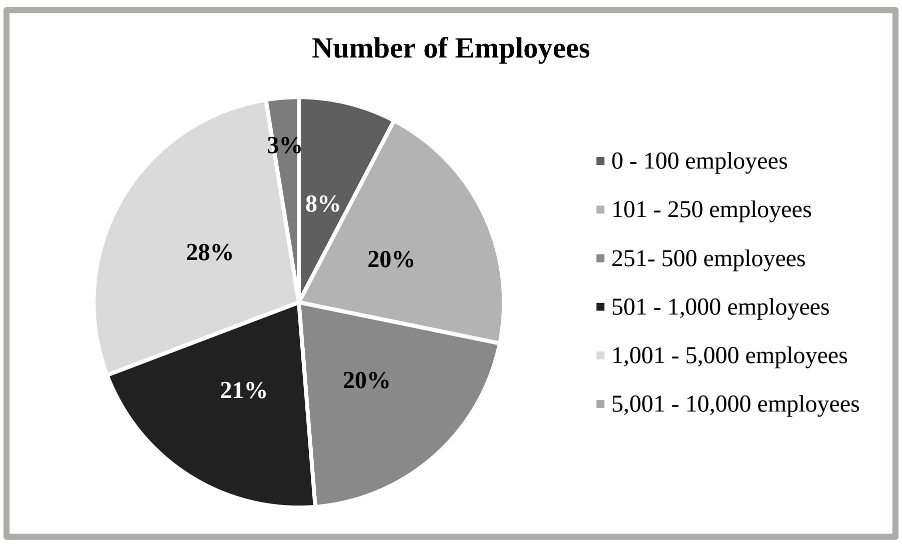


Figure 4.2 Distribution of Responses Based on Reported Number of Employees

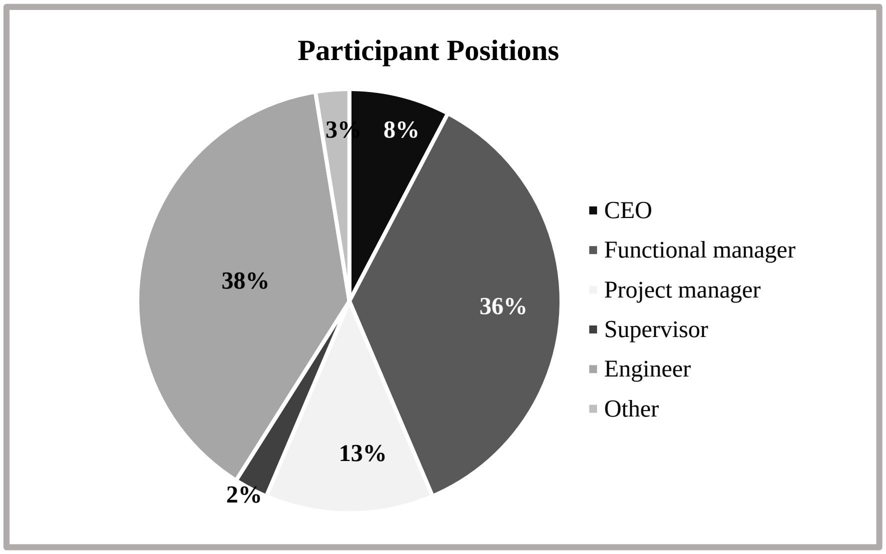


Figure 4.3 Participant Position Representation

4.1.2 Lean Use

This research focused on studying organizations, which implemented lean in NPD processes. Survey Section 1 asked participants to identify whether or not their organizations had implemented lean in manufacturing processes and whether or not their organizations had implemented lean in NPD processes. As shown in Figure 4.4, 50 organizations or 86% of the responding organizations implemented lean in manufacturing processes. Figure 4.5 also shows that almost half of participating organizations had implemented lean in manufacturing operations for more than nine years. The average number of years participating organization had implemented lean in manufacturing was 7.5 years.

From the total of 58 organizations, only 35 organizations or 60% of responding organizations had implemented lean in NPD processes. Most organizations implemented lean in manufacturing before implementing lean in NPD processes. Three organizations implemented lean in NPD before manufacturing. Two organizations implemented lean in NPD, but had not implemented lean in manufacturing processes. The average number of years responding organizations had implemented lean in NPD was 5.5 years. Overall, organizations implemented lean in NPD after implementing lean in manufacturing.

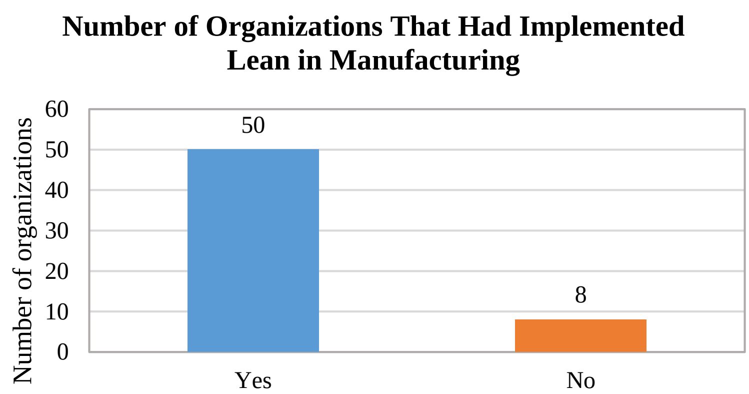


Figure 4.4   Number of Organizations Implementing Lean in Manufacturing

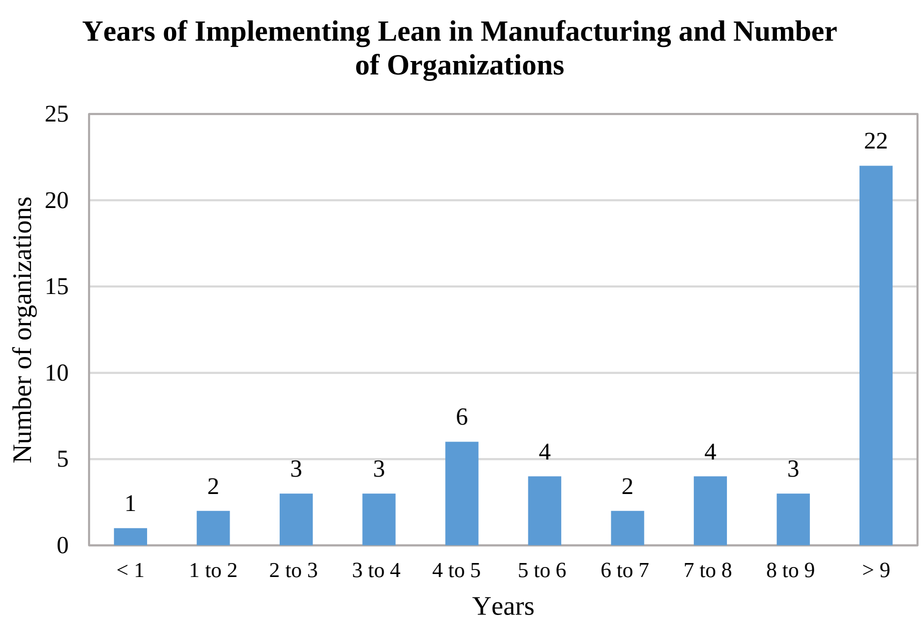


Figure 4.5   Years of Lean Implementation in Manufacturing

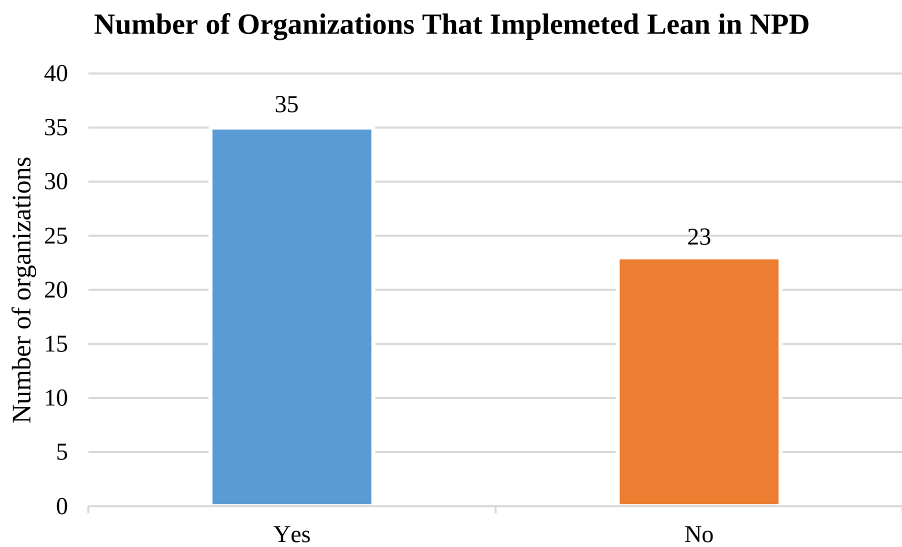


Figure 4.6 Number of Organizations Implementing Lean in NPD

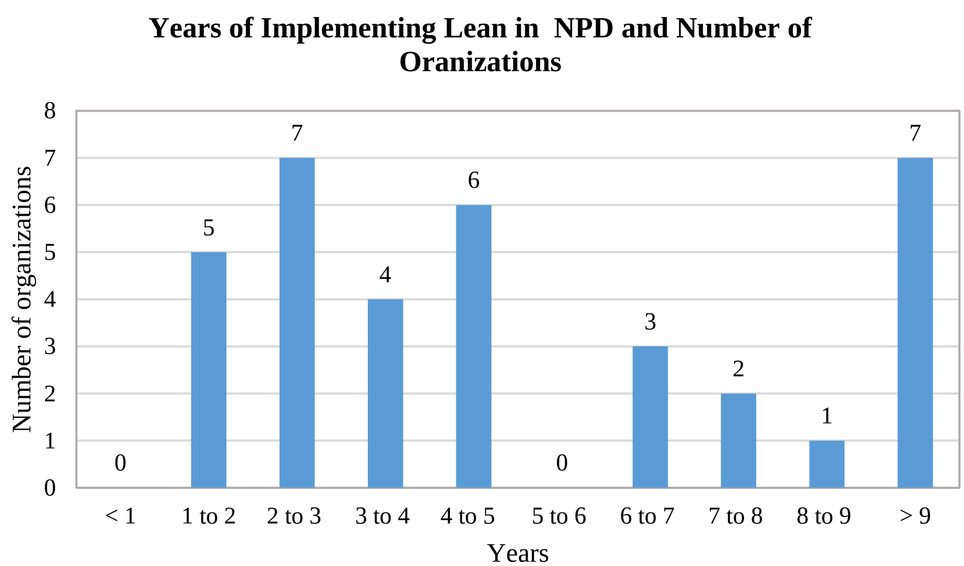


Figure 4.7 Years of Lean Implementation in NPD

4.2 Research Analyses and Results Summary

This section is structured using five subsections. The first subsection includes the analyses and results of data related to the practices used to apply lean to NPD processes. The second subsection presents the analyses and results of data related to performance indicators used to evaluate NPD processes performance and the improvement of NPD process performance after implementing lean in NPD processes. The third subsection includes the analyses and results of data on the challenges faced by organizations. The fourth subsection presents the results of analyses used to determine whether or not there was a relationship between the number of practices used by organizations and NPD process performance, as measured by time, cost, and quality performance indicators. The fifth subsection presents the results of analyses completed to determine whether or not there was a relationship between the years of experience with lean and NPD process performance, as measured by time, cost, and quality performance indicators.

To ensure that proper analysis tools were selected, the normality of data were assessed. Appendix C presents the histograms and skewness values for practice use frequency, perceived usefulness of practices, performance indicator use frequency, perceived NPD process performance improvement, challenge frequency, and perceived lean barriers. The shape of histograms and skewness values indicated that these data were not normally distributed. Thus, analyses tools must be appropriate to these data. Non-parametric statistical tests, such as, Chi-square (χ^2) Goodness of Fit and Krukal-Wallis were used to test the research hypotheses and are summarized next.

4.2.1 Practices Used to Apply Lean to NPD Processes

This section discusses the results and analysis of Hypothesis 1 and Hypothesis 2. Hypothesis 1 was focused on determining which practices organizations used in applying lean to NPD processes. Table 4.2 presents the practice use frequency of 27 organizations that responded to Survey Section 2. Chi-square goodness of fit was used to determine whether or not there was a difference in the use frequency for specific practices.

Table 4.2 Practice Use Frequency

Code	Practice	Practice Use Frequency	Total of Organizations Responding
P3	5Whys	25	27
P6	Gap Analysis	24	27
P12	Stand-up Meetings	23	27
P13	Visual Stream Mapping	23	27
P5	Fishbone Diagrams	22	27
P9	Quality Function Deployment	21	27
P14	Visual Management	21	27
P2	5S	20	27
P8	Product Families	20	27
P7	Kaizen Events	19	27
P11	Standard Work	19	27
P1	3P	17	27
P4	A3	14	27
P10	Queue Management	10	27

Table 4.3 summarizes the statistical results of chi-square goodness-of-fit to compare practice use frequencies. The chi-square value of 1.71 produced a significance level of 0.995. The results of this test indicated that there was no significant difference in the practice use frequency. Although there was no significant difference between practice use frequency, practices were grouped, based on use frequency. A hierarchical cluster

analysis was used to determine if groups of practices could be identified based on use frequency.

Table 4.3 Practice Use Frequency Chi-square (χ^2) Goodness of Fit Results

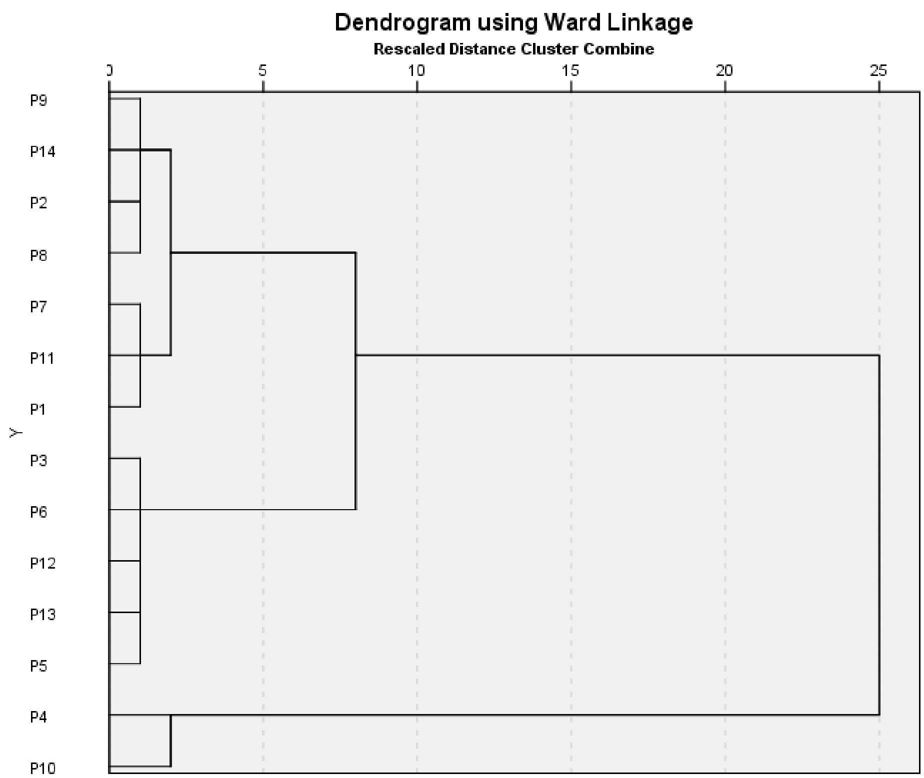
	Practice Use Frequency
Chi-Square	1.71[a]
df	9
Asymp. Sig.	0.995

a. 10 cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.4.

The results of the hierarchical cluster analysis are presented in the agglomeration schedule shown in Table 4.4 and in the dendrogram shown in Figure 4.8. The difference between the coefficients in the agglomeration schedule and the distances of linkage points in the dendrogram suggest that there were two clusters of practices. Cluster 1 included the practices that organizations used more often. Cluster 2 included the practices that organizations used less often. A summary of practice use frequency by cluster is shown in Table 4.5

Table 4.4 Agglomeration Schedule of Practice Use Frequency

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	9	14	.000	0	0	7
2	12	13	.000	0	0	6
3	7	11	.000	0	0	8
4	2	8	.000	0	0	7
5	3	6	.500	0	0	9
6	5	12	1.167	0	2	9
7	2	9	2.167	4	1	11
8	1	7	4.833	0	3	11
9	3	5	8.867	5	6	12
10	4	10	16.867	0	0	13
11	1	2	24.914	8	7	12
12	1	3	67.667	11	9	13
13	1	4	211.714	12	10	0



Rescaled Squared Euclidean Distances between Cases

Figure 4.8 Dendrogram of Practice Use Frequency

Table 4.5 Clusters of Practices Based on Use Frequency

Code	**Practices**	**Cluster**
P3	5Whys	1
P6	Gap Analysis	
P12	Stand-up Meetings	
P13	Visual Stream Mapping	
P5	Fishbone Diagrams	
P9	Quality Function Deployment	
P14	Visual Management	
P2	5S	
P8	Product Families	
P7	Kaizen Events	
P11	Standard Work	
P1	3P	
P4	A3	2
P10	Queue Management	

Hypothesis 2 was focused on determining which practices were most useful in NPD. A Kruskal-Wallis test was used to determine if perceived usefulness of specific practices varied. Tables 4.6 presents the mean ranks of perceived usefulness by practice. Table 4.7 summarizes the Kruskal-Wallis test statistics for perceived usefulness of practices. The chi-square value of 20.95 produced a significance level of 0.074. The results of this test indicated that there was no significant difference in the extent to which a particular practice was perceived to be a useful in NPD processes.

Table 4.6 Mean Ranks of Perceived Usefulness by Practice

Practice	N	Mean Rank of Usefulness of Practice
P1	17	122.53
P2	20	144.90
P3	25	144.34
P4	14	110.82
P5	22	122.02
P6	24	144.85
P7	19	164.55
P8	20	189.93
P9	21	103.55
P10	10	144.85
P11	19	152.68
P12	23	150.00
P13	23	133.80
P14	21	119.17

Table 4.7 Kruskal-Wallis Test for Differences in Practice Usefulness

	Usefulness of Practice
Chi-Square	20.95
df	13
Asymp. Sig.	0.074

a. Kruskal Wallis Test
b. Grouping Variable: Practice

Hierarchical cluster analysis was used to determine whether practices could be divided into groups, based on perceived usefulness. The results of the hierarchical cluster analysis are presented in the agglomeration schedule in Table 4.8 and in the dendrogram in Figure 4.9. The difference between coefficients in the agglomeration schedule and the distances of linkage points in the dendrogram suggest that there were two clusters of practices. Cluster 1 included practices that were more useful to NPD processes. Cluster 2 included practices that were less useful to NPD processes. A summary of practices by clusters, based on usefulness, is shown in Table 4.9

Table 4.8 Agglomeration Schedule of Practice Usefulness

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	1	5	.000	0	0	6
2	2	3	.000	0	0	4
3	6	10	.000	0	0	4
4	2	6	.002	2	3	8
5	11	12	.006	0	0	8
6	1	14	.011	1	0	9
7	4	9	.033	0	0	11
8	2	11	.058	4	5	10
9	1	13	.111	6	0	11
10	2	7	.214	8	0	12
11	1	4	.373	9	7	13
12	2	8	.915	10	0	13
13	1	2	2.723	11	12	0

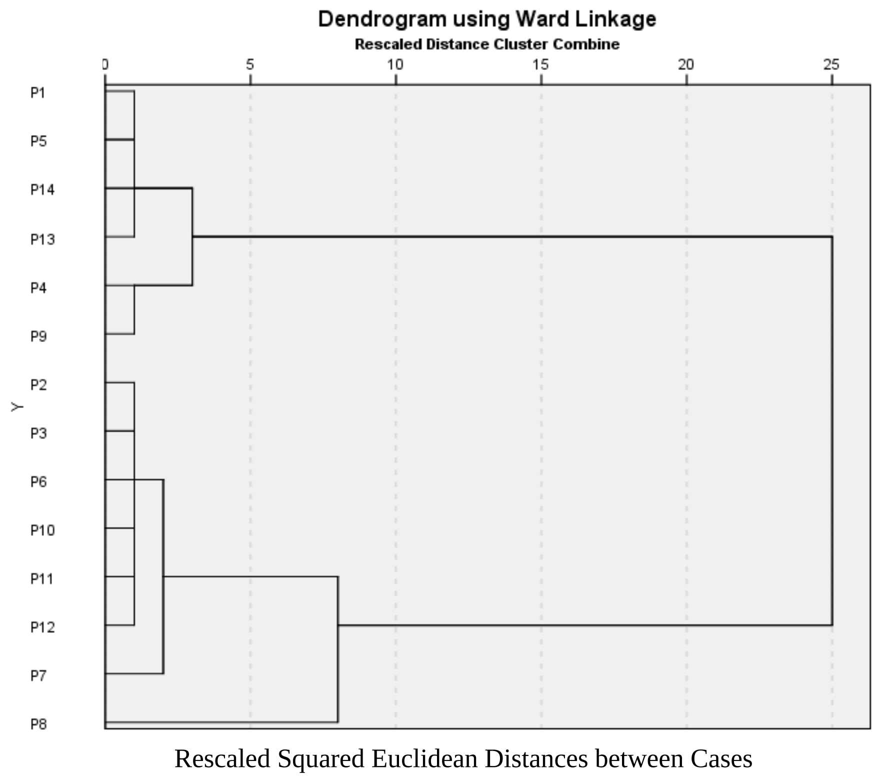


Figure 4.9 Dendrogram of Practice Usefulness

Table 4.9 Clusters of Practices Based on Usefulness

Code	Practices	Cluster
P8	Product Families	1
P7	Kaizen Events	
P11	Standard Work	
P12	Stand-up Meetings	
P10	Queue Management	
P6	Gap Analysis	
P2	5S	
P3	5Whys	
P13	Visual Stream Mapping	2
P1	3P	
P5	Fishbone Diagrams	
P14	Visual Management	
P4	A3	
P9	Quality Function Deployment	

4.2.2 Performance Indicators and the Impact of Lean on NPD Process Performance Improvement

This section discusses the results and analysis for Hypothesis 3 and Hypothesis 4. Hypothesis 3 was focused on determining performance indicators that organizations used for evaluating NPD process performance improvement, after applying lean to NPD processes. To test Hypothesis 3, data collected from Survey Section 3, Part 1 were used. A total of 20 organizations responded to Section 3, Part 1. Table 4.10 shows the use frequency of performance indicators. A Chi-square goodness of fit test was used to determine whether or not there was a difference in the frequency at which performance indicators were used to measure the impact of the application of lean practices on NPD process performance.

Table 4.10 Performance Indicators Use Frequency

Code	Indicators	Performance Indicators Use Frequency	Total of # Organizations Responding
M2	Total product development time	18	20
M9	Total cost of project	18	20
M10	Actual cost compared to the budget	18	20
M6	The number of projects delivered on time	17	20
M4	Cycle time of the new product development process	16	20
M7	Deviations from schedule	16	20
M17	The satisfaction of customers with new products	16	20
M8	Difference between actual times and target times for completion	15	20
M12	Total spending on the development phase	15	20
M13	The number of warranty claims	15	20
M3	Time spent on each stage of new product development process	14	20
M1	Lead time to market	13	20
M5	Launch time	13	20
M14	The number of errors in designs detected by customers	12	20
M18	The number of successful new product development projects	12	20
M11	The number of new product development projects completed within budget	11	20
M20	The number of specification changes	11	20
M19	The number of design reviews	10	20
M16	The number of product designs that met all product specifications	9	20
M15	The number of engineering errors	8	20

Table 4.11 summarizes the statistical results of chi-square goodness-of-fit to compare performance indicator use frequencies. The chi-square value of 4.20 produced a significance level of 0.938. The results of chi-square goodness-of-fit test indicated that there was no significant difference in the frequency that a performance indicator was used to measure the impact of lean practices on NPD process performance.

Table 4.11 Performance Indicator Use Frequency Chi-square (χ^2) Goodness of Fit Results

	Performance Indicator Use Frequency
Chi-Square	4.20[a]
df	10
Asymp. Sig.	0.938

a. 11 cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.8.

Hierarchical cluster analysis was used to determine whether performance indicators could be clustered based on performance use frequency. The results of the hierarchical cluster analysis are presented in the agglomeration schedule showing performance indicator frequencies in Table 4.12 and in the dendrogram in Figure 4.10. The difference between coefficients in the agglomeration schedule and the distances of linkage points in the dendrogram suggest that there were two clusters of performance indicators, based on performance indicator use frequencies. Cluster 1 included the performance indicators that organizations used more often. Cluster 2 included the performance indicators that organizations used less often. A summary of performance indicator by use frequency clusters is shown in Table 4.13.

Table 4.12 Agglomeration Schedule of Performance Indicator Use Frequency

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	11	20	.000	0	0	13
2	14	18	.000	0	0	13
3	7	17	.000	0	0	8
4	12	13	.000	0	0	5
5	8	12	.000	0	4	15
6	9	10	.000	0	0	7
7	2	9	.000	0	6	12
8	4	7	.000	0	3	15
9	1	5	.000	0	0	11
10	16	19	.500	0	0	14
11	1	3	1.167	9	0	16
12	2	6	1.917	7	0	17
13	11	14	2.917	1	2	16
14	15	16	4.417	0	10	18
15	4	8	5.917	8	5	17
16	1	11	11.679	11	13	18
17	2	4	23.829	12	15	19
18	1	15	46.500	16	14	19
19	1	2	176.550	18	17	0

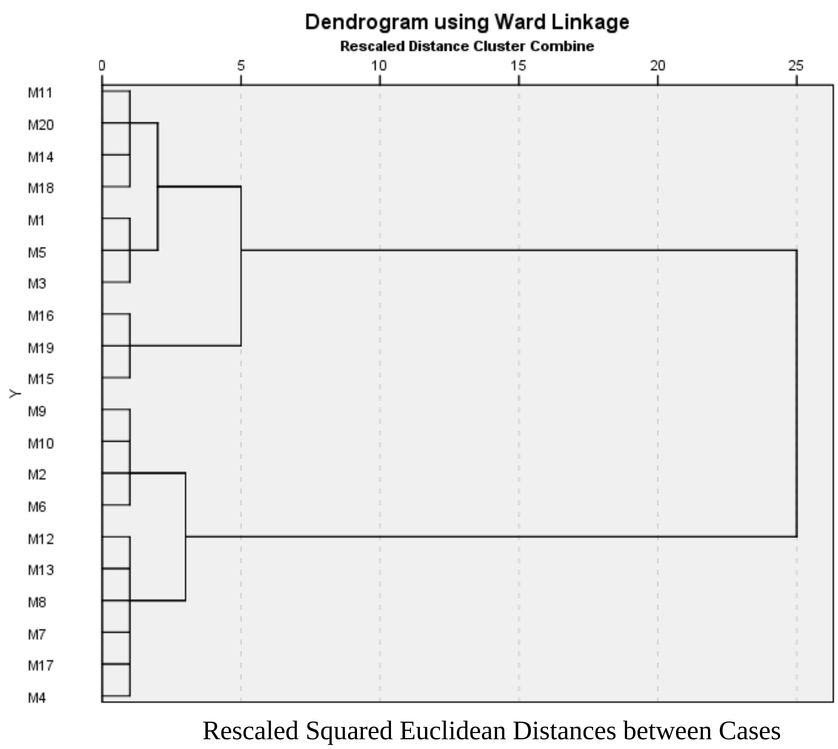


Figure 4.10 Dendrogram of Performance Indicator Use Frequency

Table 4.13 Clusters of Performance Indicators Based on Use Frequency

Code	Indicators	Cluster
M2	Total product development time	1
M9	Total cost of project	
M10	Actual cost compared to the budget	
M6	The number of projects delivered on time	
M4	Cycle time of the new product development process	
M7	Deviations from schedule	
M17	The satisfaction of customers with new products	
M8	Difference between actual times and target times for completion	
M12	Total spending on the development phase	
M13	The number of warranty claims	
M3	Time spent on each stage of new product development process	2
M1	Lead time to market	
M5	Launch time	
M14	The number of errors in designs detected by customers	
M18	The number of successful new product development projects	
M11	The number of new product development projects completed within budget	
M20	The number of specification changes	
M19	The number of design reviews	
M16	The number of product designs that met all product specifications	
M15	The number of engineering errors	

Hypothesis 4_0 was focused on comparing perceived performance improvements in NPD process after implementing lean, as measured by time, cost, and quality performance indicators. Data used to test Hypothesis 4_0 were collected in Survey Section 3, Part 2. Twenty-one organizations responded to Section 3, Part 2. A Kruskal-Wallis test statistic was used to test for differences in perceived performance improvement in NPD process, as measured by time, cost, and quality performance indicators. Table 4.14 presents the mean ranks of perceived NPD process performance improvement, as measured by time, cost, and quality performance indicators. Table 4.15 summarizes the Kruskal-Wallis test. The chi-square value of 0.38 produced a significance level of 0.826. The results of this test indicated that there was no significant difference in perceived performance improvement in NPD processes after implementing lean, as measured by time, cost, and quality performance indicators.

Table 4.14 Mean Ranks of Perceived NPD Process Performance Improvement, as Measured by Time, Cost, and Quality Performance Indicators.

NPD Process Performance Dimensions	**N**	**Mean Rank of Perceived Overall NPD process Performance Improvement**
Time	20	31.88
Cost	20	28.83
Quality	19	29.26

Table 4.15 Kruskal-Wallis Test Statistics for Perceived NPD Process Performance Improvement, as Measured by Time, Cost, and Quality Performance Indicators.

	Overall NPD process Performance Improvement
Chi-Square	0.38
df	2
Asymp. Sig.	0.826

a. Kruskal Wallis Test
b. Grouping Variable: NPD Process Performance Dimensions

4.2.3 Challenges Faced by Organizations

This section discusses the results and analysis of Hypothesis 5 and Hypothesis 6. Hypothesis 5 was focused on identifying the key challenges faced by organizations when implementing lean in NPD processes. Table 4.16 lists challenges for the 20 organizations, which responded to Survey Section 4. A Chi-square goodness of fit test was used to determine whether or not there was a difference in challenge frequency.

Table 4.16 Challenge Frequency

Code	Challenges	Challenge Frequency	Total Organizations Responding
C2	Lack of effective communications across the organization	18	20
C5	Misunderstanding of lean	17	20
C3	Unsupportive organizational culture for change	15	20
C1	Lack of top management commitment and support	13	20
C4	Lack of employee engagement	13	20
C6	Lack of connection with stakeholders	13	20

Table 4.17 summarizes the results of chi-square goodness-of-fit test. The chi-square value of 2.00 provided a significance level of 0.57. The results of this test indicated that there was no difference in challenge frequency.

Table 4.17 Challenge Frequency Chi-square (χ^2) Goodness of Fit Results

	Challenge Frequency
Chi-square	2.00[a]
df	3
Asymp. Sig.	0.572

a. Four cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.5.

Hierarchical cluster analysis was used to determine whether challenges could be clustered according to frequency. The results of the hierarchical cluster analysis are presented in the agglomeration schedule showing the challenge frequencies in Table 4.18 and in the dendrogram in Figure 4.11. The difference between the coefficients in the agglomeration schedule and the distances of linkage points in the dendrogram suggest that there are two clusters of challenges. Cluster 1 included the challenges faced more often by participating organizations. Cluster 2 included challenges faced less often by organizations. A summary of performance challenge frequency by clusters is shown in Table 4.19.

Table 4.18 Agglomeration Schedule of Challenge Frequency

	Cluster Combined			Stage Cluster First Appears		
Stage	**Cluster 1**	**Cluster 2**	**Coefficients**	**Cluster 1**	**Cluster 2**	**Next Stage**
1	4	6	.000	0	0	2
2	1	4	.000	0	1	4
3	2	5	.500	0	0	5
4	1	3	3.500	2	0	5
5	1	2	24.833	4	3	0

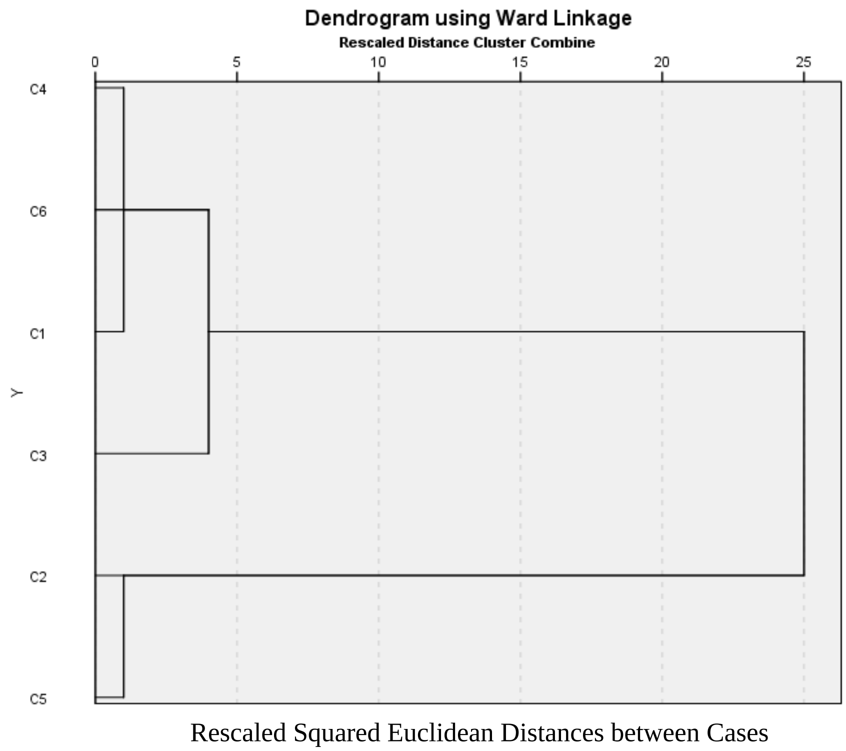


Figure 4.11 Dendrogram of Challenge Frequency

Table 4.19 Clusters of Challenges Based on Challenge Frequency

Code	Challenges	Cluster
C2	Lack of effective communications across the organization	1
C5	Misunderstanding of lean	
C1	Lack of top management commitment and support	2
C3	Unsupportive organizational culture for change	
C4	Lack of employee engagement	
C6	Lack of connection with stakeholders	

Hypothesis 6 was focused on determining which challenges presented barriers to organizations in their lean implementation lean in NPD. A Kruskal-Wallis test was used to see if there were any differences in the extent to which a particular challenge was perceived to be a barrier to the implementation of lean in NPD processes. Table 4.20 presents the mean ranks of perceived lean barriers. Table 4.20 summarizes the Kruskal-Wallis test statistic. The chi-square value of 5.538 produced a significance level of 0.364. The results of this test indicated that there was no significant difference in the extent to which a particular challenge is perceived to be a barrier to lean implementation in NPD processes.

Table 4.20 Mean Ranks of Perceived Lean Barriers

Challenge	**N**	**Mean Rank of Perceived Lean Barriers**
C1	13	50.35
C2	18	41.64
C3	15	56.00
C4	13	41.58
C5	17	37.44
C6	13	44.92

Table 4.21 Kruskal-Wallis Test Statistics for Perceived Lean Barriers

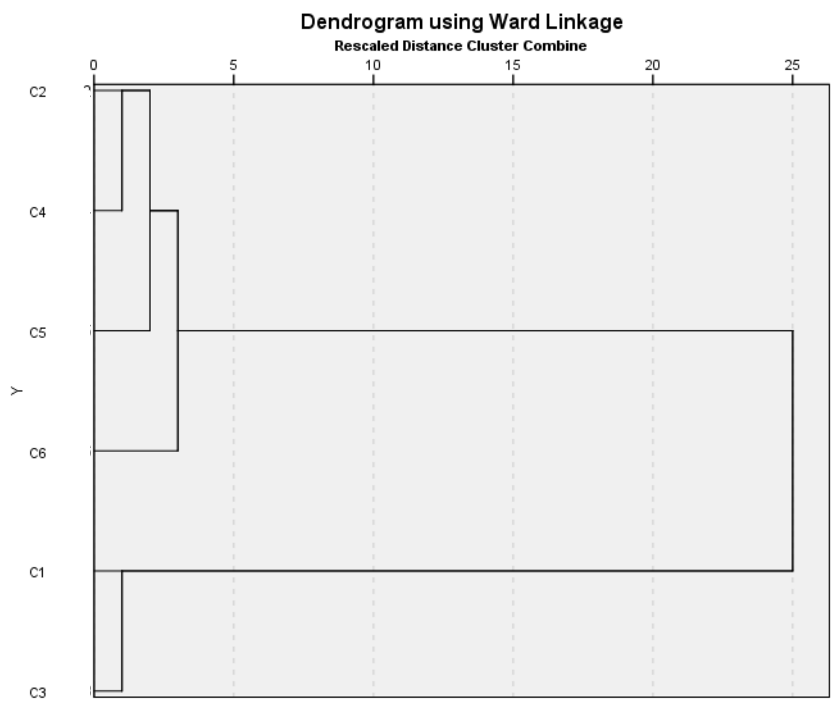
	Perceived Lean Barriers
Chi-Square	5.53
df	5
Asymp. Sig.	0.354

a. Kruskal Wallis Test
b. Grouping Variable: Challenge

Hierarchical cluster analysis was used to determine whether challenges could be divided into groups, based on perceived lean barriers. The results of the hierarchical cluster analysis are presented in the agglomeration schedule in Table 4.22 and in the dendrogram in Figure 4.12. The difference between the coefficients in the agglomeration schedule and the distances of linkage points in the dendrogram suggest that there were two clusters of challenges, based on perceived lean barriers. Cluster 1 included challenges that were more often perceived as lean barriers. Cluster 2 included challenges that were less often perceived as lean barriers. A summary of the clusters is shown in Table 4.23.

Table 4.22 Agglomeration Schedule of Perceived Lean Barriers

	Cluster Combined			Stage Cluster First Appears		
Stage	Cluster 1	Cluster 2	Coefficients	Cluster 1	Cluster 2	Next Stage
1	2	4	.000	0	0	3
2	1	3	.022	0	0	5
3	2	5	.049	1	0	4
4	2	6	.111	3	0	5
5	1	2	.764	2	4	0



Rescaled Squared Euclidean Distances between Cases

Figure 4.12 Dendrogram of Perceived Lean Barriers

Table 4.23 Clusters of Challenges Based on Perceived Lean Barriers

Code	Challenges	Cluster
C1	Lack of top management commitment and support	1
C3	Unsupportive organizational culture for change	
C2	Lack of effective communications across the organization	2
C4	Lack of employee engagement	
C5	Misunderstanding of lean	
C6	Lack of connection with stakeholders	

4.2.4 The Number of Practices Used and NPD Process Performance

This section describes the results of linear regression analysis used to test Hypothesis $7a_0 – 7c_0$. Hypothesis $7a_0 – 7c_0$ focuses on determining the relationship between the number of practices used by organizations and NPD process performance improvement, as measured by time, cost and quality performance indicators, respectively. The data used for this analysis came from 21 organizations, completing Survey Section 2 and Survey Section 3, Part 2. Scatter plots of the number of practices used and perceived NPD process performance improvement, as measured by time, cost and quality performance indicators, are presented in Figures 4.13 – 4.15.

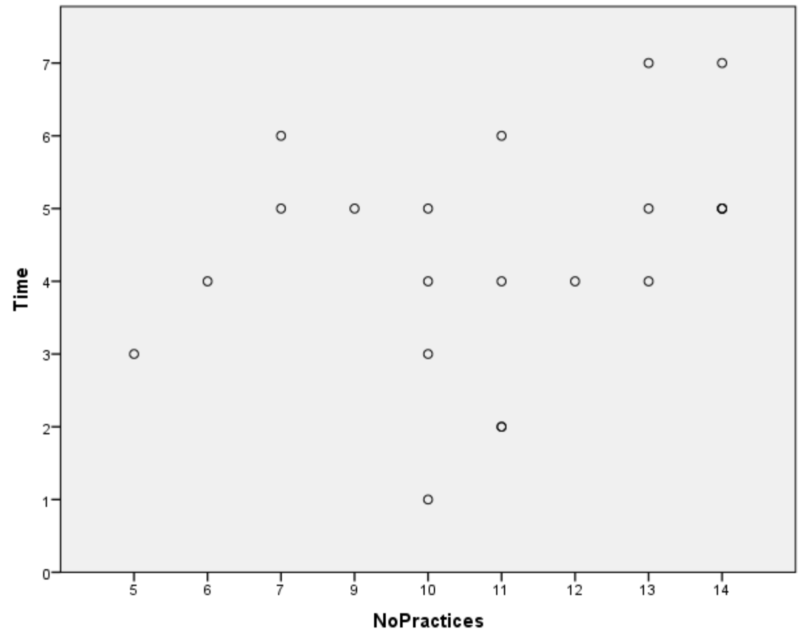


Figure 4.13 Scatter Plot of Number of Practices Used and Perceived NPD Process Performance Improvement, as Measured by Time Performance Indicators

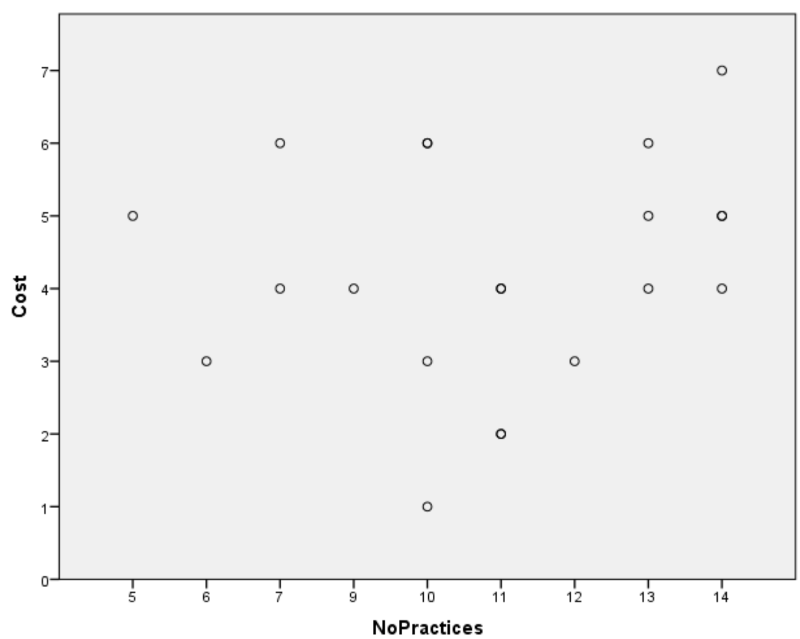


Figure 4.14 Scatter Plot of Number of Practices Used and Perceived NPD Process Performance Improvement, as Measured by Cost Performance Indicators

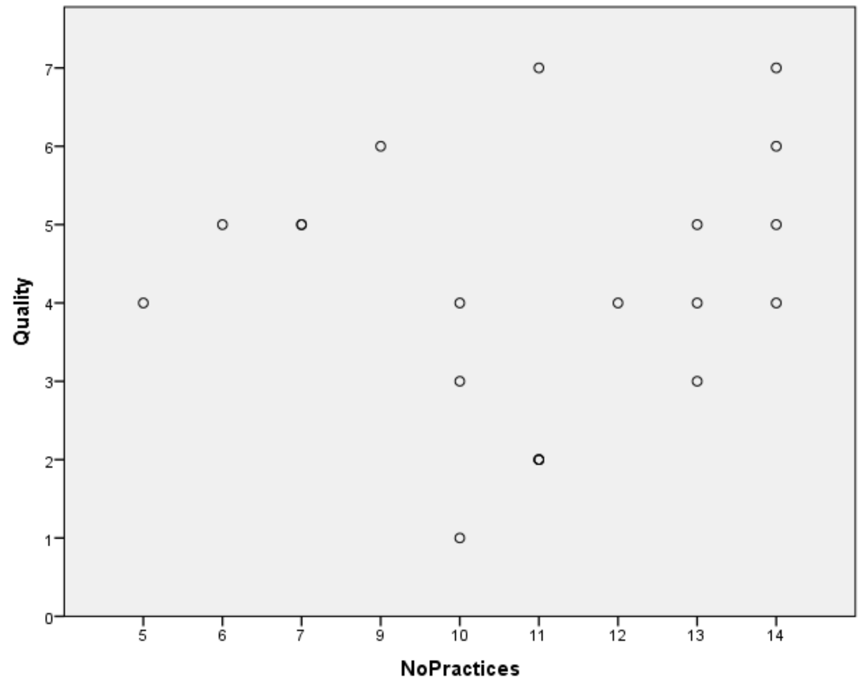


Figure 4.15 Scatter plot of Number of Practices Used and Perceived NPD Process Performance Improvement, as Measured by Quality Performance Indicators

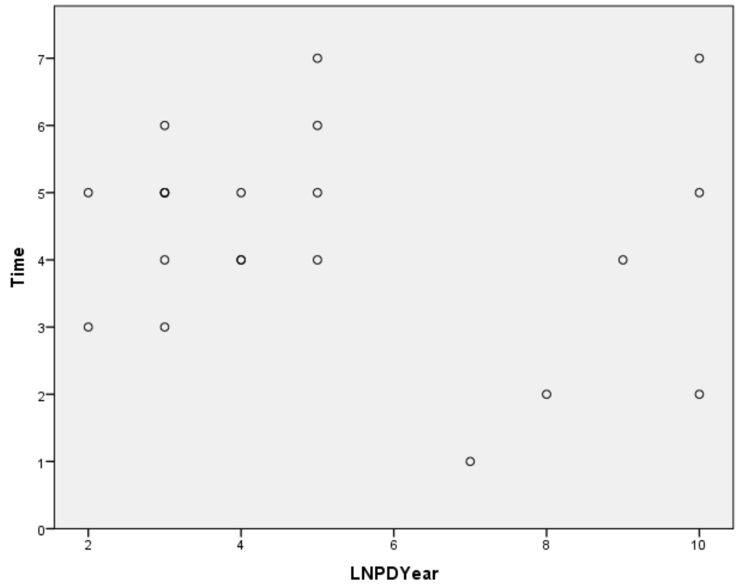
The details of the linear regression models and coefficients are summarized in Appendix D. Overall, the results are summarized in Table 4.24. The results indicated that there was no relationship between the number of practices used by organizations and NPD process performance, as measured by time, cost or quality performance indicators.

Table 4.24 Regression Coefficients and Significance Levels: Regression of Number of Practices Used and NPD Process Performance Improvement

Independent Variable	Dependent Variable	Hypothesis	Regression Coefficient (β)	Significance Level
Number of practice used	Perceived NPD process performance improvement, as measured by **time** performance indicators	$7a_0$	0.157	0.538
	Perceived NPD process performance improvement, as measured by **cost** performance indicators	$7b_0$	0.084	0.523
	Perceived NPD process performance improvement, as measured by **quality** performance indicators	$7c_0$	0.041	0.777

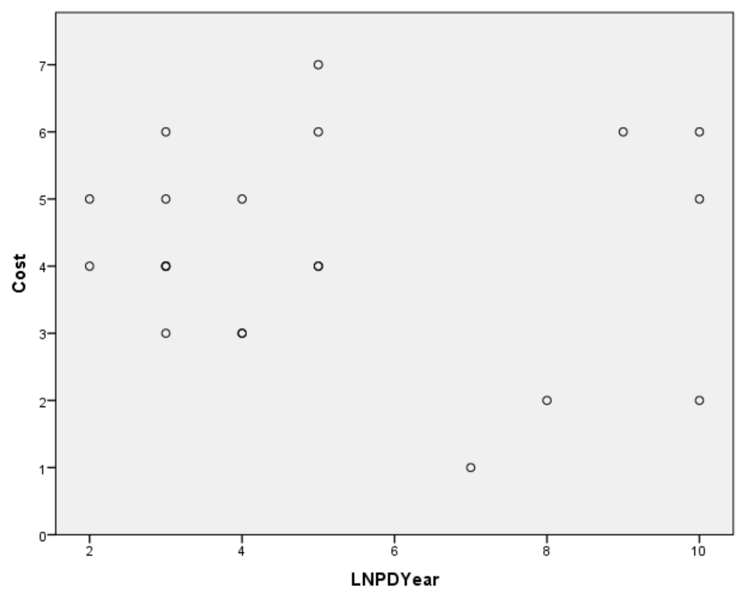
4.2.5 Years of Experience with Lean and NPD Process Performance

This section describes the results of the linear regression analysis used to test Hypothesis $8a_0 – 8c_0$. Hypothesis $8a_0 – 8c_0$ focused on determining the relationship between the number of years of experience with lean and NPD process performance improvement, as measured by time, cost and quality performance indicators, respectively. The data used for this analysis were collected from 21 organizations, completing Survey Section 1 and Survey Section 3, Part 2. The scatter plots of years of experience with lean and perceived NPD process performance improvement, as measured by time, cost and quality performance indicators, are presented in Figures 4.16 – 4.18.



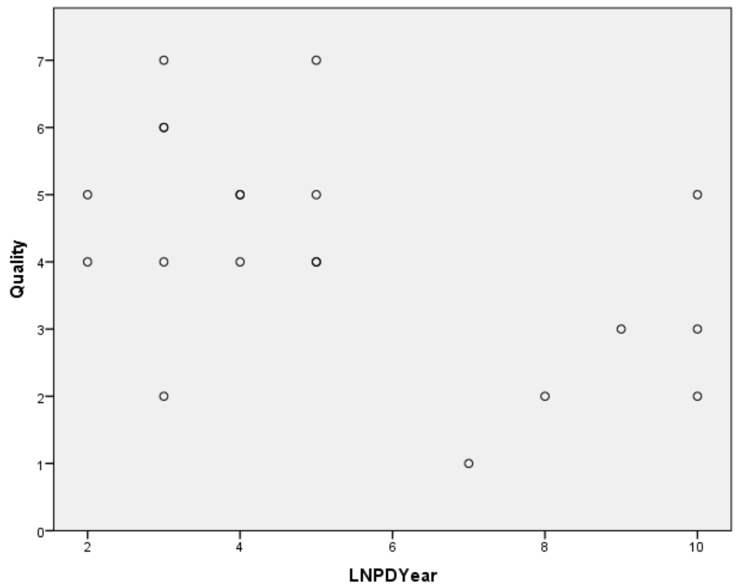
*1 = less than 1 year, 2 = 1 to 2 years, 3 = 2 to 3 years, 4 = 3 to 4 years, 5 = 4 to 5 years, 6 = 5 to 6 years, 7 = 6 to 7 years, 8 = 7 to 8 years, 9 = 8 to 9 years, and 10 = more than 9 years

Figure 4.16 Scatter Plot of Years of Experience with Lean and Perceived NPD Process Performance Improvement, as Measured by Time Performance Indicators



*1 = less than 1 year, 2 = 1 to 2 years, 3 = 2 to 3 years, 4 = 3 to 4 years, 5 = 4 to 5 years, 6 = 5 to 6 years, 7 = 6 to 7 years, 8 = 7 to 8 years, 9 = 8 to 9 years, and 10 = more than 9 years

Figure 4.17 Scatter Plot of Years of Experience with Lean and Perceived NPD Process Performance Improvement, as Measured by Cost Performance Indicators



*1 = less than 1 year, 2 = 1 to 2 years, 3 = 2 to 3 years, 4 = 3 to 4 years, 5 = 4 to 5 years, 6 = 5 to 6 years, 7 = 6 to 7 years, 8 = 7 to 8 years, 9 = 8 to 9 years, and 10 = more than 9 years

Figure 4.18 Scatter Plot of Years of Experience with Lean and Perceived NPD Process Performance Improvement, as Measured by Quality Performance Indicators

The details of the linear regression models and coefficients are summarized in Appendix E. The results of the linear regression analysis are summarized in Table 4.25. Overall, the results indicated that there was no relationship between the years of experience with lean and NPD process performance, as measured by time or cost performance indicators. For Hypothesis $8c_0$, the results indicated that there was a relationship between the years of experience with lean and NPD process performance, as measured by quality performance indicators.

Table 4.25 Regression Coefficients and Significance Levels: Regression of Years of Experience with Lean and NPD Process Performance Improvement

Independent Variable	Dependent Variable	Hypothesis	Regression Coefficient (β)	Significance Level
Years of experience with lean	Perceived NPD process performance improvement, as measured by **time** performance indicators	$8a_0$	-0.082	0.538
	Perceived NPD process performance improvement, as measured by **cost** performance indicators	$8b_0$	-0.068	0.770
	Perceived NPD process performance improvement, as measured by **quality** performance indicators	$8c_0$	-0.292	0.032*

*significant at the 0.05 level

4.3. Post-Hoc Analyses

This section summaries the results of practices used by organizations, which self-identified as not using lean in NPD. These 17 participating organizations were identified as a result of the responses to a question in Survey Section 1. These 17 organization were divided into two groups. The first group included organizations that indicated that they implemented lean in manufacturing, but not in NPD processes. The second group included organizations that did not apply lean to either manufacturing or NPD processes. There were 12 participating organizations in the first group and 5 participating organizations in the second group. The percentage of practices used by organizations in each group are summarized in Table 4.25. The average usefulness of these practices is presented in Table 4.26.

Table 4.26 Percentage of Practices Used by Organizations that Applied Lean in Manufacturing but Not in NPD and by Organizations that Had Not Applied Lean in Either Manufacturing or NPD

1: Applying Lean in Manufacturing but NOT in NPD			**2: Not Applying Lean in Both Manufacturing and NPD**		
Code	**Practice**	**% of Total (12 responses)**	**Code**	**Practice**	**% of Total (5 responses)**
P5	Fishbone Diagrams	83%	P5	Fishbone Diagrams	60%
P8	Product Families	75%	P6	Gap Analysis	60%
P12	Stand-up Meetings	75%	P8	Product Families	60%
P14	Visual Management	67%	P13	Value Stream Mapping	60%
P11	Standard Work	58%	P14	Visual Management	60%
P13	Value Stream Mapping	58%	P1	3P	40%
P6	Gap Analysis	58%	P3	5Whys	40%
P7	Kaizen Events	58%	P4	A3	40%
P2	5S	58%	P7	Kaizen Events	40%
P3	5Whys	50%	P9	Quality Function Deployment	40%
P9	Quality Function Deployment	50%	P11	Standard Work	40%
P10	Queue Management	42%	P12	Stand-up Meetings	40%
P4	A3	42%	P2	5S	20%
P1	3P	25%	P10	Queue Management	20%

Hierarchical cluster analysis was used to determine if practices used by organizations in Group 1 could be clustered. The results of hierarchical cluster analysis are summarized in an agglomeration schedule table, as shown in Table 2.26, and a dendrogram, as shown in Figure 4.19. Hierarchical cluster analysis indicated that there were two clusters of practices based on use frequency: more often used practices and less often used practices. The practices used more often by organizations in Group 1 were fishbone diagrams, product families, stand-up meetings, visual management, standard work, value stream mapping, gap analysis, kaizen events, and 5S. The less frequently used practiced by organizations in Group 1 were 5whys, quality function deployment, queue management, A3, and 3P. Since the number organizations in Group 2 was small, statistical analyses were not completed. Practices that were most used, by more than 50% of organizations in Group 2 were gap analysis, product families, value stream mapping, and visual management. A summary of the average usefulness of each practice for organizations in Group 1 and Group 2 is shown in Table 4.27

Table 4.27 Agglomeration Schedule of Practice Use Frequency by Organizations that Applied Lean in Manufacturing but Not in NPD

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	12	13	.000	0	0	9
2	10	11	.000	0	0	9
3	8	9	.000	0	0	4
4	5	8	.000	0	3	6
5	6	7	.000	0	0	6
6	5	6	.000	4	5	12
7	2	3	.000	0	0	8
8	2	4	.667	7	0	10
9	10	12	1.667	2	1	11
10	1	2	3.000	0	8	12
11	10	14	8.000	9	0	13
12	1	5	16.889	10	6	13
13	1	10	43.714	12	11	0

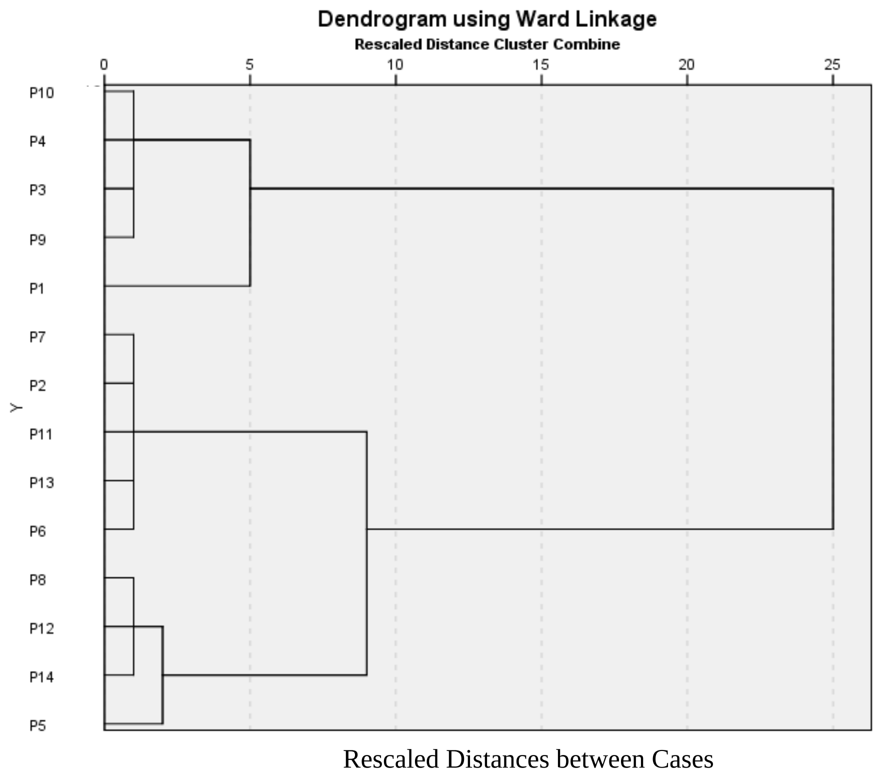


Figure 4.19 Dendrogram of Practice Use Frequency by Organizations that Applied Lean in Manufacturing but Not in NPD

Table 4.28 Perceived Usefulness of Practices Used by Organizations that Applied Lean in Manufacturing but Not in NPD and by Organizations that Had Not Applying Lean in Manufacturing or NPD

1: Applying Lean in Manufacturing but NOT in NPD			2: Not Applying Lean in Both Manufacturing and NPD	
Code	**Practice**	**Average Practice Usefulness**	**Average Practice Usefulness**	**Rank of Practices**
P8	Product Families	5.11	4.33	5
P3	5Whys	4.33	3.50	1
P14	Visual Management	4.00	3.33	13
P13	Value Stream Mapping	3.86	3.33	13
P5	Fishbone Diagrams	3.80	3.67	9
P12	Stand-up Meetings	3.78	5.50	1
P6	Gap Analysis	3.71	4.33	5
P11	Standard Work	3.71	5.50	1
P10	Queue Management	3.60	5.00	3
P7	Kaizen Events	3.43	4.00	7
P4	A3	3.40	3.50	10
P2	5S	3.14	4.00	7
P1	3P	2.67	3.50	10
P9	Quality Function Deployment	2.33	4.50	4

Chapter 4 summarized the results of statistical analyses of data collected from the survey. Different statistical analyses were used to test the eight research hypotheses. The details of post-hoc analyses performed to investigate differences in practices used by organizations that had applied lean to NPD processes and organizations that did not implement lean in NPD processes were also summarized. In the next chapter, these results will be discussed and used to draw conclusions. The limitations and future research will also be presented.

5 Discussion and Conclusion

This chapter begins with a summary of statistic results in Chapter 4. The second section discusses the findings of this research for each of the five research objectives. The third section discusses findings resulting post-hoc analyses of data from organizations which indicated that the organization was not using lean in NPD. The fourth section summarizes the implications of this research. The fifth section discusses the limitations of the research. The final section presents for suggestions future research, based on the finding of this research.

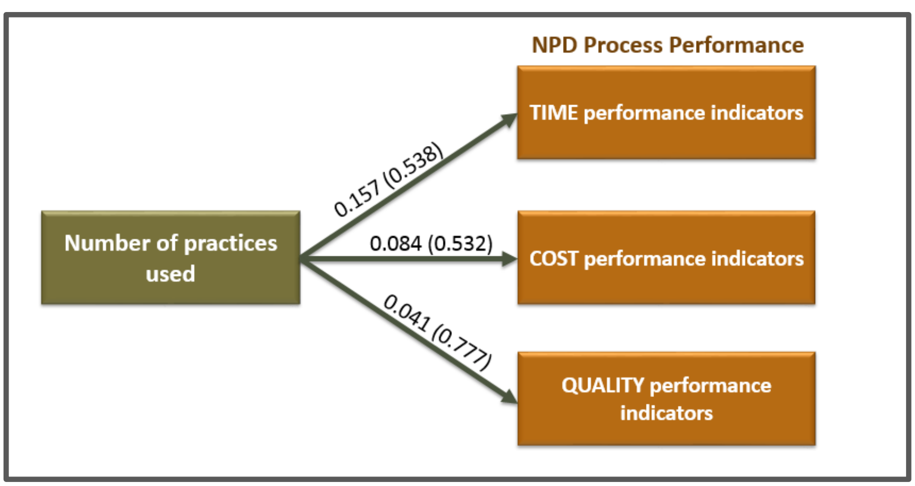
5.1 Summary of Results

This section summarizes the results of statistical analysis from Chapter 4. Three statistical analyses were used to test the eight research hypotheses, including Chi – square (χ^2) Goodness-Of-Fit analysis, Kruskal-Wallis analysis, and linear regression analysis. Table 5.1 presents the results of testing Hypothesis 1 – 5. Figures 5.1 and 5.2 present the linear regression results of testing of Hypothesis 7 and Hypothesis 8.

Table 5.1 Results of Statistical Analysis of Hypothesis 1 – 5

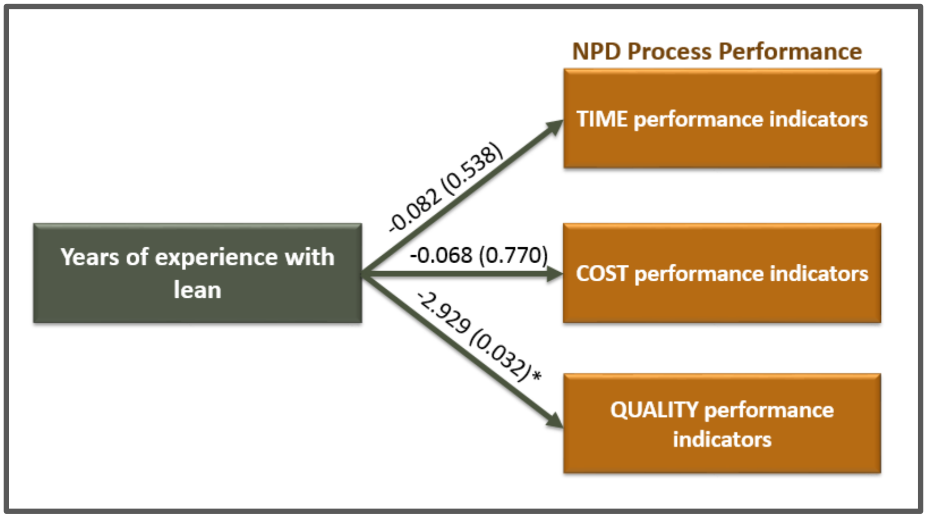
Hypotheses	**Variables**	**Analysis Methods**	**Results***
$H1_0$: There is no difference in the frequency at which a specific practice is applied in NPD processes.	Practice use frequency	Chi – square (χ^2) Goodness-Of-Fit Analysis	1.71 (0.995)
$H2_0$: There is no difference in the perceived usefulness of specific lean practices in NPD processes.	Perceived usefulness of practice	Kruskal-Wallis Analysis	20.95 (0.074)
$H3_0$: There is no difference in the frequency at which a performance indicator is used to measure the impact of the application of practices used in implementing lean in NPD processes.	Performance indicator use frequency	Chi – square (χ^2) Goodness-Of-Fit Analysis	4.20 (0.938)
$H4_0$: There is no difference in the perceived performance improvement in NPD processes after implementing lean, as measured by time, cost, and quality performance indicators.	Perceived NPD process performance improvement	Kruskal-Wallis Analysis	0.38 (0.826)
$H5_0$: There is no difference in the frequency at which a specific challenge is faced by organizations when implementing lean to NPD processes.	Challenge frequency	Chi – square (χ^2) Goodness-Of-Fit Analysis	2.00 (0.572)
$H6_0$: There is no difference in the extent to which a particular challenge is perceived to be a barrier to lean implementation in NPD processes.	Perceived lean barriers	Kruskal-Wallis Analysis	5.53 (0.354)

* Test statistic value (significance level)



*Regression coefficients (significance level)

Figure 5.1 Linear Regression Results of Hypothesis 7



*Regression coefficients (significance level)

Figure 5.2 Linear Regression Results of Hypothesis 8

5.2 Summary of Findings

This section is structured using five subsections. Each subsection corresponds with the five research objectives developed in Chapter 1. First, findings related to practices used to apply lean in NPD processes are discussed. Second, performance indicators and the impact of lean on NPD process performance are discussed. Third, challenges faced by organizations are explored. Fourth, the relationship between the number of practices and NPD process performance are discussed. Fifth, the relationship between the years of experience with lean and NPD process performance are discussed.

5.2.1 Practices Used to Apply Lean to NPD Processes

Researchers and practitioners have suggested a variety of practices that organizations can use in applying lean to NPD processes. One research objective for this study was to investigate which practices are most useful for applying lean principles to NPD processes. A list of fourteen practices, based on the literature, was studied. The participating organizations had applied lean to NPD processes for an average of 4.5 years.

Overall, results from an analysis of practice use frequency indicated that there were no significant differences in the use frequencies of individual practices. The results of a hierarchical cluster analysis of practices, however, suggested that two clusters of practices exist. Practices in Cluster 1 were used by most participating organizations such as 5whys, gap analysis, and stand-up meetings. Most practices in Cluster 1 are generally easy to use and do not require specialized training. It was also interesting to note that value stream mapping (VSM) was used by 23 of 27 organizations. VSM, however, requires more specialized training, data from multiple departments, and involvement from multiple functions (Liker & Morgan, 2011; Tapping, Luyster, & Shucker, 2002). A reason that VSM were used by most participating organization because VSM is a well-known lean practice and has been suggested by both practitioners and researchers to use in improving NPD processes. Thus, VSM is a more complicated practice to apply than others from Cluster 1; nonetheless its value to NPD seems to be understood, given the high number of organizations using VSM in NPD.

The results also indicated that there were no significant differences in the perceived usefulness of the 14 practices. Overall, the results indicated that all 14 practices included in this research were useful in improving NPD process as measured by an average usefulness score of 4.74 on a 7-point scale. The level of practice usefulness did vary. Hierarchical analysis results suggested that there are two clusters of practices based on practice usefulness. Practices in Cluster 1 were perceived as more useful than practices in Cluster 2. Practices in Cluster 1 included product families, kaizen events, standard work, stand-up meetings, queue management, gap analysis, 5S, and 5whys.

Table 5.2 Practices Used by Participating Organizations

Practices	Traditional Lean Practice	Use Frequency	Perceived Usefulness Average		
			≤ 5 years Applying lean (19 organizations)	**> 5 years** Applying Lean (8 organizations)	**Overall** (27 organizations)
Product Families	yes	20	5.87	5.40	5.75
Kaizen Events	yes	19	5.09	5.50	5.26
Standard Work	yes	19	4.86	5.60	5.05
Stand-up Meetings	no	23	4.94	5.00	4.96
Queue Management	no	10	4.43	6.00	4.90
Gap Analysis	no	24	4.71	5.29	4.88
5S	yes	20	4.79	5.00	4.85
5Whys	yes	25	4.88	4.75	4.84
Value Stream Mapping	yes	23	4.63	4.71	4.65
3P	yes	17	4.46	4.25	4.41
Fishbone Diagrams	yes	22	4.19	5.00	4.41
Visual Management	yes	21	4.31	4.40	4.33
A3	yes	14	4.55	3.00	4.21
Quality Function Deployment	no	21	3.38	5.00	4.00

* Practices in the bold box are in Cluster 1.

Table 5.2 presents all 14 practices grouped by cluster and ordered by average practice usefulness. It is interesting that practices in Cluster 1 included both traditional lean practices and non-traditional lean practices. These results imply that NPD processes can be improved by applying both types of practices. This finding is important because most lean literature focused on only practices defined within a lean framework. This research suggests that future studies of lean in NPD should include a wide range of practices whether or not they are traditionally included in the lean toolbox.

The results also seem to suggest that most practices were perceived to be more useful in organizations that had applied lean for more than five years. Organizations that have applied lean practices for longer periods of time may be more mature in their ability to adopt and use practices appropriately for NPD processes. This finding suggests that the successful implementation of lean practices may require an investment of time by organizations. A3 seemed to be more useful in organizations that had applied lean in NPD because A3 is easy to use for organizations that just started implementing lean and can be adapted to use in different ways, such as a progress report or a product concept from. For organizations that had more experience in lean implementations, they might perceive A3 less useful because it cannot used to improve in advanced issues in NPD.

5.2.2 Performance Indicators and the Impact of Lean on NPD Process Performance Improvement

There have been a limited number of empirical studies that have focused on the impact of lean on NPD process performance. This research aimed to identify the performance indicators used by organizations to measure the impact of lean on NPD processes. From the NPD literature, there were three main performance perspectives that organizations can use to measure NPD process performance improvement: time, cost, and quality (Griffin & Page, 1996; Iamratanakul, Patanakul, & Milosevic, 2008; Meredith & Mantel, 2008). Twenty performance indicators from these three performance perspectives suggested by previous studies on NPD, new product project management, and lean in NPD, were included in this study.

The results suggest that there were no significant differences in the frequency at which performance indicators were used to measure the impact of the application of lean practices on NPD processes. These results also imply that all perspectives (time, cost, and quality) are important when measuring the impact of lean on NPD process performance. In addition to the 20 performance indicators include in this survey, many participating organizations identified revenue as an additional indicator that were used to measure NPD process performance after applying lean. Overall, these results suggest that organizations can use any performance indicator included in this research to evaluate NPD process performance improvement. This finding is important because it means that organizations can select from a variety of performance indicators and still be able to measure the impact of lean on NPD process performance.

The next research task was to verify the perceived perspective to be most impacted by a lean implementation in NPD. Participating organizations were asked to rate the overall level of NPD process performance improvement observed, as measured by time, cost, and quality performance indicators. The results indicated that there were no significant differences in perceived performance improvement in NPD processes, as measured by time, cost, and quality performance indicators. Table 5.3 summarizes the average impact of lean on NPD process performance, as measured by time, cost, and quality performance indicators. The overall average perceived level of improvement was greater than 4.2 for all three perspectives (on a 7-point scale), representing fairly large improvements. These results imply that, overall, organizations found that NPD process performance was improved by applying lean. This result is consistent with previous research by Anand and Kodali (2008) and Haque and Moore (2004), where case studies were used to provide evidence that lean could create a positive impact on NPD process performance.

Table 5.3 Average Performance Improvement for Time, Cost, Quality Performance Indicators

NPD Performance Indicators	Average Performance Improvement
Time	4.38
Cost	4.24
Quality	4.20

Previous studies suggested that applying lean in NPD processes could improve time and cost performance (Anand & Kodali, 2008; Haque & James-Moore, 2004; Reinertsen, 2009; Schulze & Stormer, 2012; Welo, 2011). Fewer studies, e.g. Ward (2007), have suggested that lean can have an impact on NPD process performance, as measured by quality performance indicators. The results of this research provide evidence that the application of lean in NPD processes can positively impact NPD process performance, as measured by quality indicators. This finding is important because it means that organizations can apply lean to NPD processes and can expect to see NPD process performance improvement from all three critical performance perspectives.

Overall, these results indicate that organizations can improve NPD performance through the application of lean practices. The application of lean appears to be a viable option for performance improvement, especially for organizations that have experience with lean in manufacturing. These organizations can effectively apply the knowledge and lessons learned from implementing lean in manufacturing to NPD.

Although the overall results indicate that lean can improve NPD processes, the data also indicate that there is variability in the level of improvement. Some participating organizations in this research indicate only very small levels of improvement (a rating of

2 on a 7-point scale) of improvement. The variation observed in individual organizational ratings of improvement suggests that additional research is needed to better understand the factors that might influence how impactful lean is on NPD.

5.2.3 Challenges Faced by Organizations

There are many changes and adaptations required in applying lean principles. Many organizations have been unable to successfully navigate this transformation. Knowing challenges that an organization may face during a lean transformation could enable managers to develop contingency plans to handle challenges that might occurs. The six challenges included in this research were based on research from manufacturing, healthcare, and construction industries. The results indicate that there were no significant differences in the frequency of organizations that identified having experienced these six challenges. There were also no significant differences between the extent to which any challenge was perceived to be barrier. A summary of these results is presented in Table 5.4.

Table 5.4 Summary of Challenges Faced by Participating Organizations

Challenges	**Frequency**	**% of Organizations** (20 Organizations in Total)	**Average Barrier Levels**
Lack of effective communications across the organization	18	90%	4.33
Misunderstanding of lean	17	85%	4.12
Unsupportive organizational culture for change	15	75%	**5.13**
Lack of top management commitment and support	13	65%	**4.92**
Lack of employee engagement	13	65%	4.31
Lack of connection with stakeholders	13	65%	4.54

* Challenges in the bold box are in Cluster 1.

Hierarchical cluster analysis results suggested that there are two clusters of challenges based on challenge frequency. Cluster 1 included two challenges: lack of effective communication across organization and misunderstanding of lean. Most of the participating organizations had implemented lean in NPD within the previous five years. Thus, the level of lean implementation experience was low for the sample of organizations studied. It is possible that as a result of this inexperience with lean, organizations did not pay sufficient attention to communication plans and channels. They might have focused on implementing lean practices in NPD processes rather than interacting with collecting feedback on the lean implementation from employees. Misunderstanding lean is also a challenge that may be more prevalent in the early stages of a lean implementation. The impact of lean on employee jobs along with in-depth conceptual understanding of lean are often not obtained in the early phases of implementation. This finding is important because it highlights how important it is for managers to create effective plans for the lean implementation in NPD and the value of training plans to help clarify the impact of lean and to improve employee buy-in of the lean approach.

Challenges can become a barrier to a lean implementation in NPD. Hierarchical cluster analysis results indicated that there were two clusters of challenges, based on the perceived ratings of the extent to which a challenge was a barrier. Cluster 1 included challenges that were perceived most often to be barriers to a successful lean implementation in NPD. Challenges in Cluster 1 were lack of management commitment and support and unsupportive organizational cultures for change. Top management generally provides the resources and training needed for lean (Sarhan & Fox, 2013; Scherrer-Rathje, Boyle, & Deflorin, 2009). Top management must also encourage employees to be involved in a lean implementation (Grove, Meredith, MacIntyre, Angelis, & Neailey, 2010). Without top management support, a lean implementation in NPD is unlikely to be successful. This finding is important because it confirms the important role that managers and leaders must play to ensure a successful lean implementation in NPD. This finding extends similar finding from manufacturing on the roles of readership in a successful lean implementation.

Additionally, within any organizations, norms and beliefs can be difficult to change. If organizations have an unsupportive culture for lean, conflicts between departments and resistance to change can dominate a lean transformation (Sarhan & Fox, 2013). This finding is important because it means that organizations that implement lean in NPD processes and that have an unsupportive culture are unlikely to experience performance improvement.

5.2.4 The Number of Practices Used and NPD Process Performance

Previous researchers and practitioners have suggested that in order for organizations to successfully implement lean, they must apply all lean principles (Bhasin, 2012; Liker & Morgan, 2011). To apply all lean principles, different practices are needed, since a particular practice often only supports a couple of lean principles (Shah & Ward, 2003). If organizations use more practices, it is more likely that multiple lean principles are implemented.

Based on the results of this research, no relationship between the number of practices and NPD process performance were observed. Since the data from this research were collected from organizations that had implemented lean in NPD for less than 5 years, it is possible that employees were not fully adept in the use of lean practices. So, the organizations did not see substantial improvements with increased numbers of practices. Future research could further explore the complex relationship between lean maturity, the number of practices, and the level of performance improvement realized.

5.2.5 Year of Experience with Lean and NPD Process Performance

In the lean manufacturing and lean in NPD literature, there were some studies that investigated the length of a lean implementation and the relationship between lean experience and improved performance. Overall, the results suggest that there is no relationship between the years of experience with lean and NPD processes performance, as measured by time or cost for the sample of organizations in this research. The results, however, do support a relationship between the years of experience with lean and NPD process performance, as measured by quality performance indicators. The regression coefficient for the model including years of experience with lean and NPD process performance, as measured by quality performance indicators is negative. The negative regression coefficient would indicate on inverse relationship between years of experience with lean and NPD process performance, as measured by quality performance indicators. These results imply that organizations with less lean experience perceived more performance improvement; whereas, organizations that have applied lean in NPD processes for a longer period of time do not perceive as large of an improvement in NPD performance.

These results are different from previous research. In Total Quality Management (TQM) studies, the adoption time of TQM has a positive relationship with the level of performance improvement (Powell, 1995; Taylor & Wright, 2003). In the lean implementation, Bhasin (2011) suggested that organizations perceived small improvement at the beginning of a lean implementation but would not perceive major changes in manufacturing processes until years after the initial lean implementation. The results of this research require additional insight to understand.

Arthur and Huntley (2005) found that the level of perceived performance improvement from employee suggestions decreased over time. This finding may be explain as follows:

After employees experience initial improvement, they expect to see larger gains as time goes on. If the level of improvement does not increase, employees perceive a decreasing impact. It is possible that the results of this research may have uncovered a similar phenomenon. As data used in this study measured perceptions of performance improvement, additional research is needed to see if actual performance improvements slowed down or if higher expectations negatively impacted perceptions.

Another factor that may be responsible for a the perception decreased improvement may be related to lack of knowledge by employees of what to expect (Arthur & Huntley, 2005). When organizations decide to implement lean in NPD processes, they might initially provide lean training focused on basic lean knowledge and know-how of use some lean practices. These employees can use this basic knowledge and practices to solve some of the simple problems in NPD. At time goes, issues needing to be addressed may require more advanced knowledge of lean. However, if employees cannot solve these more complex problems, they may perceive the impact of lean to be more limited. To maintain the impact of lean on NPD process improvement, organizations must provide specialized training on lean practices and principles appropriate to the complexity of problems being faced. This finding is important because it means that organizations must interest in lean training beyond the initial lean implementation in NPD and pay attention to feedback from employees to ensure that sufficient support and training in being provided. The next section discusses the findings resulting from a post-hoc analysis completed on data from organizations, responding to the survey, which did not identify as having applied lean in NPD.

5.3 Post-Hoc Analysis Related to Practices Used

Data collected in this research came from three groups of organizations Group 1 included organizations that had implemented lean in both manufacturing and NPD. Group 2 included organizations that had implemented lean in manufacturing, but not in NPD. Group 3 included organizations that had not implemented lean in wither manufacturing or NPD. The goal of this analysis was to see if lean practices were actually used by organizations in Group 2 and Group 3, which self-identified as not having applied lean in NPD.

Table 5.5 presents the percentage of organizations using each practice based on Group. The results indicate that all fourteen practices used by at least some organizations in all three groups. The decision use to lean practices in NPD may be influenced by whether or not an organization has implemented lean practices elsewhere, such as manufacturing. The relatively high percentage of organizations in Group 3 using lean practices to improve NPD processes was unexpected.

Table 5.6 summarizes the average usefulness of each practice by Group. Overall, organizations in Group 2 had the lowest overall average usefulness rate (3.63 out of 7 in average). Group 3 rated the usefulness of practices (4.41 out of 7 in average) lower than organizations in Group 1 (4.75 out of 7 in average) but higher than Group 2. It is interesting that Group 2, which did have experience with lean in manufacturing, rated the usefulness of practices lower than Group 3, which did not have previous experience with lean. It is possible that the application of lean practices in manufacturing is more intuitive making it more difficult for organizations to successfully applying practices to NPD. In other words, Group 2 organizations may not have been able to use lean practices in the same way as for manufacturing operations. These results suggest that additional training focused on using lean practices in NPD may be appropriate. It is interesting to note that organizations in Group 3 found lean practices to be more useful than in Group 2. It is possible that Group 3 may also have implemented other approaches, such as Total Quality Management or Six Sigma, along with a handful of lean practices to create improvements in NPD. Based on these results, Group 3 clearly perceive lean practices to be useful.

These findings are important and suggest that organizations must understand how to apply lean principles to NPD processes and that practices need to be adapted for use with NPD processes. The findings also confirm that lean practices are used by organizations that do not identify as “lean” organizations. Future research is needed to determine if “lean” organizations and “non-lean” organizations experience the same level of impact results when lean practices are applied to NPD processes.

Table 5.5 Percent Use of Practices

Group 1 * (27 organizations)		Group 2** (12 Organizations)		Group 3*** (5 organizations)	
Practice	**% Use of Total**	**% Use of Total**	**Rank**	**% Use of Total**	**Rank**
5Whys	93%	50%	5	40%	2
Gap Analysis	89%	58%	4	60%	1
Stand-up Meetings	85%	75%	2	40%	2
Value Stream Mapping	85%	58%	4	60%	1
Fishbone Diagrams	81%	83%	1	60%	1
Quality Function Deployment	78%	50%	5	40%	2
Visual Management	78%	67%	3	60%	1
5S	74%	58%	4	20%	3
Product Families	74%	75%	2	60%	1
Kaizen Events	70%	58%	4	40%	2
Standard Work	70%	58%	4	40%	2
3P	63%	25%	7	40%	2
A3	52%	42%	6	40%	2
Queue Management	37%	42%	6	20%	3

* Group 1 included organizations that identified as having implemented lean in both manufacturing and NPD processes

** Group 2 included organizations that identified as having implemented lean in manufacturing processes but not in NPD processes.

*** Group 3 included organizations that identified as not having implemented lean in manufacturing processes or NPD processes

Table 5.6 Usefulness of Practices

Group 1 * (27 organizations)		Group 2** (12 Organizations)		Group 3*** (5 organizations)	
Practice	**Average Usefulness**	**Average Usefulness**	**Rank**	**Average Usefulness**	**Rank**
Product Families	5.75	5.11	1	4.33	4
Kaizen Events	5.26	3.43	9	4.00	5
Standard Work	5.05	3.71	7	5.50	1
Stand-up Meetings	4.96	3.78	6	5.50	1
Queue Management	4.90	3.60	8	5.00	2
Gap Analysis	4.88	3.71	7	4.33	4
5S	4.85	3.14	11	4.00	5
5Whys	4.84	4.33	2	3.50	7
Value Stream Mapping	4.65	3.86	4	3.33	8
3P	4.41	2.67	12	3.50	7
Fishbone Diagrams	4.41	3.80	5	3.67	6
Visual Management	4.33	4.00	3	3.33	8
A3	4.21	3.40	10	3.50	7
Quality Function Deployment	4.00	2.33	13	4.50	3

* Group 1 included organizations that identified as having implemented lean in both manufacturing and NPD processes
** Group 2 included organizations that identified as having implemented lean in manufacturing processes but not in NPD processes.
*** Group 3 included organizations that identified as not having implemented lean in manufacturing processes or NPD processes

5.4 Implications

This research is one of the very first empirical studies to explore how organizations actually apply lean principles to NPD processes. The findings from this research are useful for engineering managers who are interested in improving NPD and illuminate new topics for future research. Results from this research also provide further insight into areas for study.

5.4.1 Implications for Engineering Managers

Researchers and practitioners have found that the application of lean principles can be used in NPD and can improve NPD performance. Because NPD processes are complex and involve many stakeholders from inside and outside the organization and have characteristics that differ from those in manufacturing, applying lean in NPD processes seems to be difficult. Four implications identified as a result of this research are important for engineering managers.

First, the application of lean practices can improve NPD process performance. The impact of a lean implementation in NPD can be assessed through different performance measures. Time is important for NPD. If organizations can shorten NPD process time, it means that they can release new products more quickly than competitors and will see greater benefit from the new product. The lean implementation in NPD can also help organizations in reducing costs in NPD processes. Controlling or reducing NPD costs are essential for competitive markets. Organizations will be able to offer lower prices for new products to customers if they have lower NPD costs. With quality, organizations must develop new products that meet the customer requirements and that are marketable. Higher quality can enable organizations to sell more products and gain more market share. Thus, for engineering managers who are looking for an approach to improve NPD, the application of lean practices is an effective option, and organizations can see NPD improvements resulting from a lean implementation, even in the early stages of the implementation.

Second, besides traditional lean practices, well-known continuous improvement and NPD practices are useful in furthering the implementation of lean principles. Non-traditional lean practices, such as practices in project management or marketing, can be used to apply lean principles.

The third point is related to the evaluation of NPD performance improvement after applying lean. This research provides a variety of indicators, from different perspectives, that can be used to evaluate the impact of lean in NPD. Organizations can use a variety of indicators to see if the results of a lean implementation are helping to meet organizational goals.

The fourth point is related to challenges that can occur during a lean implementation. The transition to lean involves changes and collaboration among stakeholders. Organizations face many challenges during this transition. Managers have to develop contingency plans to manage and resolve these challenges. Two challenges found in this research that create barriers to a lean implementation in NPD are lack of top management support and unsupportive organizational culture. For managers who are interested in applying lean in NPD, they should consider these two challenges when rolling out lean.

5.4.2 Implications for Researchers

Although this research supports the usefulness of lean in NPD, some of the results suggest that further study is needed. First, most researchers suggest that only traditional lean practices are useful in NPD. Because NPD involves many functions, such as marketing, engineering, and manufacturing, traditional lean practices need to be supplemented with other types of improvement practices. Additional research should expand this study beyond the 14 practices identified to identify whether an even large set of practices are applicable to NPD.

Second, this research found that the application of lean principles results in a positive impact on NPD performance. However, there was also evidence that participating organizations that were more mature in the lean implementation perceived lower levels of NPD performance improvement. Additional research is needed to understand this finding and to identify factors that may have contributed to this result.

5.5 Limitations

There were three limitations related to the design of this research that should be noted. The first limitation was the low variability in the level of organizational experience with lean in NPD. The majority of participating organizations had implemented lean in NPD for fewer than five years. Thus, the data collected in this research were dominated by organizations that were in the early stages of their lean adoption. Therefore, the results of this research are primarily descriptive of organizations within limited experience with lean in NPD, and consequently, do not provide much insight into the use of lean in NPD by more mature adopters.

The second limitation was a result of uncontrolled factors. This research was not experimental. One factor that could not be controlled or accounted for, but may have impacted the data was the approach used by the organizations to implement lean. Some organizations may have developed better or worse approaches for implementing lean in NPD or provided adequate or inadequate resources for training employees. It is possible that the details of the implementation may have been as important as the practices used.

The third limitation was the number of participants. Although 58 organizations completed the survey, only 27 of these organizations identified as having applied lean in NPD processes. The relatively small sample size of lean implementers makes it more difficult to identify small, but significant differences in the variables studied. A larger number of organizations could provide additional insight into potential differences in practices used, performance indicators, challenges, and barriers to lean.

5.6 Future Research

The results of this study provide some important insights that can be used to identify future recommendations. First, the results suggest that organizations can use a variety of practices to apply lean in NPD processes. This research included as an analysis of 14 practices. All practices were identified as providing some value. Future research focusing on investigating additional lean practices would provide additional insight into a fuller set of practices that organizations can use to support lean principles and that are suitable to NPD processes.

Second, the research found that the application of lean practices in NPD could positively impact NPD process performance. However, the ratings indicated variability in the level of improvement experienced by participating organizations. These results suggest that other factors may influence the level of improvement resulting from the use of lean practices on NPD processes. In particular, the approach used to implement lean might be important. Future research focusing on identifying influential factors that impact the level of improvement would provide valuable insights for organizations that seek to improve NPD processes.

Third, this research revealed six challenges faced by organizations when applying lean to NPD processes. These challenges can create barriers to NPD improvement. Future research to determine the relationship between these challenges and NPD process performance improvement could provide important information to organizations wishing to be proactive in their lean implementations.

Fourth, the results indicated that there was no relationship between the number of practices used by organizations and NPD process performance improvement. Most participating organizations were in the early stages of lean implementation. Future research to identify organizations with greater lean maturity would help determine if the results found in this research can be expanded to more mature adopters.

Fifth, this research found that years of lean experience had an inverse relationship with NPD process performance improvement. Arthur and Huntley (2005) found that the level of perceived performance improvement decreased over time because of the higher expectations created from early successes. Future research should determine if actual performance decreases or if higher expectations impact perceptions of the level of improvement.

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APPENDICES

Appendix A Survey

Cover Page of the Survey

The Application of Lean to New Product Development Processes

Dear Participant,

Your help is needed for an important research study. Woraruthai Choothian, a PhD student working on her dissertation in the School of Mechanical, Industrial and Manufacturing Engineering, is working on a research project to understand the application of lean practices to improve new product development (NPD) processes. The results of this study are aimed at helping organizations successfully apply lean to NPD processes.

We are looking for volunteers, who are involved in new product development. Participants will complete a survey. The survey will take approximately 20 minutes to complete. You can exit the survey webpage or stop taking the survey at any time. You are not required to provide your name. However, we ask you to provide a general job title. Your name and e-mail address will not be linked to survey results. Information collected from you will be confidential. The principal investigator of this study, Dr. Toni Doolen, and the student researcher, Woraruthai Choothian, are the only individuals who will have access to your individual survey results. The security and confidentiality of information collected online cannot be guaranteed. Confidentiality will be kept to the extent permitted by the technology being used. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

If you have any questions or comments, you may contact Woraruthai Choothian at choothiw@onid.oregonstate.edu or Dr. Toni Doolen at toni.doolen@oregonstate.edu. If you have questions about your rights as a research subject, please contact the Oregon State University Institutional Review Board (IRB) at irb.oregonstate.edu or 541-737-8008.

Kind Regards,

Woraruthai Choothian
Ph.D. Candidate
School of Mechanical, Industrial, and Manufacturing Engineering
Oregon State University

Appendix A Survey (Continued)

Survey Section 1

The Application of Lean to New Product Development Processes

Section 1 Lean Use

Has your organization implemented lean?

- Yes
- No

Approximately, how long has your organization been involved in implementing lean?

- Less than 1 year
- 1 to 2 years
- 2 to 3 years
- 3 to 4 years
- 4 to 5 years
- 5 to 6 years
- 6 to 7 years
- 7 to 8 years
- 8 to 9 years
- More than 9 years

Has your organization implemented lean in new product development processes?

- Yes
- No

Approximately, how long has your organization been involved in implementing lean in new product development processes?

- Less than 1 year
- 1 to 2 years
- 2 to 3 years
- 3 to 4 years
- 4 to 5 years
- 5 to 6 years
- 6 to 7 years
- 7 to 8 years
- 8 to 9 years
- More than 9 years

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Appendix A Survey (Continued)

Survey Section 2 (For Organizations that indicated that they had applied lean to NPD Processes)

Oregon State University

The Application of Lean to New Product Development Processes

Section 2 Practices

This section was created to identify practices used by your organization when applying lean to new product development processes. The definition of each practice can be seen by clicking on the practice name. If your organization has used a practice in applying lean to new product development processes, please select "yes" and rate the extent to which this practice has been useful in improving new product development performance.

	Does your organization use this practice?		Please rate the extent to which each practice has been useful in improving NPD performance.						
	Yes	No	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
3P	○	○	○	○	○	○	○	○	○
5S	○	○	○	○	○	○	○	○	○
5Whys	○	○	○	○	○	○	○	○	○
A3	○	○	○	○	○	○	○	○	○
Fishbone Diagrams	○	○	○	○	○	○	○	○	○
Gap Analysis	○	○	○	○	○	○	○	○	○
Kaizen Events	○	○	○	○	○	○	○	○	○
Product Families	○	○	○	○	○	○	○	○	○
Quality Function Deployment (QFD)	○	○	○	○	○	○	○	○	○
Queue Management	○	○	○	○	○	○	○	○	○
Standard Work	○	○	○	○	○	○	○	○	○
Stand-up Meetings	○	○	○	○	○	○	○	○	○
Visual Steam Mapping	○	○	○	○	○	○	○	○	○
Visual Management	○	○	○	○	○	○	○	○	○

Please list and rate the usefulness of other practices used by your organization to implement lean in your new product development processes.

		Please rate the extent to which each practice has been useful in improving NPD performance.						
	Additional Practices	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
1		○	○	○	○	○	○	○
2		○	○	○	○	○	○	○
3		○	○	○	○	○	○	○
4		○	○	○	○	○	○	○
5		○	○	○	○	○	○	○
6		○	○	○	○	○	○	○
7		○	○	○	○	○	○	○
8		○	○	○	○	○	○	○
9		○	○	○	○	○	○	○
10		○	○	○	○	○	○	○

Appendix A Survey (Continued)

Survey Section 2 (For Organizations that indicated that they *did not* applied lean to NPD Processes)

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Section 2 Practices

A list of continuous improvement practices has been provided below. Identify any of these used to improve new product development processes in your organizations. If your organization has used a particular practice, please select "yes" and rate the extent to which this practice has been useful in improving new product development. The definition of practices can be seen by clicking on the practice name.

	Does your organization use this practice?		Please rate the extent to which each practice has been useful in improving NPD performance.						
	Yes	No	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
3P	○	○	○	○	○	○	○	○	○
5S	○	○	○	○	○	○	○	○	○
5Whys	○	○	○	○	○	○	○	○	○
A3	○	○	○	○	○	○	○	○	○
Fishbone Diagrams	○	○	○	○	○	○	○	○	○
Gap Analysis	○	○	○	○	○	○	○	○	○
Kaizen Events	○	○	○	○	○	○	○	○	○
Product Families	○	○	○	○	○	○	○	○	○
Quality Function Deployment (QFD)	○	○	○	○	○	○	○	○	○
Queue Management	○	○	○	○	○	○	○	○	○
Standard Work	○	○	○	○	○	○	○	○	○
Stand-up Meetings	○	○	○	○	○	○	○	○	○
Visual Steam Mapping	○	○	○	○	○	○	○	○	○
Visual Management	○	○	○	○	○	○	○	○	○

Please list other practices used by your organization to improve your new product development processes.

		Please rate the extent to which each practice has been useful in improving NPD performance.						
	Additional Practices	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
1	[ ]	○	○	○	○	○	○	○
2	[ ]	○	○	○	○	○	○	○
3	[ ]	○	○	○	○	○	○	○
4	[ ]	○	○	○	○	○	○	○
5	[ ]	○	○	○	○	○	○	○
6	[ ]	○	○	○	○	○	○	○
7	[ ]	○	○	○	○	○	○	○
8	[ ]	○	○	○	○	○	○	○
9	[ ]	○	○	○	○	○	○	○
10	[ ]	○	○	○	○	○	○	○

Appendix A Survey (Continued)

Survey Section 3

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The Application of Lean to New Product Development Processes

Section 3 Performance Indicators

This section lists performance indicators used by some organizations to evaluate new product development process performance. If your organization has used a particular performance indicator to evaluate new product development process performance, please select "yes" and rate the extent to which performance has improved, as a result of your lean implementation.

	Does your organization use this perfromance indicator?		Please rate the extent to which NPD process performance has improved in this area, as a result of applying lean						
	Yes	No	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
Lead time to market	○	○	○	○	○	○	○	○	○
Total product development time	○	○	○	○	○	○	○	○	○
Time spent on each stage of new product development process	○	○	○	○	○	○	○	○	○
Cycle time of the new product development process	○	○	○	○	○	○	○	○	○
Launch time	○	○	○	○	○	○	○	○	○
The number of project delivered on time	○	○	○	○	○	○	○	○	○
Deviations from schedule	○	○	○	○	○	○	○	○	○
Difference between actual times and target times for completion	○	○	○	○	○	○	○	○	○
Total cost of project (all costs that the organization incurred in an individual new product development project)	○	○	○	○	○	○	○	○	○
Actual cost compared to the budget	○	○	○	○	○	○	○	○	○
The number of new product development projects completed within budget	○	○	○	○	○	○	○	○	○
Total spending on the development phase	○	○	○	○	○	○	○	○	○
The number of warranty claims	○	○	○	○	○	○	○	○	○
The number of errors in designs detected by customers	○	○	○	○	○	○	○	○	○
The number of engineering errors	○	○	○	○	○	○	○	○	○
The number of product designs that met all product specifications	○	○	○	○	○	○	○	○	○
The satisfication of customers with new products	○	○	○	○	○	○	○	○	○
The number of successful new product development projects	○	○	○	○	○	○	○	○	○
The number of design reviews	○	○	○	○	○	○	○	○	○
The number of specification changes	○	○	○	○	○	○	○	○	○

Appendix A Survey (Continued)

Survey Section 3 (Continued)

Please list other performance indicators used by your organization to evaluate new product development process performance and the extent of improvement resulting from lean.

	Additional Performance Indicators	Please rate the extent that NPD process performance has improved in this area, as a result of applying lean.						
		Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
1		○	○	○	○	○	○	○
2		○	○	○	○	○	○	○
3		○	○	○	○	○	○	○
4		○	○	○	○	○	○	○
5		○	○	○	○	○	○	○
6		○	○	○	○	○	○	○
7		○	○	○	○	○	○	○
8		○	○	○	○	○	○	○
9		○	○	○	○	○	○	○
10		○	○	○	○	○	○	○

Overall, since implementing lean in your new product development processes, how much have you seen new product development process performance improve, as measured by time performance indicators?

Not at all	Very small Improvement Small	Small Improvement	Moderate Improvement	Fairly large Improvement	Large Improvement	Very large Improvement	Not applicable
○	○	○	○	○	○	○	○

Overall, since implementing lean in your new product development processes, how much have you seen new product development process performance improve, as measured by cost performance indicators?

Not at all	Very small Improvement Small	Small Improvement	Moderate Improvement	Fairly large Improvement	Large Improvement	Very large Improvement	Not applicable
○	○	○	○	○	○	○	○

Overall, since implementing lean in your new product development processes, how much have you seen new product development process performance improve, as measured by quality performance indicators?

Not at all	Very small Improvement Small	Small Improvement	Moderate Improvement	Fairly large Improvement	Large Improvement	Very large Improvement	Not applicable
○	○	○	○	○	○	○	○

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Appendix A Survey (Continued)

Survey Section 4

OSU Oregon State University

The Application of Lean to New Product Development Processes

Section 4 Challenges

This section lists challenges faced by some organizations when applying lean to new product development processes. If your organization has faced a particular challenge when applying lean to new product development processes, please select "yes" and rate the extent to which a particular challenge has been a barrier to lean implementation. The definition of each challenge can be seen by clicking on the practice name.

	Does your organization face this challenge?		Please rate the extent to which each challenge has been a barrier to lean implementation.						
	Yes	No	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
Lack of top management commitment and support	○	○	○	○	○	○	○	○	○
Lack of effective communications across the organization	○	○	○	○	○	○	○	○	○
Unsupportive organizational culture for change	○	○	○	○	○	○	○	○	○
Lack of employee engagement	○	○	○	○	○	○	○	○	○
Misunderstanding of lean	○	○	○	○	○	○	○	○	○
Lack of connection with stakeholders	○	○	○	○	○	○	○	○	○

Please add any other challenges faced by your organization related to the implementation of lean practices to your new product development processes?

		Please rate the extent to which each challenge has been a barrier to lean implementation.						
	Additional Challenges	Not at all	A very small extent	A small extent	A moderate extent	A fairly large extent	A large extent	A very large extent
1		○	○	○	○	○	○	○
2		○	○	○	○	○	○	○
3		○	○	○	○	○	○	○
4		○	○	○	○	○	○	○
5		○	○	○	○	○	○	○
6		○	○	○	○	○	○	○
7		○	○	○	○	○	○	○
8		○	○	○	○	○	○	○
9		○	○	○	○	○	○	○
10		○	○	○	○	○	○	○

<< >>

Appendix A Survey (Continued)

Survey Section 5

OSU Oregon State University

The Application of Lean to New Product Development Processes

Section 5 Participant and Organizational Information

What industrial sector is your organization most closely associated with?

- ○ Automotive
- ○ Aerospace Manufacturing
- ○ Computers and Electronics
- ○ Machinery
- ○ Electrical Equipment
- ○ Other: __________

Approximately how many employees work at this site?

- ○ 0 - 100 employees
- ○ 101 - 500 employees
- ○ 501 – 1,000 employees
- ○ 1,001 – 1,500 employees
- ○ More than 1,500 employees

What is your position or title?

- ○ CEO
- ○ Functional manager
- ○ Project manager
- ○ Supervisor
- ○ Engineer
- ○ Other: __________

<< >>

Appendix B IRB Documents

RESEARCH PROTOCOL

8/01/2014

1. **Protocol Title** The Application of Lean Principles to New Product Development Process

PERSONNEL

2. **Principal Investigator** Dr. Toni Doolen

3. **Student Researcher(s)** Woraruthai Choothian

4. **Investigator Qualifications:**

Dr. Toni Doolen is a Professor in the School of Mechanical, Industrial, and Manufacturing Engineering. Dr. Doolen has extensive experience in conducting research studies in the application of process improvement methodologies and innovation to improve organizational performance. She has over 50 publications in these areas and has supervised over 25 students in their graduate studies in this area. She has great familiarity with studies that involve human subjects, since nearly all of her research includes surveys and interviews of organizational members. In addition, she spent 11 years in manufacturing engineering and management roles at Hewlett-Packard Company. She received a BS in Electrical Engineering and in Materials Science and Engineering from Cornell University, an MS in Manufacturing Systems Engineering from Stanford University, and a Ph.D. in Industrial Engineering from Oregon State University.

Dr. Chinweike Eseonu is an Assistant Professor in the School of Mechanical, Industrial, and Manufacturing Engineering. Dr. Eseonu has been conducting research studies in the engineering management area. He has experience in working on research that related with human subjects since his research uses survey and interviews as the research method. He holds a BASc in Mechanical Engineering from University of Ottawa, and a MS in Engineering Management from University of Minnesota-Duluth. He received his Ph.D. in System and Engineering Management from Texas Tech University.

Woraruthai Choothian – Administers the survey in organizations. She has responsibility for connecting with managers, engineers, and supervisors who are willing to participate in the study. She has a good understanding of what the research aims to achieve and has a proper background in the field of lean product development.

5. **Student Training and Oversight:**

The PI has supervised multiple students conducting survey research. Dr. Doolen will meet with Woraruthai Choothian on weekly basis during the academic year to supervise all aspects of this project, including data collection, analysis and summary.

FUNDING

6. Sources of Support for this project (unfunded, pending, or awarded)

This research is unfunded.

Appendix B IRB Documents (Continued)

RESEARCH PROTOCOL

DESCRIPTION OF RESEARCH

7. Description of Research

The main research objective is to gain a better understand how organizations applying lean to new product development (NPD) processes. The desired outcomes of this research were five-fold. First, the research identified common practices used when organizations apply lean to NPD processes. Second, the research identified performance indicators used to evaluate NPD process performance and the impact of applying lean on NPD process performance improvement, as measured by time, cost, and quality. Third, the research identified challenges faced by organizations when applying lean to NPD processes. Fourth, the research studied whether or not there was a relationship between the number of practices used by organizations and NPD process performance as measured by time, cost, and quality performance indicators. Finally, the research studied whether or not there was a relationship between the years of experience with lean and NPD process performance as measured by time, cost, and quality performance indicators. The research is a study of the student researcher's dissertation. The results of this research will be included in conferences and journal papers.

8. Background Justification

The local and global markets are highly competitive and rapidly changing. If an organization is the first to launch a new product, it can be in a better position in the market. The time-to- market of new products is one of the key success factors in NPD. Thus, organizations are pressured to improve the speed at which new products are needed. The quality of new products and reducing new product costs are also important in the NPD process. Researchers have developed many methods to assist organizations in creating NPD processes that are faster and cheaper. Lean principles, especially minimizing waste and maximizing flow, can be applied to the NPD process. Lean principles have been successfully deployed and implemented in many different industries and organizations. Research has confirmed that lean principles can be used to improve NPD processes, making them faster, cheaper, and better. To determine how organizations applied lean to NPD processes, and whether NPD processes have improved by lean, this research is conducted. This research is focused on confirming that the application of lean principles will lead to improvement in NPD process.

9. Subject Population

The approximate number of participants to be recruited over the life of the study will be 3,300 participants. The population is not restricted to any gender or ethnic group. The only requirement for participation is that the participant has experience applying lean principles to new product development processes.

10. Consent Process

Since the study presents no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required outside of the research context (the required data for this study will be collected only through surveys), a waiver of documentation (signature) of informed consent is sought. A written statement in the cover page (Appendix C) will be provided to participants at the beginning of the online survey. This statement is an "explanation of research study" that informs participants the research activity and provides them with information about the survey, the potential risks and benefits associated with participation, and contact information for the principal investigator, student researcher, and the IRB.

Appendix B IRB Documents (Continued)

RESEARCH PROTOCOL

11. Methods and Procedures

11.1. Subject Identification and Recruitment

The survey participants will be self identified by responding to notifications about the survey on society webpages including ASEM and PICMET. Other participants may hear about the study from an email sent to organizations, which have implemented lean principles and from an e-mail sent to managers, engineers, or supervisors who are working in organizations implementing lean principles. For those participating organizations, the first e-mail will be sent to recruit managers, engineers, and supervisors to contribute to this research and complete the survey. The first email is included the content in Appendix B. Subsequent reminder e-mails, shown in Appendix D, will be sent three weeks after the first email was sent, and will be used to remind participants, who did not complete the survey, as well as to those who might have missed the first e-mail.

Some participants will be contacted via phone to ask if they would like to participate in the research. The script used to recruit participants is in Appendix E. If the participants agree to complete the survey, they will be asked if they would like to complete the survey on the website online or would like to receive a hard copy of the survey. If they would like to complete the survey online, an e-mail, including the survey link and content in Appendix B, will be sent to them. If they would like to receive a hard copy of the survey, a physical mail, including the cover page (Appendix C), the survey (Appendix A), and a returned envelop, will be sent to them.

11.2. Scheduling Survey

The web page will open with a cover letter which will be the waiver of informed consent. The cover letter will provide information about the study, participant rights, confidentiality information, instructions for completing the survey, and contact information for the principal investigator, student researcher, and the IRB. Upon reading the cover letter, participants can decide whether or not they wish to complete the survey. The survey should take no longer than 20 minutes to complete. Participants may choose to complete the survey immediately upon opening it or can return to complete the survey at another time.

11.3. Survey Questions

The survey used for this study is included in Appendix A. There are two versions of the survey used in this research: online survey and hard copy survey. The information collected through the online survey will be recorded in an online database. This study will use Qualtrics. The information collected by hard copies of the survey will be recorded in Qualtrics. The hard copies of the survey will kept in storage on OSU campus until the research project is terminated.

11.4. Analysis Plan

The analysis of survey data will begin by entering each response into a centralized spreadsheet. Different statistical analyses will be used to test research hypotheses.

Appendix B IRB Documents (Continued)

RESEARCH PROTOCOL

12. Anonymity or Confidentiality

Informed consent signatures will not be collected. The only personal information that will be collected is the job title of participant. If participants would like to participate in the future research, they will provide their name and e-mail address. All information and data collected will be confidential and securely stored on the online database. Accessing the online database requires user name and password to protect information and data collected. Only the principal investigator and student research can access to the online database used in this esearch. After the research project is terminated, information and data collected will be kept in the secure storage on OSU campus only accessed by the only principal investigator, the co-investigator, and student researcher. Information and data collected stored on the online database will be deleted. All hard copies of the survey will be shredded as well. The information and data will be kept in the in the secure storage on OSU campus for 3 years. After 3 years, all information and data will be terminated.

13. Risks

The risks of this study are minimal. The security and confidentiality of information collected form participants online cannot be guaranteed. Confidentiality will kept to the extent permitted by the technology being used. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

14. Benefits

We do not believe there are any direct benefits to individuals who participate in the study. No names or other identifying titles will be used in the data summaries. In addition, findings will be summarized in general terms. We believe that the findings will be beneficial to organizations and help them appropriately assess the improvements in NPD process resulting from applying lean principle and to organizations that are interested to applying lean principles to NPD processes, helping them to anticipate the benefits.

15. Assessment of Risk-Benefit ratio

We do not believe there are any discernible risks or benefits to the participants in this research.

16. Attachments:

Appendix A: Survey
Appendix B: Recruitment letter
Appendix C: Cover page
Appendix D: Reminding letter
Appendix E: The script used for phone calls

Appendix B IRB Documents (Continued)

Attachments: Recruitment letter

The recruitment letter will be sent to organizations via e-mail and posted on webpages.

Study Title: The Application of Lean Principles to New Product development Process

Dear Participant,

Your help is needed for an important research study. Woraruthai Choothian, a PhD student working on her dissertation in the School of Mechanical, Industrial and Manufacturing Engineering, is conducting research to understand the application of lean principles and methods to new product development (NPD). The results of this study are aimed to help guide organizations in applying lean to NPD processes.

We are looking for volunteers who have contributed in new product development processes and are experienced in improving NPD processes. The survey will take approximately 20 minutes to complete. If you choose to participate, please go to the Survey to complete the survey. You can stop filling out the survey at any time and return to complete the survey later. When you come back, please go to the survey link. You will start at the section where you exited the survey.

If you have any questions or comments, you may contact Woraruthai Choothian (Aom) at choothiw@onid.orst.edu or Dr. Toni Doolen, who is the principal investigator for this research, at toni.doolen@oregonstate.edu. If you have questions about your rights as a research subject, please contact the Oregon State University Institutional Review Board (IRB) at irb@oregonstate.edu or 541-737-8008.

Best Regard,

Woraruthai Choothian
Ph.D. Candidate
School of Mechanical, Industrial and Manufacturing Engineering
Oregon State University

If you do not want to receive any further information about this survey, please Click here to unsubscribe.

Appendix B IRB Documents (Continued)

Attachments: Cover page

Dear Participant,

Your help is needed for an important research study. Woraruthai Choothian, a PhD student working on her dissertation in the School of Mechanical, Industrial and Manufacturing Engineering, is working on a research project to understand the application of lean practices to improve new product development (NPD) processes. The results of this study are aimed at helping organizations successfully apply lean principles to NPD processes.

We are looking for volunteers who are involved in new product development. Participants will complete a survey. The survey will take approximately 20 minutes to complete. You can exit the survey webpage or stop taking the survey at any time. You are not required to provide your name. However, we ask you to provide your general job title. If you would like to participate in the future research, you may provide your name and e-mail address. Your name and e-mail address will not be linked to survey result. Information collected from you will be confidential. The principal investigator of this study, Dr. Toni Doolen, the co-investigator, Dr. Chinweike Eseonu, and the student researcher, Woraruthai Choothian, are the only individuals who will have the access to your individual survey results. The security and confidentiality of information collected online cannot be guaranteed. Confidentiality will be kept to the extent permitted by the technology being used. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

If you have any questions or comments, you may contact Woraruthai Choothian at choothiw@onid.oregonstate.edu or Dr. Toni Doolen who is the principal investigator for this research at toni.doolen@oregonstate.edu. If you have questions about your rights as a research subject, please contact the Oregon State University Institutional Review Board (IRB) at irb.oregonstate.edu or 541-737-8008.

Kind Regards,

Woraruthai Choothian
Ph.D. Candidate
School of Mechanical, Industrial and Manufacturing Engineering
Oregon State University

Appendix B IRB Documents (Continued)

Attachments: Reminder Letter

The reminder e-mail letter will be sent to organizations after the first e-mail was sent.

Study Title: The Application of Lean Principles to New Product development Process

Dear Participant,

Your help is needed for an important research study. Woraruthai Choothian, a PhD student working on her dissertation in the School of Mechanical, Industrial and Manufacturing Engineering, is conducting research to understand the application of lean principles and methods to new product development (NPD). The results of this study are aimed to help guide organizations in applying lean to NPD processes.

We are looking for volunteers who have contributed in new product development processes and are experienced in improving NPD processes. The survey will take approximately 20 minutes to complete. If you choose to participate, please go to **the Survey** to complete the survey. You can stop filling out the survey at any time and return to complete the survey later. When you come back, please go to the survey link. You will start at the section where you exited the survey. Please complete the survey by xx/xx/2014. After completing the survey, if you would like to receive the results of this research, please send e-mail to choothiw@onid.oergonstate.edu.

If you have any questions or comments, you may contact Woraruthai Choothian (Aom) at choothiw@onid.oregonstate.edu or Dr. Toni Doolen, who is the principal investigator for this research, at toni.doolen@oregonstate.edu. If you have questions about your rights as a research subject, please contact the Oregon State University Institutional Review Board (IRB) at irb@oregonstate.edu or 541-737-8008.

Best Regard,

Woraruthai Choothian
Ph.D. Candidate
School of Mechanical, Industrial and Manufacturing Engineering
Oregon State University

If you do not want to receive any further information about this survey, please Click here to unsubscribe.

Appendix B IRB Documents (Continued)

Attachments: The script used for phone calls

The script used for phone called to recruit participants

Good morning/Afternoon,

My name is Woraruthai Choothian and I am a PhD student in the School of Mechanical, Industrial and Manufacturing Engineering, Oregon State University. I am working on my dissertation and conducting a research to understand the application of lean principles and methods to new product development (NPD). The results of this study are aimed to help guide organizations in applying lean to NPD processes. I am looking for volunteers who have contributed in new product development processes and are experienced in improving NPD processes to complete the survey. If you would like to participate in this research, I can send the survey link to your e-mail. Please let me know your email address that you would like me to send the survey to you. If you prefer to complete the survey in a hard copy, I can send the survey to your physical mail address. Please provide your physical address.

If you have any questions or comments, you may contact me at 541-9085653 or choothiw@onid.oregonstate.edu.

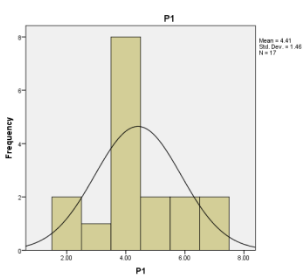
Thank you very much for your time

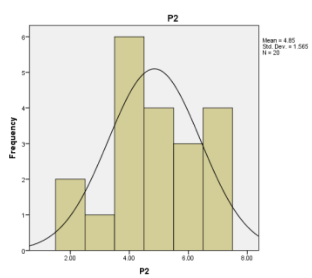
Appendix C Normality Tests: Practice Usefulness

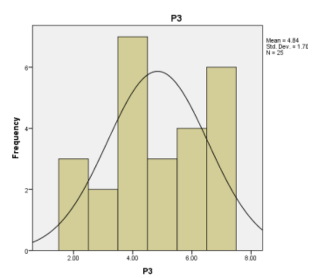
Statistics

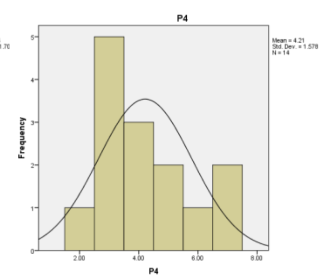
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
N	Valid	17	20	25	14	22	24	19	20	21	10	19	23	23	21
	Missing	10	7	2	13	5	3	8	7	6	17	8	4	4	6
Mean		4.4118	4.8500	4.8400	4.2143	4.4091	4.8750	5.2632	5.7500	4.0000	4.9000	5.0526	4.9565	4.6522	4.3333
Std. Error of Mean		.35416	.35000	.34000	.42165	.36431	.26452	.39620	.31519	.32367	.50442	.30081	.35273	.34783	.36078
Median		4.0000	5.0000	5.0000	4.0000	4.0000	5.0000	6.0000	6.0000	4.0000	5.0000	5.0000	6.0000	4.0000	4.0000
Mode		4.00	4.00	4.00	3.00	4.00	4.00[a]	7.00	7.00	3.00[a]	3.00	6.00	6.00	4.00	4.00
Std. Deviation		1.46026	1.56525	1.70000	1.57766	1.70878	1.29590	1.72698	1.40955	1.48324	1.59513	1.31122	1.69164	1.66812	1.65328
Variance		2.132	2.450	2.890	2.489	2.920	1.679	2.982	1.987	2.200	2.544	1.719	2.862	2.783	2.733
Skewness		**.265**	**-.183**	**-.172**	**.687**	**.296**	**-.272**	**-.455**	**-1.135**	**.000**	**-.004**	**-.272**	**-.543**	**.159**	**.068**
Std. Error of Skewness		.550	.512	.464	.597	.491	.472	.524	.512	.501	.687	.524	.481	.481	.501
Kurtosis		-.160	-.681	-1.112	-.556	-1.127	-.449	-1.267	.970	-.215	-1.589	-1.143	-.969	-1.205	-1.114
Std. Error of Kurtosis		1.063	.992	.902	1.154	.953	.918	1.014	.992	.972	1.334	1.014	.935	.935	.972
Range		5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	6.00	4.00	4.00	5.00	5.00	5.00
Minimum		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	3.00	3.00	2.00	2.00	2.00
Maximum		7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Sum		75.00	97.00	121.00	59.00	97.00	117.00	100.00	115.00	84.00	49.00	96.00	114.00	107.00	91.00
Percentiles	25	4.0000	4.0000	4.0000	3.0000	3.0000	4.0000	4.0000	5.0000	3.0000	3.0000	4.0000	4.0000	3.0000	3.0000
	50	4.0000	5.0000	5.0000	4.0000	4.0000	5.0000	6.0000	6.0000	4.0000	5.0000	5.0000	6.0000	4.0000	4.0000
	75	5.5000	6.0000	6.5000	5.2500	6.0000	6.0000	7.0000	7.0000	5.0000	6.2500	6.0000	6.0000	6.0000	6.0000

a. Multiple modes exist. The smallest value is shown

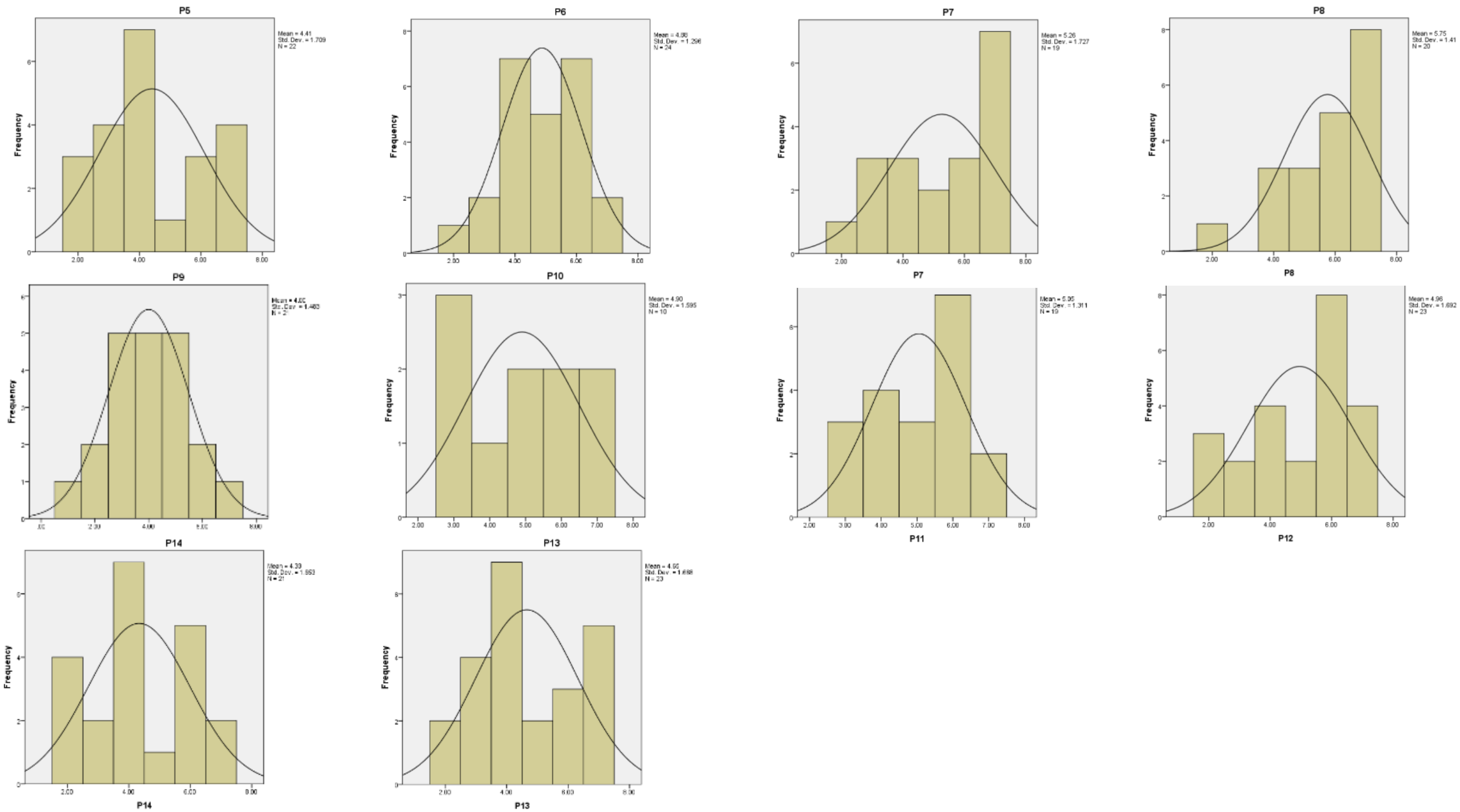








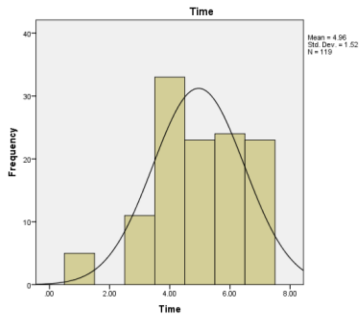
Appendix C   Normality Tests: Practice Usefulness (Continued)

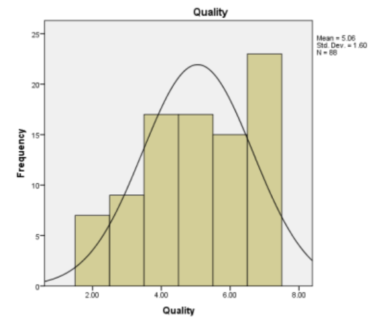


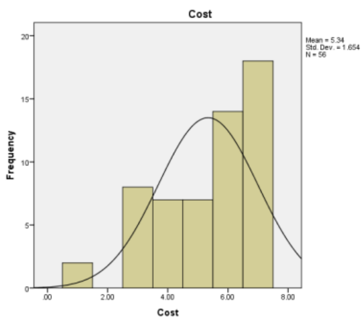
Appendix C Normality Tests: Improvement of NPD Process Performance (Time, Cost, and Quality)

Statistics

		Time	Cost	Quality
N	Valid	119	56	88
	Missing	25	88	56
Mean		4.9580	5.3393	5.0568
Std. Error of Mean		.13938	.22109	.17056
Median		5.0000	6.0000	5.0000
Mode		4.00	7.00	7.00
Std. Deviation		1.52045	1.65449	1.59999
Variance		2.312	2.737	2.560
Skewness		**-.487**	**-.818**	**-.336**
Std. Error of Skewness		.222	.319	.257
Kurtosis		.000	-.165	-.977
Std. Error of Kurtosis		.440	.628	.508
Range		6.00	6.00	5.00
Minimum		1.00	1.00	2.00
Maximum		7.00	7.00	7.00
Sum		590.00	299.00	445.00
Percentiles	25	4.0000	4.0000	4.0000
	50	5.0000	6.0000	5.0000
	75	6.0000	7.0000	7.0000





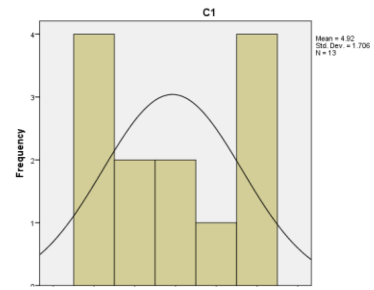


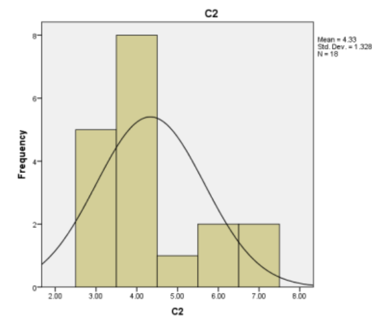
Appendix C Normality Tests: Barriers

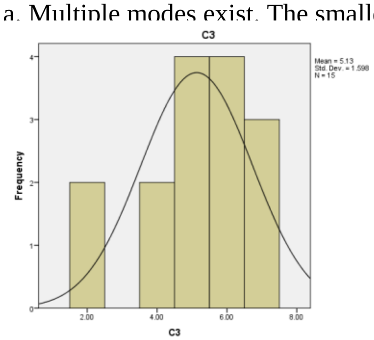
Statistics

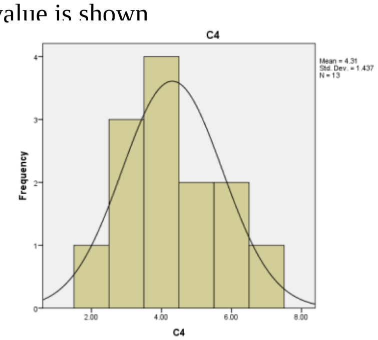
		C1	C2	C3	C4	C5	C6
N	Valid	13	18	15	13	17	13
	Missing	7	2	5	7	3	7
Mean		4.9231	4.3333	5.1333	4.3077	4.1176	4.5385
Std. Error of Mean		.47314	.31311	.41250	.39847	.34173	.40216
Median		5.0000	4.0000	5.0000	4.0000	4.0000	4.0000
Mode		3.00[a]	4.00	5.00[a]	4.00	3.00	4.00
Std. Deviation		1.70595	1.32842	1.59762	1.43670	1.40900	1.45002
Variance		2.910	1.765	2.552	2.064	1.985	2.103
Skewness		**.140**	**.997**	**-.856**	**.357**	**.678**	**.782**
Std. Error of Skewness		.616	.536	.580	.616	.550	.616
Kurtosis		-1.779	-.042	.191	-.478	-.497	-.813
Std. Error of Kurtosis		1.191	1.038	1.121	1.191	1.063	1.191
Range		4.00	4.00	5.00	5.00	5.00	4.00
Minimum		3.00	3.00	2.00	2.00	2.00	3.00
Maximum		7.00	7.00	7.00	7.00	7.00	7.00
Percentiles	25	3.0000	3.0000	4.0000	3.0000	3.0000	3.5000
	50	5.0000	4.0000	5.0000	4.0000	4.0000	4.0000
	75	7.0000	5.2500	6.0000	5.5000	5.5000	6.0000

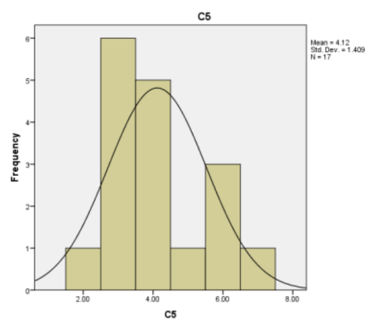
a. Multiple modes exist. The smallest value is shown

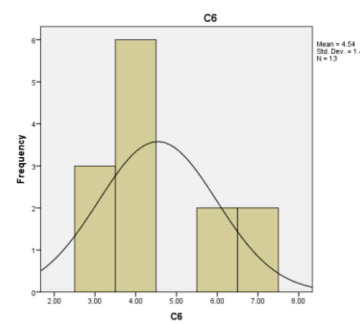












Appendix D Linear Regression Models for Hypothesis 7a - 7c

1. The numbers of practices used and NPD process performance improvement, as measured by time performance indicators

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	NoPractices[b]	.	Enter

a. Dependent Variable: Time
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.273[a]	.075	.026	1.544

a. Predictors: (Constant), NoPractices

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.657	1	3.657	1.534	.231[b]
	Residual	45.296	19	2.384		
	Total	48.952	20			

a. Dependent Variable: Time
b. Predictors: (Constant), NoPractices

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.698	1.400		1.928	.069
	NoPractices	.157	.127	.273	1.238	.231

a. Dependent Variable: Time

Appendix D Linear Regression Models for Hypothesis 7a - 7c (Continued)

2. The numbers of practices used and NPD process performance improvement, as measured by cost performance indicators

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	NoPractices[b]	.	Enter

a. Dependent Variable: Cost
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.148[a]	.022	-.030	1.569

a. Predictors: (Constant), NoPractices

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.042	1	1.042	.423	.523[b]
	Residual	46.768	19	2.461		
	Total	47.810	20			

a. Dependent Variable: Cost
b. Predictors: (Constant), NoPractices

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.340	1.422		2.348	.030
	NoPractices	.084	.129	.148	.651	.523

a. Dependent Variable: Cost

Appendix D Linear Regression Models for Hypothesis 7a - 7c (Continued)

3. The numbers of practices used and NPD process performance improvement, as measured by quality performance indicators

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	NoPractices[b]	.	Enter

a. Dependent Variable: Quality
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.068[a]	.005	-.051	1.715

a. Predictors: (Constant), NoPractices

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.244	1	.244	.083	.777[b]
	Residual	52.956	18	2.942		
	Total	53.200	19			

a. Dependent Variable: Quality
b. Predictors: (Constant), NoPractices

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.763	1.565		2.405	.027
	NoPractices	.041	.141	.068	.288	.777

a. Dependent Variable: Quality

Appendix E Linear Regression Models for Hypothesis 8a - 8c

1. Years of experience with lean and NPD process performance improvement, as measured by time performance indicators

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LNPDYear[b]	.	Enter

a. Dependent Variable: Time
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.142[a]	.020	-.031	1.589

a. Predictors: (Constant), LNPDYear

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.992	1	.992	.393	.538[b]
	Residual	47.960	19	2.524		
	Total	48.952	20			

a. Dependent Variable: Time
b. Predictors: (Constant), LNPDYear

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.801	.755		6.362	.000
	LNPDYear	-.082	.130	-.142	-.627	.538

a. Dependent Variable: Time

Appendix E Linear Regression Models for Hypothesis 8a - 8c (Continued)

2. Years of experience with lean and NPD process performance improvement, as measured by cost performance indicators

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LNPDYear[b]	.	Enter

a. Dependent Variable: Cost
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.068[a]	.005	-.048	1.583

a. Predictors: (Constant), LNPDYear

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.220	1	.220	.088	.770[b]
	Residual	47.590	19	2.505		
	Total	47.810	20			

a. Dependent Variable: Cost
b. Predictors: (Constant), LNPDYear

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.436	.752		5.901	.000
	LNPDYear	-.038	.130	-.068	-.296	.770

a. Dependent Variable: Cost

Appendix E Linear Regression Models for Hypothesis 8a - 8c (Continued)

3. Years of experience with lean and NPD process performance improvement, as measured by quality performance indicators

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LNPDYear[b]	.	Enter

a. Dependent Variable: Quality
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.480[a]	.231	.188	1.508

a. Predictors: (Constant), LNPDYear

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12.271	1	12.271	5.397	.032[b]
	Residual	40.929	18	2.274		
	Total	53.200	19			

a. Dependent Variable: Quality
b. Predictors: (Constant), LNPDYear

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.734	.741		7.734	.000
	LNPDYear	-.292	.126	-.480	-2.323	.032

a. Dependent Variable: Quality