Computer-Aided Engineering, Information Technology and Supplier Influence on Product Development Time in Lean Product Development

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Computer-Aided Engineering, Information Technology and Supplier Influence on Product Development Time in Lean Product Development

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Abstract

To be sustainable and more competitive, organizations need to focus on reducing cost and decreasing time to market in the product development process. Lean product development (LPD) is noted as a suitable solution to current product development issues to reduce cost and product development time to be more competitive. The main objectives of LPD are to minimize waste, improve quality, and reduce product life cycle and cost in the product development process. In this quantitative nonexperimental study, computer-aided engineering (CAE), computer-aided design (CAD) software, information technology (IT), and supplier involvement in product development cycle time in LPD were the predictor variables and cycle time (waste) was the outcome variable. The sample of this proposed study was 61 product design engineers working in design and manufacturing companies in the United States. Data were collected through an online survey on SurveyMonkey™. SPSS (version 20) statistical software was used to analyze normality and statistical significance of the variables.

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Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Lean theory is a method that can be used to eliminate waste in the product development process (Gecevska, Stefanic, Veza, & Cus, 2012). In the manufacturing process, the lean theory is known as lean manufacturing (LM) and in the product development process, the lean theory is known as lean product development (LPD; L. Wang, Ming, Kong, Li, & Wang, 2012). Understanding the importance of eliminating waste, many organizations are working to practice lean theories to reduce cost and improve quality to gain a competitive advantage (Sun, 2011). However, as a result of the complexity and difficulty of implementation of LPD, LM is much more popular in industries compared to LPD processes; LPD requires contribution from different functional areas due to this complexity (León & Farris, 2011). In product development, it is not clear what the final item will be until the end of the product development cycle (León & Farris, 2011). Therefore, lean theories are strongly focused on manufacturing (Hoppmann, Rebentisch, Dombrowski, & Zahn, 2011). However, there are many benefits of applying lean theories in the field of product development (Hoppmann et al., 2011). Therefore, LPD is currently the focus of many corporations to maximize value, improve quality, reduce lead times, and reduce product development costs (León & Farris, 2011).

Lean theory consists of waste eliminating systems like total productive maintenance, just-in-time (JIT), and total quality management (Bonavia & Marin-Garcia, 2011). Moreover, in manufacturing processes, stocks, extra manufacturing, scraps, motion, waiting, and carrying have been categorized as waste (Kovács, 2012; Laureani, Antony, & Douglas, 2010). In the product development process, the quality and cost of the product, time and cost required for development, and ability of production are identified as waste (Wang et al., 2012). The main objectives of LPD are to minimize waste, improve quality, and reduce product life cycle and cost in product development (Sören & Torgeir, 2013). The reduction of waste in the product development process appears to be an important task in LPD.

Implementation of lean theory is important to business success in the fast moving global market (Pitta & Pitta, 2012). After the Toyota Corporation invented and used lean theories, many managers in other organizations have successfully used lean as quality productivity initiatives to gain economic advantages in recent years (Gershon, 2010; Marin-Garcia & Poveda, 2010). However, Vicencio-Ortiz and Kolarik (2012) found that project managers were not earnestly assessing the possible impact of other processes outside their focus process when implementing quality productivity initiatives. For example, the product design manager could implement lean theory in the product development process without considering the effect of the other areas, such as the type of computer-aided design (CAD) software used in part designing. In such situations, product design managers may not receive the full benefits of LPD to reduce waste unless they combine other areas that could be potential contributors of waste.

There are seven types of waste that the lean theory is used to reduce: (a) extra production, (b) extra stock, (c) extra processing, (d) scraps, (e) moving, (f) waiting, and (g) carrying (Laureani et al., 2010). Many researchers are currently working on the lean theories, especially associated with the LPD process, as LPD is much more difficult to implement compared to LM to find new ways to reduce waste further (León & Farris, 2011).

Background

Cost savings and consumer satisfaction are the main reasons for the popularity of lean in LPD and LM in product design and the manufacturing industry (Luo & Brozovsky, 2013). LPD and LM are leading concepts that many companies are applying to their existing manufacturing and product development processes to reduce cost and satisfy customers (Tirpak, 2012). The lean concept is used to reduce waste in organizations (Pasquire & Salvatierra-Garrido, 2011). Any resource in an organization that does not provide value to the consumer is called waste (Arfmann & Federico, 2014). There are seven types of waste that lean theory is used to reduce: (a) extra production, (b) extra stock, (c) extra processing, (d) scraps, (e) moving, (f) waiting, and (g) carrying (Laureani et al., 2010). Moreover, if a company can reduce waste, the company can improve profits and productivity to be more competitive in the global market (Keyes, 2013). With an understanding of the importance of lean thinking, many scholars have been conducting research on lean theories, such as LPD and LM, to reduce waste and improve productivity (Hoppmann et al., 2011; León & Farris, 2011; Wang et al., 2012).

In LM, controlled manufacturing of products, efficient layout, total productive maintenance, 5S (5S represents sorting, straightening, sweeping, standardizing, and self-discipline; Browning & Heath, 2009) and visual control, a single minute exchange of dies, supplier development, a single piece flow, cell design, and process mapping and value stream mapping techniques are used for cost saving and customer satisfaction (Suarez Barraza, Smith, & Dahlgaard-Park, 2009). In LPD, there are requirements for contribution from different functional areas as compared to LM and the LPD process is more complex (León & Farris, 2011). The main objectives of LPD are to minimize waste, improve quality, and reduce product life cycle and cost to satisfy the customer (Sören & Torgeir, 2013). Furthermore, the LPD concept is used to increase value, improve quality, reduce cycle time, and reduce costs for product development processes (León & Farris, 2011).

The product development process are considered as a set of development and operational value streams that should be designed to consistently execute product development activities effectively and efficiently by creating usable knowledge through learning (Ward, 2007). Product development projects include idea generation, part manufacturing resource design, product design, testing and validation, and manufacturing of parts (León & Farris, 2011). LPD is also viewed as cross-functional design practices that are controlled by lean theory—value, value stream, flow, pull, and perfection, and can be used to maximize value and eliminate waste (León & Farris, 2011). Value has been described as customer needs and value stream as the necessary steps to stop unnecessary activities (Kovács, 2012). Flow is defined as the action of stopping all processes to make the manufacturing flow without any unnecessary delays, while pull is making products to customer demand, and perfection is making things right the first time. These five elements in lean theory can be used to reduce waste in LPD if applied properly (Kovács, 2012).

There are two types of waste in LPD (Sören & Torgeir, 2013). Type 1 waste consists of non-value activities, such as administration, coordination, testing, validation, and checking. However, these non-value activities are still needed for value generation. Therefore, minimizing these non-value activities (Type-1 waste) can reduce waste and improve productivity. Type 2 waste is pure waste, such as defects, waiting, and underutilization of people (Sören & Torgeir, 2013). Thus, it is necessary to eliminate completely Type 2 waste because it does not contribute any value to LPD. Moreover, it is necessary to find elements, such as a type of design software, human resources practices, and supplier involvements, that can reduce Type 1 waste and eliminate Type 2 waste to reduce product life cycle time, improve product quality, and reduce product cost (Sören & Torgeir, 2013).

Implementation of lean theory is important to business success in the fast moving global market (Pitta & Pitta, 2012). As discussed above, waste elimination by implementing the LPD concept is popular among organizations to reduce cost, reduce product life cycle, and improve product quality to satisfy the customer (Upadhye, Deshmukh, & Garg, 2010). Furthermore, the customer is the most important part of the business cycle. If the management of a company can satisfy their customers, it is clear that they will be successful in their business since sales increase with customer satisfaction (Banker & Mashruwala, 2009). Therefore, it is necessary to find more elements of LPD to be applied to reduce waste, such as product development cycle time, to satisfy customers and increase company profits.

Statement of Problem

To be sustainable and more competitive, organizations need to focus on reducing cost and decreasing time to market in the product development process (Letens, Farris, & Van Aken, 2011). However, many organizations are still struggling to optimize the product development process (Costa, Rozenfeld, Amaral, Marcacinit, & Rezende, 2013). It takes 3 to 4 years to develop a new product and about 50% of the costs incurred in product development are waste (Gurumurthy & Kodali, 2012). Therefore, managers are continuously working to reduce cost and cycle time and improve quality in their organizations (Holtzman, 2011).

The main objectives of LPD are to minimize waste, improve quality, and reduce product life cycle and cost (Sören & Torgeir, 2013). The Goodyear Corporation in Peru was able to improve product delivery rates from 30 to 90% after implementing LPD (Kihn, 2012) and ABC Manufacturing was able to reduce cycle time by 32% in the first phase after implementing LPD theories (Nepal, Yadav, & Solanki, 2011). However, LPD is much more difficult to implement compared to LM (León & Farris, 2011; Liker & Morgan, 2011); thus, more study on LPD is recommended, especially the application of LPD instead of the theoretical aspect (León & Farris, 2011).

The impact on cost, quality, and manufacturing lead-times is much bigger in product development than during production (Liker & Morgan, 2011). The LPD process is the most suitable solution to current product development issues (Nepal et al., 2011). Therefore, it is necessary to conduct more research in LPD to find factors, such as part design CAD software used, supplier involvement, computer aided engineering (CAE) analysis tools (computational fluid dynamic [CFD], finite element analysis [FEA]) used, and information technology (IT) involvement in the LPD to reduce waste (cycle time) in the product development process (León & Farris, 2011; Nepal et al., 2011).

Purpose of Study

The purpose of this quantitative non-experimental correlational study is to examine factors that affect product development cycle time in LPD. Part design CAD software used, supplier involvement, computer aided engineering analysis tools (FEA and CAE) used, and IT involvement are the predictor variables and cycle time (waste) is the outcome variable. The target population of this proposed study includes engineers in design and manufacturing companies in the U.S. Based on G*Power 3 with an alpha level of .05, power level of .80, four predictor variables, and an effect size of 0.25, the total sample size must be 53 (see Appendix A). According to Bartlett, Kotrlik, and Higgins (2001), response rates for educational research surveys are well below 100%. Therefore, assuming the response rate for this survey is 10%, the survey questionnaire was sent to over 650 individuals through SurveyMonkey™. Data were gathered through an online survey (see Appendix B) using SurveyMonkey™. The study was conducted to find the effect of part design CAD software used, supplier involvement, CAE tools (FEA and CFD) used, and IT involvement in the LPD process in reduction of cycle time (waste) in the design and manufacturing industries. Linear regression analysis was originally going to be used to determine the predictive relationships between the variables, but the data did not meet the assumptions for linear regression; therefore, ordinal logistic regression was used to determine these predictive relationships, since it does not have the same assumptions as linear regression (Agresti, 2013; Long, 1997; O'Connell, 2006). In addition, the nonparametric Kurskal-Wallis H test was used to determine whether model hours differed significantly between types of CAD software and the Wilcoxon signed-rank test was used to test the additional null hypotheses and determine how differently the inclusion of the associated factors were from the standard. Design and manufacturing companies in the United States currently use different CAD software, such as Unigraphics, Catia, Solidworks, and ProEng (Brunnermeier & Martin, 2002). The efficacies of these CAD software systems may vary in terms of efficiency to reduce design time and improve product quality. Furthermore, the effects of CAE tools used, supplier, and IT involvement on LPD cycle time were analyzed.

Theoretical Framework

Companies, such as Toyota Corporation (Gershon, 2010; Marin-Garcia & Poveda, 2010), Goodyear Corporation (Kihn, 2012), and ABC Manufacturing (Nepal et al., 2011), and researchers such as Wang et al. (2012), León and Farris (2011), and Vinodh (2011) are working to find solutions to be competitive in the market place (Moyano-Fuentes & Sacristán-Díaz, 2012). Lean theory is one of the approaches industries such as Ford motor company, Apple, and General Electric are currently interested in since applying lean theories increases customer value and reduces waste in an organization (Pedersen & Huniche, 2011). However, lean theory is broadly applied in manufacturing processes that focus in material supply, part manufacturing, and product delivery to reduce waste (L. Wang et al., 2012). In recent years, researchers started applying lean theories to product development to reduce waste, which is recognized as LPD (L. Wang et al., 2012).

Implementation of lean theory is important to business success in the global market (Pitta & Pitta, 2012). After the Toyota Corporation invented and used lean theories, many managers in other organizations have successfully used lean as quality productivity initiatives to gain economic advantages in recent years (Gershon, 2010; Marin-Garcia & Poveda, 2010). However, Vicencio-Ortiz and Kolarik (2012) found that project managers were not earnestly assessing the possible impact of other processes outside their focus process when implementing quality productivity initiatives. For example, the product design manager could implement lean theory in the product development process without considering the effect of the other areas, such as the type of CAD software used in part designing. In such situations, product design managers may not receive the full benefits of LPD to reduce waste unless they combine other areas that could be potential contributors of waste.

The impact on cost, quality, and manufacturing lead-times (waste) is much bigger in product development than during production (Liker & Morgan, 2011). Therefore, it is worthy to study components that effect product development to reduce waste (product development cycle time). In fact, the LPD process is the most suitable solution to current product development issues (Nepal et al., 2011). However, there are many elements, such as CAD software used, CAE tools used, IT, and supplier involvement, that could affect the product development cycle time in LPD. Therefore, the effect of CAD software used, CAE tools used, IT, and supplier involvement on product development life cycle (waste) in LPD was conducted.

CAD software is used to create functions and different parts or features to evaluate engineering solutions (Veisz, Namouz, Joshi, & Summers, 2012). Giuliana, Massimo, and Rabbiosi (2004) studied the complementarity between CAD and innovative company practices, and found that adopting one innovation practice, such as using CAD software, can promote adopting another innovative practice. This indicates that implementing CAD software in an organization can improve its productivity. CAD software and CAE tools have been used to reduce product design cycle time in product development (Zehtaban & Roller, 2013). In fact, CAD and CAE are very important for reducing waste in the product development process (Vinodh & Kuttalingam, 2011). However, CAD and CAE software do not perform in the same way; some CAD and CAE software are more accurate and faster than other software (Zehtaban & Roller, 2013). For example, a case study of an automotive sprocket manufacturer indicated the application of CAD and CAE reduced the product deployment cycle time and improved the flexibility of designing new products (Vinodh & Kuttalingam, 2011). Similarly, adoption of IT improves complementarity effects between organizational practices (Bocquet, Brossard, & Sabatier, 2007). The manufacture of quality products with less waste is important to sustaining an organization (Agus & Mohd, 2012). It is for this reason the practice of supplier chain management has been popular among lean organizations in the last two decades (Agus & Mohd, 2012). Therefore, supplier involvement in LPD may be important for the success of an organization. Therefore, in this quantitative non-experimental study, the type of CAD software used, CAE tools (FEA and CFD) used, IT, and supplier involvement in LPD were predictor variables, and product development cycle time (waste) was the outcome variable.

Research Questions

A non-experimental, correlational quantitative research was conducted using engineers in the design and manufacturing industries. The purpose of this quantitative non-experimental study is to examine distinct factors that affect product development cycle time in LPD, part design CAD software used, supplier involvement, CAE tools used, and IT involvement are the predictor variables and cycle time (waste) is the outcome variable.

Q1. To what extent, if any, does the type of part design CAD software, such as Unigraphics, Solidworks, and ProEng, used in the LPD process influence product development cycle time?

Q2. To what extent, if any, does supplier involvement in the LPD process influence product development cycle time?

Q3. To what extent, if any, does CAE tools (FEA and CFD) used in the LPD process influence product development cycle time?

Q4. To what extent, if any, does IT involvement in th eLPD process influence product development cycle time?

Hypotheses

H1$_0$. The type of part design CAD software used in the LPD process, such as Unigraphics, Solidworks, and ProEng, does not affect product development cycle time, as measured by the online survey.

H1$_a$. The type of part design CAD software used in the LPD process, such as Unigraphics, Solidworks, and ProEng, affects product development cycle time, as measured by the online survey.

H2$_0$. The supplier involvement in the LPD process does not affect product development cycle time, as measured by the online survey.

H2$_a$. The supplier involvement in the LPD process affects product development cycle time, as measured by the online survey.

H3$_0$. CAE tools (FEA and CFD) used in the LPD process do not affect product development cycle time, as measured by the online survey.

H3$_a$. CAE tools (FEA and CFD) used in the LPD process affect product development cycle time, as measured by the online survey.

H4$_0$. IT involvement in the LPD process does not affect product development cycle time, as measured by the online survey.

H4$_a$. IT involvement in the LPD process affects product development cycle time, as measured by the online survey.

Nature of the Study

The purpose of this quantitative non-experimental study is to examine factors that affect product development cycle time in LPD. The type of CAD software used, CAE tools (FEA and CFD) used, IT and supplier involvements in LPD were predictor variables and product development cycle time (waste) was the outcome variable. Upon Northcentral University's (NCU) institutional review board (IRB) approval, the research was conducted in compliance with ethical standards. The target population of this proposed study included engineers in design and manufacturing companies in the United States. Data were collected from at 61 participants who were currently employed within U.S. design and manufacturing industries through an online survey questionnaire. SPSS (version 20) statistical software was used to analyze normality and statistical significance of the predictor variables and scale reliability and internal consistency was calculated using Spearman's correlation coefficients and coefficient alpha. Linear regression analysis was originally going to be used to determine whether the predictor variables were statistically significant ($p < .05$) in relation to the outcome variable (cycle time) in LPD; however, the data did not meet the assumptions for linear regression. Therefore, ordinal logistic regression was used to determine these predictive relationships and test the hypotheses, since it does not have the same assumptions as linear regression (Agresti, 2013; Long, 1997; O'Connell, 2006). In addition, the nonparametric Kurskal-Wallis H test was used to determine the extent of the difference, if any, for hypothesis one and the Wilcoxon signed-rank test was used to determine the extent of the differences, if any, for the additional hypotheses.

Significance of the Study

Implementation of lean theory is essential to business success in the fast-moving global market (Pitta & Pitta, 2012). However, application of LPD is a difficult and complex process (León & Farris, 2011), although, there are a number of benefits of applying it in the field of product development (Hoppmann et al., 2011). Additionally, many organizations are struggling to optimize the product development process (Costa et al., 2013). Development of a new product is estimated to take 3 to 4 years, and approximately 50% of the costs incurred in product development are waste (Gurumurthy & Kodali, 2012). Elimination of waste is one of the most important parts of lean performance (Behrouzi & Wong, 2011). Therefore, application of LPD theories in the field of product development is the current focus of many organizations to maximize value, improve quality, reduce lead times, and reduce product development costs (León & Farris, 2011).

Although LPD literature is large and growing, there remains a gap regarding the theoretical development in LPD (León & Farris, 2011). Based on a literature review of 273 LPD related publications, only 37% involved academic research, 23% were clinical studies, and only 12% were centered on methodologies associated with LPD theory building (León & Farris, 2011). Exploring current LPD theories further is a promising area for future studies to improve the product development process (Hoppmann et al., 2011; León & Farris, 2011). Therefore, conducting this research regarding CAD, IT, and supplier influence on product development cycle time in LPD is important not only to possibly reducing product cycle time and cost of in the field of product development, but expanding LPD theory. The finding of this quantitative non-experimental study will likely be beneficial to the field of product development to reduce costs and product development cycle times to meet global market demands and sustain businesses as well as provide insight into the theoretical applications of LPD.

Definition of Key Words

Computer-aided design (CAD). The CAD model is a computer system used to create three-dimensional meshes of a design (Wang & Lin, 2012). CAD is used to create functions and different parts or features to evaluate engineering solutions (Veisz et al., 2012).

Computer-aided engineering (CAE). CAE is a computer program used to simulate and test engineering designs (Flumerfelt, Halada, & Kahlen, 2012). CAE can eliminate reworks, thus shortening design times and improving product quality (Amasaka, 2010; Onodera & Amasaka, 2012).

Computational fluid dynamic (CFD). CFD is a computer program used to solve and analyze fluid flow problems (Satyanarayana, Varun, & Naidu, 2013). In CFD, a computer model is used to simulate the fluids and gas interaction with surfaces of a system by giving necessary boundary conditions (Satyanarayana et al., 2013).

Design for six sigma (DFSS). DFSS, structured project model used for product design activities in six-sigma theories, is used to build defect and error free products (Chang & Su, 2007; Lee & Chang, 2010; Yang & Cai, 2009). DFSS is used to design products with greater tolerance and specification variances without affecting design performances (Gremyr & Fouquet, 2012).

Finite element analysis (FEA). FEA is a computer program used to solve elasticity, plasticity, heat transfer, and fluid dynamic problems in the engineering field

(Rizzo, 1994). In FEA, a large computer model is divided into many small elements and then these small elements are used to find the response of loads or stresses of a particular location (Flumerfelt et al., 2012).

Lean. Lean theory is a rule-based proven method that can be used to eliminate waste and maximize customer value in an organization. Waste can be over production, inventory, scraps, motion, waiting, and carrying and other non-value added activities in an organization (Laureani et al., 2010).

Lean product development (LPD). Application of lean theory-based theories to the product development processes is called LPD (Wang et al., 2012).

Lean manufacturing (LM). LM is a lean-based principle used to increase competitive advantage in manufacturing organizations by eliminating waste (Kovács, 2012).

Summary

Many manufacturing and design organizations are working to implement lean theories to eliminate waste, improve quality of products, and reduce product lead time to market to gain a competitive advantage (Sun, 2011). The main objectives of LPD are to minimize waste, improve quality, and reduce product life cycle and cost to satisfy the customer (Sören & Torgeir, 2013). LPD is currently the focus of many corporations to maximize value, improve quality, reduce lead times, and reduce product development costs (León & Farris, 2011). Implementation of lean theory is important to business success in the fast moving global market (Pitta & Pitta, 2012). Therefore, the purpose of this quantitative non-experimental study is to examine factors that affect product development cycle time in LPD. Part design CAD software used, supplier involvement, computer aided engineering analysis tools (FEA and CAE) used, and IT involvement are the predictor variables and cycle time (waste) is the outcome variable. The target population of this proposed study is U.S. design and manufacturing company engineers who currently use different CAD software, such as Unigraphics, Solidworks, and ProEng. Data was collected using online surveys via SurveyMonkey™. Nonparametric tests were performed to analyze and determine whether the data were significant.

The exploration of current LPD theories has been stated to be a promising area for future studies with respect to improving the product development process (Hoppmann et al., 2011; León & Farris, 2011). Therefore, the significance of this study lies in gathering data that is deemed important to possibly reducing product cycle time and cost of in the field of product development as well as expanding upon the theory of LPD. The finding of this quantitative non-experimental study will likely be beneficial to the field of product development in their efforts to meet global market demands and sustain businesses.

Chapter 2: Literature Review

The purpose of this quantitative non-experimental study is to examine factors that affect product development cycle time in LPD. The purpose is based on the problem U.S. manufacturing and product design companies are experiencing regarding waste and the goal to become lean in terms of eliminating time without sacrificing quality and customer satisfaction. With the help from various sections of U.S. industries to collect data through online surveys using SurveyMonkey™, the study was conducted to find the effect of part design CAD software used, supplier involvement, CAE tools (FEA and CFD) used, and IT involvement in the LPD process in reduction of cycle time (waste) in the design and manufacturing industries. Therefore, the content of the literature review centers on research regarding varying views and applications of lean theory, alluding to the gap that exists in the knowledge of the field and the need for this study.

A brief overview of the databases and search terms successfully utilized to locate sources of literature is provided in the documentation section. The history of lean theory is then presented followed by description of various applications of current lean theory and lean theory-based practices (LM and LPD). Benefits of lean practices to the environment and success factors for lean implementation are discussed in the subsequent sections. Successful LPD applications within different industries as well as the negative side of lean theory are discussed in the eighth and ninth sections. In the next three sections, (a) the effects of part design CAD software , such as Unigraphics, Solidworks, and ProEng, and CAE (FEA and CFD) tools on LPD, (b) effect of supplier involvement on LPD, and (c) effect of IT involvement on LPD are addressed. Lastly, the need for additional research, which provides supportive reasoning for the proposed study, is presented prior to the summary of the chapter.

Documentation

The journal articles and books used as references in this document were located utilizing from ProQuest, EBSCOhost, ScienceDirect, and SAGE databases through NCU's online library portal. For extracting articles, Boolean searches were performed using terms and phrases, such as lean product development, lean manufacturing, lean and information technology, lean and computer aided design, lean and computer aided engineering, lean and computer aided design, computer aided design, computer aided design tools, lean and supplier, lean practices and the environment, and lean theory.

History of Lean

The valuable lean theories of focusing on eliminating waste were born in the manufacturing sector of the industry. Womack, Jones, and Roos (1990) introduced five dimensions of lean theory: (a) specify the value according to customer demand: specify value from the view of the customer, (b) map—recognize the value stream: specify the team required to manufacture the product, (c) flow: make the value stream flow by eliminating barriers to improve lead time, (d) pull: let the customers pull the products they want and make products to match with customer demand, and (e) perfection: no end to the process, and continuous improvement. LM theories were introduced by Toyoda and Ohno of the Toyota Corporation in the 1950s and 60s (Womack et al., 1990). LM first started at the Toyota Corporation in Japan with the name Toyota Production System in the 1960s (Taj, 2008). The objective of the LM system is to identify and eliminate any processes and resources that have no value to a product (Upadhye et al., 2010). According to Moyano-Fuentes and Sacristán-Díaz (2012), LM is a management system that provides competitive advantages for an organization. Even though lean is well implemented in manufacturing to reduce waste, there are still other areas such as product development, process, marketing, quality, and shipping that need lean implementation to reduce waste further (Chiarini 2012). Moreover, eliminating waste in manufacturing cannot be reached only through manufacturing; it requires changes in other areas, such as product development, IT, supply chain, and marketing (Upadhye et al., 2010).

The focus of lean theories is to find the waste and achieve sustainable development through continuous improvements (Upadhye et al., 2010). The LM is based on the JIT theory, building parts required by the next process, and a pull system (Liker & Morgan, 2011). The applications of lean theories have been spread from manufacturing to service organizations and from job shop to process organizations (Upadhye et al., 2010). One of the areas that lean theories have been spread is in product development and is strongly focused on manufacturing (Hoppmann et al., 2011). However, it was realized that there are high benefits of applying lean theories in the field of product development (Hoppmann et al., 2011). Furthermore, expanding application of lean theories in product development is important to maximize customer value (Gudem, Steinert, Welo, & Leifer, 2013). Therefore, LPD is the focus of many corporations (e.g., Ford, General Electric) to maximize value, improve quality, reduce lead times, and reduce product development costs (León & Farris, 2011).

Current Lean Theory-Based Processes, Categories, and Tools

With technology and IT advancement and customers' high demand, manufacturers need to optimize their manufacturing process and improve supplier chain involvement to deliver high quality products faster to the market to beat global competition (Karim & Arif-Uz-Zaman, 2013). To overcome global competition and meet customer demand, organizations use lean theory to eliminate waste from production, supplier chain, product design, customer relationships, and plant management (Karim & Arif-Uz-Zaman, 2013). Lean theorists seek ways in which to reduce waste by optimizing core resources and establishing a dedicated corporate culture to satisfy customer requirements. Moreover, the objectives of lean theoretical application are to make quality products economically with less product development cycle time, human involvement, inventory, and space (Karim & Arif-Uz-Zaman, 2013). To achieve lean objectives, manufacturers implement many different lean tools and theoretical application to reduce non value added activities and waste (Karim & Arif-Uz-Zaman, 2013).

Lean philosophy has five core theatrical tenants: (a) finding customer defined values, (b) optimizing the value steam, (c) creating smooth flow by eliminating and controlling waste, (d) responding to demand pull by customer, and (e) maintaining quality of all products, services, and processes (Womack & Jones, 2003). The customers establish the value of the product based on demand, price, and time to market, which creates the value stream of the product, while value added steps find the product flow for manufacturing (Karim & Arif-Uz-Zaman, 2013). Next, customers pull final products through product order and the final principle, maintenance of quality, is implemented to integrate and perfect the process to implement the first four tenets (Karim & Arif-Uz-Zaman, 2013).

According to manufacturing organizations, it is important to select the best fit lean theories that have overall impact to identify waste (Karim & Arif-Uz-Zaman, 2013). Therefore, applying appropriate lean tools is valuable to the success of an organization

(Karim & Arif-Uz-Zaman, 2013). Wan and Chen (2009) introduced 12 lean tools: (a) concurrent engineering, (b) automation, (c) single minute die exchange, (d) cellular manufacturing, (e) efficiency of manufacturing, (f) line balancing, (g) quality, (h) standard work, (i) value stream mapping, (j) pull, (k) flexibility of workers, and (l) visual control. Twenty-two lean practices were established and grouped into four categories: (a) total productive maintenance, (b) total quality management, (c) just-in-time, and (d) human resource management (Shah & Ward, 2003).

Concurrent engineering. Concurrent engineering is a method that is implemented in the product development process using cross-functional teams (Nandedkar & Deshpande, 2012). There is a modified version of concurrent engineering called set-based concurrent engineering (Khan et al., 2011b). There are five set-based concurrent engineering theories: (a) value research: definition of the project based on innovation incorporation level and customer value, (b) map design space: definition of design scope and feasibility by design participants, (c) concept set development: developing and testing conceptual designs by each participant, (d) concept convergence: integration of a sub system to find the final optimum design, and (e) detail design: conclusion of final design and specifications (Khan et al., 2011b). Al-Ashaab et al. (2013) applied set-based concurrent engineering to Roles Royce helicopter engine LPD process. According to Khan et al. (2011b) and Raudberget (2010), there are many advantages of set-based concurrent engineering in the LPD process: eliminating reworks in the late design stage, optimizing the design, sharing and implementing knowledge throughout the product development process, and reducing product design failures. However, there can be many setbacks in set-based concurrent engineering: lack of a clear and structured model, lack of implementation guidance, and lack of case studies conducted when implementing (Al-Ashaab et al., 2013).

Single minute die exchange. Companies that make different types of products need to implement proper manufacturing process to satisfy all customers (Moreira & Pais, 2011). In lean manufacturing, single minute die exchange is used to standardize and simplify the manufacturing operations to reduce cycle time to response quickly to customers (Moreira & Pais, 2011). Single minute die exchange was developed in Japan to respond quickly to small production orders that required flexibility of customer demand (Ulutas, 2011). Moreira and Pais (2011) recommended more research on single minute die exchange using knowledge-based approach.

Cellular manufacturing. Cellular manufacturing creates multi cells by categorizing similar parts and required machines are placed into different machine cells to reduce cycle time in lean manufacturing (Torabi & Amiri, 2012). Additionally, value stream mapping gives current state and future maps of a process (Yang & Lu, 2011), while pull or kanban focuses to meet just-in-time production (Kumar, Choe, & Venkataramani, 2013). The goal of the pull (kanban) is that each station in the production line pulls only the required amount based on customer demand (Kumar et al., 2013). In the value stream, the scheduling point of the manufacturing system in pull is called the pacemaker process (Yang & Lu, 2011). Given the options with respect to lean theories, there are no logical procedures to select suitable lean theories for an organization from existing lean methods and implementing incorrect lean theories can increase waste, cost, and cycle time of a product (Karim & Arif-Uz-Zaman, 2013). Furthermore, little research has been conducted regarding the development of a structural method to implement lean properly (Karim & Arif-Uz-Zaman, 2013). Therefore, it is necessary to conduct more research on lean to find logical procedures to implement lean theories, such as total productive maintenance and LPD (Karim & Arif-Uz-Zaman, 2013).

5S. Good housekeeping can increase the overall productivity of a company (Oon, 2013). 5S, a good housekeeping process, is a lean theory that stands for sort, straighten (place in order), shine, systematize, and standardize (Feld, 2001). Lean companies are very neat by applying 5S to keep everything in order and in certain places to avoid needless transportation and other waste (Brennan, 2011). If 5S is not implemented properly in an organization, 5D (delays of delivering products, dissatisfaction of customers, defects of products, and declining profits) can occur (Singh, Gohil, Shah, & Desai, 2013).

Total productive maintenance. In manufacturing industries around the world, there are vast amounts of waste occurring in production shop floors (Singh et al., 2013). Machine failures, idle machines, scrap parts, startup loss, machine efficiency, process bottle necks, and idle labors are responsible for this waste (Singh et al., 2013). Total productive maintenance lean theory focuses to eliminate equipment breakdown, set-up time, machine idling, machine slow down, defects, rework, and improve production output (Ahuja & Khamba, 2007). The total productive maintenance offers a complete maintenance methodology to reduce waste in lean (Chong, Chin, & Hamzah, 2012). Furthermore, total productive maintenance is used in many design and manufacturing organizations to address idle machines, scrap parts, startup loss, machine efficiency, process bottle necks, and idle labors issues waste (Singh et al., 2013).

Total productive maintenance starts with 5S implementation in an organization (Singh et al., 2013). In total productive maintenance, the next step is autonomous maintenance (Jishu hozen) of machines by machine operators to manage small preventive maintenance such as cleaning of machines in order to free skilled maintenance staff (Singh et al., 2013). Planned maintenance is performed to achieve zero machine breakdowns, optimize maintenance cost, and improve maintainability and reliability of machines in the total productive maintenance process to produce quality products (Singh et al., 2013). Change for betterment (kaizen) is put into practice on a daily basis with a group of people of all levels to implement small improvements in an organization (Singh et al., 2013). Fail safing (poka yoke) methods are used to reduce mistakes in the lean total productive maintenance process (Singh et al., 2013). In their case study, Singh et al., (2013) increased machine effectiveness from 63% to 79% by applying total productive maintenance; this improves productivity and quality of product.

Total quality management. Maintaining competitive advantages leads to success of a company in the competitive global market by increasing productivity and profitability (Gürel, 2014). Since the product cost increases due to poor quality, the total quality maintenance approach provides an important contribution to reduce product cost, improve product quality, and customer satisfaction (Gürel, 2014). Total quality management technique involves the use of a Plan-Do-Check-Act procedure to determine root causes, as well as design, test, and implement a solution to reduce waste once a problem is found (Iyer, Saranga, & Seshadri, 2013).

Just-in-time. Just-in-time is an element of the lean manufacturing system (Ouma, Njeru, & Dennis, 2013). The objective of just-in-time is to reduce the inventory level by setting firm delivery dates and delivery intervals to have flexibility for the production (Akbalik & Penz, 2011). However, just-in-time is not economical in terms of the total transportation cost (Akbalik & Penz, 2011). Integration of transportation and storage decisions in the production planning process can improve supplier chain inefficiency within the just-in-time practice (Akbalik & Penz, 2011). In just-in-time lean manufacturing, companies can manufacture products when and what customers want (Ouma et al., 2013).

Process layout. Design and manufacturing companies are working to design their facilities to be lean and flexible to support customer's demand (El Khalil & Halawi, 2013). Therefore, companies focus on process layout to maximize the efficiency and productivity to reduce cost (El Khalil & Halawi, 2013). There are four different process layouts: (a) flexible-flow layout,- which is where equipment and resources are arranged by function (e.g., milling, welding, and drilling sections);, (b) line-flow layout,- which entails processes, zones, and systems are being organized in a linear pattern (e.g., automotive, and electronics companies);, (c) Hybrid layout,- which is a combination of flexible-flow and line-flow, and (d) fixed-position layout,- wherein equipment and employees do their work in fixed places (e.g., shipbuilding, and aerospace; Meyers, 1993).

Line balancing. Assembly line balancing is an important task in lean manufacturing, especially for mass production (Görener, Baser, & Türkyilmaz 2013). If the assembly line is imbalanced, productivity of the production reduces, as workload for workers is unequal (Görener et al., 2013). By line balancing, works are grouped and work stations are arranged accordingly (Görener et al., 2013).

Automation. Product and system designers face great tension to meet growing mass customization requirements to satisfy customers (Fasth-Berglund & Stahre, 2013). Automation of the manufacturing line is one of the solutions to meet mass customization (Fasth-Berglund & Stahre, 2013). According to Fasth-Berglund and Stahre (2013), the right automation strategy is required to maintain product sustainability in a globalized market. In their three case studies, Fasth-Berglund and Stahre found product automation becomes important to meet mass customization.

Human resource management. Adoption of lean theories needs organizational changes as it requires strategic changes in an organization (Bhasin, 2012). Listening to employees and convincing employees to adopt to lean are important factors to implement lean successfully (Sim & Chiang, 2012). The intent of human resource management is to interface with other subsystems to improve efficiency and effectiveness of an organization (Emanoil & Nicoleta, 2013).

Lean accounting. Lean accounting is another lean theory that organizations are adopting in order to better understand the cost management system (Ofileanu & Topor, 2014). In traditional accounting, mass production (push system) is used that create overproduction (Ofileanu & Topor, 2014). Overproduction is a critical loss according to lean theories as it requires all the cost of the continues function of all machines without any demand from customers (Ofileanu & Topor, 2014). In lean accounting, target cost is obtained from value stream to reduce cost to bring value stream cost and target cost to the same level ensuring customer value and company benefit (Ofileanu & Topor, 2014). Value stream is a process improvement tool in LM used to visualize the material and information flow of the manufacturing process (Singh & Singh, 2013). According to

Ofileanu and Topor (2014), applying lean accounting theory in an organization can eliminate waste and reduce cost.

Though many lean theories are available, concurrent engineering, cellular manufacturing, 5S, process layout, total quality management, line balancing, single minute die exchange, and automation are the most used lean theories in the industries (Karim & Arif-Uz-Zaman, 2013). While most of these lean theories can be applied in LM, they cannot be implemented in LPD. LM is much more popular in industries compared to LPD processes; LPD requires contribution from different functional areas due to this complexity (León & Farris, 2011). Therefore, it is necessary to find more lean theories related to LPD.

Benefits of Lean Practices on the Environment

Global warming is a big concern among people in the world, and researchers are continually working to reduce global warming (Fowler, 2012). Lean thinking is a key method that can be integrated with environmental sustainability to reduce global warming and support the ecosystem (Pampanelli, Found, & Bernardes, 2013). Lean practices can have a positive impact on the reduction of global warming (Dües, Tan, & Lim, 2013). In fact, lean companies are greener than non-lean companies, lean application can be beneficial to reduce the negative impact on the environment, and integration of lean and green can be beneficial to organizations (Dües et al., 2013). To become green or environmentally friendly, it is necessary to reduce or eliminate pollution in production. There are two types of environmental practices: pollution prevention and pollution controlling (Hart 1995). Verrier, Rose, Caillaud, and Remita (2013) conducted a literature review from 150 papers on lean and green topics and found only 47% of U.S.

companies are practicing lean and green. Moreover, there was a lack of focus on product life cycle when applying green lean theories (Verrier et al., 2013). However, there was significant improvement in lean application in the supplier chain (Verrier et al., 2013). In spite of the low percentage of U.S. companies practicing lean and green, lean and green practices are growing in corporations and academic institutions (Mollenkopf, Stolze, Tate, & Ueltschy, 2010). The growth in concern and practice indicates lean theories are important to having a green world and there is more opportunity to conduct research on lean theories in order to increase the development of more green companies.

Different materials used to make products cause different levels of damage to the ecosystem (Menikpura, Sang-Arun, & Bentsson, 2013). Damage to the ecosystem is measured by the potentially disappeared fraction (PDF) in the following formula: PDF m2global year (Carvalho, Serra, & Lozano, 2011). The meaning of the formula, PDF m2global year, is the potentially disappeared fraction of a square meter of land in a given year, anywhere in the world (Carvalho et al., 2011). Based on this formula, the amount of damage to the ecosystem caused by recycling one tonne of paper was measured at 15,800, plastic was 38,500, glass was 12,100, aluminum was 5,490, and metal was 12,100 (Menikpura et al., 2013). Similarly, damage to the ecosystem by virgin production of one tonne of paper was 14,500, plastic was 72,900, glass was 16,800, aluminum was 167,000, and metal was 33,300. Net damage to the ecosystem by recycling one tonne of paper was 1,380, plastic was -34,400, glass was -4,740, aluminum was -161,000, and metal was -52,500. Clearly, aluminum causes minimum damage to the ecosystem by recycling, and metal, plastic, glass, and paper follow respectively in terms of damage. While recycling can reduce the damage to the environment, recycling alone cannot solve the environmental damages (Menikpura et al., 2013). Therefore, a supplier's involvement in manufacturing is vital to becoming environmentally friendly (Yang, Lin, Chan, & Sheu, 2010). Supplier collaboration in production is important to becoming green as is the selection of material and supplier involvement to improve the environmental impact of the LPD process (Galeazzo, Furlan, & Vinelli, 2013; Hart, 1995).

Success Factors for Lean Implementation

Many organizations have failed in implementing lean theories due to a lack of implementation methodology, and a clear understanding of lean execution (Behrouzi & Wong, 2011). To avoid failure of lean applications, Anvari, Norzima, Rosnay, Hojjati, and Ismail (2010) identified 11 lean success factors: (a) leadership and management, (b) purpose and objectives, (c) company cultures, (d) troubleshooting, (e) continuous improvement, (f) financial ability, (g) execution measure, (h) change, (i) plan, and (j) education. To obtain these success factors, there are three lean steps: (a) preparation, (b) design, and (c) implementation (Anvari et al., 2010). Similarly, Parry, Mills, and Turner (2010) introduced a four step method to implement lean successfully: (a) market study, (b) financial construction, (c) visible values stream, and (d) customer values study. Thus, it is important to adopt a proper method of implementation of lean theories to be successful as there are many factors to be considered in order to implement lean theories properly (Karim & Arif-Uz-Zaman, 2013). However, few researchers have conducted studies regarding the development of a solid method to implement lean theories (Karim & Arif-Uz-Zaman, 2013).

Application of Lean

When it comes to lean, many think that lean can be applied only to the manufacturing sector of an organization (Eisenhardt & Martin, 2010). However, evidence indicates that lean has spread to areas like healthcare and public sectors (Plowman, 2010). Pedersen and Huniche (2011) analyzed the effect of lean theories in the Danish public sector organizations. They concluded that the processes and outcomes of lean depend not only on the technology fields, such as manufacturing and product development, but also in other areas, such as the public sector (Pedersen & Huniche, 2011). Kestle, Potangaroa, and Storey (2011) studied integration of lean design and design management thinking influence of the development of a conceptual design management model for remote site projects in the drilling fields in New Zealand and Australia. Lean design management and design management literature have been found to be an important contribution of process integration and value generation to the development of the conceptual design management model for remote sites, such as the drilling fields in New Zealand and Australia (Kestle et al., 2011). This finding indicated lean theories can be applied not only to product development and manufacturing industries, but also to other areas, such as the public sector as suggested by Pedersen and Huniche (2011). Therefore, it is clear to say that lean theories can be applied universally for any field, and there are many areas to discover in lean theories.

Vinodh, Arvind, and Somanaathan (2011) focused on finding various issues of sustainability using lean initiatives and found that after applications of lean theories, a company can gain benefits in both lean and green at the same time without spending extra money. Further, waste, such as over-production, over-processing, waiting, defects, inventory, and storage are considered deadly environmental waste (Vinodh et al., 2011). Based on the findings, a company can gain environmental benefits by adopting lean theories. This indicated that lean is an essential component of sustainability of the world, therefore, spending more time to research lean is beneficial for sustainability of both the environment and an organization.

A company cannot only gain environmental benefits as substantiated by Vindoh and Somannaathan (2011), but also worker benefits may be gained by the adoption of lean theories (Bonavia & Marfin-Garcia, 2011). Bonavia and Marin-Garcia (2011) conducted a non-experimental quantitative study in a ceramic manufacturing company in Spain to find the effects of lean theories on the policy of human resource management, and to determine if practicing human resource management related to lean production effects on the performances of workers. Bonavia and Marin-Garcia found that the combination of lean theories with human resource management practices reduces inventory and improve productivity. Also, it found that companies that use most of lean practices train workers and provide workers' job security (Bonavia & Marin-Garcia, 2011).

The LM system is implemented to maximize customer value and minimize waste (Gecevska et al., 2012). The five steps of lean practice in lean product life cycle management are (a) identify value, (b) map the value stream, (c) create flow, (d) establish pull, and (e) seek perfection (Gecevska et al., 2012). These five steps of lean product life cycle management need many essentials fulfilled to be successful. However, application of lean theories in product development is more difficult compared to application of lean theories in manufacturing (Soares, Bastos, Gavazzo, Pereira, & Baptista, 2013). Despite the difficulties of applying lean in product development, it is beneficial to apply lean theories in product development (Soares et al., 2013). Furthermore, lean theories can be applied to a new product introduction environment (Winter et al., 2013), which indicates the application of lean in product development is possible.

The conventional product development procedure (stage-gate process) was viewed by Nepal et al. (2011) as not being enough to meet requirements for the future global market. However, Hoppmann et al. (2011) argued that current LPD was built on small empirical studies that were biased to the Toyota Corporation, the inventor of the lean and LPD theories in the automotive industry (Thyssen, Emmitt, Bonke, & Kirk-Christoffersen, 2010). Moreover, Nepal et al. discussed an improved product development process (concurrent engineering) to reduce product development time in their case study. Furthermore, the LPD process is the most suitable solution to the current product development process issues (Nepal et al., 2011). León & Farris (2011) described LPD as more complex compared to LM. Liker and Morgan (2011) supported León & Farris's assertion that translating the LM theories to LPD is a challenge. In fact, Liker and Morgan conducted a study on the LPD process and found implementing the LPD process reduced production time by 50% at the Ford body and stamping plant. By applying lean theories, the Toyota Corporation improved profitability and productivity by reducing production cost by $2.6 billion out of 113 billion total cost in 2011, Zara corporation reduced cycle time by 12 times and launched 30,000 designs per year compared to 2000-4000 introduced by Zara corporation's competitors, and the Toyota Corporation improved quality and customer satisfaction by receiving maximum safety rating for the Toyota Lexus CT200h in 2111 (X. Wang, Conboy, & Cawley, 2012). This is a solid indication the LPD method can reduce cycle time (waste) significantly. However, it is noted that conducting research on LPD is more complex compared to LM theories and LM theories cannot be directly applied to LPD (Liker & Morgan, 2011).

Theories Similar to LPD

LPD and design for six sigma (DFSS) theories are applied to the product development process to improve quality and reduce the cost of products (Gremyr & Fouquet, 2012). The combination of six sigma and lean is called lean six-sigma. Lean Six-sigma theories, data-driven and result-oriented methods, are used for process improvement (Saini & Sujata, 2013). DFSS is an element of six-sigma. DFSS, structured project model used for product design activities in six-sigma theories, is utilized to build and detect error free products (Chang & Su, 2007; Lee & Chang, 2010; Yang & Cai, 2009). Furthermore, DFSS is used to design products with greater tolerance and specification variances without affecting design performances (Gremyr & Fouquet, 2012). Both six-sigma and lean theories have been applied to product development to improve the process and reduce cost in organizations (Gremyr & Fouquet, 2012). The goal of the six-sigma theories is the execution of projects using the defined system called DMAIC (define, measure, analyze, improve, and control; Saini & Sujata, 2013).

In the define step, the team identifies essential items that are critical to quality based on the voice of the customer (Arumugam, Antony, & Douglas, 2012). The team defines the problem, identifies the customer demands, and finds suitable team members for the project (Berardinelli, 2012). The defining phase will help the team to find the appropriate process through process maps and flowcharts (Arumugam et al., 2012). In the measure phase, data is collected regarding the critical to quality items (Lokkerbol, Schotman, & Does, 2012). Furthermore, in the measurement phase, measurement systems are identified and validated with reliable data (Berardinelli, 2012). In the Analyze phase, the team identifies necessary inputs and finds root causes of the problem (Berardinelli, 2012). In the Improve phase, the team identifies solutions to the problem and optimizes the process (Berardinelli, 2012). In the control phase, the team establishes the measurements and action plan (Berardinelli, 2012). Furthermore, the team implements the long-term measurement plan to avoid further mistakes in the control phase (Berardinelli, 2012).

To find the differences and similarities between DFSS and LPD practices, Gremyr and Fouquet (2012) investigated seven companies that used either LPD or DFSS theories. Although DFSS is used to meet full six-sigma performances, there are many difficulties implementing DFSS in the product development process (Gremyr & Fouquet, 2012). One difficulty of implementing DFSS is that it requires extensive training programs as many DFSS tools are advanced (Shahin, 2008). Furthermore, applying general DFSS theories without considering placing the product development process at the correct level can damage innovation culture of an organization (Goh, 2009). Robustness, reliability, and quality of product design cannot be fully achieved by implementing LPD (Yang & Cai, 2009). To overcome drawback of both DFSS and LPD, Gremyr and Fouquet (2012) suggested the merger of LPD and DFSS to improve quality and reduce product development cycle time. The merger of LPD and DFSS is called design for lean six-sigma (Gremyr & Fouquet, 2012). Benefits of merging LPD and DFSS is that it can reduce unwanted variations in DFSS and reduce product development cycle time that is the focus of LPD (Gremyr & Fouquet, 2012). This indicates that DFSS and LPD have some similarities, though they have different approaches.

Successful LPD Applications in Industries

Personnel within organizations are focused on reducing development time and cost in the product development process (Sopelana, Flores, Martinez, Flores, & Sorli, 2012). Therefore, top managers, engineers, and employees in industries around the world are continuously working to reduce the cost and improve the quality of their products to be sustainable and more competitive in the global market (Florida, 1996). These managers use many techniques to improve their manufacturing process and product development process (Psomas, Fotopoulos, & Kafetzopoulos, 2011). One of the leading methods they use is lean theory to reduce waste and the cycle time. Implementing lean theories can reduce product development cycle time in an organization (Calantone & Di Benedetto, 2012).

Although individuals at the Toyota Corporation invented and used lean theories initially, many managers in other organizations have successfully used lean as quality productivity initiatives to gain economic advantages in recent years (Gershon, 2010; Huehn-Brown & Murray, 2010). For example, when Toyota and Mazda LPD theories were applied to the Ford Body and Stamping facility, benefits were noted (Liker & Morgan, 2011). After implementing lean theories, Ford Body and Stamping management were able to reduce lead time for building a new car body by 50%, equipment costs by 45%, and decreased labor hours per tool by more than 50% (Liker & Morgan, 2011). Furthermore, Ford was able to increase the productivity by 400% and reduce die hit times from 6-7 hits to 3-4 hits in this facility (Liker & Morgan, 2011). However, based on Huehn-Brown and Murray's (2010) study to find the level of the lean and six-sigma application in the supplier chain of 179 automotive companies in the United States, only 30.23% of the companies were using lean and six-sigma theories. Six-sigma was introduced by the Motorola corporation in 1980 (Timans, Antony, Ahaus, & Van Solingen, 2012). Six Sigma theories are used to improve quality of products (Kumar, Nowicki, Ramírez-Márquez, & Verma, 2008). The conclusion was that the majority of companies in the United States were still not adopting lean theories (Huehn-Brown & Murray, 2010).

The Goodyear product development and research and development center personnel in Peru have successfully implemented LPD theories (Kihn, 2012). Before implementation of LPD, Goodyear in Peru required 1 to 2 years to develop a new product and an additional one to several days to weeks to deliver a product to the customer (Kihn, 2012). Furthermore, the company had a delivery rate of 30% before implementing LPD and interestingly, Goodyear management in Peru was able to improve the delivery rate to 90% after implementing LPD (Kihn, 2012). Plowman (2010) supported Kihn (2012) stating that implementing lean can improve the cycle time ranging from 15% to 80%.

In the LPD implementation process at ABC manufacturing, analysis of the current product development process using value stream, cause and effect matrix, and design structure matrix to identify non-value added activities was completed (Nepal et al., 2011). Through their study, Nepal et al. found significant waste in the current product development process. Significant delays in the product development process were incomplete voice of the customer (19 weeks), no business case (30 weeks), low quality tolerance loop methods (12 weeks), wrong cost modeling (15 weeks), quotations (6 weeks), and resource change (5 weeks; Nepal et al., 2011). This indicated that it took considerable time to complete the PD cycle with the existing situation at ABC manufacturing. After implementing LPD theories, ABC manufacturing management were able to reduce the product development cycle time by 32% in the first phase (Nepal et al., 2011). Therefore, the use of LPD theories indicated some significant improvements in this particular situation.

The productivity in new product development has declined, even though developing new products can satisfy customers and increase productivity (Cooper & Edgett, 2008). Cooper and Edgett (2008) analyzed 5-year sales of new products and research and development spending in various corporations. Focused on customers, spiral development, cross-functional team effects, matrices, continuous improvements, focus on effective management portfolio, and next generation stage gate process, lean theories were examined to see the effect on new product development in the study (Cooper & Edgett, 2008). The Toyota Corporation applied all these seven theories in their new product development process, Procter & Gamble applied six out of the lean theories, Danfoss Corporation adopted these lean theories to reduce waste, and Apple Computer-implemented these theories to reduce product life cycle time (Cooper & Edgett, 2008). Agus and Mohd (2012) supported Cooper and Edgett, recommending the study of customer requirement of product quality and market performance to improve LM. These examples indicate that lean implementation is practical and necessary for the success of the business in an organization (Agus & Mohd, 2012; Cooper & Edgett, 2008).

In order to investigate the relationship between lean strategies and existing resource-based view strategies in the UK aerospace industry, Parry et al. (2010) conducted a case study of Dowty Propeller Repair and Overhaul’s implementation of lean theories. The study consisted of a market study, making the value stream visible, customer value analysis and financial modeling. To identify the voice of the customers, Parry, et al. conducted customer interviews with company issued questionnaires. The market analysis was used to provide external validation. The value stream (one of the lean theories) study was performed on the composite blade product at Dowty and indicated 11 processes were needed for improvement. Twelve months after the case study, the company gained European aftermarket share rising from 5% to 50% (Parry et al., 2010).

By implementing lean theories, organizations can reduce waste and improve the quality of a product and the productivity of a company (Kovács, 2012). Furthermore, lean theories are used to eliminate waste in every area from product design to supplier management, customer relations, and plant management in industries (Karim & Arif-Uz-Zaman 2013). However, applying lean theories inappropriately can increase waste, cost, and production cycle time (Karim & Arif-Uz-Zaman 2013). Therefore, it is vital to take the necessary actions to implement lean theories correctly in organizations to reduce waste, product cycle time, and gain a competitive advantage (Karim & Arif-Uz-Zaman 2013; Wang et al., 2012).

A concurrent engineering framework for lean applications has been proposed based on research conducted by Pullan, Bhasi, and Madhu (2013). By implementing concurrent engineering lean theory, a company can reduce product development time by 50% (Pullan et al., 2013). For example, the Boeing company reduced 18 months of product development cycle time by implementing concurrent engineering when the company designed the Boeing 777, compared to the Boeing 767 product development cycle time (Sharma & Bowonder, 2004). Concurrent engineering helped the Boeing Company to introduce new aircrafts faster than its competitor, Airbus Industries (Meybodi, 2013). However, while this further shows that implementing lean theories are important for reduction of product development cycle time, few proper lean applications have been developed in the industry (Karim & Arif-Uz-Zaman, 2013). Hence, it is recommended to discover more lean theories in LPD to apply in industries to reduce waste and improve the quality of products further to improve productivity (León & Farris 2011).

Negative Side of Lean

Lean has been described as having several loopholes, such as the process is not under statistical process control, no evaluating variations in the measurement system, and no mathematical tool to diagnose the process to improve quality (Gershon & Rajashekharaiah, 2011). However, these loopholes are commonly deemed negligible when compared to the benefits of lean. Therefore, stakeholders should study the organizational structure of the companies and or industries regarding the implementation of lean theories to gain lean benefits in order to be successful (Gershon & Rajashekharaiah, 2011).

During the first decade of the 21st century, many organizations failed to practice lean theories due to the lack of proper lean implementation methods and better understanding of lean performances (Behrouzi & Wong 2011). For example, the impact of nonfinancial manufacturing performance on LM and financial performance was studied (Fullerton & Wempe, 2009). Fullerton and Wempe (2009) found that nonfinancial manufacturing performance measures can be utilized to mediate LM and financial performance relationships. However, the evidence showed that lean production effect on financial performance is mixed (Callen, Fader, & Krinsky, 2000; Hansson & Eriksson, 2003; Kinney & Wempe, 2002). Besides, though many organizations think the application of lean theories is critical for the sustainability of organizations, some company leaders are still not willing adopt lean theories (Dombrowski & Mielke, 2013). Thus, it is important to analyze if the practice of lean theory has a large effect on the financial side of an organization.

With respect to the financial perspective of implementing lean theoretical practices, variation of performance effects has been noted to be due to unsystematic adoption of lean by managers (Cua, McKone, & Schroeder, 2001). According to Radnor and Johnston (2013), organizations focused on cost reduction by implementing lean theories without considering the value of customers. This is an example of lean theories applied in the wrong way in the lean service sector (Radnor & Johnston, 2013). This issue could be resolved if a company's management adopts lean theories by teaching managers and employees in the organization (Cua et al., 2001). Specifically, Balakrishnan, Linsmeier, and Venkatachalam (1996) found small financial benefits could be gained by adopting the JIT lean concept. JIT is a lean concept that is employed to minimize inventory (Nicholas, 1998). Fullerton and Wempe's (2009) study indicated that workers and managers should find the reasons for problems which hinder success in lean strategies. In fact, there is a relationship between lean theory and application if proper actions are taken to implement lean theories (Fullerton & Wempe, 2009). Additionally, manufacturers may use LM continuously if they practice lean regularly (So & Sun, 2010). Therefore, it is important shop-floor employees and management have regular involvement in successfully implementing lean theories (Balakrishnan et al., 1996; Cua et al., 2001; Fullerton & Wempe, 2009; So & Sun, 2010).

To test a theoretical model on LM practice, So and Sun (2010) conducted research involving 558 manufacturing companies in 17 countries. The companies were divided into two groups (small and large firms) to find if there was any significant difference between these two groups. Supplier integration had a positive effect on small and medium companies, but not for larger companies (So & Sun, 2010). However, small and medium size companies are more willing to implement LM theories compared to large companies (Krishnamurthy & Yauch, 2007; So & Sun, 2010). The reason for this is that small and medium size companies have simple organizational structure and supply chain (Krishnamurthy & Yauch, 2007). This could be one of the negative sides of lean.

A study of the relationship between LM and workers' commitment indicated that workers' commitment is not supported by lean theories, but designing and operating the lean theories must be backed by management and human resource practices (Angelis, Conti, Cooper, & Gill, 2011). The implication is that lean theories cannot be implemented by themselves; lean theories need management support. If the management is incapable of designing and operating lean, lean theories are not effective (Angelis et al., 2011). It is necessary for organizations to have managers who are knowledgeable of lean theories and application techniques before implementation of lean. This is also a negative side of lean implementation. Furthermore, Angelis et al. (2011) stated that multiskilled workers' commitment to do overtime voluntarily is also important for the success of implementing lean theories. Therefore, it is likely necessary to change the culture at the workplace to implement lean properly (Angelis et al., 2011).

The effect of lean on working conditions and the health and happiness of employees was the purpose of the study by Hasle, Bojesen, Jenson, and Bramming (2012). Halse et al. (2012) found that lean has negative effects on working conditions and employee health in manual work conditions. Similarly, Sim and Chiang (2012) discovered in their study of three U.S. firms that the management requested over works in LM system, causing poor work life. Including actions, such as assessing the shop floor condition before implementing lean, is recommended in order to be successful (Moyano-Fuentes & Sacristán-Díaz, 2012). With respect to workers' health and safety issues, Nike, for example, included improvements of labor compliance to Nike lean practices (Distelhorst, Hainmueller, & Locke, 2013). Furthermore, including labor compliances to lean was also noted as improving labor conditions at the Nike corporation (Distelhorst et al., 2013). Moreover, lean cannot exist in a corporation if the culture is against it (Atkinson, 2010; Schein, 2010). Lean implementation can fail due to culture and change (Bhasin, 2012).

Although lean and green have many common focuses, there are areas where lean and green cannot be combined (Dües et al., 2013). There are differences between lean and green views: lean views the environment as a valuable resource, while green views the environment as a constraint for product designing, manufacturing, and services (Franchetti, Bedal, Ulloa, & Grodek, 2009). This indicates there is a potential conflict between lean theories and focuses of environmentally friendly practices (Dües et al., 2013). Moreover, Rothenberg, Pil, and Maxwell (2001) conducted a study on the painting process of 17 manufacturing plants and found that there is no trade-off between lean and green. For example, painting cars with the same color reduces air pollution, but it does not align with lean (JIT) theories; lean practices are aimed at elimination of reworks to reduce cost, manufacturing of spray paint to reduce cost, and improving quality (Rothenberg et al., 2001). This shows that lean is not always green. Therefore, lean companies may need to compromise some of their lean practices to achieve environmental friendliness (Dües et al., 2013).

Effect of Part Design CAD Software and CAE Tools (FEA and CFD) on LPD

Even in the 21st century, many companies use drawing boards and pencils to design parts, create drawings, and part assemblies (Mclaren, 2008). However, usage of CAD software has become a standard practice in product design (Brière-Côté, Rivest, & Maranzana, 2013). Compared to the manual method, the CAD method is faster in meeting customer demand and gaining competitive advantages (He & Fiorito, 2007). Industries are using CAD and CAE software in product development process to meet cost and timing (Son, Na, & Kim, 2011). In 2011, the number of CAD users in the development and design industry was 19 million with it estimated to have continued to expand (Thilmany, 2013). Moreover, using CAD software can reduce development time and lower the cost compared to conventional methods (Fixson & Marion, 2012). Utilization of CAD in each step of design is important (Veisz et al., 2012). Due to this reason, many corporations currently use CAD software for part design, creating two dimensional drawings, and making part assemblies during the product development process to reduce time and improve quality. However, few studies have been conducted to find the effect of CAD implementation on design quality and creativity (Robertson & Radcliffe, 2009). The impact of CAD usage and its effect on cross-functional team performances in product development process should be studied (Nandedkar &

Deshpande, 2012).

CAD feature information is vital to improve the product development process, which is the scope of product lifecycle management (Eigner, Handschuh, & Gerhardt, 2010). Furthermore, the consistent use of light weight feature information in the CAD system is important (Eigner et al., 2010). Eigner et al. (2010) compared JT (a data formatting system developed by Unigraphics Solutions) to the standard for the exchange of product model data (STEP), another CAD data formatting system. Eigner et al. discovered that JT file formatting system is lean as JT needs less storage compared to STEP. This finding is interesting as usage of the CAD formatting system can influence product development cycle time. However, Eigner et al. did not compare data formatting systems that use other major CAD software developers, such as ProEng, SolidWorks, and Unigraphics.

CAD software has been used to reduce product design cycle time in product development (Zehtaban & Roller, 2013). In fact, CAD and CAE were deemed important for reducing waste in the product development process (Vinodh & Kuttalingam, 2011). However, CAD and CAE software do not perform in the same way; some CAD and CAE software are more accurate and faster than other software (Zehtaban & Roller, 2013). For example, a case study of an automotive sprocket manufacturer indicated the application of CAD and CAE reduced the product deployment cycle time and improved the flexibility of designing new products (Vinodh & Kuttalingam, 2011). However, only one CAD software package (ProEng CAD) was used (Vinodh & Kuttalingam, 2011), when in fact, organizations use many different CAD software packages, such as Unigraphics, I-DEAS, and Catia, to design parts, prepare engineering drawings, and model assemblies

(Brunnermeier & Martin, 2002). Moreover, some software may be efficient compared to other CAD software programs regarding saving design time and improving the quality of the part. The recommendation was made for future research to be conducted on topology, shape, and size optimization for design optimization using CAD and CAE software (Vinodh & Kuttalingam, 2011).

Due to the complexity of current product designs, application of CAD and CAE tools in product development has increased in recent years (Su, Liu, Huang, & Hsu, 2012). With experiments to verify reliability and accuracy, CAD and CAE tools (FEA and CFD) can be used for multiple design changes in product design and process optimization to reduce time and cost required for the product development process and improve the quality of the product (Su et al., 2012). However, as there are two different teams in CAD and CAE departments, there tends to be poor communication between CAD and CAE teams, which decreases the integration benefit (Su et al., 2012). Su et al. (2012) suggested having a seamless CAD and CAE integration to verify and validate designs effectively, comparing to the traditional trial and error method.

Besides the reduction of production cost, organizations are working to make green and clean products to be more sustainable in the market (Bevilacqua, Ciarapica, & Giacchetta, 2007). The practice of environmental friendly design involves less material usage, easy disassembly, reusable products, less energy consumption, and manufacturing without dangerous waste using clean technologies (Chu, Luh, Li, & Chen, 2009). To fulfill these requirements, design engineers are working to design environmentally friendlier products (Vinodh, 2011). Vinodh (2011) conducted a sustainability analysis using a CAD model to find the environmental impact. In this case study, an existing rotary switch was modeled using CAD software and the design was optimized using CAE software. Vinodh discovered that proper design modifications using CAD and CAE could reduce the environmental impact. Therefore, it was concluded that it is important to use CAD and CAE software to design and optimize parts in LPD to reduce waste and improve quality (Vinodh, 2011). However, Brière-Côté et al. (2013) compared different CAD software and found that they are different in performances. Therefore, it is also vital to identify the most efficient CAD software to design parts as the CAD software can impact the time required to design parts as well as the quality of the parts (Brière-Côté et al., 2013). However, it is noted that there has been no research conducted on a combination of CAD and CAE (Vinodh, 2011). In addition, conducting more research to minimize the environmental impact at the early stage of the product development process is recommended (Vinodh, 2011). Accordingly, it is necessary to conduct more research on CAD and CAE software impact on LPD to reduce waste, improve product quality, and reduce environmental hazards (Vinodh, 2011).

CAD operators' performances can be varied based on many factors. Alducin-Quintero and Contero (2012) conducted research to find the relationship between CAD user performances and design annotations. There is a significant relationship between CAD user performances and design annotations, thus indicating that CAD operators' performances can be outcome on other factors, such as CAD software type (Alducin-Quintero & Contero, 2012). However, there is no research regarding the relationship between CAD software type, such as Unigraphics, ProEng, and SolidWorks, and CAD user performances that could affect the product development cycle time in LPD (Alducin-Quintero & Contero, 2012).

Effect of Supplier Involvement on LPD

Supplier involvement in the new product development process is one of the important components to improve the productivity of a company (Johnsen, 2011). Proper supplier involvement is critical to the success of a corporation in a comparative market (Merzifonluoglu & Feng, 2014). Supplier involvement management has long and short term benefits (Al-Abdallah, Abdallah, & Hamdan, 2014). In the long term, it increases profits and market share while creating value customers and improving efficiency of production (Williams, 2006). In the short term, it reduces cycle time and inventory and improves productivity (Wisner & Tan, 2000). Many successful firms get suppliers' support to develop their products to reduce cost and time (Marion & Friar, 2012). To meet global market requirements, organizational personnel are also integrating suppliers into their research and product development process (Perng, Lyu, & Lee, 2013). Supplier involvement in the early stage of the product development process can reduce cycle time and cost of the product (Perng et al., 2013). Moreover, application of lean to the supplier chain system can reduce product cost in the industry (Hongpiriyakul, Sirivongpaisal, Suthummanon, Kongkaew, & Penchamrat, 2014). However, companies are still behind the methodical approach to integrate suppliers to their product development process (Perng et al., 2013). As market competition continues and technology advances, management at firms collaborate with their suppliers to achieve technological innovation (Naqshbandi & Kaur, 2011). Furthermore, supplier involvement in the new product development process increases the productivity and allows companies to gain a competitive advantage (Lau, 2011; Oh & Rhea, 2010). In fact, building a close relationship with the supplier is part of lean strategies (Jayaram, Vickery, & Droge, 2008).

In the fast moving business world, innovation is the key to organizations' sustainment (Chang, Tsai, & Hung, 2013). To become innovative, companies require a close relationship with suppliers and customers (Naqshbandi & Kaur, 2011). Therefore, the supplier is one of the important components of an organization to be successful. In addition, over 50% of the cost of a product is component costs (i.e., supplier costs; Handfield, Ragatz, Petersen, & Monczka, 1999). In fact, in recent years, product cycle time has become shorter than previously as customers are demanding shorter delivery time (Li, Gu, & Wang, 2010). To fulfill the customer's tough demand, it is necessary to reduce company waste, such as product cycle time and cost, as described in LPD to deliver product in time at a competitive price (Li et al., 2010). Furthermore, to meet shorter product cycle time and lower cost, suppliers' cooperation is imminent (Che, Chiang, Tu, & Chiang, 2010). Therefore, it is important to find the most suitable component suppliers for an organization to be successful (Che et al., 2010).

New product development is a major strategic activity and shorter lead time to the market is critical to the long term success of a corporation (Hilletofth & Eriksson, 2011). In fact, for both of these goals, the supplier is the key to the success as the supplier is the driving factor of these goals. Furthermore, if an organization has a close relationship with the supplier, who is continuously willing to discover new methods to reduce product cycle time, cost, and improve quality to fulfill lean concept, this organization has a more competitive advantage over other companies in the industry. Hilletofth and Eriksson (2011) conducted a case study of an internationally operated Swedish furniture wholesaler to find the relationship between new product development and supply chain management. Hilletofth and Eriksson argued the necessity of having concurrent product design with collaboration of supplier chain to meet global competition and improve profits. Kotler, Keller, Brady, Goodman, and Hansen (2009) supported Hilletofth and Eriksson stating that cross-functional or multifunctional teams should be a component of new product development teams. However, new product development is not an easy task (Hilletofth & Eriksson, 2011); the failure rate of new product introduction can be as high as 95% in the United States and 90% in Europe (Ogama & Pillar, 2006). Cooper and Edgett (2008) supported Ogama and Pillar (2006) stating that productivity of new product development has declined in recent years.

Eliminating waste in order to be successful is a big issue for companies (Sun, 2011). In fact, eliminating waste in the product development is the major goal of LPD (Wang et al., 2012). By monitoring customer requirements closely in the new product development process, a Swedish furniture wholesaler was able to successfully launch one new product development project per year and increase production by three times (Hilletofth & Eriksson, 2011). However, the delivery time of the product was 16 weeks as the supply chain did not support the new product development process (Hilletofth & Eriksson, 2011). Therefore, coordinating with the supply chain is important in the new product development process in order to be competitive (Hilletofth & Eriksson, 2011).

Coordinating with the supply chain is an integrated activity in LM and supplier chain management designed to achieve mass production and flexible manufacturing using minimum stocks (Agus & Mohd, 2012). The integration of supplier chain management and new product development is necessary to meet customer demand (Esper, Ellinger, Stank, Flint, & Moon, 2010; Hilletofth & Eriksson, 2011). Karim and Arif-Uz-Zaman

(2013) suggested conducting more research on integrating supplier chain with manufacturing in lean applications. Furthermore, further studies on new product development and supplier chain management coordination methods to improve company productivity and reduce product development cycle time are recommended (Hilletofth & Eriksson, 2011).

An empirical case study in Spain was conducted by Perez, deCastro, Simons, and Gimenez (2010) regarding a Catalan pork supply chain's effect on lean. According to Perez et al., international evidence showed that integrated supply in the pork industry increases supply chain effectiveness. This indicated that supplier integration is vital in lean management to improve the productivity of an organization. Perez et al. concluded that Catalan pork sector has applied lean theories, though it still needs more work to become fully implemented. The recommendation was for future research on culture support for lean collaboration to apply lean theories (Perez et al., 2010).

A study to investigate IT impact on the supply chain practices and performances when implementing lean theories was conducted by P. C. Hong, Dobrzykowski, and Vonderembse (2010). The focus was on the use of supply chain IT for buying and selling electronically, and manufacturing resource planning when implementing lean theories to meet supply chain product personalization effort (P. C. Hong, Dobrzykowski, & Vonderembse, 2010). For the mass customization platform, use of IT is necessary to manage business transactions within organizations and supply chain (P. C. Hong et al., 2010). In their study, P. C. Hong et al. found that lean practices were positively related to mass customization performances and supply chain IT e-commerce use and supply chain IT e-procurement use positively affected mass customization performances. Further studies were recommended to find the other elements that help the supply chain performance of firms (P. C. Hong et al., 2010).

The lean management and supplier chain systems' effect on environmental performances among Canadian manufacturing organizations was investigated by Hajmohammad, Vachon, Klassen, and Gavronski (2013). Only few studies have been conducted on lean management and supplier chain systems effect on environmental performances (Hajmohammad et al., 2013). In fact, Hajmohammad et al. found that there is a relationship between environmental practices and lean managements as lean focuses on eliminating waste. Furthermore, lean management, supply management, and environmental actions were shown to improve environmental performances (Hajmohammad et al., 2013). Lean practices can also have a positive impact on the environment (Dües et al., 2013). However, only 47% of U.S. companies are practicing lean to support environmental impact (Verrier et al., 2013); nevertheless, there has been a significant improvement in lean application in the supplier chain (Verrier et al., 2013). Ergo, integration of lean and green can be beneficial to organizations (Dües et al., 2013). After reviewing 58 articles related to lean management, supply chain management, and sustainability, the conclusion was that future researchers should focus on lean supply chain management (Martinez-Jurado & Moyano-Fuentes, 2013). However, Hajmohammad et al. suggested more studies on lean supplier management with respect to social performances.

Research to examine supplier interface in product development was conducted by Y. Hong and Hartley (2011). According to Y. Hong and Hartley, it is necessary to have a continuous integration of components from first-tier suppliers. Similarly, Borgatti and Li

(2009) stated that buyer and supplier connections improve problem solving. Moreover, supplier involvement in the product development process can positively affect cost and time by reducing it and improving quality (Mishra & Shah, 2009). Researchers have highlighted the importance of the buyer-supplier relationship in the supply chain network (Choi & Dooley, 2009). Supplier integration has also had a positive effect on long-term use of LM (So & Sun, 2010).

Suppliers' involvement in the early stage of the product development process is significant to the success of the LPD process (Qudrat-Ullah, Seong, & Mills, 2012). For example, to implement LPD successfully, Toyota Motor Company maintains a close relationship with suppliers during their product development process (Qudrat-Ullah et al., 2012). Moreover, suppliers provide vital information and expertise in product development for an organization as supplier involvement in product development is important to achieve company goals (Koufteros, Chang, & Lei, 2007). According to León and Farris (2011), supplier management plays a major role in improving and adopting LPD theories. Supplier involvement in LPD can produce higher quality, and less expensive products with less product development cycle time. Further studies on LPD and supplier involvement were recommended (León & Farris , 2011). Additionally, more research is recommended on buyer-supplier relationships with respect to product development (Y. Hong & Hartley, 2011).

Effect of IT involvement on LPD

In order to meet the requirements for a competitive global market, manufacturing companies are working to introduce IT as part of their business strategy (Chong, Chan, Ooi, & Darmawan, 2011). In recent years, conventional system engineering has been changed dramatically to software and network driven system to improve cycle time (Turner, & Lane 2013). According to C. S. Wang and Chen (2014), developing information technology in an organization can reduce product life cycle time. Qrunfleh, Tarafdar, and Ragu-Nathan (2012) conducted a research to examine the relationship between IT and lean supplier practices in the retail industry. In their study, Qrunfleh et al. (2012) found there was a positive effect on supplier chain integration through IT. Specifically, Wal-Mart was noted to have successfully implemented IT to integrate lean supplier practices (Qrunfleh et al., 2012).

Although benefits of IT are widely known in the industry, many organizations are still having difficulties with IT implementation (Chong et al., 2011). One third of software failed to be an assist in meeting the goals due to the individuals having a difficult time adopting proper IT and software, which could lead to the creation of waste in the company (Denning & Riehle, 2009). In fact, this is against the lean theories. There have been a few studies conducted to find if the employees of a company aligned with business-IT affect the success of an organization (Chong et al., 2011). Moreover, new product development processes require support from IT and senior management (Barczak, Griffin, & Kahn, 2009; Schmidt, Sarangee, & Montoya, 2009). IT used during the product development process was found to have a positive relationship between CAD use and product development performance and cost (Tan & Vonderembse, 2006). Furthermore, in LPD process, design engineers, manufacturing engineers, CAE engineers, CAD operators mostly interact with the IT department. Therefore, it is necessary to find if employees' interaction with IT could reduce waste in LPD.

Need for LPD Research

Researchers of LPD have typically focused on the types of items that need to be done to improve product development processes rather than recommendations for LPD implementation (León & Farris, 2011). Furthermore, León & Farris (2011) recommended additional research on some special topics on the LPD in their literature review case study on LPD. Based on a literature review of 273 publications, León and Farris (2011) found that 37% were academic research, 23 % clinical studies, 12% publications, and 12% involved methodologies associated with LPD theory building. According to León and Farris, although LPD literature is large and growing, there is still need for theoretical development in LPD. The findings indicate the current product development process can be improved by implementing LPD practices. Therefore, the recommendation is that practitioners and researchers should conduct more studies on LPD to improve the product development process (León & Farris, 2011). Moreover, Hoppmann et al. (2011) recommended conducting LPD research on component and system levels.

The most of conventional product development projects are reported to fail to meet company business goals (Neugebauer, 2014). Furthermore, Costa et al. (2013) stated that many organizations are still struggling to optimize the product development process, and recommended to conduct more research to improve the new product development process related to lean waste. Moreover, to gain competitive advantages, companies are working to implement lean in the product development process (Welo, Tonning, & Rølvåg, 2013). However, it is challenging to apply LPD theories as it is new compared to LM theories in the industry (Schulze & Störmer, 2012) as LPD requires contribution from different functional areas compared to already known LM theories (León & Farris, 2011).

The application of the lean theories in NPD is not direct; only few companies have successfully implemented LPD outside the Toyota Corporation (Welo, 2011). Qudrat-Ullah et al., (2012) conducted research to find how LPD theories integrate with LM theories. From their conceptual model, Qudrat-Ullah et al. (2010) demonstrated that LPD theories improve the company profitability. This indicates there are many opportunities for components and system level research that could be pursued regarding LPD. According to León & Farris (2011), there are seven major directions in future LPD research: (a) performance-based, (b) decision-based, (c) process modeling, (d) strategy, (e) supplier and partner, (f) knowledge-based networks, and (g) LM based. Within these seven major directions, there are many essential components that need to be addressed in LPD. As current LPD models are not optimized, León and Farris (2011) recommended finding advance LPD models that can integrate other essential components in current LPD in cross function of business. Exploring current LPD theories more is a promising area for future studies toward improvement of the product development process (León & Farris, 2011).

Summary

Many organizations fail to practice lean due to lack of proper lean implementation methods and better understanding of lean performances (Behrouzi & Wong 2011). The investigation of the essentials for the LPD system is needful as LPD involves more complex and difficult processes to implement compared to LM (León & Farris, 2011; Liker & Morgan, 2011). Researchers of LPD have focused on what was needed to be accomplished to improve the product development processes rather than recommendations for the LPD (León & Farris, 2011); ergo, there appears to be many unsolved effective essential components that still exist in LPD. Implementation of CAD is useful to improve the product development process and CAD feature information is vital to improve the product development process (Eigner et al., 2010). Eigner et al. (2010) compared a JIT data formatting system developed by Unigraphics to the STEP data formatting system and found JIT is lean compared to STEP. This finding is important as usage of the CAD formatting system can influence the product development process cycle time. However, other data formatting systems used by other major CAD software developers, such as ProEng, SolidWorks, and Catia, were not compared. This indicates the possible necessity to compare the time required to design parts, store CAD data, and the speed of other CAD software could affect product development cycle time.

The application of CAD and CAE tools in product development has increased since the start of the 21st century (Su et al., 2012). With experiments to verify reliability and accuracy, CAD and CAE tools (FEA and CFD) can be used for multiple design changes in product design and process optimization to reduce time and cost required for the product development process and improve the quality of the product (Su et al., 2012). However, as there are two different teams in CAD and CAE departments, there tends to be poor communication between CAD and CAE teams, which decreases the integration benefit (Su et al., 2012). Su et al. (2012) suggested having a seamless CAD and CAE integration to verify and validate designs effectively, comparing to the traditional trial and error method.

Supplier involvement in the new product development process is important to improve the productivity of a company (Johnsen, 2011). Supplier involvement in LPD can produce higher quality, and less expensive products with less product development cycle time. Further studies on LPD and supplier involvement were recommended (León & Farris, 2011). As market competition continues and technology advances, firms collaborate with their suppliers to achieve technological innovation (Naqshbandi, & Kaur, 2011). Furthermore, supplier involvement in the new product development process increases the productivity and competitive advantage (Lau, 2011; Oh & Rhea, 2010). In fact, building a close relationship with the supplier is part of lean strategies (Jayaram et al., 2008). Therefore, it is necessary to study the effect of supplier involvement in LPD to reduce waste, such as product development cycle time and cost in the product development process.

One-third of software failed to be used to deliver the goals set (Denning & Riehle, 2009). The implication is that one third of company employees are having a difficult time adopting proper IT and software, which could lead to create waste in the company. Furthermore, there have been few studies conducted to find if the employees of a company are aligned with business-IT, and if the employee and IT alignment affect the success of an organization (Chong et al., 2011). Employees' interactions with IT could affect the amount of waste in LPD (Chong et al., 2011). Therefore, it is necessary to find if employees' interaction with IT could reduce waste in LPD.

Many organizations fail to practice lean due to lack of proper lean implementation methods and better understanding of lean performances (Behrouzi & Wong 2011). The current product development process can be improved by implementing LPD practices and practitioners and researchers should conduct more studies on LPD to improve product development process (León & Farris 2011). In fact, CAD software used to design parts, the supplier involvement method, engineering tools used, and IT involvement in the product development process are essential components of LPD to be successful in a competitive global market. This suggests that it is worthy to find essential components of LPD to reduce waste, such as product development cycle time and cost. Therefore, it is deemed necessary to conduct research on essential components, such as CAD software packages used in parts design, supplier involvement, and IT involvements in product development to reduce LPD cycle time, cost, and improve quality of product in LPD.

Chapter 3: Research Method

To be sustainable and more competitive, organizations are currently focusing to reduce cost and decrease time to market in the product development process (Letens et al., 2011). In fact, it takes 3 to 4 years to develop a new product and about 50% of the costs are incurred in the product development process are waste (Gurumurthy & Kodali, 2012). Therefore, the top managers in industries around the world are continuously working to reduce cost, reduce product development cycle time, and improve the quality of the products (Holtzman, 2011).

The purpose of the quantitative non-experimental study was to examine the relationship between the type of part design CAD software used in part design and LPD cycle time, the supplier involvement in the LPD process and LPD cycle time, CAE tools (FEA and CFD) used in LPD process and LPD cycle time, and IT involvement in the LPD process and LPD cycle time. Quantitative research was used for this study by analyzing collected data through survey questionnaires. Quantitative research is a research method wherein the researcher can ask narrow questions from participants to collect data and analyze these data using statistical methods (Creswell, 2009). Moreover, conventional experimental designs are used to evaluate relationships between the variables; one variable is controlled while the other is measured (Cozby, 2009). Therefore, a quantitative methodology was the best fit for this research because it can be used in empirical studies to assess a theory (Vogt, 2006).

SurveyMonkey™ was used to conduct the survey after receiving approval from the IRB at NCU. Internet surveys have many advantages, such as being less expensive, easier to get more numerous responses, and being fast (Wiley, Han, Albaum, & Thirkell, 2009). Therefore, it was beneficial to use SurveyMonkey™ to collect data for this study.

The following research questions and hypotheses were used for the study based on the literature and theoretical construct:

Q1. To what extent, if any, does the type of part design CAD software, such as Unigraphics, Solidworks, and ProEng, used in the LPD process influence product development cycle time?

Q2. To what extent, if any, does supplier involvement in the LPD process influence product development cycle time?

Q3. To what extent, if any, does CAE tools (FEA and CFD) used in the LPD process influence product development cycle time?

Q4. To what extent, if any, does IT involvement in the LPD process influence product development cycle time?

Hypotheses

$H1_0$. The type of part design CAD software used in the LPD process, such as Unigraphics, Solidworks, and ProEng, does not affect product development time, as measured by the online survey.

$H1_a$. The type of part design CAD software used in the LPD process, such as Unigraphics, Solidworks, and ProEng, affects affect product development time, as measured by the online survey.

$H2_0$. The supplier involvement in the LPD process does not affect product development time, as measured by the online survey.

$H2_a$. The supplier involvement in the LPD process affects product development time, as measured by the online survey.

$H3_0$. CAE tools (FEA and CFD) used in the LPD process do not affect product development time, as measured by the online survey.

$H3_a$. CAE tools (FEA and CFD) used in the LPD process affect product development time, as measured by the online survey.

$H4_0$. IT involvement in the LPD process does not affect product development time, as measured by the online survey.

$H4_a$. IT involvement in the LPD process affects product development time, as measured by the online survey.

Studies that have more than one factor are called factorial studies and can be analyzed by various statistical methods, such as analysis of variance, chi squared test, simple regression analysis, multi-regression analysis, logistic regression analysis, and the general linear model. Depending on whether the data are nonparametric or parametric and types of the variables, such as being discrete or continuous, one of these statistical methods can be used to analyze the data. To have a normally distributed data set, it is necessary to collect enough data for the study.

A quantitative method is most suitable for this study since a quantitative method permits measuring constructs with scales, rejecting or failing to reject null hypotheses, and assessing strengths of relationships among multiple variables (Noorossana, Eyvazian, Amiri, & Mahmoud, 2010). Unlike a qualitative method, the quantitative method can be used to collect measurable data from a random sample of a large population (Vogt, 2007). A quantitative method provides results that can be generalized to a wider population of engineers from various design and manufacturing industries in the United States.

Moreover, variables used in the study were utilized to measure and quantify to use the quantitative methodology (Black, 1999). According to Black (1999), regression analysis is the most suitable method to find the effect of predictor variables on outcome variables. Although the study comprised four predictor variables and one outcome variable; the research questions were only interested in the direct effect of each predictor on the criterion variable; therefore, linear regression analysis is the most suitable statistical method. Linear regression analysis is a statistical tool to determine the linear relationship between the variables (Pal & Bhattacharya, 2013). Linear regression analysis can be used to predict the value of the outcome variable from the values of the predictor variables (Azen & Budescu, 2006). Unfortunately, the data did not meet the assumptions for linear regression analysis; therefore, ordinal logistic regression was used to determine these predictive relationships, since it does not have the same assumptions as linear regression (Agresti, 2013; Long, 1997; O'Connell, 2006). In addition, the nonparametric Kurskal-Wallis H test was used to determine the extent of the difference, if any, for the first hypothesis (type of CAD software used) and the Wilcoxon signed-rank test was used to determine the extent of the differences, if any, for the additional hypotheses (CAE tools used, IT, and supplier involvements in LPD).

Research Method and Design

Quantitative research was used for this study by analyzing data collected through survey questionnaires. Quantitative research is a research method wherein the researcher can ask narrow questions from participants to collect data and analyze these data using statistical methods (Creswell, 2009). Moreover, conventional experimental designs are used to evaluate relationships between the variables; one variable is controlled while the other is measured (Cozby, 2009). Therefore, a quantitative methodology is the best fit for this research as it can be used in empirical studies to assess a theory (Vogt, 2006).

Moreover, variables used in the study were utilized to measure and quantify it using the quantitative methodology (Black, 2009). The study comprised four predictor variables (type of CAD software used, CAE tools used, IT, and supplier involvements in LPD) and one outcome variable (product development cycle time); therefore, linear regression analysis was the most suitable statistical method for this study. Linear regression analysis can be used to predict the value of the outcome variable from the values of the predictor variables (Azen & Budescu, 2006).

Population

The target population of the study was engineers from various design and manufacturing industries in the United States. Finding the target population is not a difficult task as universities in the United States award many undergraduate engineers. In 1994, universities in the United States awarded 112,013 bachelor's degrees in engineering (Lynn, 2003). The total population needed for the study is engineers who work in design and manufacturing industries in the United States (see Appendix A). Therefore, informed consent was obtained to conduct the research as human participants were involved. Informed consent is required to conduct ethical research with human participants (Erlen, 2010).

Sample

According to Faul, Erdfelder, Lang, and Buchner (2007), G*Power 3 can be used to calculate the minimum sample size for statistical analysis. Therefore, for this study, the necessary sample size was calculated using G*Power 3. G*Power 3 with an alpha level of .05, power level of .80, four predictor variables, and an effect size of 0.25 was used to determine the total sample size must be at least 53 participants (see Appendix A). According to Leedy and Ormrod (2009), the 0.25 effect level is commonly used in quantitative research. According to Bartlett et al. (2001), response rates for educational research surveys are well below 100%. Therefore, assuming the response rate for this survey is 10%, the survey questionnaire was sent to over 650 individuals through SurveyMonkey™. These individuals should have been engineers who worked in the design or manufacturing industries in the USA. In the survey, there was a question asking whether the individual was working as an engineer in the design or manufacturing industries in the USA. Only engineers who work in the design or manufacturing industries in the USA were selected to participate through the survey. Therefore, the participants needed to indicate their position prior to proceeding with the survey questions. When participants indicated a position not listed or did not respond to that question, that participant's survey responses were ignored and deleted.

Materials/Instruments

There were four predictor variables and one outcome variable in this quantitative study. SurveyMonkey™ was used to collect survey data for this quantitative study. After an extensive search of instrument databases as well as multiple studies, no existing instrument was located.

Reliability and validity of the questionnaire were considered to ensure the stability and consistency in the study. Specifically, the survey was given to three experts to ascertain feedback regarding the wording and scope of the questions to ensure the survey could be easily understood and would garner the needed data to answer the research questions. Then, the survey was piloted by requesting 20 individuals, who matched the criteria of potential participants to complete it. The piloted responses were statistically reviewed using Cronbach's alpha to determine validity (not less than .70). As the first pilot was successful, there were no revisions made to the questions. Data collected from the pilot were not used in the research, but the Cronbach's alpha was reported.

Operational Definition of Variables

Table 1 indicates the various variables that were used in this study as well as the type. Each variable was operationalized using the survey instrument. Further detail regarding each variable and the operationalization is presented after Table 1.

Table 1

Operational Variables

Variable	predictor / outcome	Variable type
CAD software time used in product development in LPD	predictor	Continuous
Supplier involvement in LPD	predictor	Continuous
CAE tools (FEA and CFD) used in product development in LPD	predictor	Continuous
IT involvement in LPD	predictor	Continuous
Product development cycle time (waste) in LPD	outcome	Continuous

CAD software time used in product development in LPD. This continuous variable was operationalized using the responses from engineers in design and manufacturing industries in the United States to the survey questions. In the survey questions, product development cycle time required in different types of CAD software (such as Unigraphics, ProEng, SolidWorks) used in an LPD process was measured in hours for the CAD model given in the picture (see Appendix B).

Supplier involvement in LPD. This continuous variable was operationalized using the responses from design and manufacturing industry engineers. In the survey questions, the supplier involvement in the LPD process was measured as a percentage (% of time reduced or % of time added) of total product development cycle time.

CAE tools (FEA and CFD) used in product development in LPD. This continuous variable was operationalized using the responses from engineers in design and manufacturing industries. In the survey questions, CAE tools (such as FEA and CFD) used in LPD process was measured as a percentage (% time reduced/ % time added) of total product development cycle time.

IT involvement in LPD. This continuous variable was operationalized using the responses from engineers in design and manufacturing industries. In the survey questions, IT involvement in LPD process reduces product development cycle time was measured as a percentage (% time reduced/ % time added) of total product development cycle time.

Product development cycle time (waste) in LPD. This outcome variable was the outcome of the above predictor variables.

Data Collection, Processing, and Analysis

This quantitative research study was conducted using engineers in design and manufacturing industries in the United States. The necessary sample data were collected through surveys (SurveyMonkey™) to conduct a quantitative study. Empirical statistical research is the most suitable method for the area of interest since a large amount of data may be collected through surveys and analyzed using inferential statistics to view relationships between variables (Meredith, Raturi, Amoako-Gyampah, & Kaplan, 1989).

SPSS (version 20) statistical software was used to analyze normality and the statistical significant of the predictor variables. Furthermore, scale reliability and internal consistency was calculated using Spearman's correlation coefficients and coefficient alpha using SPSS (version 20). Linear regression analysis was originally going to be used to determine whether the predictor variables (type of CAD software used, CAE tools used, IT, and supplier involvements in LPD) were statistically significant ($p < .05$) in relation to the outcome variable (product development cycle time) in LPD. The data did not meet the assumptions for linear regression; therefore, ordinal logistic regression was used to determine these predictive relationships and test the hypotheses, since it does not have the same assumptions as linear regression (Agresti, 2013; Long, 1997; O'Connell, 2006). In addition, the nonparametric Kurskal-Wallis H test was used to determine the extent that model hours differed significantly between types of CAD software and the Wilcoxon signed rank test was used to determine the extent of the differences for the additional hypotheses.

Since the survey was conducted through SurveyMonkey™ participants may not be from the requested group (engineers from design and manufacturing industries) for the study. Because the results of the survey questionnaires may be inaccurate, resulting in an incorrect prediction, it was necessary to prevent participation of unqualified participants for the surveys. Therefore, the participants needed to indicate their position prior to proceeding with the survey questions. When any of the participants indicated a position not listed or did not respond to the question, the participant's survey responses were ignored and deleted.

To conduct the survey, it was necessary to have engineers who had knowledge of CAD software packages. These engineers were asked to respond to the survey questions:

1. Are you an engineer in the design or manufacturing industry who uses CAD software? (yes /no).
2. How much time does it take you to model and assemble parts in the picture from the software you know (hrs)?
3. How much product development cycle time does it reduce/ add (%), if the supplier involved in the product development process?
4. How much product development cycle time does it reduce/add (%) if CAE tools (such as FEA and CFD) used in product development process.
5. How much product development cycle time does it reduce /add (%) if IT involved in product development process

Linear regression analysis was originally going to be used to determine whether the type of part design CAD software used, the supplier involvement, CAE tools (such as FEA and CFD) used, and or IT involvement in LPD process affected product development cycle time in LPD process were statistically significant ($p < .05$) in relation to the outcome variable (product development cycle time) in LPD. The data did not meet the assumptions for linear regression, and nonparametric testing of significance was conducted instead.

Assumptions

The first assumption was that all the participants were aware of anonymity and confidentiality of the study. The informed consent was used to ensure this assumption was met, since the participants were required to acknowledge awareness and consent prior to taking the survey. The second assumption was that participants were honest when answering survey questions. Since the questions were not of a personal nature and there was no right or wrong response, there was not a valid reason for the participants to falsify their responses.

It was necessary to find 53 engineers who used different CAD software and CAE tools to design parts and interact with suppliers and IT personnel, since these individuals were the only suitable participants for this study. Therefore, the third assumption was that only qualified personnel will respond to the survey; however, there is the possibility that unqualified participants may participate in the survey. Since it is not possible to trace whether the participants are from the requested group, the qualifications to participate were listed prior to accessing the survey and the initial question on the survey is to identify their position. Should a participant not reply or lists an unqualified position, the survey for that individual was discarded.

Limitations

For this quantitative research, it is necessary to find 53 engineers who use different CAD software and CAE tools to design parts and interact with suppliers and IT personnel, as these individuals are the only suitable participants for this study. As many engineers know only one or two CAD software programs and there are many CAD software programs used in different industries, the conducting of this research was challenging to meet statistical requirements of the study.

The major limitation to quantitative research is the honesty of the survey participants (Leedy & Ormrod, 2009). However, as the survey was anonymous and conducted through the Internet, participants may provide honest answers to questions.

Nevertheless, as there is a possibility to have unqualified participants involved in the survey, it is important to trace participants of the survey. If it is not possible to trace whether the participant from the requested group, that responses were taken out of the study data as they would have questionable validity.

Delimitations

In this study, only engineers who were working in design and manufacturing industries in the United States selected to participate in the survey though there are many engineers in other sectors in the United States and around the world. The reason for choosing engineers from design and manufacturing industries in the United States is to focus the study in design and manufacturing industries in United States.

Ethical Assurances

Once NCUs IRB approval was received, the research was conducted in compliance with ethical standards. When conducting research with human participants, it is important to protect the dignity, rights, and well-being of all participants, including the interests of research (Dickert, 2009). According to Phillips (1985), it is necessary to communicate to all human participants and recipients of the research process, free everyone from harm, and inform participants that the outcome of the research were beneficial to the public. Furthermore, research must be designed to ensure minimum risks to human participants, provide expected benefits, provide the participants informed consent, inform participants of important information related to the purpose of the research, maintain the privacy of participants, and the confidentiality of data (Dickert, 2009). According to Van-Deventer (2009), the researcher should assess the risk and benefits of the research to avoid danger to the research process and the recipients of the research results. Moreover, when conducting research with human involvement, it is necessary that researchers obtain approval from the IRB (Bledsoe et al., 2007). Accordingly, participants were informed that participation was voluntary, responses were anonymous, the benefits of the research, and that they could withdraw at any time. As there were no disadvantaged groups, such as prisoners and special ethnic groups, involved in the study, there were fewer risks to human participants and minimal ethical issues that needed to be considered for this study

Statistical data analysis was used to conduct the research using parametric or nonparametric based on the normality of the data collected. Since the histogram of data had a bell curve shape, parametric data analysis could be used, otherwise, non-parametric data analysis would have been used. Based on collected data and data analysis, nonparametric statistical tests were used to test the null hypothesis.

Summary

The purpose of this quantitative study was to compare the effect of the type of part design CAD software, supplier involvement method, CAE tools (FEA and CFD) used, and IT involvement on LPD cycle time. SurveyMonkey™ was used to collect data through survey questionnaires after receiving approval from the IRB at NCU. For this study, engineers in design or manufacturing industries in the United States were asked to respond to the survey questions. SPSS (version 20) statistical software was used to analyze normality and statistical significance of the predictor variables with respect to the outcome variable. Furthermore, scale reliability and internal consistency were calculated using Spearman's correlation coefficients and coefficient alpha using SPSS (version 20). Linear regression analysis was originally going to be used to determine whether the predictor variables were statistically significant ($p < .05$) in relation to the outcome variable (product development cycle time) in LPD. Since the data did not meet the assumptions for linear regression, nonparametric tests were utilized instead to determine whether significant relationships existed between the variables.

The research was conducted in a manner that protects the dignity, rights, and well-being of all participants involved in the research. Furthermore, participants were informed that participation was voluntary, responses would be anonymous, the benefits of the research, and that they could withdraw at any time. Accordingly, informed consents were obtained from participants to conduct the research. For the study, it assumed that all the participants were honest when answering the survey questions.

Chapter 4: Findings

The purpose of the quantitative non-experimental study was to examine the relationship between the type of part design CAD software used to design parts in the LPD process and LPD cycle time, the supplier involvement in the LPD process and LPD cycle time, CAE tools (FEA and CFD) used in LPD process and LPD cycle time, and IT involvement in the LPD process and LPD cycle time. The impact on cost, quality, and manufacturing lead-times is much bigger in product development than during production (Liker & Morgan, 2011). The LPD process is the most suitable solution to current product development issues (Nepal et al., 2011). Therefore, the problem of this study is to find factors, such as part design CAD software used, supplier involvement, computer aided engineering (CAE) analysis tools (CFD and FEA) used, and information technology (IT) involvement in the LPD to reduce waste (product development cycle time) in LPD process (León et al., 2011; Nepal et al., 2011). Therefore, the quantitative non-experimental study was used to examine these factors that affected product development cycle time in LPD process.

Part design CAD software used, supplier involvement, computer aided engineering analysis tools (FEA and CAE) used, and IT involvement in the LPD were the predictor variables and product development cycle time (waste) was the outcome variable. The following research questions and hypotheses were used for the study based on the literature and theoretical construct.

Q1. To what extent, if any, does the type of part design CAD software, such as Unigraphics, Solidworks, and ProEng, used in the LPD process influence product development cycle time?

Q2. To what extent, if any, does supplier involvement in the LPD process influence product development cycle time?

Q3. To what extent, if any, does CAE tools (FEA and CFD) used in the LPD process influence product development cycle time?

Q4. To what extent, if any, does IT involvement in the LPD process influence product development cycle time?

Hypotheses.

$H1_0$. The type of part design CAD software used in the LPD process, such as Unigraphics, Solidworks, and ProEng, does not affect product development cycle time, as measured by the online survey.

$H1_a$. The type of part design CAD software used in the LPD process, such as Unigraphics, Solidworks, and ProEng, affects product development cycle time, as measured by the online survey.

$H2_0$. The supplier involvement in the LPD process does not affect product development cycle time, as measured by the online survey.

$H2_a$. The supplier involvement in the LPD process affects product development cycle time, as measured by the online survey.

$H3_0$. CAE tools (FEA and CFD) used in the LPD process do not affect product development cycle time, as measured by the online survey.

$H3_a$. CAE tools (FEA and CFD) used in the LPD process affect product development cycle time, as measured by the online survey.

$H4_0$. IT involvement in the LPD process does not affect product development cycle time, as measured by the online survey.

$H4_a$. IT involvement in the LPD process affects product development cycle time, as measured by the online survey.

The target population of this proposed study included engineers in design and manufacturing companies in the United States. According to Faul et al. (2007), G*Power 3 can be used to calculate sample size for statistical analysis. Therefore, for this study, the necessary sample size was calculated using G*Power 3. G*Power 3 with an alpha level of .05, power level of .80, four predictor variables, and an effect size of 0.25 to determine the total sample size must be 53 (see Appendix A). SurveyMonkey™ was used to collect data through survey questionnaires after receiving approval from the IRB at NCU. Data were collected from 61 participants who are currently employed within U.S. design and manufacturing industries through online survey questionnaires. SPSS (version 20) statistical software was used to analyze normality and statistical significance of the predictor variables. Originally, linear regression analysis was going to be used to determine whether the predictor variable, CAD software used in LPD, was statistically significant ($p < .05$) in relation to the outcome variable (modeling time) in LPD. Data did not meet the assumptions for using linear regression analysis, so ordinal logistic regression was used to determine these predictive relationships and test the hypotheses, since it does not have the same assumptions as linear regression (Agresti, 2013; Long, 1997; O'Connell, 2006). In addition, the non-parametric Kruskal-Wallis H test was used to determine the extent of any differences. Linear regression was also going to be used to determine whether the predictor variables; supplier involvement, CAE tool used, and IT involvement in LPD, were statistically significant ($p < .05$) in relation to the outcome variable (product development cycle time) in LPD. Data did not meet the assumptions for using linear regression analysis, so ordinal logistic regression was used to determine these predictive relationships and test the hypotheses, since it does not have the same assumptions as linear regression (Agresti, 2013; Long, 1997; O'Connell, 2006). In addition, the non-parametric Kruskal-Wallis H test was used to determine the extent of any differences for the remaining hypotheses. Table 2 contains the descriptive statistics for the four predictor variables, part design CAD software used, supplier involvement, computer aided engineering analysis tools (FEA and CAE) used, and IT involvement in the LPD and the outcome variable product development cycle time.

Table 2

Descriptive Statistics of Distributive CAD software used, supplier involvement, CAE tools used, and IT involvement in LPD process

Predictor variables		Mean	Median	Std. Dev	Minimum	Maximum
Time (hrs) required to design part with CAD software used in LPD	Unigraphics (NX)	6.55	3.50	6.32	1.00	24.00
	ProEng	7.37	5.00	6.72	1.00	36.00
	SolidWorks	6.89	5.00	6.01	1.00	20.00
	Others (Catia)	9.57	10.00	6.90	3.00	20.00
Supplier involvement in LPD process (%)	Cycle time reduce (-%) Cycle time add (+%) No effect (0%)	-21.48	-20.00	12.21	-50.00	0.00
CAE tools (FEA and CFD) used in LPD (%)	Cycle time reduce (-%) Cycle time add (+%) No effect (0%)	-20.10	-20.00	16.03	-50.00	25.00
IT involvement in LPD process (%)	Cycle time reduce (-%) Cycle time add (+%) No effect (0%)	-5.08	0.00	12.40	-50.00	20.00

Note**:** Cycle time reduce is –ve, cycle time add is +ve, no effect is 0

Results

An online survey was conducted through SurveyMonkey™ to collect data for this quantitative non-experimental study. In total, 86 engineers who work in design and manufacturing industries responded to the survey questionnaire. Twenty-five respondents were disqualified because they did not complete the survey. Sixty-one participants answered all questions. The final post hoc power analysis included the 61 survey responses and the actual means and sample size, demonstrating power at .852. The data were analyzed to determine its standard deviation, median, mean, minimum, and maximum values. Descriptive statistics were performed to examine the data and confirm the assumptions for statistical tests prior to analysis. Predictor variables (Part design CAD software used, supplier involvement, computer aided engineering analysis tools (FEA and CAE) used, and IT involvement in the LPD) and outcome variable (product development cycle time) were tested for normal distribution, homoscedasticity, linearity, and equality of variances.

Relationship between CAD software used in LPD and product development cycle time.

Q1. To what extent, if any, does the type of part design CAD software, such as Unigraphics, Solidworks, and ProEng, used in the LPD process influence product development cycle time?

$H1_0$. The type of part design CAD software used in the LPD process, such as Unigraphics, Solidworks, and ProEng, does not affect development cycle time, as measured by the online survey.

$H1_a$. The type of part design CAD software used in the LPD process, such as

Unigraphics, Solidworks, and ProEng, affects development cycle time, as measured by the online survey.

Descriptive Statistics

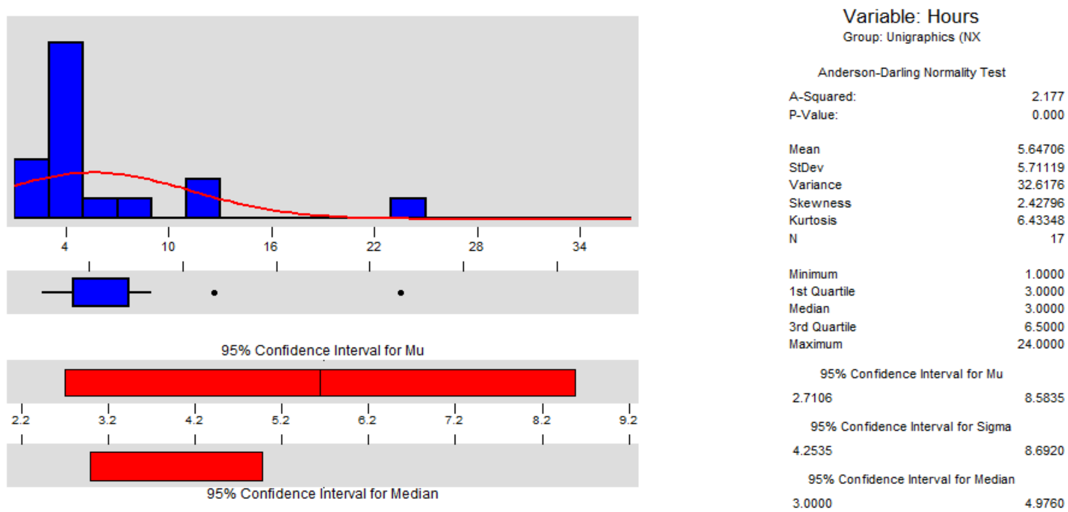

Figure 1. Descriptive statistics and Confidence Intervals for Unigraphics

Descriptive Statistics

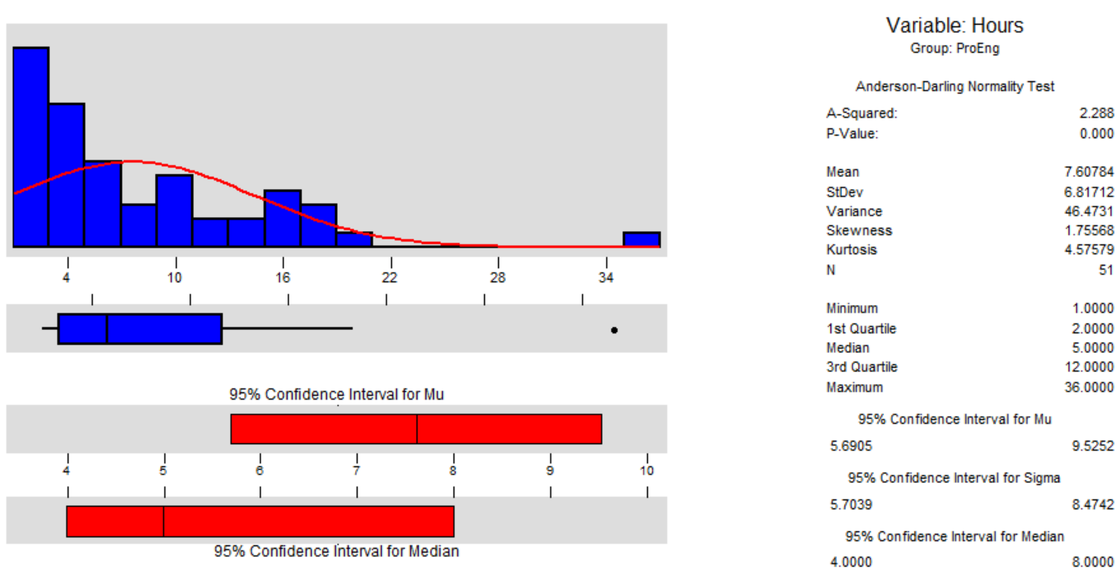

Figure 2. Descriptive statistics and Confidence Intervals for ProEng

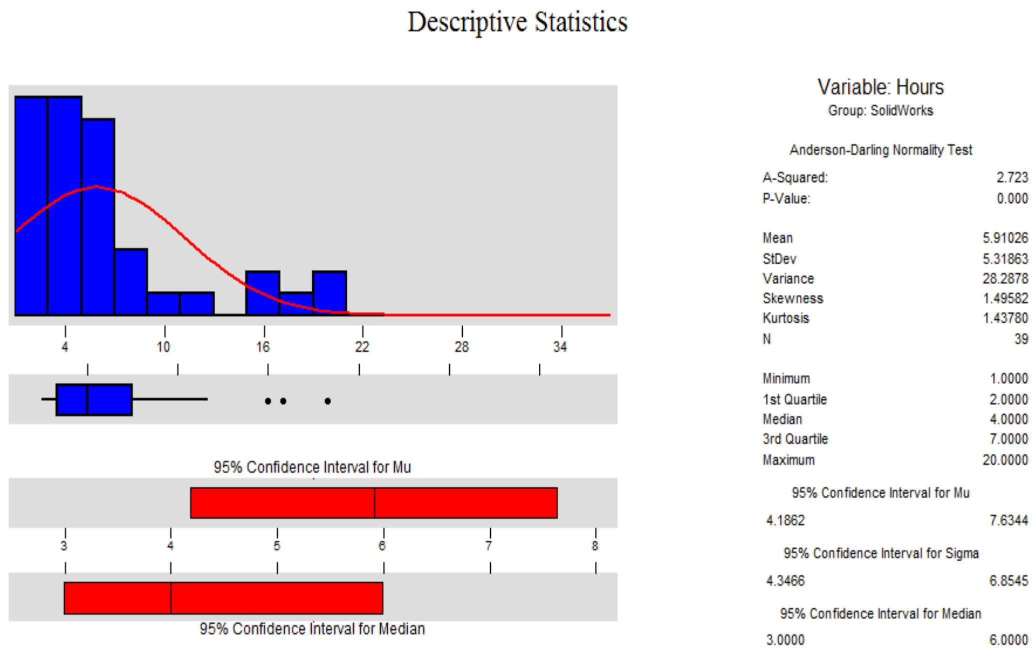

Figure 3. Descriptive Statistics and Confidence Intervals for SolidWorks

Linear regression is based on a number of assumptions, that when violated can make the results still usable to completely irrelevant. For linear regression to be a valid test the data must have (a) independence of errors, (b) linearity between the predictor variable and the output variable, (c) homoscedasticity of residuals, (d) lack multicollinearity, (e) no significant outliers or influential points, and (f) the residuals must be normally distributed (Miles & Shevlin, 2001). While it is not uncommon for one or more of these assumptions to be violated, some violations are worse than others (Miles & Shevlin, 2001). The assumption of independence of errors was examined using the Durbin-Watson statistic of 0.931, indicating that residual values were not independent and linear regression was not a suitable method of analysis for this data (Polit, 2010). Further violations of linear regression assumptions were that a visual inspection of a histogram (Figure 4) and normal P-P plot (Figure 5), as well as a Shapiro-Wilk test found data for all groups to be non-normal ($p < .001$).

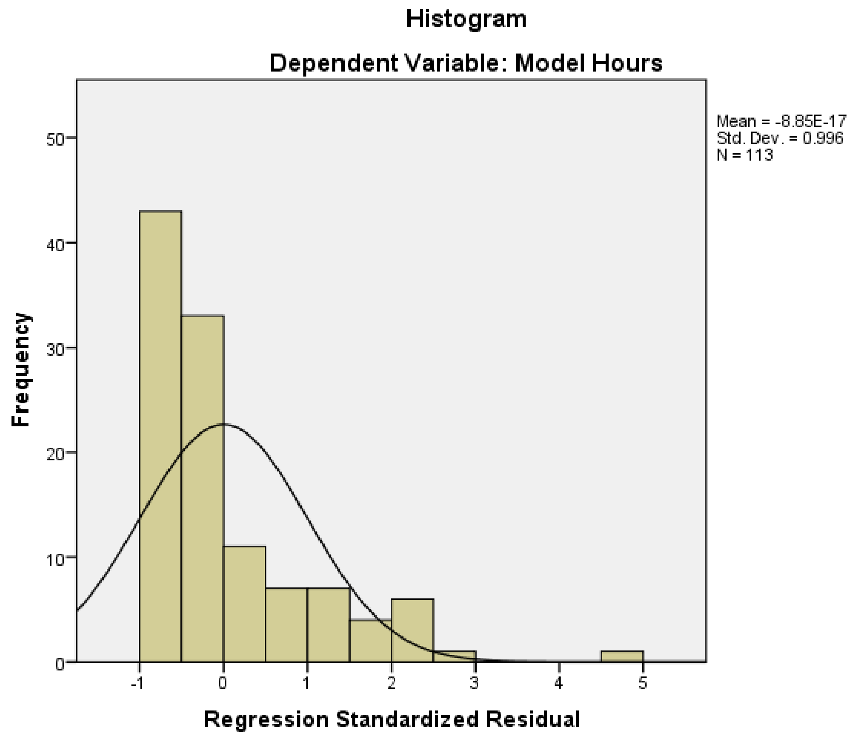

Figure 4. Histogram of Model Hours of Cases and Normal Curve.

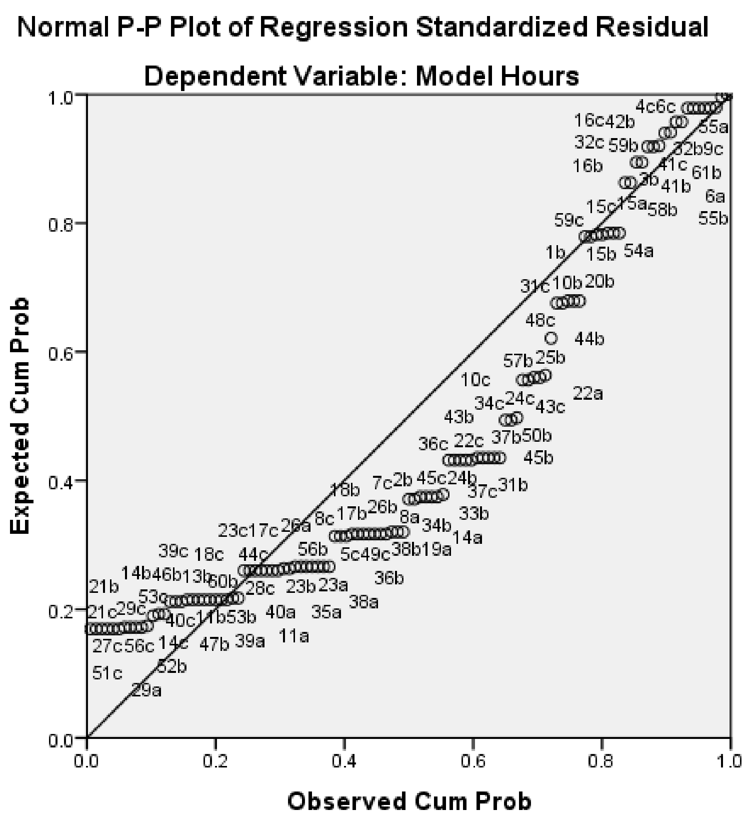

Figure 5. Normal P-P Plot of Standardized Residuals

Homogeneity of variances was tested using the Lavene test on the mean, the median, the median and adjusted degrees of freedom, and the trimmed mean. In each case the test was significant ($p = .925$, $p = .875$, $p = .875$, $p = .948$ respectively), identifying that the data failed the assumption of homogeneity of variances. Transformations of the data (Log 10, inverse, squared, square root) were attempted to normalize the data, but all transformations failed on one or more groups. Each CAD Software type was charted and tested, and the assumptions for ProEng were violated.

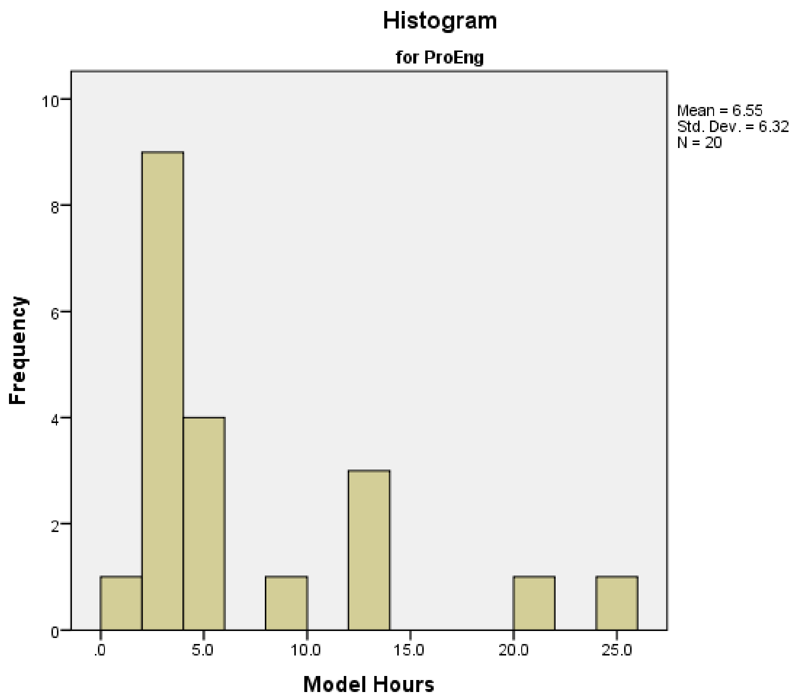

Figure 6. Histogram of Model Hours for ProEng

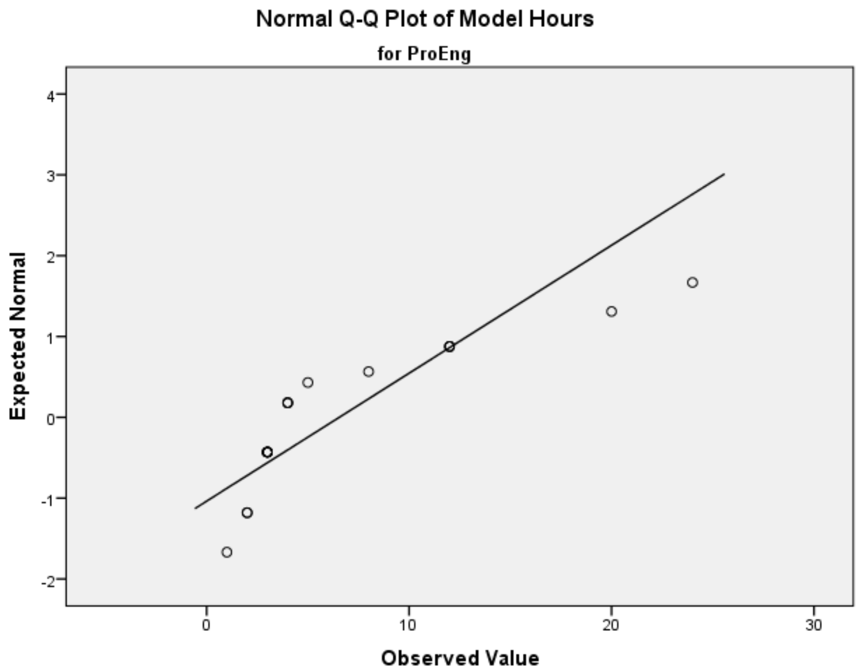

Figure 7. Normal Q-Q Plot or Model Hours for ProEng.

The assumptions of linear regression were violated for SolidWorks.

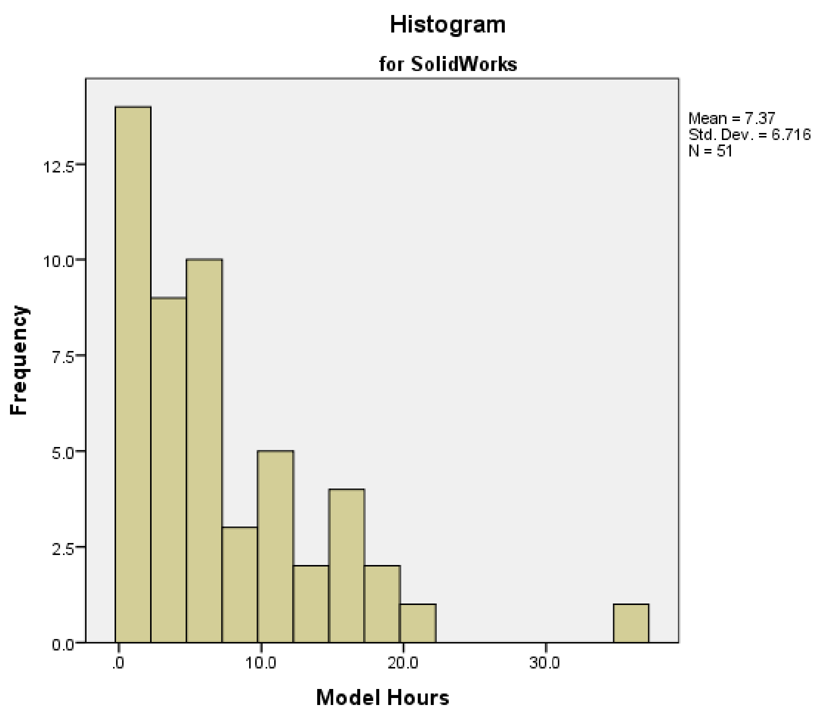

Figure 8. Histogram of Model Hours for SolidWorks

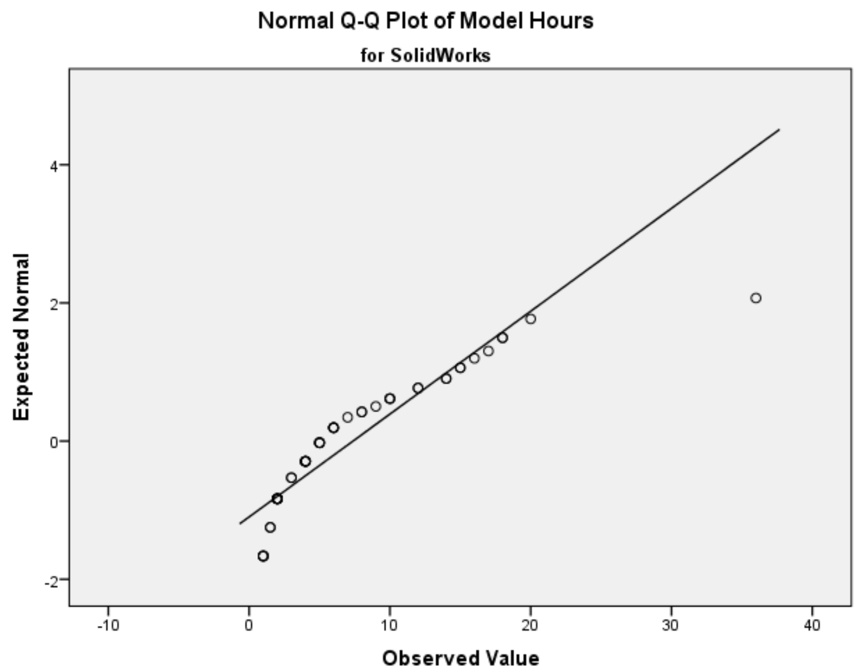

Figure 8. Normal Q-Q Plot of Model Hours for SolidWorks.

The assumptions of Linear regression were violated for Unigraphics (NX), as well.

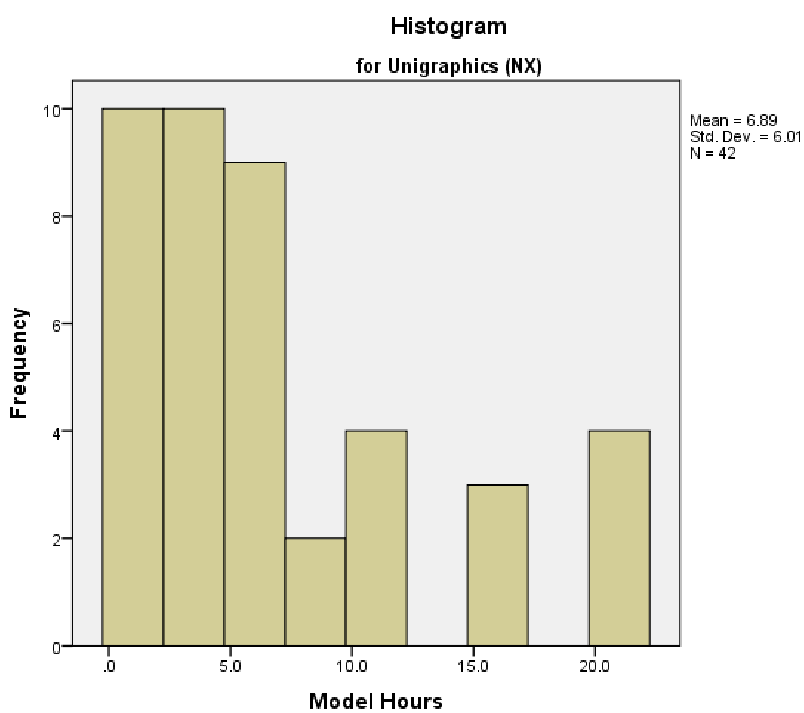

Figure 10. Histogram of Model Hours for Unigraphics (NX)

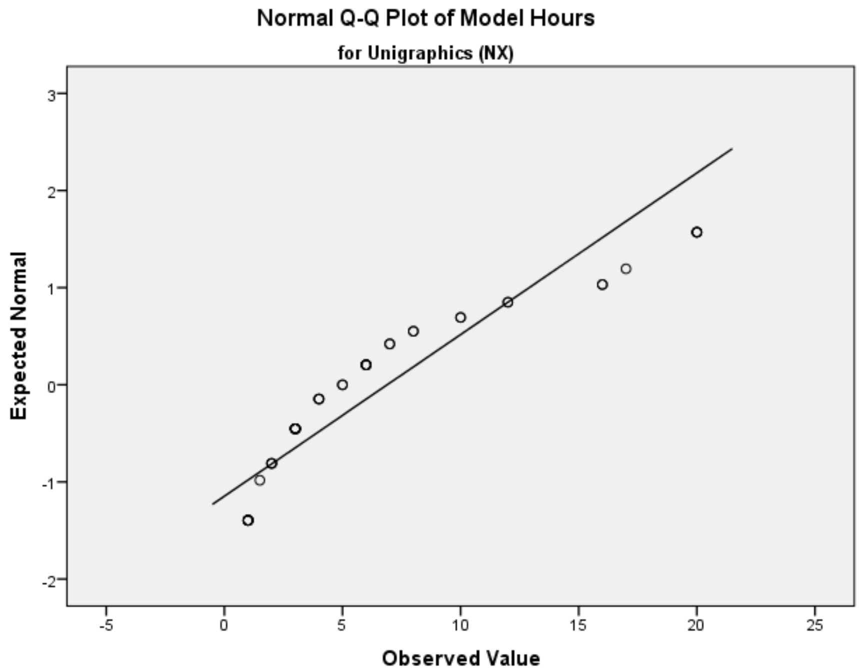

Figure 9. Normal Q-Q Plot of Model Hours for Unigraphics (NX).

Since linear regression is a test that determines prediction, and the assumptions of linear regression were violated, another predictive test was substituted, ordinal regression, which does not have the same assumptions as does linear regression. For ordinal regression to be a valid test the data must have (a) a single dependent variable measured on an ordinal scale, (b) one or more independent variables which can use any scale, (c) no multicollinearity, meaning the independent variables cannot be highly correlated with each other, and (d) the independent variable must have an identical effect at each cumulative split of the dependent variable, or proportional odds (Hosmer, Lemeshow, & Sturdivant, 2013). In this case, the dependent variable was the modeling time that each CAD software type (the independent categorical variable) took, meeting the first two assumptions of the test. Since the CAD software type was represented by three distinct pieces of software the independent variable meets the assumption of no multicollinearity. However, for this test the assumption of proportional odds was violated, as assessed by a full likelihood ratio test comparing the fitted model to a model with varying location parameters, $\chi^2(2) = 1.45$, p = .484. Hosmer et al. (2013) recommended running a multinomial logistic regression and comparing the results in a situation where this assumption is violated. Hence, to test hypothesis one, a multinomial logistic regression and an ordinal logistic regression was conducted on the same data. The multinomial logistic regression indicated that CAD software type was not a significant predictor of modeling hours, meaning that CAD software does not affect development cycle time, $\chi^2(34) = 38.51$, p = .273. This result was further supported by the ordinal logistic regression test that showed no statistically significant effect of CAD software type predicting modeling hours, Wald $\chi^2(2) = 1.36$, p = .506.

Since another way to look at the research question is whether there is a difference between the product development cycle time (modeling hours) and the CAD software used, a difference test using the non-parametric Kruskal-Wallis H test was used to determine the extent that model hours differed significantly among the CAD software used. It was expected that since the prediction tests were non-significant that there would also be no difference between each category of software but if there was a difference the researcher wanted to be able to identify the amount of the difference. The test indicated that there were no significant relationships between model hours based on CAD software type, $\chi^2(2) = .323$, p = .851. A box plot of the data quartiles by CAD software type demonstrates that no significant differences between the means were apparent (Figure 12).

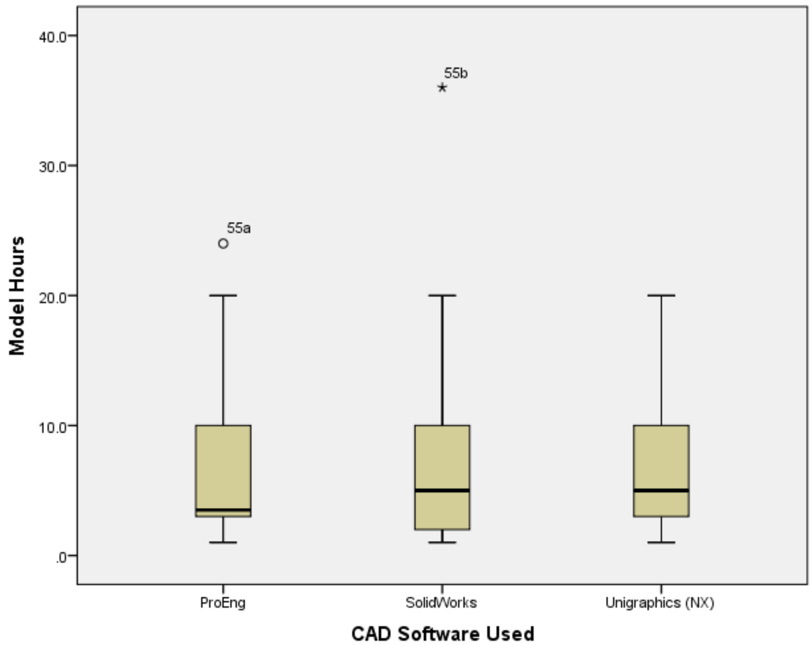

Figure 10. Box Plot of Model Hours by CAD Software Used

Thus, support was not found for the alternate hypothesis, and the null hypothesis is retained. The type of part design CAD software used in the LPD process, such as Unigraphics, Solidworks, and ProEng, does not affect LPD cycle time, as measured by the online survey.

Relationship between supplier involvement in LPD and product development cycle time.

Q2. To what extent, if any, does supplier involvement in the LPD process influence product development cycle time?

H2$_0$. The supplier involvement in the LPD process does not affect product development cycle time, as measured by the online survey.

H2$_a$. The supplier involvement in the LPD process affects product development cycle time, as measured by the online survey.

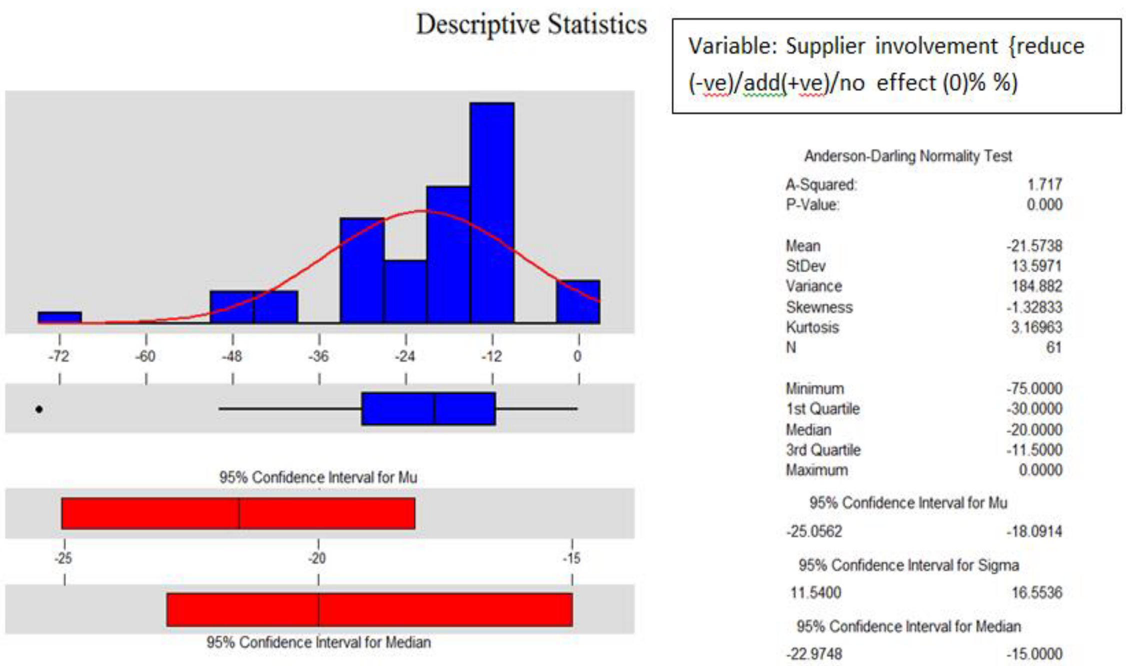

Figure 13. Descriptive Statistics and Confidence Intervals for Supplier Involvement

Linear regression was originally going to be used to find the relationship between supplier involvement in LPD and product development cycle time. Based on descriptive analysis, the data does not meet assumptions of linear regressions as previously discussed. Thus, linear regression analysis cannot be used for the study as planned. Therefore, a cumulative odds ordinal logistic regression with proportional odds was conducted to determine the effect of supplier involvement on product development cycle time. All assumptions for this test were met including proportional odds, as assessed by a full likelihood ratio test, $\chi^2(11) = 0.00$, p = 1.00. Both the Pearson and deviance goodness-of-fit models, which measure how poorly the model fits the data, indicated that the model was a good fit to the observed data, $\chi^2(11) = 0.00$, p = 1.00, but many cells had zero (46.2%) or low frequencies owing to the no value of supplier involvement being a standard and constant 1.0 (all other cells had at least a single value). The final model significantly predicted product development cycle time over and above the intercept-only model, $\chi^2(1) = 107.50$, $p < .001$. The odds of supplier involvement resulting in a product development cycle time differing from the standard 1.0 approached infinity as opposed to non-supplier involvement, which was held constant at 1.0, Wald $\chi^2(1) = 0.000$, $p = .996$. Based on the data results, one can definitively predict that if the supplier is involved in a project, the product development cycle time will be less than if the supplier is not involved.

While the predictiveness of supplier involvement in LPD helps to answer the research question it does not go far enough to determine the extent of how much supplier involvement in LPD influences product development cycle time in LPD. To determine this, and because of the violation of the assumption of normality, a nonparametric Wilcoxon signed-rank test was used to analyze data. Based on the non-parametric Wilcoxon signed-rank test the null hypothesis ($H2_0$) was rejected as the p-value was less than .001. Therefore, a Wilcoxon signed-rank test showed that supplier involvement in LPD elicited a significant change in product development cycle time, $Z = -6.64$, $p < .001$.

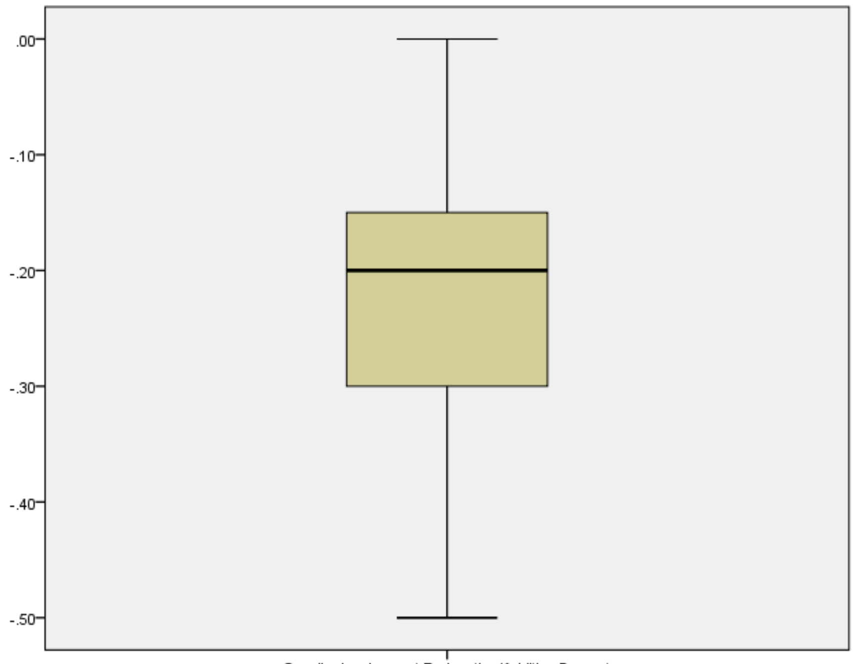

Figure 11. Boxplot of Reduction/Addition Percent Based on Supplier Involvement.

Thus, support was found for the alternate hypothesis, and the null hypothesis was rejected. Supplier involvement in the LPD process affects product development cycle time in that it predicts almost perfectly a decrease in product development cycle time, and shows a huge difference of over six standard deviations under the mean.

Relationship between CAE tools used in LPD and Product development cycle time.

Q3. To what extent, if any, does CAE tools (FEA and CFD) used in the LPD process influence product development cycle time?

$H3_0$. CAE tools (FEA and CFD) used in the LPD process do not affect product development cycle time, as measured by the online survey.

$H3_a$. CAE tools (FEA and CFD) used in the LPD process affect product development cycle time, as measured by the online survey.

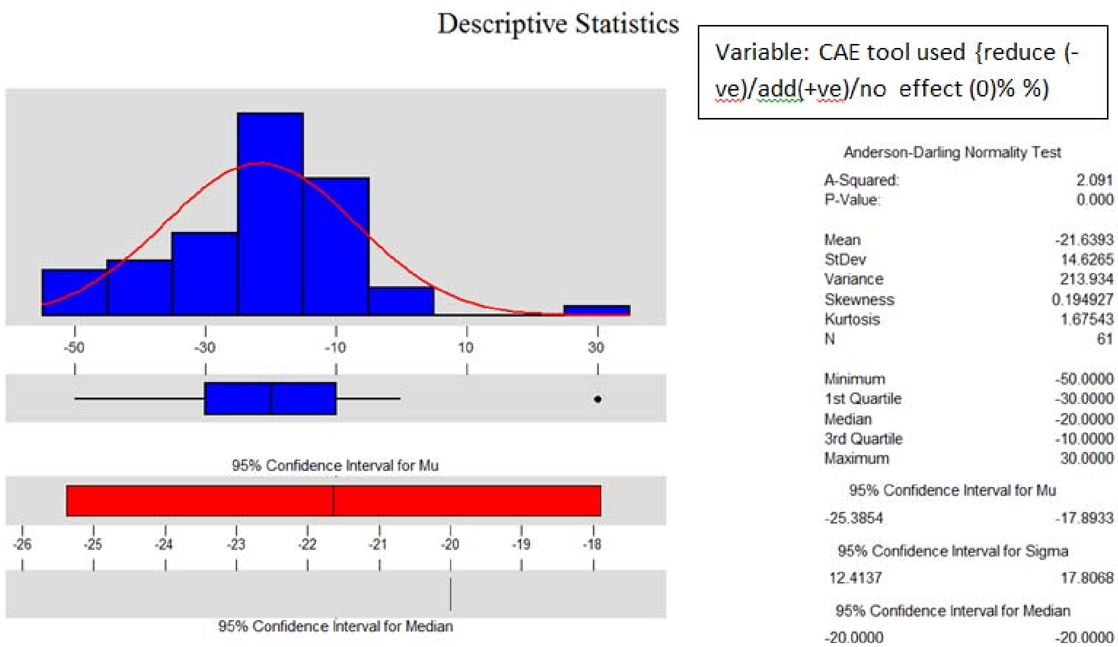

Figure 15. Descriptive Statistics and Confidence Intervals for CAE Tool Used

Linear regression was originally going to be used to find the relationship between CAE tools used in LPD and product development cycle time. Based on descriptive analysis, the data does not meet assumptions of linear regressions as discussed above. Thus, linear regression analysis cannot be used for the study as planned. Therefore, ordinal logistic regression was conducted to determine whether the use of CAE tools in LPD could be used to predict product development cycle time. The assumption of proportional odds was violated for this data, as assessed by a full likelihood ratio test, $\chi^2(11) = 47.06$, $p < .001$. The deviance goodness-of-fit model indicated that the model was a good fit to the observed data, $\chi^2(11) = 14.90$, $p = .187$, but many cells had zero (46.2%) or low frequencies owing to the no value of CAE usage being a standard and constant 1.0 (all other cells have at least a single value). The final model significantly predicted product development cycle time over and above the intercept-only model, $\chi^2(1) = 98.02$, $p < .001$. The odds that CAE tool usage would result in a different product development cycle time than the standard 1.0 was 540 times that of non-use of CAE tools (540:1), which was held constant at 1.0, Wald $\chi^2(1) = 30.70$, 95% CI [58.33, 4999.57], $p < .001$. Because of the violation of proportional odds a multinomial logistic regression was conducted, confirming the results of the ordinal logistic regression, with CAE tool usage explaining approximately 34% of the variance in the model (McFadden = .338), the model confirming that it is more likely that product development cycle time will decrease if CAE tools are used, $\chi^2(12) = 112.92$, $p < .001$. Based on the data results, one can definitively predict that if CAE tools are used in a project, the product development cycle time will be less than if CAE tools are not used.

While the predictability of CAE tool usage is helpful to know. The research question asks to what extent CAE tools usage in the LPD process influences product development cycle time. To determine this, a nonparametric Wilcoxon signed-rank test was used to analyze data. Based on the Wilcoxon signed-rank test the null hypothesis ($H3_{0}$) was rejected as the p-value was less than .001. Therefore, a Wilcoxon signed-rank test showed that CAE tools used in LPD elicited a significant change in product development cycle time, $Z = -6.03$, $p < .001$.

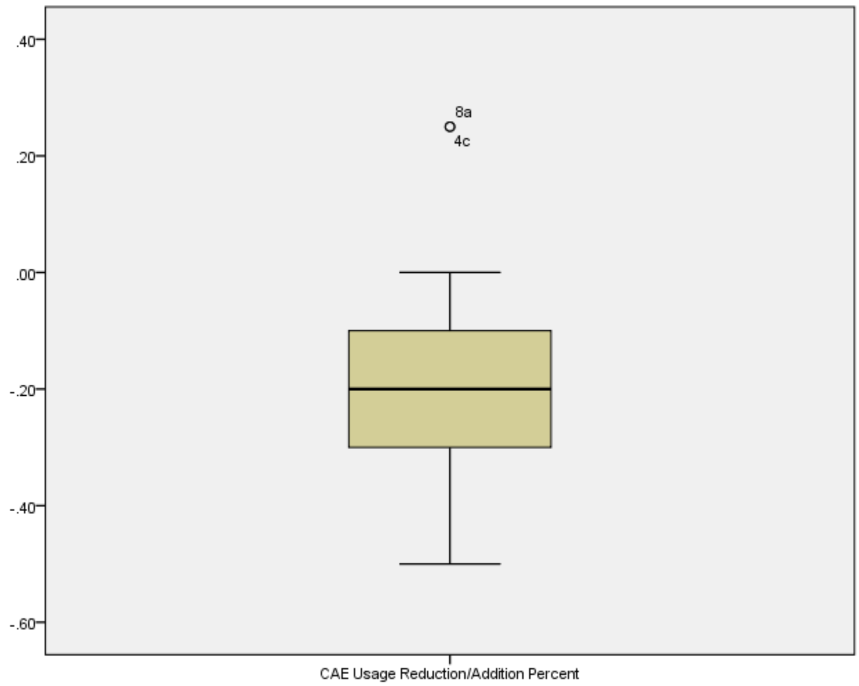

Figure 12. Box Plot of Reduction/Addition Percent Based on CAE Usage.

Thus, support was found for the alternate hypothesis, and the null hypothesis was rejected. CAE tool usage in the LPD process affects product development cycle time in that it predicts 540 to 1 a decrease in product development cycle time, and shows a huge difference of six standard deviations under the mean.

Relationship between IT involvement in LPD and Product development cycle time.

Q4. To what extent, if any, does IT involvement in the LPD process influence product development cycle time?

H4$_0$. IT involvement in the LPD process does not affect product development cycle time, as measured by the online survey.

H4$_a$. IT involvement in the LPD process affects product development cycle time, as measured by the online survey.

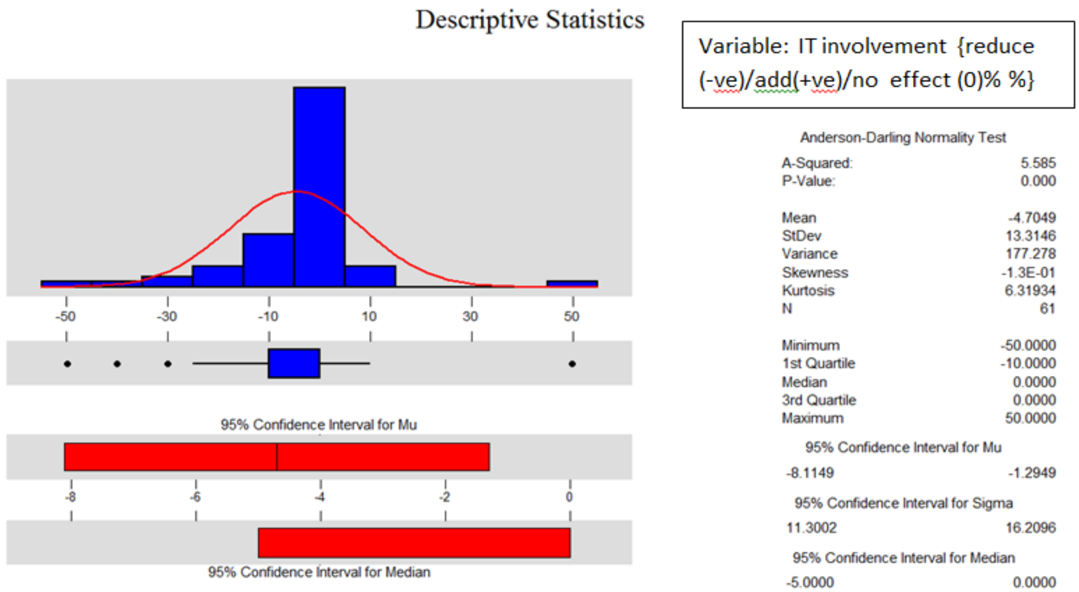

Figure 113. Descriptive Statistics and Confidence Intervals for IT Involvement

Linear regression was going to be used to find the relationship between IT involvement in LPD and Product development cycle time. Based on descriptive analysis, the data does not meet assumptions of linear regressions as discussed above. Thus, linear regression analysis cannot be used for the study as planned. Therefore, a cumulative odds ordinal logistic regression with proportional odds was performed to determine the effect of IT involvement on product development cycle time. All assumptions for this test were met including proportional odds, as assessed by a full likelihood ratio test, $\chi^2(12) = 20.09$, $p = .066$. The deviance goodness-of-fit model indicated that the model was a good fit to the observed data, $\chi^2(12) = 20.09$, $p = .066$, but many cells had zero (46.4%) or low frequencies owing to the no value of IT involvement being a standard and constant 1.0 (most other cells had at least a single value). The final model significantly predicted product development cycle time over and above the intercept-only model, $\chi^2(1) = 14.83$, $p < .001$. The odds of IT involvement resulting in a product development cycle time differing from the standard 1.0 was 8.9 times as opposed to non-IT involvement

(8.9:1), which was held constant at 1.0, Wald $\chi^2(1) = 34.82$, 95% CI [2.38, 33.26], $p < .001$. Based on the data results, one can definitively predict that if IT is involved in a project, the product development cycle time will be less than if IT is not involved.

While the predictability of IT involvement is helpful to know. The research question asks to what extent IT involvement in the LPD process influences product development cycle time. To determine this, and because of the violation of the assumption of normality, a nonparametric Wilcoxon signed-rank test was used to analyze data. Based on the Wilcoxon signed-rank test the null hypothesis ($H4_{0)}$ was rejected as the p-value was less than .001. Therefore, a Wilcoxon signed-rank test showed that IT involvement in LPD elicited a significant change in product development cycle time, $Z = -6.64$, $p < .001$.

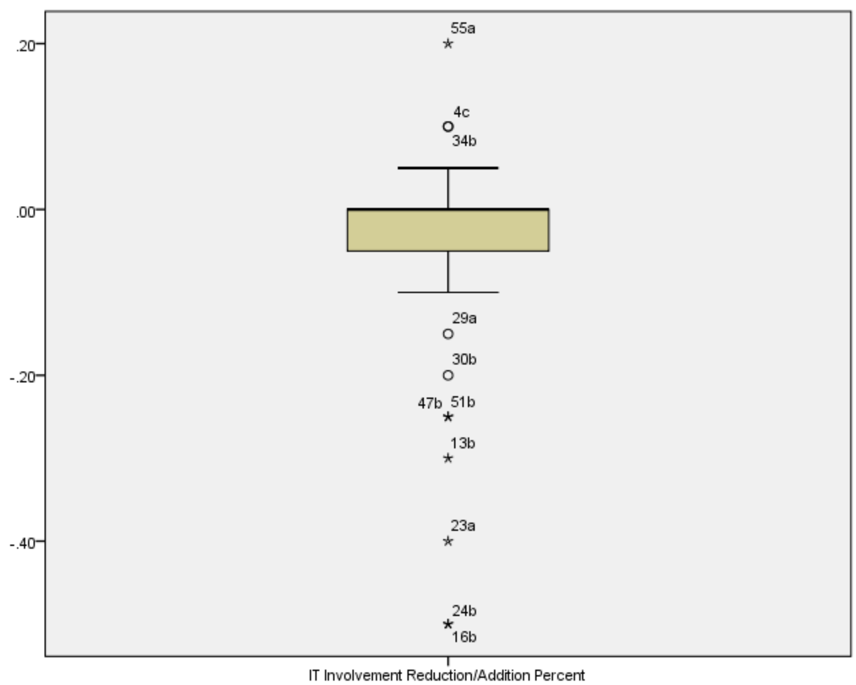

Figure 14. Box Plot of Reduction/Addition Percent Based on IT Involvement.

Thus, support was found for the alternate hypothesis, and the null hypothesis was rejected. Supplier involvement in the LPD process affects product development cycle time in that it predicts 8.9 to 1 a decrease in product development cycle time, and shows a huge difference of over six standard deviations under the mean.

Evaluation of findings

The purpose of this quantitative non-experimental study was to examine whether there was a significant relationship between product development cycle time in LPD and the type of part design CAD software used in part design and LPD cycle time, the supplier involvement in the LPD process and LPD cycle time, CAE tools (FEA and CFD) used in LPD process and LPD cycle time, and IT involvement in the LPD process.

The predictor variables of this study were part design CAD software used, supplier involvement, computer aided engineering analysis tools (FEA and CAE) used, and IT involvement in the LPD. The outcome variable of this study was the product development cycle time in LPD. The data were collected online using SurveyMonkey™. Normality was tested by an Anderson-Darling Normality test in SPSS. However, none of the variables displayed normal distributions. Therefore, ordinal logistic regression was used to determine these predictive relationships and test the hypotheses, since it does not have the same assumptions as linear regression (Agresti, 2013; Long, 1997; O'Connell, 2006). In addition, the Kruskal-Wallis H test was used to determine the extent of any difference between the predictor variable CAD software used in LPD and modeling time in LPD, although the original plan was to use linear regression to analyze data. The predictor variables supplier involvement, CAE tool used, and IT involvement in LPD were shown to reliably predict diminished product development cycle time using ordinal logistic regression tests, and in some case confirmed with a multinomial logistic regression test. In addition each predictor variable was shown to have 95% confidence intervals less than 1.0 (the stasis point) and were shown to effectively reduce the outcome variable (product development cycle time) in LPD, through use a nonparametric Wilcoxon signed-rank test, although the original plan was to use linear regression to analyze data.

Relationship between CAD software used in LPD and product development cycle time. To collect data to find the relationship between CAD software used in LPD and product development cycle time, the survey questions what kind of software do you know (mark all)?, and how much time does it take you to model and assemble parts in the below picture (Appendix B) from the software you know (hrs)? were asked from participants. Participants were asked to response to major CAD software that used in design and manufacturing industries such as Unigraphics(NX), ProEng, SolidWorks, and others (specify). If participants used other CAD software was included in the survey question to compare all of the CAD software participants knew of. Based on descriptive statistical analysis, overall mean value (time required to design) to design parts using Unigraphics (NX) was 6.55 hrs, maximum value was 24.00 hrs, and minimum value was 1.00 hr. The mean value (time required to design) to design parts using SolidWorks was 6.89 hrs, maximum value was 20.00 hrs, and minimum was 1.00 hrs. The mean value (time required to design) to design parts using ProEng was 7.37 hrs, maximum value was 36.00 hrs, and minimum value was 1.00 hrs. Out of Unigraphics (NX), ProEng, and SolidWorks CAD software, Unigraphics (NX) required the least mean time (6.55 hrs) to design parts shown in Table-2, ProEng required the most mean time (7.37 hrs), and mean time (6.89 hrs) for SolidWorks was in between Unigraphics (NX) and ProEng. However, box plot (Fig-4) shows that time required to design parts from each CAD software overlaps. There were no significant relationships between mean times for designing parts using any CAD software. Based on descriptive analysis, the data did not meet the assumptions for conducting linear regressions, as data were not normal and did not have homogeneity of variance. Thus, linear regression analysis could not be used for the study as planned. Hence, ordinal logistic regression and multinomial logistic regression was used to determine the predictive relationship between different CAD software and modeling hours. Both tests confirmed that there was no statistical relationship between modeling hours based on CAD software type used, $\chi^2(34) = 38.51$, $p = .273$ and Wald $\chi^2(2) = 1.36$, $p = .506$, respectively. In addition, the Kruskal-Wallis H test was used to analysis data. Based on the Kruskal-Wallis results, the null hypothesis ($H1_{0}$) could not be rejected because the p-value was .851. Therefore, predictively or based on the difference between groups there was no statistically significant relationship between CAD software used in LPD and product development cycle time.

Relationship between supplier involvement in LPD and Product development cycle time. To collect data to find the relationship between supplier involvement in LPD and product development cycle time, the survey question how much product development cycle time does it reduce/add/no effect (%) if the supplier is involved in the product development process was asked from participants. Based on descriptive analysis, the data does not meet assumptions of linear regressions as data were not normal. Thus, linear regression analysis could not be used for the study as planned. Hence, ordinal logistic regression was used to determine the predictive relationship between supplier involvement and product development cycle time. The final model indicated that supplier involvement conclusively predicted product development cycle time almost perfectly, Wald $\chi^2(1) = 0.000$, $p = .996$. In addition, the nonparametric Wilcoxon signed-rank test was used to analyze data. Based on the Wilcoxon signed-rank test the null hypothesis ($H2_{0}$) was rejected as the p-value was less than .001. According to the Wilcoxon signed-rank test, supplier involvement in LPD elicited a significant change in product development cycle time, $Z = -6.64$, $p < .001$. Therefore, predictively and based on group differences there was a statistically significant relationship between supplier involvement in LPD and product development cycle time.

Relationship between CAE tools used in LPD and product development cycle time. The data to find the relationship between CAE tools used in LPD and product development cycle time, used the survey question how much product development cycle time does it reduce/add/no effect (%) if CAE tools (such as FEA and CFD) are used in the product development process. Based on descriptive analysis, the data does not meet assumptions of linear regressions as data were not normal. Thus, linear regression analysis could not be used for the study as planned. Hence, ordinal logistic regression and multinomial logistic regression was used to determine the predictive relationship between CAE tool usage and product development cycle time. Both tests confirmed that a statistical difference in product development cycle time based on CAE tool usage. The final model indicated that CAE tool usage conclusively predicted product development cycle time 540 to 1, Wald $\chi^2(1) = 30.70$, 95% CI [58.33, 4999.57], $p < .001$ and $\chi^2(12) = 112.92$, $p < .001$, respectively. In addition, the nonparametric Wilcoxon signed-rank test was used to analyze data. Based on the Wilcoxon signed-rank test the null hypothesis ($H3_{0}$) was rejected as the p-value was less than .001. According to the Wilcoxon signed-rank test, CAE tools used in LPD elicited a significant change in product development cycle time, Z = -6.03, $p < .001$. Therefore, predictively or based on the difference between groups there was a statistically significant relationship between CAE tool usage in LPD and product development cycle time.

Relationship between IT involvement in LPD and product development cycle time. To collect data to find the relationship between IT involvement in LPD and product development cycle time, the survey question how much product development cycle time does it reduce/add (%) if IT is involved in the product development process. Based on descriptive analysis, the data does not meet assumptions of linear regressions as data were not normal. Thus, Linear regression analysis could not be used for the study as planned. Hence, ordinal logistic regression was used to determine the predictive relationship between IT involvement and product development cycle time. The final model indicated that IT involvement predicted product development cycle time 8.9 to 1, Wald $\chi^2(1) = 34.82$, 95% CI [2.38, 33.26], $p < .001$. In addition, the Wilcoxon signed-rank test was used to analyze data. Based on the Wilcoxon signed-rank test the null hypothesis ($H4_{0)}$ was rejected as the p-value was less than .001. According to the Wilcoxon signed-rank test, IT involvement in LPD elicited a significant change in product development cycle time, Z = -3.22, $p = .001$. However, since the mean value of the reduction was 5.1% (LPD time reduce) compared to 21.5% for supplier involvement and 20.1% for CAE tool used, the effect of IT involvement was less than either supplier involvement and CAE tool used in LPD. Therefore, predictively and based on group differences there was a statistically significant relationship between IT involvement in LPD and product development cycle time.

Summary

The purpose of the quantitative non-experimental study was to examine the relationship between the type of CAD software used in part design in LPD and product development cycle time in LPD, the supplier involvement in LPD and product development cycle time in LPD, CAE tools (FEA and CFD) used in LPD and product development cycle time in LPD, and IT involvement in LPD and product development cycle time in LPD. The type of CAD software used in part design in LPD, the supplier involvement in LPD, CAE tools (FEA and CFD) used in LPD, and IT involvement in LPD were predictor variables. The product development cycle time in LPD was the outcome variable.

Both predictive and group difference tests were used to determine whether the relationship between CAD software used in LPD and product development cycle time was significant. Based on descriptive analysis, the data did not meet the assumptions of linear regression since data were not normal nor did it meet the assumption of homogeneity of variances. Therefore, linear regression analysis could not be used for the study as planned. Hence, ordinal logistic regression was used to determine these predictive relationships and test the hypotheses, since it does not have the same assumptions as linear regression (Agresti, 2013; Long, 1997; O'Connell, 2006). In addition, the non-parametric Kruskal-Wallis H test was used to determine the extent of the differences between software types, if they existed. Neither ordinal logistic regression nor multinomial logistic regression showed a statistically predictive relationship between the CAD software types used in LPD and product development cycle time in LPD. Also, according to the Kruskal-Wallis results the null hypothesis

($H1_{0)}$ could not rejected because the p-value was .851. Therefore, predictively or based on group differences there was no statistically significant relationship between CAD software used in LPD and product development cycle time.

There was a significant relationship between supplier involvement in LPD and product development cycle time in LPD, predictively based on ordinal logistic regression and based on group differences through the Wilcoxon signed-rank test results. If the supplier was involved in LPD process, it reduced the estimate of product development time in LPD conclusively. Therefore, supplier involvement in LPD is important to reduce product development time.

There was a significant relationship between the CAE tools (FEA and CFD) used in LPD and product development time in LPD, predictively based ordinal and multinomial logistic regression and based on group differences through the Wilcoxon signed-rank test results. If CAE tools (FEA and CFD) were used, it reduced the estimate of product development time in LPD, and the odds of this reduction were 540 to 1. Therefore, it is important to use CAE tools to reduce product development time in LPD.

There was a significant relationship between IT involvement in LPD and product development cycle time in LPD, predictively based on ordinal logistic regression and based on group differences through the Wilcoxon signed-rank test results. If IT was involved in LPD process, it reduced the estimate of product development time in LPD, and the odds of this reduction were 8.9 to 1. Therefore, IT involvement in LPD is important to reduce product development time in LPD.

Lean theory consists of waste eliminating systems like total productive maintenance, just-in-time (JIT), and total quality management (Bonavia et al., 2011).

Moreover, in manufacturing processes , stocks, extra manufacturing, scraps, motion, waiting, and carrying have been categorized as waste (Kovács, 2012; Laureani et al., 2010). In the product development process, the quality and cost of the product, product development time and cost required for development, and ability of production are identified as waste (Wang et al., 2012). The main objectives of LPD are to minimize waste, improve quality, and reduce product development time and cost in product development (Sören & Torgeir, 2013). The reduction of waste in the product development process appears to be an important task in LPD. Therefore, using CAE tools in product development process, involving suppliers in product development, and getting IT support for product development in LPD can reduce waste described in lean theories.

Chapter 5: Implications, Recommendations, and Conclusions

To be sustainable and more competitive, organizations need to focus on reducing cost and decreasing time to market in the product development process (Letens et al., 2011). However, many organizations are still struggling to optimize the product development process (Costa et al., 2013). It takes 3 to 4 years to develop a new product and about 50% of the costs incurred in product development are waste (Gurumurthy & Kodali, 2012). Therefore, managers are continuously working to reduce cost and cycle time and improve quality in their organizations (Holtzman, 2011). The impact on cost, quality, and manufacturing lead-times is much bigger in product development than during production (Liker & Morgan, 2011). The LPD process is the most suitable solution to current product development issues (Nepal et al., 2011). Therefore, LPD is currently the focus of many corporations to maximize value, improve quality, reduce lead times, and reduce product development costs (León et al., 2011). Implementation of lean theory is important to business success in the fast moving global market (Pitta & Pitta, 2012). Therefore, more studies needed to find lean theories related to the LPD.

The purpose of the quantitative non-experimental study was to examine the relationship between the type of part design CAD software used in part design and LPD cycle time, the supplier involvement in the LPD process and LPD cycle time, CAE tools (FEA and CFD) used in LPD process and LPD cycle time, and IT involvement in the LPD process and LPD cycle time. The problem investigated in this study was the effect of CAD software used in part design and LPD cycle time, the supplier involvement in the LPD process and LPD cycle time, CAE tools (FEA and CFD) used in LPD process and LPD cycle time, and IT involvement in the LPD process on product development cycle time in the LPD. Linear regression analysis was originally planned to be performed on the collected date using SPSS (version 22) to find the predictability of the predictor variables on the outcome variable. However, the data did not meet the assumptions for using Linear regression analysis; therefore, ordinal logistic regression was used to determine these predictive relationships and test the hypotheses, since it does not have the same assumptions as linear regression (Agresti, 2013; Long, 1997; O'Connell, 2006). In addition, non-parametric statistic difference tests were conducted to aid in hypothesis testing. Neither ordinal logistic regression, multinomial logistic regression, or the Kruskal-Wallis H test found a significant relationship between CAD software used in part design and LPD cycle time. Both ordinal logistic regression (prediction test) and the Wilcoxon signed-rank test (difference test) showed a significant change occurred with supplier involvement in the LPD process and LPD cycle time, CAE tools (FEA and CFD) used in LPD process and LPD cycle time, and IT involvement in the LPD process on product development cycle time in the LPD.

The study followed the guidelines of Northcentral University's IRB, as well as, the ethical framework established by Belmont Report (1979) and the American Psychological Association (APA). The study held minimal risk to participants since there were no minors under age 18, prisoners, pregnant women, or any other disadvantaged groups such as uneducated people involved in the survey. The participants were engineers (no gender preference) who worked in design and/or manufacturing industries in the United States of America. There was a question in the survey questionnaire asking whether the participant was an engineer. If the participant was not an engineer, he or she was asked not to proceed with the questions. Appropriate precautions were taken to protect the privacy and breach of confidentiality by keeping all research materials (i.e., completed surveys, consent forms, etc.) in a safe; accessible only to the primary investigator. To comply with the principle of respect for persons, participants were informed of the purpose of the study, that participation was voluntary, and of their ability to withdraw at any time through the informed consent form (APA, 2010; Belmont Report, 1979). All the participants were requested to read, sign and send the informed consent form to the researcher. All informed consent forms were kept in a safe place to protect the privacy of participants.

The main limitation for this study was finding engineers who work in design and/or manufacturing industries in the United States of America. For this reason, only 61 participants were found out of 650 invitations sent through SurveyMonkey. However, based on G*Power 3 calculation, a total sample size of 53 engineers was the minimum to ensure sufficient power to find significant results. Therefore, the 61 samples size was more than enough for the study.

Implications

This study consisted of four questions and associated hypotheses. The research Q1 in this study was designed to investigate whether there were relationships between the type of part design CAD software, such as Unigraphics, Solidworks, and ProEng, used in the LPD process and product development cycle time in the LPD. The research Q2 in this study was designed to investigate whether there were relationships between supplier involvement in the LPD process and product development cycle time in the LPD. The research Q3 in this study was designed to investigate whether there were relationships between CAE tools (FEA and CFD) used in the LPD process and product development cycle time in the LPD. The research Q4 in this study was designed to investigate whether there were relationships between IT involvement in the LPD process and product development cycle time in the LPD.

The samples in this study; four predictor variables; type of CAD software used, CAE tools used, IT, and supplier involvements in LPD were tested using ordinal logistic regression to determine these predictive relationships and test the hypotheses, since this type of regression does not have the same assumptions as linear regression (Agresti, 2013; Long, 1997; O'Connell, 2006). In addition, the non-parametric Kruskal-Wallis H test was used to determine the extent of any differences for Q1, and the non-parametric Wilcoxon signed-rank test was used to determine the extent of any differences for Q2, Q3, and Q4. Based on these tests the null hypothesis conclusions are summarized in

Table 3

Conclusions for Null Hypotheses

Null Hypothesis	Description	Conclusion
$H1_0$	The type of part design CAD software used in the LPD process, such as Unigraphics, Solidworks, and ProEng, does not affect product development cycle time in the LPD, as measured by the online survey.	Null hypothesis not rejected
H2	Supplier involvement in the LPD process does not affect product development cycle time in the LPD, as measured by the online survey.	Null hypothesis rejected
$H3_0$	CAE tools (FEA and CFD) used in the LPD process do not affect product development cycle time in the LPD, as measured by the online survey.	Null hypothesis rejected
$H4_0$	IT involvement in the LPD process does not affect product development cycle time in the LPD, as measured by the online survey.	Null hypothesis rejected

Relationship between CAD software used in LPD and product development cycle time. The sub-question, to what extent, if any, does the type of part design CAD software, such as Unigraphics, Solidworks, and ProEng, used in the LPD process affect LPD cycle time of Q1 was used to find the relationship between CAD software used in LPD and product development cycle time. The survey results indicated that the null hypothesis was not rejected as there were no significant difference between model hours based on CAD software type, $\chi^2(2) = .323$, p = .851. Further, predictive modeling showed no statistical predictive relationship between modeling hours and CAD software type, $\chi^2(34) = 38.51$, p = .273 and Wald $\chi^2(2) = 1.36$, p = .506. Therefore, there was no statistically significant relationship between CAD software used in LPD and product development cycle time.

Relationship between supplier involvement in LPD and product development cycle time. The sub-question, to what extent, if any, does supplier involvement in the LPD process affect LPD cycle time of Q1 was used to find the relationship between supplier involvement in LPD and product development cycle time. The Wilcoxon signed-rank test showed that supplier involvement in LPD elicited a significant change in product development cycle time, $Z = -6.64$, $p < .001$. Predictively, an ordinal logistic regression demonstrated a statistically conclusive predictive relationship between supplier involvement in LPD and product development cycle time, Wald $\chi^2(1) = 0.000$, $p = .996$. Therefore, there was a statistically significant relationship between supplier involvement in LPD and product development cycle time. If a supplier is involved in the LPD, it reduces product development cycle time an estimated 21%.

Supplier involvement in the new product development process is one of the important components to improve the productivity of a company (Johnsen, 2011). Proper supplier involvement is critical to the success of a corporation in a comparative market (Merzifonluoglu & Feng, 2014). The study results demonstrate that if a supplier is involved in the LPD, it reduces product development cycle time. Moreover, application of lean to the supplier chain system can reduce product cost in the industry (Hongpiriyakul et al., 2014). However, companies are still behind the methodical approach to integrate suppliers to their product development process (Perng et al., 2013). Therefore, it can be concluded that company managers should involve suppliers in their LPD process to reduce product development cycle time, which is one of the waste in lean theories to meet global competition and shareholders expectation.

The relationship between CAE tools used in LPD and product development cycle time. The sub-question, to what extent, if any, does the CAE tools (FEA and CFD) used in the LPD process affects LPD cycle time of Q1 was used to find the relationship between CAE tools used in LPD and product development cycle time. The Wilcoxon signed-rank test showed that CAE tools used in LPD elicited a significant change in product development cycle time, Z = -6.03, $p < .001$. Predictively, an ordinal and multinomial logistic regression determined a statistically predictive relationship (540 to 1) between CAE tool usage in LPD and product development cycle time, Wald $\chi^2(1)$ = 30.70, 95% CI [58.33, 4999.57], $p < .001$and $\chi^2(12) = 112.92$, $p < .001$, respectively. Therefore, there was a statistically significant relationship between CAE tools (such as FEA and CFD) used in LPD and product development cycle time. The result showed that if CAE tools (such as FEA and CFD) are used in product development process reduces product development cycle time an estimated 20%.

Vinodh (2011) discovered that proper design modifications using CAD and CAE could reduce the environmental impact. Vinodh (2011) concluded that it is important to use CAE software to design and optimize parts in LPD to reduce waste and improve quality. Therefore, it concluded that CAE tools should be used in the LPD to reduce product development time and environmental damages to meet lean expectation and shareholders requirements.

Relationship between IT involvement in LPD and product development cycle time. The sub-question, to what extent, if any, does the IT involvement in the LPD process affects LPD cycle time of Q1 was used to find the relationship between IT involvement in LPD and product development cycle time. Based on a Wilcoxon signed-rank test showed that IT involvement in LPD elicited a significant change in product development cycle time, $Z = -6.64$, $p < .001$. Predictively, an ordinal logistic regression found a statistically predictive relationship (8.9 to 1) between IT involvement in LPD and product development cycle time, Wald $\chi^2(1) = 34.82$, 95% CI [2.38, 33.26], $p < .001$. Therefore, there was a statistically significant relationship between IT involvement in LPD and product development cycle time. The results showed that if IT involved in product development process reduces product development cycle time an estimated 5%.

To meet the requirements for a competitive global market, manufacturing companies are working to introduce IT as part of their business strategy (Chong et al., 2011). In recent years, conventional system engineering has been changed dramatically to software and network driven system to improve cycle time (Turner, & Lane 2013). According to Wang and Chen (2014), developing information technology in an organization can reduce product life cycle time. Although benefits of IT are widely known in the industry, many organizations are still having difficulties with IT implementation (Chong et al., 2011). Therefore, it can be concluded that company managers should involve IT department during the LPD process to reduce product development cycle time to meet lean expectation and shareholders expectation.

Recommendations

If a company can bring products to the market faster than competitors, a company can not only gain profits but also competitive advantage. Understanding the importance of eliminating waste, many organizations are working to practice lean theories to reduce cost and improve quality to gain a competitive advantage (Sun, 2011). The findings of the research offer several opportunities for both future research and practical application in lean theories.

To gain competitive advantage, companies are working to implement lean in the product development process (Welo et al., 2013). The one way to bring product faster to market is reducing product development time. Furthermore, supplier involvement in new product development process increases the productivity and competitive advantage (Lau, 2011; Oh & Rhea, 2010). Findings showed that supplier involvement in product development in LPD reduces product development time. Therefore, it is recommended to get supplier involvement during product development process to reduce waste, improve productivity as described in lean to bring products to market faster to meet global competition.

CAD and CAE tools (FEA and CFD) can be used for multiple design changes in product design and process optimization to reduce time and cost required for the product development process and improve the quality of the product (Tsung-Min et al., 2012). However, as there are two different teams in CAD and CAE departments, there tends to be poor communication between CAD and CAE teams, which decreases the integration benefit (Tsung-Min et al., 2012). Tsung-Min et al. (2012) suggested having a seamless CAD and CAE integration to verify and validate designs effectively, comparing to the traditional trial and error method. Findings demonstrated that if CAE tools (FEA and CFD) were used in product development in LPD product development time was reduced. Therefore, it is recommended to use CAE tools such as FEA and CFD in the product development process to reduce waste, improve quality as described in lean to bring products to market faster to meet global competition.

To meet the requirements for a competitive global market, manufacturing companies are working to introduce IT as part of their business strategy (Chong et al., 2011). In recent years, conventional system engineering has been changed dramatically to software and network driven systems to improve cycle time (Turner, & Lane 2013). According to Wang and Chen (2014), developing information technology in an organization can reduce product life cycle time. Findings showed that IT involvement in product development in LPD reduced product development time. Therefore, it is recommended to get IT involvement during the product development process to reduce waste described in lean to bring products to market faster to meet global competition.

Future works. Global warming is a big concern among people in the world, and researchers are continually working to reduce global warming (Fowler, 2012). Lean thinking is a key method that can be integrated with environmental sustainability to reduce global warming and support the ecosystem (Pampanelli et al., 2013). Lean companies are greener than non-lean companies, and integration of lean and green can be beneficial to organizations (Dües et al., 2013). However, only 47% of U.S. companies are practicing lean and green (Verrier et al., 2013). Moreover, there was a lack of focus on product life cycle when applying green lean theories (Verrier et al., 2013).

Different materials used to make products cause different levels of damage to the ecosystem (Menikpura et al., 2013). Net damage to the ecosystem by recycling one tonne of paper was 1,380 m2global year, plastic was -34,400 m2global year, glass was -4,740 m2global year, aluminum was -161,000 m2global year, and metal was -52,500 m2global year (Menikpura et al., 2013). Clearly, aluminum causes minimum damage to the ecosystem by recycling, and metal, plastic, glass, and paper follow respectively in terms of damage. Therefore, when selecting materials in LPD process, it is important to give priority to environmentally friendly materials to become more lean and green to save the world. Hence, more studies should be conducted in the future on product life cycle and green lean theories.

Lean can be applied to homes, online education, schools, and universities to reduce waste such as over storing of foods and goods, extra energy and water consumption, and extra-long cycle time of courses. Therefore, future research should be conducted to apply lean theories to homes, online education, schools, and universities to reduce waste.

LPD and design for six sigma (DFSS) theories are applied to the product development process to improve quality and reduce cost of products (Gremyr & Fouquet, 2012). DFSS is used to design products with greater tolerance and specification variances without affecting design performances (Gremyr & Fouquet, 2012). DFSS is used to meet full six-sigma performances, there are many difficulties implementing DFSS in the product development process (Gremyr & Fouquet, 2012). Applying general DFSS theories without considering placing the product development process at the correct level can damage innovation culture of an organization (Goh, 2009). Scrap rate expectation in six sigma is 3.4 parts per million (Yahia, 2013). To achieve 3.4 defects per million, it is necessary to have a wider dimension tolerances range for parts and assemblies. For example, to keep a clearance fit between a pin and a hole, it is necessary to make a much larger hole and a smaller pin. To achieve this, it is necessary to have a wider tolerance range for both pin and hole parts. Though a wider tolerance range meets 3.4 defects per million to satisfy six sigma expectations, it raises customer dissatisfaction since the pin and hole joint is too loose (e.g., refrigerator door hinge). Therefore, following six sigma principles makes poor quality assemblies, causing customer dissatisfaction and even higher assembly defects than expected (Antony, 2006). Therefore, it is necessary to keep tighter tolerances for these two features of these two parts to make better quality assembly by controlling the process. This can be done by monitoring manufacturing process (statistical process control) to replacing necessary tools when they wear out to a certain limit. Six sigma doesn't support statistical process control (Antony, 2006).

By implementing six sigma in Home Depot, the company went from first in customer satisfaction to the worst (Hindo & Grow, 2007). After implementing six sigma, employees at 3M Corporation suffered negative effects in innovation and creativity (Chakravorty, 2009). Both 3M and Home Depot were not satisfied with their Six Sigma implementation (Hindo, 2007; Hindo and Grow, 2007). Robustness, reliability, and quality of product design cannot be fully achieved by implementing LPD (Yang & Cai, 2009). To overcome drawback of both DFSS and LPD, Gremyr and Fouquet (2012) suggested the merger of LPD and DFSS (called design for lean six-sigma) to improve quality and reduce product development cycle time. Benefits of merging LPD and DFSS is that it can reduce unwanted variations in DFSS and reduce product development cycle time that is the focus of LPD (Gremyr & Fouquet, 2012). Therefore, more research should be conducted in future on merger of LPD and DFSS to reduce waste further, and to improve quality of products.

Finally, more research should be conducted in the future to bring all the sections of an organization under one lean umbrella to motivate employees, adapt to lean culture, and to find more lean theories to reduce waste and cost further and to meet global demands and shareholders' expectations.

Conclusion

Lean theory is a method that can be used to eliminate waste in the product development process (Gecevska et al., 2012). Understanding the importance of eliminating waste, many organizations are working to practice lean theories to reduce cost and improve quality to gain a competitive advantage (Sun, 2011). However, as a result of the complexity and difficulty of implementation of LPD, LM is much more popular in industries compared to LPD processes; LPD requires contributions from different functional areas due to this complexity (León et al., 2011). In product development it is not clear what the final item will be until the end of the product development cycle (León et al., 2011). Therefore, lean theories are strongly focused on manufacturing (Hoppmann et al., 2011). However, there are many benefits of applying lean theories in the field of product development (Hoppmann et al., 2011). Therefore, LPD is currently the focus of many corporations to maximize value, improve quality, reduce cycle times, and reduce product development costs (León et al., 2011).

The purpose of the quantitative non-experimental study was to examine the relationship between the type of part design CAD software used in part design in LPD and product development cycle time in LPD, the supplier involvement in the LPD process product development cycle time in LPD, CAE tools (FEA and CFD) used in LPD and product development time in LPD, and IT involvement in the LPD and product development time in LPD.

This study clearly demonstrated that there was no significant relationship between the type of CAD software used in part design and product development cycle time in LPD. However, there was a significant relationship between the supplier involvement in

LPD and product development cycle time in LPD, based on Wilcoxon signed-rank results. If the supplier is involved in LPD process, it reduced product development time in LPD. Therefore, supplier involvement in LPD is important to reduce product development time. Therefore, it is important company engineering managers work closely with suppliers during the LPD process to reduce product development cycle time to bring quality products to market faster, to gain competitive advantage, and meet shareholders' expectations.

There was a significant relationship between the CAE tools (FEA and CFD) used in LPD and product development time in LPD, based on Wilcoxon signed-rank results. If CAE tools (FEA and CFD) are used, it reduced product development time in LPD. Therefore, it is important for company CAE teams and LPD teams to work closely together during the LPD process to reduce product development cycle time, to bring quality products to market faster, to gain competitive advantage, and meet shareholders' expectations.

There was a significant relationship between IT involvement in LPD and product development cycle time in LPD, based on Wilcoxon signed-rank results. If IT was involved in LPD process, it reduced product development time in LPD. Therefore, it is important for company IT teams and LPD teams to work closely together during the LPD process to reduce product development cycle time, to bring quality products to market faster, to gain competitive advantage, and meet shareholders expectations.

The main objectives of LPD are to minimize waste, improve quality, and reduce product life cycle and cost in product development (Sören & Torgeir, 2013). The reduction of waste in the product development process appears to be an important task in

LPD. Therefore, it is important to conduct more research on LPD to minimize waste, improve quality, and reduce product life cycle and cost in product development to gain competitive advantage and meet shareholders' expectations.

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Appendices

Appendix A: Sample Size Calculation using G*Power 3

Input Data

$\alpha = .05$

Number of predictors = 4

Effect size of 0.25

Power ($1-\beta$ err probability) = .80

F tests – Linear regression

The result

α err probability = 0.05

Output: Noncentrality parameter $\lambda = 13.25$

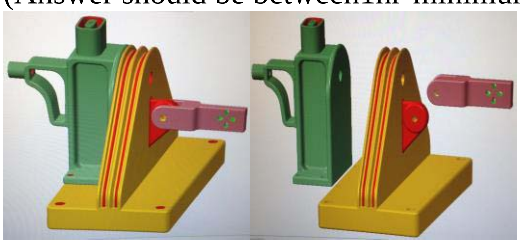
Critical F = 2.565241

Numerator df = 4

Denominator df = 48

Total sample size = 53

Appendix B: Survey Questions

1	Are you an engineer (working in the design or manufacturing industry in the USA) who uses CAD software?	☐ Yes ☐ No	
	If yes, please answer to the following survey questions:		
2	What kind of software do you know (mark all)?	☐ Unigraphics(NX) ☐ ProEng ☐ SolidWorks ☐ Others (Specify below)	
3	How much time would it take you to model and assemble the parts in the picture below with the software you know (hrs)? (Answer should be between1hr-minimum and 20 hrs-maximum) 	Unigraphics(NX)	
		ProEng	
		SolidWorks	
		Others (Specify	
	For the following questions, assume product development time is 18 months from concept design to start production; including tooling, testing, and validation.		
4	How much product development cycle time does it reduce/add (%) if the supplier is involved in the product development process?	reduce (%)	add (%)
5	How much product development cycle time does it reduce/add (%) if CAE tools (such as FEA and CFD) are used in the product development process?	reduce (%)	add (%)
6	How much product development cycle time does it reduce/add (%) if IT is involved in product development process?	reduce (%)	add (%)

Appendix C: Informed Consent Form

Computer-Aided Engineering, Information Technology and Supplier Influence on Product Development Time in Lean Product Development

What is the study about? You are invited to participate in a research study being conducted for a dissertation at Northcentral University in Prescott Valley, Arizona. The researcher is interested in your thoughts and opinions about how you view computer-aided engineering, information technology, and supplier influence on product development time in lean product development. There is no deception in this study.

What will be asked of me? You will be asked to answer a few questions about how you view computer-aided engineering, information technology, and supplier influence on product development time in lean product development. It is estimated it will take 10 minutes to complete the survey.

Who is involved? The following people are involved in this research project and may be contacted at any time:

Student: Danister Abeygunawardana D.Abeygunawardana2229@email.ncu.edu
Committee Chair: Michael Brizek (PhD) mbrizek@ncu.edu

Are there any risks? There are no expected risks in this study. Only two questions or a semi-personal nature will be asked. The first, are you an engineer who works in design and manufacturing industries in the USA. The second, are you familiar with some computer aided design software. These questions could be distressing to some people. You may stop the study at any time. You can also choose not to answer any question that you feel uncomfortable in answering.

What are some benefits? There are no direct benefits to you of participating in this research. No incentives are offered. The results will have scientific interest that may eventually have benefits to the financial, environment, employees, and shareholders of companies.

Is the study anonymity/ confidential? The data collected in this study are confidential. Your name or personal information is not linked to data. Only the researchers in this study will see the data.

Can I stop participating the study? You have the right to withdraw from the study at any time without penalty. You can skip any questions on any questionnaires if you do not want to answer them.

What if I have questions about my rights as a research participant or complaints? If you have any questions about your rights as a research participant, any complaints about your participation, or encounter any problems, please contact the researchers identified above. If you would prefer to talk to someone outside the research team, you may contact Northcentral University's Institutional Review Board at irb@ncu.edu or 1-888-327-2877 ex 8014.

We would be happy to answer any question that may arise about the study. Please direct your questions or comments to: Danister Abeygunawardana (734-740-7878, email: D.Abeygunawardana2229@email.ncu.edu), or Dr. Michael Brizek (928-541-8220, email: mbrizek@ncu.edu).

Participant Online Consent Signature

I have read the description above for The Computer-aided Engineering, Information Technology and Supplier Influence on Product Development Time in Lean Product Development study. I understand what the study is about and what is being asked of me. In lieu of a signed consent form, my participation in the study by answering the questions in the survey indicates that I have read and understand the informed consent form and agree to participate in the study.