Exploring the Impact of Lean Design and Lean Supply Chain Management on an Organization's Innovation Capability

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ABSTRACT

This thesis analyzes and discusses how implementing lean design and lean supply chain management affect an organization's innovation capabilities. Since lean concepts focus on low risk, short-term gradual improvement of existing processes and products with an emphasis on eliminating any and all wastes in the system, applying lean to an organization often implies difficulties in promoting innovations that involve high risks and dramatic changes. Little is known about how lean design and lean supply chain management concepts might affect an organization's innovation capability and its responsiveness to react quickly to changes brought by radical innovations. These relationships were investigated and analyzed based on findings from two online surveys. Seventy-six and seventy-seven respondents were acquired from the two surveys, respectively. Results suggest that the stressed importance of standardization in lean design has a negative effect on an organization's radical and architectural innovation capability. It is also shown that disruptive innovation capability will be negatively influenced by value analysis in lean design, especially in terms of how an organization ranks product attributes and allocates resources based on customer requirements. For the impact on an organization's responsiveness to radical innovations, the findings suggest no impact from minimizing buffers in a lean supply chain but a positive impact from increasing supplier commitment and involvement levels.

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1.0 Introduction

The current state of the economy is creating a more risk-averse environment that emphasizes efficiency and short-term returns. Consider a local engineering organization that has recently adapted the concepts of lean throughout its system from new product development to manufacturing. Company executives stress the importance of maintaining a high level of efficiency and quality throughout the entire process while removing any wastes that do not add to the value of the final product. A set of standardized rules have been placed upon the organization for the product design to prevent any forms of activities that are not value adding. Variability in the system is diminished by standardizing and formalizing all aspects of the system, from standardized parts and materials to standardizing the design processes. The organization has also recently implemented lean management into its supply chain by minimizing the number of suppliers in its system. The company has emphasized that in order to benefit during this state of the economy, the goal is to satisfy the values and requirements of its current customers. This includes identifying the importance of certain product attributes and defining its costs and resource allocation based on the needs and requirements of its customers. These approaches have increased the efficiency of the organization while removing significant levels of variability. But does this lean system come at the expense of its innovation capability? Does the lean supply chain management reduce the firm's flexibility in responding to radical innovations to stay on top of the competition? This organization may become heavily reliant on short-term improvements and may overlook the potential long-term advantages associated with certain levels of risk. The innovative design teams of this firm are capable of generating creative new ideas that have the potential to benefit the entire organization. These new ideas however require resources including people, time, and capital investments. There is the possibility that some of these new ideas may not succeed, but some of these may result in radical new innovations that can bring long-term success to the company. According to the concepts of lean, any activity that does not add value to the current customers should be removed. Should activities that generate ideas that could possibly lead to nothing be discouraged? Should activities that do not add value to the current customers but may create value for a new market also be discouraged? How do the different aspects of lean design and lean supply chain management affect an organization's innovation capability?

Differing or conflicting objectives of the lean and innovation management concepts are likely to cause discrepancies within an organization that is striving to be lean and innovative. The goal of a lean organization is to design and manufacture products of high quality and low cost in an efficient manner. The main focus of lean is to improve the overall value of its products by eliminating all waste [1-3], which ranges from overproduction and additional transportation to wastes of motion and correction [4]. Innovation is characterized as the commercialization of newly designed and implemented products or processes [5]. The key to successful innovation is to promote creativity among all individuals within an organization, conducting experimentations, and disregarding the chances of failure. Innovation often requires an organization to support specific levels of variability or risk in order to achieve a long-term competitive advantage. Flexibility is required in the system to promote dramatic changes to product designs and to be able to rapidly respond to design changes made by competitors. The lean approach of eliminating anything that does not provide gains in the current products valued by its customers may prevent creative and innovative ideas from becoming a reality. As stated in [6], "…creativity is undermined unintentionally every day in work environments that were established…to maximize business imperatives such as coordination, productivity, and control." Lean concepts are successful at eliminating waste, increasing productivity and quality, and lowering costs, but may destabilize the ideas of innovation in the process.

This research will investigate the effects of lean design on an organization's innovation capability at different levels (e.g. architectural, radical, and disruptive). The study will also test whether reducing the number of suppliers will have a negative effect on an organization's responsiveness to radical innovations and whether such effect can be reduced by increasing supplier commitment.

For this research, a series of hypotheses will be tested. Online surveys will be constructed and distributed to different engineering organizations to collect data. Statistical analyses will then be performed based on the survey results to test the hypotheses. Main concepts in lean management and innovation management will be reviewed and summarized in the next section.

2.0 Literature Review

2.1 Innovation Concepts and Techniques

2.1.1 Categories of Innovation

Innovation is defined as the implementation and institutionalization of new and creative ideas [5, 7]. The importance of innovation within an organization, defined by the need for the company to continuously improve, has been emphasized by literature [5].

Based on the degree of changes an innovation brings to the technology and market, whether it is a product or process, and whether it is implemented to sustain competitive advantage or not, researchers have categorized innovation into different groups. The layouts for these categories include: product and process innovation; architectural, revolutionary, regular, and market niche creation innovation; radical and incremental innovation; and sustaining and disruptive innovation.

Product innovation is the commercialization of newly designed and implemented products [5], and is a yield or output implemented for the benefit of a customer [8]. It is generally concerned with developing ideas or creating something new that is revealed in changes to the final product or service. Criteria used to measure an organization's level of product innovation include: its level of newness for the organization's products, its use of the latest technology in products, and the speed of new product introduction [9].

Process innovation is the implementation of a new or improved process or practice. It is identified as an alteration in the way an organization produces its final products through the diffusion or implementation of a pre-existing innovation [9]. Criteria used to measure an organization's level of process innovation include: its technological competitiveness, its speed of implementing the latest technology, and the degree of updated technologies used in its process [9]. Process innovation is also defined as an instrument, piece of equipment, or knowledge in processing that mediates between inputs and outputs [8]. The rate of implementation for product and process innovation is based on the stages of development of the organization. Therefore, there is a significant relationship between these two forms of innovation.

In the initial stages of the technology life cycle, product innovation is identified as the dominant type of innovation and is directed at improving the performance of a particular product [10]. At this early stage, process innovation is fairly minor with processes identified by flexibility and skill levels of labor. Consecutive product innovations can result in a dominant design, signifying an optimal configuration for that product or service, and the leveling of product innovation. It is at this stage in the cycle that the focus of innovation activities shifts to process innovation with a purpose to minimize the processing costs. As the dominant process is achieved, process innovation levels and both types decline until a new technology or service is introduced. Then the technology life cycle replicates. Figure 2.1 depicts this cycle in the Abernathy/Utterback model.

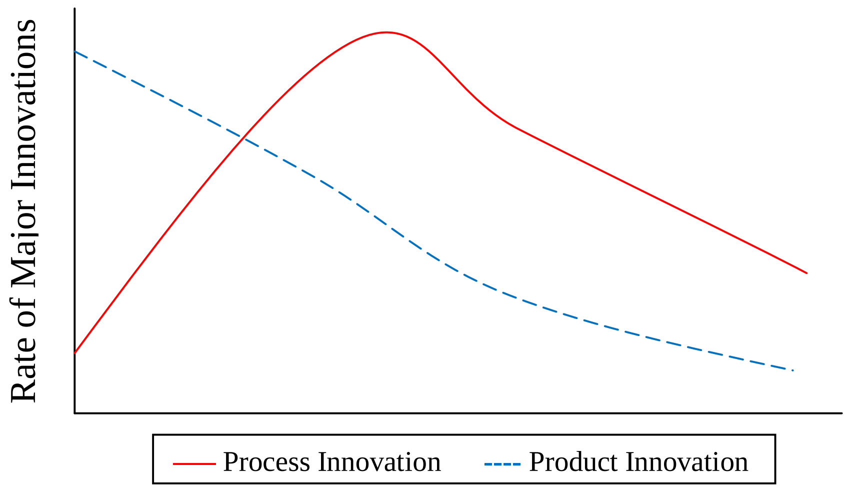

Figure 2.1 - Abernathy/Utterback Model [11]

The author in [12] performed a study on the relationship between product and process innovation, and how one can impact the other. It was determined that product innovation has a positive impact on process innovation, but evidence could not be identified to prove that process innovation has an impact on product innovation. In any system, implementation of a new product is often successful if a new process is constructed. New product introduction often magnifies the current process technology as insufficient. Even if this is not the case, it is common for the organization to use a new product design as a suitable reason to improve upon the process. The reverse trend is not as reasonable. It is possible that process innovation may incidentally improve the product, but it is not directly related.

Depending on how much change an innovation brings to the technology or market, Abernathy and Clark placed innovation into four main types: architectural, revolutionary, regular, and niche creation [13]. Architectural innovation includes the structural design and basic configurations of a product. The configurations of the components are changed while upholding the core design. An example of this category is the change from rear-wheel vehicles to front-wheel vehicles; the core concepts remained the same but the interactions and linkages are changed. This innovation identifies the broad design of the products and sets the aim for competition that will develop in the industry. The major importance of architectural innovation is to disperse from prior industries to define the new configurations for the industry. Revolutionary innovation occurs when a new product design renders all other products in the field obsolete [13]. An example of this in the automotive industry is the steel closed body. After this innovation all other designs for this automotive characteristic were deemed obsolete. This revolutionary innovation is the new design or strategy of how the organization does business. Regular innovation is a form of incremental innovation in which improvements are made on a pre-existing design or process [13]. The innovation is applied to already existing industries and improves upon the established technical competence of the industry. Finally, the innovation in market niche creation focuses on defining the overall needs and requirements of the customer and alters and improves the technology of the product accordingly [13].

All four types of innovation discussed are critical to the overall success of an organization. The timing of the type of innovation, though, is based on the phase of the current system. The pattern of the industry is separated into three phases: fluid, transitional, and specific [11]. In 2002, Roberts and Liu identified a fourth stage: the discontinuities phase [14]. The rate of major innovations for an industry based on these phases is displayed in the Abernathy/Utterback model, as shown in Figure 2.2.

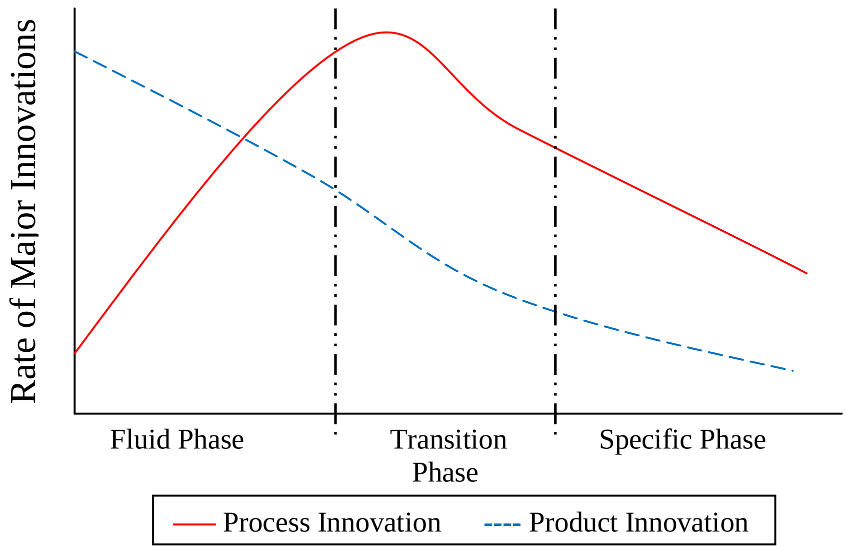

Figure 2.2 - Abernathy/Utterback Model with Phases [11]

The fluid phase has an emphasis on the overall performance of the product and the innovation is determined by the needs and inputs of the customers [11]. At this stage innovation is defined by frequent changes in the design, or architectural innovation. The next phase of the system is the transitional stage. This stage has an emphasis on the variation of products and expanding the overall technical capabilities of the organization [11]. In this stage, the organization tries to meet the needs of the customer and also identifying regular improvements to the existing products. Therefore, market niche and regular innovations are usually implemented in this stage. The third phase of the model is named the specific stage, which is emphasized by cost reduction and quality improvement [11]. This phase starts when the rates of both innovations begin to decrease. Innovations occurring during this stage are generally in the category of incremental or regular with a goal to improve the overall productivity and quality in the system. The final stage of the system is the discontinuities phase. This stage is identified at the end of the Abernathy/Utterback model where a revolutionary or radical innovation is introduced into the industry, rendering all other technologies obsolete. The pattern then cycles back to the beginning where architectural innovation will be enforced [14].

It was previously stated that architectural innovation changes the configurations and linkages among the components of the product while maintaining the current core design. Research has identified potential problems that may lead to difficulties for companies to deal with this type of innovation [15]. First, it requires significant organizational resources to identify the need for and develop an architectural innovation. Significant interactions within the organization are needed to make it happen. The second problem is that the organization will need to build and apply new architectural knowledge. The current infrastructure of established firms may make this a very difficult process due to the path dependence feature of technologies as well as the way companies are organized around the technology. Resources and new types of learning must be invested into the organization to comprehend innovation that is deemed architectural. Knowledge must be obtained to identify innovation that enhances the business and innovation that is detrimental to the competence within it. The effects of architectural innovation are also impacted by the type of organizational learning. Organizational decision making and learning is required in order for the innovation to be beneficial.

For revolutionary innovation, the key to success is that it must be timed correctly to meet the needs of the market. Revolutionary innovation is focused on existing markets, yet renders the current technology in the field obsolete [13]. This leads to a new criteria for the given product or process that must be accepted by market needs. If a unique, significant innovation is not a concept that is beneficial to market needs, it may not be successful [13].

Regular innovation on the other hand is not as significant on the individual scale. This type of innovation involves a series of gradual, progressive changes to a pre-existing product or process. The cumulative sum of the individual changes results in a significant impact on the original product or process. The key to success of this type of innovation is organizational and managerial support. Each individual innovation may not appear to alter the overall performance, so it is the support of the organization towards incremental improvements that positions the technology to success [13].

Market niche creation refers to making improvements to pre-existing products or processes in order to open new market opportunities [13]. To be beneficial to a firm, the key is timing and rapid reaction time. First, timing is necessary to create a niche to improve the standing of the organization. However, if competition is heavy in this niche market, long-term competitive advantage cannot be achieved through the improving technology alone. This success is set by the rapid reaction to the need for new products and processes in order to surpass the competition in the niche market.

An additional approach for defining innovation is to characterize the type as either incremental or radical. With this set-up, innovation is identified based on the associated level of change. Radical innovation is representative of a different approach from the existing product or process in an organization [8]. It creates a new functionality to the product or process, or it dramatically modifies the existing technology by changing or improving different characteristics of the system or lowers the overall costs [16]. An example of a radical innovation is the introduction of personal computers. Radical innovations have a significant impact on the overall structure of the industry. It consists of the creation of primary changes in the activities of an organization, causing increased uncertainty in the work settings and an overall transformation of the system.

Incremental innovation is characterized by gradual changes from the existing practices of an organization and is known for supporting or strengthening the current capabilities of the system [8]. The changes to the product or process look to improve only on the current systems. The organization, therefore, generates new ideas that endorse the development and enhancement of its existing product designs [17, 18]. Incremental innovation brings a marginal change to the current technology system in terms of its performance or quality without affecting the functionality [16]. While the changes are minor, they are definitive improvements to the product or process. A contributing factor to an organization's incremental innovation capability is the sustained development of its core competencies [19]. An example of incremental innovation is the evolutionary, gradual changes to the modern motor vehicle in terms of safety, performance and fuel economy.

To better illustrate the relationship between radical and incremental innovations, the concept of the technology S-curve is introduced. As shown in Figure 2.3, the S-curve is based on performance and effort/time.

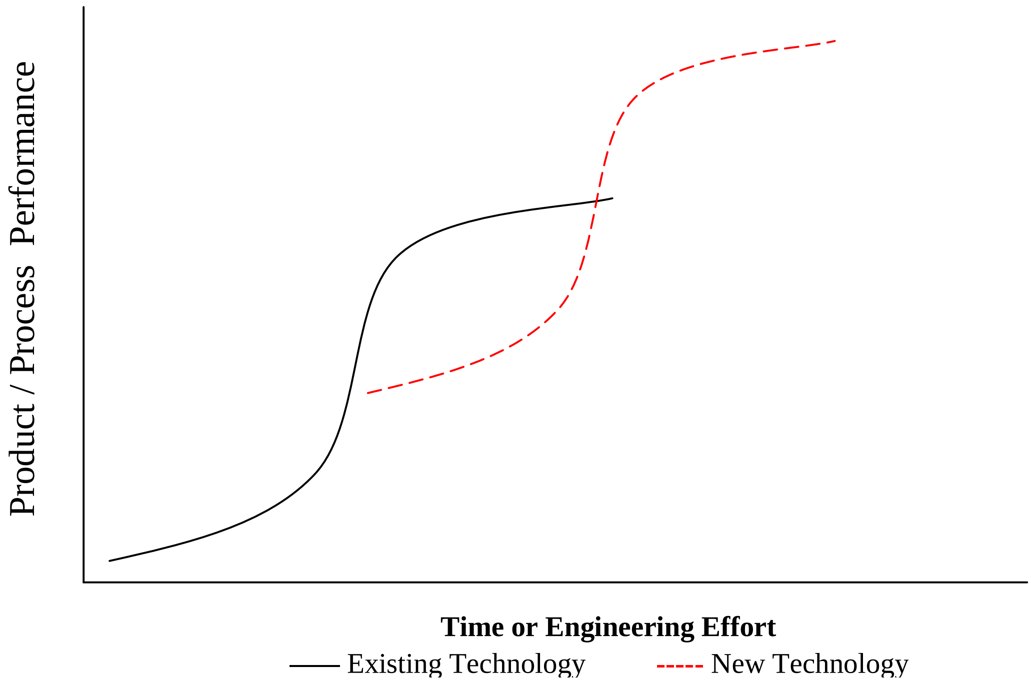

Figure 2.3 – Technology S-Curve [20]

The technology S-curve is helpful in defining the transition from existing to new technologies in an industry. The S-curve also identifies the rate of improvement in performance for a particular product or process as time or engineering effort increases [21]. Usually, a technology experiences exponential growth in performance when it is first introduced then grows linearly until it finally reaches a limit when the technology has fully matured. At this point additional improvements to the technology are considered either impossible or no longer cost effective. The technology may now become obsolete in the current market. The improvements that are made on a single S-curve are representative of incremental innovations. The key to success for this type is to continuously incorporate gradual improvements to the existing technology.

While an incremental innovation contributes to improving the existing technology, a radical innovation is likely to structure a completely new type of technology and start a new S-curve. This new S-curve is formed to achieve higher performance levels when the existing technology matures and incremental innovations no longer bring in dramatic improvements [20]. Ideas or technologies that lead to radical innovation may be introduced while the previous S-curve starts to level off. A radical innovation that starts a new S-curve may have lower performance initially than the existing technology but has the potential to exceed its predecessor.

Companies are often faced with difficult decisions when confronted with market and technological change. The company must determine if and when it should listen to its customers or if it should follow different approaches of innovation management. Technological changes can be either sustaining or disruptive [21]. A sustaining innovation is similar to a regular innovation in that it "sustains" and improves upon the performance of an existing technology. Disruptive innovation refers to technologies that are initially worse in a specific area, or areas, of performance valued by current mainstream customers but offers other valuable features [21]. This translates to an initial unsatisfying return on investment. Due to its significant potential, though, this type of innovation can eventually better more established technologies and dominate the market. Examples of disruptive innovation include digital photography and mobile telephones, which were originally worse in performance than its established counterparts but became dominant later. For mobile telephones, the innovation originally performed worse in terms of higher prices and lower coverage and reliability as compared to land-line telephones but had other attractive attributes such as convenience and portability. The innovation eventually dominated the market due to its development in the underperforming areas and the growing popularity of those other attractive attributes.

Successful sustaining innovations require a company to have a valued capability of bringing new technologies to the current market [21]. This is made possible by providing continuous improvements to the products and processes based on the values of the customer. This viewpoint would not be successful in terms of disruptive innovation. Due to its lower levels of performance in areas most valued by mainstream customers, disruptive technology would not be accepted in the existing market at the beginning. The key to success for disruptive innovation is to identify a new market that finds value towards the current overall performance of the technology. With support from the new market, the technologies can then get improved and eventually meet the needs of and attract the mainstream customers with its special offerings and features. The organization must also be willing to support and experiment on these new technologies that offer new attractive attributes that may not be initially valued by its mainstream customers [21].

The differences among the innovations in all of the categories discussed translate to alternative keys to successful implementation, which are summarized in Table 2.1.

Table 2.1 - Keys to the Successful Implementation of Innovation

Keys to Successful Innovation	
Innovation Type	**Key Characteristics**
Architectural	• Significant interactions within the organization. • Resources and new types of learning must be invested. o Apply new architectural knowledge
Revolutionary	• Correct timing of innovation to meet the needs of the market.
Regular	• Organizational and managerial support of continuous improvement.
Market Niche Creation	• Timing and rapid reaction to market needs.
Radical	• Organizational support and commitment.
Incremental	• Continuous gradual improvement to the pre-existing technology.
Sustaining	• Base continuous improvements on the values of the customer.
Disruptive	• Identify a new market that finds value to this technology. o Don't base system on the values of the existing customers. o Support technologies that underperform in certain areas but have other valuable features and the potential to be improved to dominate.

2.1.2 Contributors of Innovation, Process of Innovation

In addition to the specific factors that were identified to be critical to each type of innovation, some general rules can be followed to improve an organization's innovation capability. For example, an environment that supports and stimulates creative thinking is a greater contributor to innovation. To promote innovations, it is essential for managers and other top-order executives to inspire creativity among its employees and identify creative ideas that may lead to future success. Expertise, creative-thinking skills, and motivation are the three aspects that constitute creativity [6]. Expertise is measured by the knowledge that an individual possesses. Creative-thinking skills define an individual's approach to solving problems and understanding certain situations. Motivation is the intrinsic value an individual places on solving these problems. It is recommended that management inspires these components in order for innovation to flourish in the organization. Supervisory and organizational support can assist in strengthening these aspects. The work environment itself can stimulate intrinsic motivation, in combination with expertise and creative-thinking, which can lead to proactive and creative employees. If an employee feels as though their new ideas are encouraged or supported rather than refuted, they will have an increase in their creative-thinking approaches. Creative employees can be a source of competitive advantage and improve upon the levels of innovation [6].

Examples of inspired innovation suggested by executives and innovators include [22]:

- Address innovation and creative-thinking as normal activities in an organization.
- Encourage people to expand their perceptions and improve upon how they work.
- Place people in new environments to support new ideas and ways of thinking.
- Identify failure as not being a problem when being innovative; support all forms and levels of risk.
- Introduce people to a topic that has new and diverse perspectives; promote strategic innovation by identifying areas within a design that have not yet been approached.
- Encourage all forms of new ideas, no matter how incremental or radical.

- Promote innovation through continuous experimentation of problems that need to be solved.

Radical change among upper management can promote new ideas and innovation within an industry. New ideas that are continuously questioned and dissected can have a detrimental effect on the extent of an organization's innovative success [6].

An organization has the potential to become more successful with innovations if it employs a proper innovation process. This process describes the overall view of the organization's innovative approaches in order to locate its weaknesses and determine priorities for improvement. One such process is entitled the "innovation value chain" [23]. The innovation value chain is separated into three main phases and six critical activities that are performed throughout the entire process. Since it is the weakest link that defines the company's overall capabilities for innovation, the process directs them towards the weakest link on the innovation value chain and prevents excessive resources from being placed towards its strengths.

The first link of the innovation value chain is "idea generation" [23]. The formulation of ideas comes from three different activities. The first is "in-house" idea generation and is the most common starting point for a company. The initial ideas are created within the unit of the company. The second activity for idea generation is "cross-pollination". This involves collaborating different ideas across the entire company. It allows for an outsider's perspective from other fields and for identifying new concepts that may have been missed from the in-house viewpoint. The final activity in this first stage is "external" idea generation. This is a similar view to outsourcing innovative ideas. The firm collaborates with parties that are not part of its organization. Breaking the idea generation into these three activities helps to avoid missed ideas or opportunities.

The second link on the innovation value chain is "idea conversion" where ideas are selected for funding and are developed into a particular product or process [23]. It is in this phase that a company converts the generated ideas into something beneficial through the stages of selection and development. In the selection stage, the generated ideas are screened and the appropriate options are funded. This activity will determine if a company is too strict on screening and if there is sufficient money available to support a variety of projects. The development stage transitions the concept in the selected ideas into a successful product or service. In the final phase, the diffusion phase, companies need to support and distribute the new products or processes to attain monetary gain from the original ideas [23]. The main activity in this stage is "spread" where the developed ideas are distributed and supported across the organization.

The knowledge of the strengths and weaknesses of the innovation value chain will allow an organization to focus on specific areas for improvement. It is this thorough assessment and strengthening of the weak link that transitions an unstable innovation value chain to a successful one.

An additional approach to the innovation process is entitled the unitary sequence model. This approach views innovation as sequential linear stages [8]. The phases of this model differ depending on whether the organization engages in either, or both, the generation and adoption of innovations.

The generation of innovation phase refers to the problem-solving and decision-making in the development of new products or processes and is separated into five stages [8]. The first stage is to generate ideas similar to the innovation value chain. The next two stages define the project and identify a problem that will be solved with this generated innovation. These first three stages use different activities that lead to an original design through the combination of information about value for that particular innovation and the technology necessary to attain the innovation. The final two stages accentuate the product or process development and commercial exploitation, after the innovation has been defined as a feasible solution.

The second phase is the adoption of innovation [8]. This phase refers to the process of change in the organization which has an effect on the technical and social aspects of the system. This phase is defined in two stages: initiation and implementation. The initiation stage incorporates awareness for the innovation, formation of value, and evaluation of the innovation based on the organization. Implementation begins when the organization decides to adopt the innovation and is separated into two types: trial and sustained. Trial implementation uses initial testing to determine the product or processes suitability to the needs of the organization. Sustained innovation is the final section of the adoption phase and includes the complete integration of the innovation into the organization.

The author in [5] identified two main types of processes frequently used in management and their resulting impacts on innovation capability. Table 2.2 presents the main points of the two principles.

Table 2.2 - Institutional and Technical Processes [5]

Type of Process	Founding Ideals	Socialization	Leadership	Formalization
Institutional Processes	Creativity; expansion of ideology	Direct contact with founders: Sharing of information	Charismatic, Transformational	Ideals dominant; structure tentative
Technical Processes	Structure, goals of the organization	Procedures and rules learned through colleagues	Problem solving, Transactional	Early standardization, routine; reduce uncertainty levels

The institutional process defines the approach for an organization to be innovative. The focus is on creating new principles and approaches to support the new idea or innovation. Comparatively the technical process, which is an extreme representation of a lean organization, is more standardized. Certain goals and guidelines are placed leaving insufficient areas for creative thinking and innovation. The technical process is defined to reduce uncertainty and waste in the system while the institutional process maintains some forms of uncertainty. This diversity of an organization enables the environment to support creativity and innovation. The charismatic leadership allows flexibility throughout the organization while the problem solving approach in the technical process is constrained to its productivity [5].

In [24], the authors describe the overall tension and conflict between how an organization generates knowledge in practice, such as innovation or creativity, and how the organization implements these ideas through process, such as the structure of the system. When the two concepts are isolated in an organization there is a high probability of failure. If the concepts are combined, it can produce creativity and growth. Shared knowledge and an organizational understanding are necessary to have a unified innovation become successful. In organizations where members are separated and there is little discussion, it is difficult for both concepts to sustain in the system. The problem with this is associated with the main conflict of creativity and structure. Knowledge has the potential to emerge in the close innovative groups but wealth comes from growth. Growth often leads to the destruction of such groups. Business processes need to be established that allow rigor without having the system become too rigid. The structure is defined by the process, which is the hierarchical directive and tactical commands of the organization. This structure is often created through the standardization of the lean approach. Practice deals with the creativity and innovation of the organization. A system without process can become unmanageable. If practice is absent there will be a lack of creativity resulting in less innovative ideas. The best approach is to identify a trade-off between practice and process that can maintain the most successful case for forward process.

The following section documents the concepts and components of lean management, followed by the overall impact of lean on innovation and creativity.

2.2 Lean Concepts

While the philosophy of lean was originated by Toyota in the 1950s, the term was originally defined in the book, *The Machine That Changed the World*, in 1990 which documented the research results of a study performed at the Massachusetts Institute of Technology (MIT) on the vehicle industry [1, 3]. Lean practices were implemented based on several ideologies that appeared prior to it, including total quality management and just-in-time production (JIT). These ideas sparked some of the key elements of lean including the focus of producing high quality products at relatively low cost as items are needed [3]. The early stages of lean were performed at Toyota Motor Corporation under the guidance of Taiichi Ohno. The techniques of eliminating waste and excess from the product flows were first introduced to automotive engine manufacturing, then to the assembly of the automobile, and later to other parts of the Toyota supply chain. At this final point the concepts of lean were introduced to organizations outside of the Toyota Corporation. New lean principles were formed to identify the value of the customer, implement value stream mapping through the system, develop flow production capabilities and a pull-based system, and identify and eliminate all forms of waste in the system [25]. The main components of lean including overall definitions, lean design, and lean supply chain management are discussed in detail in the following sections.

2.2.1 Definition of Value, Waste, and Quality

The concepts of lean include three levels. The first level consists of the basic identity of the system to define value and waste. The second level involves the strategies used to enhance and achieve these definitions. The third level is the implementation stage of the strategies imposed in the second level [2]. The three levels are used to identify and accommodate the three main objectives of lean: (1) improving the flow of the system; (2) applying only value added time and steps into the organization; and (3) eliminating all muda, or waste [1]. The goal of an organization is to develop and maintain production or service value for the customer while reducing waste in the system [25]. Any tasks performed by the organization that do not add to this value are considered as waste in the system [2]. Muda, the Japanese term for waste, is categorized into seven different types [4]:

- Overproducing more items than included in customer orders.
- Inventory due to increasing finished goods and work-in-process.
- Motion that does not add value to the final product.
- Waiting for any resource throughout the flow of design and production.
- Transportation or the additional movement that is not of value to the product.
- Over-processing or additional steps that do not increase the overall value of the product.
- Not being right the first time or the costs and time associated with repairing or correcting a product.

The underlining definition of these seven categories is that waste is represented by any item in the system that uses cost or time in the organization, but does not add value to the customer's final product. Value is based on the customer's perspective and is often defined by cost and the requirements of the customer [25]. This value is introduced to an organization as internal wastes are reduced or if products or services are offered that are of value to the customer. The importance of the customer value is institutionalized by the two levels of the lean approach: strategic and operational. The strategic level of lean thinking requires understanding the value of the customer; the operational level achieves requirements set by customers through the practice of lean production techniques. The facility eliminates waste to a certain level, while still meeting the value of the customer [25].

Quality and continuous improvement are additional concepts of lean management [3]. Specific traits from the Total Quality Management (TQM) approach along with key characteristics from the Just-in-Time approach defined the overall components of a lean manufacturing environment. One of the key aspects of lean introduced by Total Quality Management is the promotion of high quality products to the customer at relatively low costs. The focus of quality and waste is based on the perspective of the customer, ensuring that operations are completed at the right price and at the right time [3].

An additional aspect of TQM that is necessary for a lean environment is quality measurement. Quality management and process capability techniques are incorporated to reduce variability and increase quality of products and processes. A typical quality management technique is Statistical Process Control (SPC), a methodology established by Walter Shewhart [26]. This technique enables workers to ensure that a process supplies defect free parts to the subsequent process by locating and preventing quality problems in the current system [26]. Once the process criteria are defined, the next step of the TQM approach is to verify the process capability [27]. In this stage the capability of a process must meet its purpose set by management and the process definition structures. This is completed by ensuring that the variability of the system is within the specifications or tolerances.

Total Quality Management also stresses the importance of continuous improvement. Continuous improvement, or Kaizen, is defined by incremental changes aimed to eliminate waste in the system. This is achieved through cost and quality improvements to improve upon the overall efficiency of the system [2].

The authors in [9] have concluded that Total Quality Management may not be beneficial to innovative thinking. It was shown that the origins of this system are set towards the concept of quality control. This controlling of the system can be viewed as contrary to the "spirit" of innovation. The focus on the customer to define what is considered quality and what is considered waste can prevent the inspiration of product and process innovation.

2.2.2 Lean Practice versus Lean Thinking

An organization may adopt lean management at the practices level, strategic level, or both. Lean practices refer to tools that an organization can use to improve its system. Examples include the implementation of the 5s workplace, standardized work procedures, Kaizen events, Kanban implementation, and statistical process control, as discussed in the previous sections. The purpose of these tools is to meet the requirements to improve efficiency through elimination of waste and increase the overall quality of the products [2].

Applied at the strategic level, lean thinking represents a form of organizational learning. It is an approach used to modify the way a company does business. Lean thinking, like lean practice, stresses the importance of value. Its primary goal is to satisfy the customer by adding value to the product or process and eliminating any and all forms of waste [25]. The value definition thus affects the value stream of the system in creating a continuous flow. This approach then implements the demand pull approach and stresses continuous improvement throughout its organization.

In summary, lean thinking guides the way an organization behaves and performs and lean practice provides a set of specific tools and procedures. Both approaches have the same goal: an improved, efficient, value-adding lean system.

2.2.3 Lean Design

Design for Manufacturability (DFM)

Design for manufacturability (DFM) is a common component for lean design that refers to recognizing the interactions between product design and the sections of manufacturing in order to achieve global optimization of the system [28]. This approach is intended to minimize the costs and resources to design and manufacture a new product. The objectives of DFM include: simplifying product designs; minimizing parts count; and compatibility of product designs with existing manufacturing processes [29].

Simplification is attained through commonality and part re-use as well as by minimizing changes between rounds of product designs [30, 31]. Common interfaces and existing parts are used instead of creating a new design. In many cases, simplification through commonality is performed through the use of modules or platforms. Modules are components with standard qualities to allow for combinations with other components. This allows for the use of common components across product families. Each module is assigned to a different design team allowing for freedom within that particular design [32, 33]. The main concern with this approach is the path dependency of modularity. If the design rules are not obeyed to ensure the proper fitting of modules, it may impact an organization's architectural innovation capability. Part re-use is incorporated to prevent the firm from having to “reinvent the wheel” with new products [30, 31]. Established parts can be reused to simplify the new product design.

Minimizing the parts count is achieved through part integration and introducing multi-functionality to designs. Part integration questions the need for separate parts in a product [30]. This minimization of the parts count serves to diminish the need for specific aspects of the design process including unnecessary assembly. Part integration also involves constructing multiple functioning features for a given part [30]. The parts count can be further reduced by eliminating any features that do not add value to the customer; only value-adding features should be integrated. These aspects of simplification and part integration are incorporated to improve the efficiency of the system and reduce variability.

DFM is also aimed at matching the product design with the manufacturing processes thereby ensuring that a created design can be manufactured [28, 29]. This practice, along with standardization and value analysis, encompass the lean design strategy of responding to the needs of the customers for new products. The main purpose is to use as many existing components as possible and ensure that the designs and existing processes are compatible [29].

Standardization of Production / Process

Among the lean techniques, standardization is a key component of lean design and production. It defines how the process is to be completed by sequencing all the tasks and eliminating non-value adding activities. By simplifying and formalizing the work procedures, the system is less prone to variability and attains higher levels of process visibility [34, 35]. The standardization approach can be applied to parts used in product designs, processes and procedures in the design process, and materials used for new products. This formalization is set in place to minimize variability in all aspects of the system [30]. Special parts are often avoided to prevent part dimensional and property variations and standard procedures are set in place to eliminate variations within the steps of a design process [29-31].

It has been noted that this formalization may pose potential problems for the lean work environment. A system where employees are required to strictly follow production and process guidelines can discourage employees from taking the initiative for a particular product and introducing new and creative ideas. This predefined work process can decrease the freedom an individual has with the production and can potentially decrease employee discretion [34]. The study in [36] suggested a negative impact between constricting work environments experienced through standardization of the system and its workers.

Value Analysis

Value in a lean environment refers to any aspect of the product, or process, that the final customer is willing to pay for [2]. The final component of lean design, value analysis, uses this customer perspective to evaluate the necessary characteristics and attributes of a product as well as defining the associated costs [29, 37]. This allows companies to accurately predict customer demand. The value for a product is defined by matching customer requirements with the product design, and ranking product attributes and associated costs based on the level of importance defined by the mainstream customer [2, 29, 38, 39]. A lean organization would likely identify activities or concepts that do not meet the requirements of the mainstream customers as waste and should be eliminated accordingly [29]. The value analysis approach is set to improve customer satisfaction through incremental improvements by exclusively assessing value in terms of customer requirements.

For rank-ordering of product attributes, a lean organization would place significant weight towards attributes that are required by its current customers [21, 38]. The valued activities meet the needs of the customer in terms of performance, quality, options, and other attributes. Value attributes are then identified and ranked according to importance [21, 38]. Specific costs are defined by customer value based resource allocation which is set to improve products per the requirements of the current customer [2, 29, 38].

In addition, a lean system in customer management would also focus more towards short-term value adding activities than long-term capabilities [40]. This is due to the higher levels of risk associated with the long-term innovative activities. The lean approach would be more dedicated towards the short-term incremental value than the potential long-term value of the system.

2.2.4 Lean Supply Chain Management

Supply chain management (SCM) refers to the set of approaches efficiently used to integrate suppliers, manufacturers, warehouses, and distributors so products are produced and shipped to the right locations at the right time in order to minimize overall costs while still meeting the service level requirements [41]. In a lean supply chain the objective of minimizing waste, in terms of buffers and number of suppliers, is introduced in order to improve upon the supply chain efficiency [37, 41]. The minimization of vendors and buffers within the system is defined as the lean supply chain with limited breadth.

The depth of the lean supply chain is based on the commitment of suppliers to continuous improvement [37]. This commitment includes the involvement of the supplier in all processes and the level of contact with each part of the supply chain. Suppliers in lean management are considered partners within the organization and are, at times, involved in product and process design practices [42]. Information on the product design is obtained and the process from idea generation to the final product is analyzed. This supplier commitment is a key element of a lean supply chain and can aid in synchronization of the flow. The process of involving the suppliers must be adapted in a way that promotes a successful supply chain [43]. Capabilities of the supplier in terms of new product development need to be identified to create a close relationship and support mutual benefits for all aspects of the supply chain.

In addition to continuous improvement, there are other aspects relating to the depth of a lean supply chain: supplier feedback, just-in-time delivery by suppliers, and supplier development [37]. The just-in-time delivery is based on the successful completion of feedback and development. Supplier feedback is characterized as presenting advice and opinions on a regular basis to one's suppliers about their performance. This involves frequent contact among each level of supply chain. Supplier development is incorporated to increase the involvement of suppliers in the production process. These improvements can be achieved through training and development of the suppliers. It is based on these aspects that the overall success of the JIT delivery is defined. Just-in-time delivery by the suppliers in the lean supply chain ensures that products are delivered to the right location with the right quantity at the right time [37, 41]. If the relationship with the supplier has not been developed and feedback has not been introduced, this just-in-time delivery may not be achievable and responsiveness to product changes may be reduced.

A second paradigm of supply chain management exists at the opposite spectrum of lean supply, defined as an agile supply chain [44-47]. A lean supply chain, as mentioned previously, is dedicated to minimizing the levels of waste using a value stream. An agile supply chain is dedicated to using knowledge to take advantage of beneficial opportunities in a volatile system. The primary motive is to create flexibility within the supply chain in order to accommodate for demand uncertainty and changing markets.

The author in [46] showed that the type of supply chain used to benefit the system is dependent on the product type for that industry. An efficient lean supply chain is beneficial for functional products with a rather smooth demand. The lean concept may not have as positive results for innovative products that require a more responsive process. The use of common modules in the lean design can be preventative of product differentiation [44]. The stability of the efficient lean system is often helpful. This is true primarily in the case where quick response times to competitor movement are not necessary. The lean philosophy states that all non-value added activities must be eliminated while promoting certain levels of flexibility. Responsiveness and flexibility, however, are not key metrics of the lean approach [48]. A more agile supply chain is required if innovation is necessary to respond to competitor movement [44, 45]. Whereas the lean supply chain management selects suppliers based on low costs and high quality, an agile supply chain bases its supplier selection on flexibility, speed, and quality [49]. The authors in [50] identified that, to eliminate waste, a lean supply chain incorporates no buffers and limits the number of vendors. The introduction of no buffers is set to reduce the levels of inventory in the system and improve upon efficiency. Reducing the number of vendors can aid the supply chain in minimizing the amounts of resources. However, there are potential downfalls of limiting the levels of inventory and vendors in the supply chain [50]. Without buffers in the supply chain, a slight problem at one section of the chain can be detrimental to the entire system. The combination of lean and supply chain management can also produce a "fragile" system as stated in [51]. The lack of additional resources to deal with unplanned events, or the unknown-unknown occurrences, is due to lean's concepts of no buffers including capacity, lead time, and inventory. The concepts of lean can undermine the transition from cost control to differentiation and creativity [51]. If an organization wants to maintain levels of innovation, it must support and facilitate flexibility in the supply chain. Dramatic changes to existing components and approaches result from radical innovation, thereby requiring the supply chain to be flexible if a breakthrough design is created by a competitor [51].

2.2.5 Other Components of Lean Management

Human Resource Management

The human resources in the system and employee involvement are key concepts in determining the workers' roles in problem solving for a lean organization. Human resource management is based primarily on its workers and also on implementing multi-functionality and team interdependence. In a lean environment workers are expected to perform multiple types of tasks or functions, resulting in the optimal use of the skills of the workforce [34]. However, if a worker is no longer specialized and must perform several different tasks he may lose expertise in a given field. Team interdependence is the degree of collaboration between workers in order to complete a product or process [52]. Lean human resource management stresses the importance of eliminating waste, or excess workers from the system. This incorporation of the lean approach translates to less people involved in the collaboration process. The result is fewer contributing ideas from different perspectives used in defining the overall success of a product or process.

The author in [36] identified that lean promotes productivity, elimination of waste, and efficiency with its employees through the standardization of the process as well as increased worker utilization. This also has a tendency to decrease the levels of job autonomy, skill utilization, and participation in decision making. The higher levels of stress in a lean environment can also diminish the motivation and creativeness of the workers. This decreased motivation can then result in the inability of a worker to be innovative [40].

Pull-Based System

The implementation of lean production requires the use of a pull-based system. The use of the pull-based system allows production to be completed by pulling a quantity of products through the system based on the demand of the customers. This is completed in place of pushing products through the supply chain to help eliminate inventory and improve the overall efficiency of the system [2]. The flexibility of the pull-based system allows organizations to manufacture a large variety of products at a lower cost and higher quantity.

The pull-based system of lean also facilitates Just-in-Time (JIT) production. Many companies use a technique called Kanban, or cards in Japanese, to signal when a product or process is needed [2]. With the JIT approach only the minimum level of quantities needed are produced at the latest possible time for delivery to the customer. This style of production reduces the in-process inventory and associated costs by producing based on demand. JIT manufacturing supports having a standardized production and processing system. The result of this is improved quality, efficiency, and responsiveness to customers [3]. The primary goal of Just-in-Time is to continuously reduce all forms of waste. Two main forms of waste are work-in-process (WIP) and delays in the flow time [53]. Implemented practices to reduce these wastes include lot-size reduction, lead time reduction, and set-up time reduction. To achieve these reductions, the concept of 5s is introduced to improve and standardize the conditions of the work environment [2]. The 5s represents the five principles: sort (remove unnecessary items in the system), set in order (straighten and simplify the work area), shine (clean and inspect the work area), standardize (new practices are now the standard), and sustain (maintain the improved process). This approach can assist in eliminating waste in the system but creates more constraints in the system by introducing more standardization.

Continuous flow is another concept of the pull-based system, defined as leveling the demand for production or processing in order to maintain a consistent system [2]. However, it may not be entirely possible in some cases to level the demand due to high levels of variability. In addition, a lean system based entirely on the pull-based approach can prevent technology-push opportunities [50]. Since value is defined in the current market and not potential growth, lean organizations routinely make incremental improvements set by customer requirements. This may reduce the levels of radical innovations that require a push-based approach through the system [50].

Emerging Trends of Lean Management

Since its inception by the Toyota Motor Corporations in the 1950s, lean management has made many transitional changes to its overall concepts. Table 2.3 shows the phases of lean management and how it has evolved from the 1980s through the early 2000s [25].

Table 2.3 - Evolution of Lean Management [25]

Phases	1980 – 1990 Awareness	1990 – mid 1990 Quality	Mid 1990 – 2000 Quality, Cost and Delivery	2000+ Value System
Literature Theme	Distribution of shop-floor practices	Best practice movement, benchmarking leading to emulation	Value stream, lean enterprise, supply chain collaboration	Capability at system level
Focus	Just-in-Time, Cost	Cost, training/promotion, Total Quality Management	Cost, process-based in support of flow	Value / Cost, tactical to strategic, integrated to supply chain
Key Business Process	Shop-floor manufacturing	Manufacturing and materials management	Order fulfillment	Integrated process (order fulfillment and new product introduction)
Industry	Automotive – vehicle assembly	Automotive – vehicle and component assembly	Manufacturing	High and low volume manufacturing, service industry

The term “lean production” was first introduced in the book *The Machine That Changed the World* and acknowledged the production and efficiency gap between the lean concept and traditional mass production [54]. It was during this time that the western civilization began to show interest in this concept that Toyota and other Japanese automotive industries had made well-known. The original plan of United States manufacturers was to improve the overall performance of a company but progress was often localized. The main weakness during this awareness period was that lean was applied primarily by the automotive industry, so it was unclear on how to handle demand variability for other manufacturing industries. The focus during this time period was to incorporate the ideas of Just-in-Time to vehicle assembly [25]. The early 1990s witnessed the introduction of quality aspects into the lean approach. The system approach was now set to implement both efficiency and quality. During the mid- to late 1990s, the concept of value was introduced into the lean equation [25]. Production was based primarily on the value stream and of customer value. The value stream thus incorporated the concept of eliminating all forms of waste in the system. The industry focus at this stage was now manufacturing in general. The lean concepts were now capable of identifying and managing some levels of variability. The past ten years of the lean concept have been focused on the value system, with the value being defined from the needs of the customer to original locations of the resources [25].

Identifying the transition of the lean concept from its inception allows for a better understanding of the emerging trends of lean management. One of the emerging trends of lean is its introduction into the service industry by using the concepts from the manufacturing industry.

In today's service industry setting there are many areas of waste and variability that can be eliminated that would not only save resources but also improve the experience of the customer. Lean management is fairly recent in the service industry and there has been much speculation as to how successful it can be applied to reduce costs and improve customer value creatively. When properly implemented there has been a fairly successful outcome as of now.

Lean affects the service industry by eliminating waste (such as overproduction, waiting, and rework), creating an environment free of defects, improving quality for the customer and increasing workplace satisfaction. Workplace satisfaction is increased by implementing the standardized set of steps known as 5s [2].

The authors in [55] defined process innovation in the service industry as the implementation of a new or improved method of delivering a service to the customer. These include new processes, new policies, or new technologies that improve the value of the final product to the customer. To be useful to the lean service industry the innovation must be profitable or solve a problem associated with the process. The levels of process innovation range from small incremental improvements to the service, to a complete re-design of the value stream. With the implementation of lean, innovation levels will be in the re-design stages initially but will eventually decline to the incremental levels of innovation after the system has been put into place at the organization.

At this stage in the concept of lean for service industries there have been several instances of successful practices of innovation. Process innovation was implemented in a lean environment at the Meadows Regional Medical Center Emergency Department in Georgia, according to [56]. Patients originally had an average of 247 minutes per visit in the emergency department. To reduce this process time the system was evaluated and determined that a bottleneck occurred because of the nurses. A color-coded flag system was also used to identify patient status, standardized supply stations were created, and patients with allergies were given red alarm-bands. Originally there were eighty innovative ideas that were determined to improve the system and forty-four of them were implemented to reduce the length of process time to 139 minutes.

The authors in [57] defined another lean hospital that used innovative concepts was the Midwestern NCI designated Cancer Center. The organization wanted to improve their process by creating pod systems for nurses, front load patient appointments, reformat schedule system, and establish an automated system to alert staff of medication availability. By implementing these ideas Midwestern NCI was able to improve process efficiency, patient satisfaction, wait time, and travel distance of staff.

In addition to beneficial practices of innovation in lean service industry there is the potential for failure. Service industries usually emphasize more on the human aspects and thus variability cannot be entirely eliminated. This is because some variability may be necessary to maintain the appropriate levels of customer value.

Some of the negative impacts and drawbacks of lean as well as lean management's impact on innovation and creativity will be discussed in the next section.

2.3 Negative Impacts / Drawbacks of Lean Management

Since its inception, the benefits of lean management have been well recognized. From elimination of waste and standardization of the system to incorporating customer value in its designs and enforcing continuous improvement, companies have profited from the lean concepts. Along with these benefits, however, there are potential pitfalls that can be experienced from these lean concepts [58]. Waste reduction can transition a company's focus to short-term activities that add value to the system but disregard long-term advantages that can be achieved through radical innovations. These innovative ideas may be discarded early because they are not adding value to the current customers even though there may be potential contributions to the organization. This approach can also be detrimental in terms of disruptive innovations because waste is considered anything that is not valued by the current mainstream customers. In terms of supply chain management, the concept of minimizing buffers and resources can create a rigid and fragile system that can experience harmful results in the case of any failure in the chain [50, 51, 58]. This buffer reduction can also affect the system in terms of continuous flow; without buffers or reserves any delay with the suppliers can bring the system to a halt [58]. While lean has been known to benefit companies, there must be some cause for concern for the potential pitfalls that can be experienced especially when the organization enforces the extreme levels of lean. The remainder of this section examines the negative impacts of lean and how it affects an organization's levels of innovation and creativity.

M.A. Lewis performed a study to determine if the more successfully an organization applies lean principles the less it will perform innovative activities [59]. The organization will instead focus on making incremental changes to the production because the process of innovation requires greater lengths of experimentation and risk. Two of three cases (companies) studied supported this hypothesis. The two companies followed the lean principles resulting in an overall decrease in the innovativeness of the organizations. The third company maintained an innovative process while still applying some lean concepts. The reasoning behind this is due to the trade-offs that were associated for each organization. This company incorporated a more beneficial trade-off between the concepts of lean and general innovation to sustain a competitive advantage on its products and design.

Mehri presented a case on the Toyota Production system explaining some of the negative effects associated the lean design process on product innovation [60]. First, since the focus of lean is on eliminating all forms of waste, Toyota is forced to purchase product innovation from other companies rather than supporting creativity from within the organization. Due to the standardization of the management system, creativity is not inspired in the design process. Innovation and creativity of new product design were obtained through outside sources. In addition, because of the requirement of efficient productivity, the technical skill of the design engineers was not enhanced. Rather than allowing open ideas and creative-thinking among the process, engineers were left with strict flow of the design. This resulted in employees being specialized in only one specific area, preventing diversity in group-thinking. Rather than creative thinking, the lean system promoted "benchmarking" products and using current information to improve only upon pre-existing product design at a specific cost allowance [60]. This design approach of standardization and benchmarking creates an environment with minimized internal innovation capabilities.

S.K. Parker identified that lean production had a long-term effect on the work characteristics of employees [36]. This effect translated into an overall effect on the organization. In this case, work characteristics were based on several different variables and were tested over a three-year study on three different types of lean production groups. The three lean production groups were: lean teams, assembly lines, and workflow formalization and standardization groups. The standardized process approach of the lean practice resulted in a significant reduction in job autonomy and skill utilization of the employees. Job autonomy and skill utilization decreased across all levels of lean production. There was also a reduction in the overall participation of the workers in the decision making processes as well as the employees' commitment to the organization. It was found that as the groups became more standardized, the less the employees had in the decision-making process and their overall autonomy resulting in less commitment. This may also be associated to the unfavorable effects of lean concepts on innovation.

The lean culture of reducing slack, risk, and variability has also been shown to have an influential effect on an organization's innovation culture. In [61], a research study was performed on the effects of different categories of innovation on a firm's total risk. The results showed that incremental innovation has no effect on firm risk, but breakthrough innovations were positively impacted with increases in risk. This shows that higher levels of risk are necessary for designing highly innovative products. The lean culture, however, promotes the reduction of any risks that may result in necessary corrections [4]. Eliminating risk and variability though may prevent breakthrough innovations from being achieved. A research study was also performed in [62] to determine the relationship between organizational slack and innovation. The lean culture promotes the reduction of any slack, or underutilized design resources, within the environment in order to eliminate waste [51]. The results of this research, however, showed that organizational slack to a certain extent is beneficial to an organization's level of innovation. Eliminating slack may inhibit exploratory programs and creativity that is necessary for innovation. Extra resources are necessary in order to facilitate innovation.

3.0 Research Questions

The literature review identified discrepancies associated between the aspects of lean and innovation. The comparisons between the innovation management and lean concepts lead to three propositions, each of which will be tested through a series of hypotheses.

First to be analyzed is the impact of lean design on an organization's innovation capabilities. In lean design, standardization and design for manufacturability are two closely related practices with a common goal to ensure that new product designs are compatible with existing manufacturing capabilities through the use of established components [29]. DFM involves meeting the customer requirements with increased efficiency and asset utilization while minimizing the costs of design, material, and process combinations [30]. Standardization involves simplifying and formalizing the aspects of the product design procedure through standard parts, materials, and processes [34]. The concepts and objectives of standardization and DFM can hinder an organization's product innovations that require new technical skills, changes to the components, or changes to the architectural linkages. The increased levels of efficiency and utilization may limit the design space for an organization, thereby deterring dramatic changes to the product design. Standardization and DFM also rely heavily on the existing knowledge, components, and manufacturing methods in the system. Such a design approach where only existing components are used and the new product must match the current manufacturing methods has noticeable discrepancies with innovations that require changes to any aspect of the design. For radical innovations to take place, the designs cannot depend on existing technologies [51]. Relying on established knowledge may also hinder a company's architectural innovation capabilities [15]. It is proposed that the DFM and standardization concepts of lean design (represented by simplifying the product design, integrating parts, maintaining compatibility of new designs with existing procedures, and standardizing processes, materials, and parts in new product designs [29]) will have a negative effect on an organization's radical and architectural innovation capabilities.

The third component of lean design is value analysis [29]. It states that the needs of the customers should be closely followed in product design and in manufacturing. Areas of improvement are identified through rank-ordering product attributes and specifying costs based on the values of the current customers [21, 38]. Any activities or features that do not meet the requirements of the mainstream customers are considered waste and should be eliminated accordingly, since they do not generate revenue in the current market. This value analysis approach is expected to create continuous, gradual improvements to product designs and improve customer satisfaction due to the close following of the current customers' requirements in assessing value. However, the short-sightedness of the current customers may not realize the potential growth of an innovation that may eventually disrupt the established technologies. As noted previously, disruptive innovations are often initially worse in specific areas that are required by the mainstream customers which translates to low, or unsatisfying, initial returns on investment [21]. This type of innovation does have other attractive attributes, though not of high value to the needs of the mainstream customer. These other attributes eventually grow in popularity and the underperforming areas are developed. Given enough space to be developed disruptive innovations will eventually dominate the market and surpass the established products. If a company exclusively follows the current customers' definition of value, which is often short-term, there is a minimal chance that the organization can be successful with disruptive innovations. Therefore, value analysis in lean design is expected to have a negative effect on an organization's capability to deal with disruptive innovations. Table 3.1 summarizes the key contradicting concepts in lean design and each of the three categories of innovation capability.

Table 3.1 - Research Questions (Lean Design vs. Innovation Capability) [40]

Lean Design vs. Innovation Capability	
Standardization: Use standard process, standard materials, and standard parts in designing new products. Match new designs with existing components and manufacturing methods [29, 34]. *Design for manufacturability (DFM):* Simplify the product design and minimize the parts count. Designs need to be compatible with existing manufacturing procedures and processes [29].	*Radical innovation:* Requires a different approach from the existing ones in product design [8, 16]. Causes increased uncertainty in the work setting; design cannot depend on existing technologies [51]. Requires changes to core concepts and the linkages between them [15]. *Architectural innovation:* Requires changes to the interactions and linkages between the core concepts and components. Using existing architectural knowledge may hinder this form of innovation [15].
Value Analysis: Current customers' requirements are exclusively followed to assess value in product design [25, 29]. Non-value adding activities are eliminated.	*Disruptive innovation:* Exclusively focusing on mainstream customer value in existing market may prevent this type of innovation [21].

The comparisons presented in the table led to two propositions, as shown below. Each proposition is further separated into several hypotheses that are to be tested in this research.

Proposition 1: Standardization and DFM in lean design has a negative effect on a company's radical innovation capability and architectural innovation capability.

Hypothesis 1a: Standardization in lean design has a negative effect on a company's radical innovation capability.

Hypothesis 1b: DFM in lean design has a negative effect on a company's radical innovation capability.

Hypothesis 1c: Standardization in lean design has a negative effect on a company's architectural innovation capability.

Hypothesis 1d: DFM in lean design has a negative effect on a company's architectural innovation capability.

Proposition 2: The value analysis in lean design has a negative effect on a company's capability to successfully deal with disruptive innovations.

Hypothesis 2a: The value analysis in lean design has a negative effect on a company's capability to encourage the development of new products that may underperform in certain areas but offer new areas of attractiveness.

Hypothesis 2b: The value analysis in lean design has a negative effect on a company's capability to tolerate projects with unsatisfying returns on investment.

Hypothesis 2c: The value analysis in lean design has a negative effect on a company's capability to frequently experiment on new technologies that offer attributes not valued by mainstream customers.

Figure 3.1 and Figure 3.2 list the independent and dependent variables and their proposed relationships in the first two propositions, respectively.

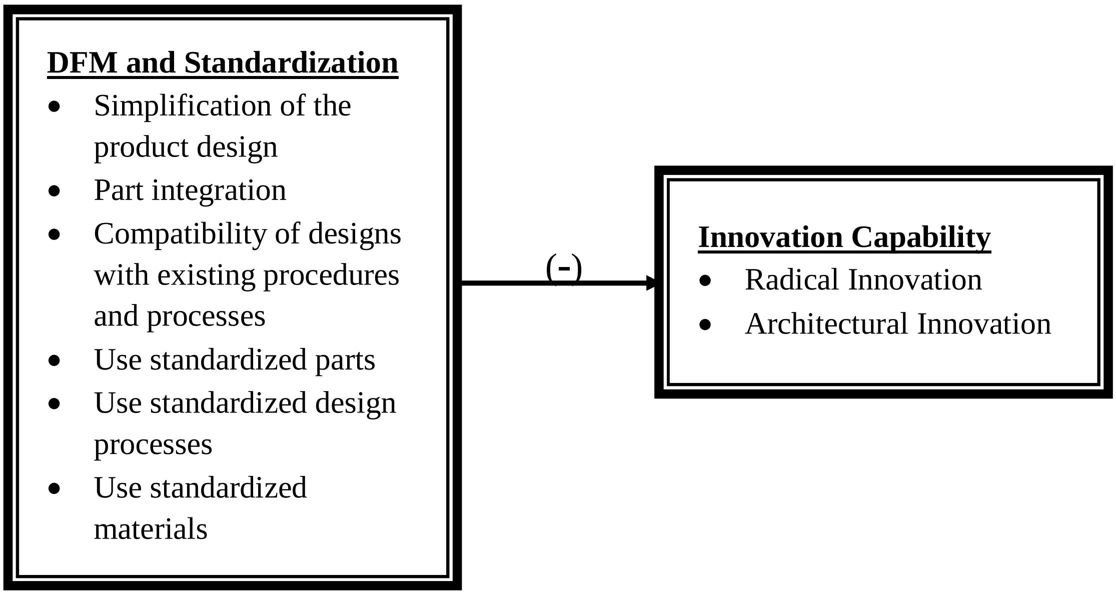

Figure 3.1 – DFM and Standardization / Innovation Capability Relationship

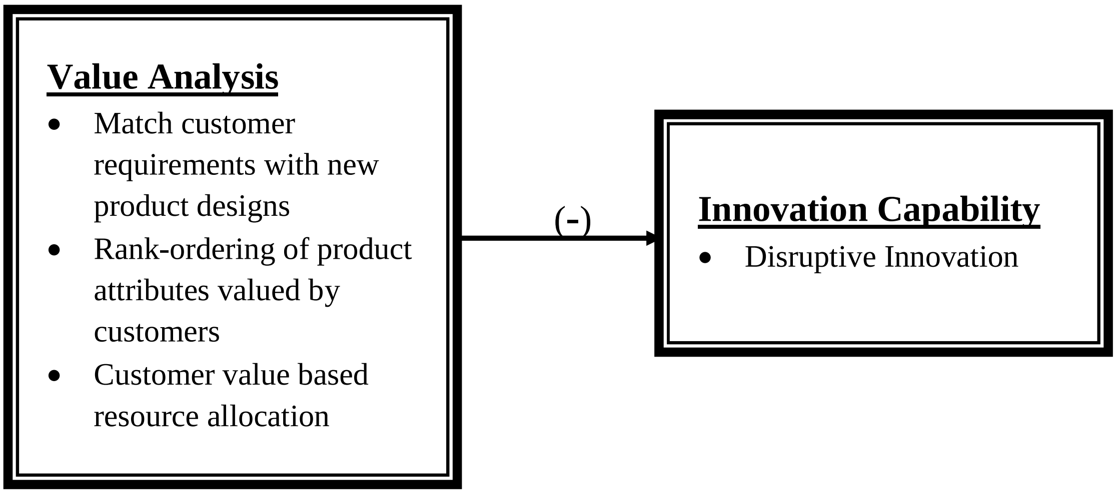

Figure 3.2 – Value Analysis / Innovation Capability Relationship

Minimizing buffers in the supply chain and limiting the number of vendors is a key characteristic of lean supply chain management to eliminate waste and improve efficiency [37, 41]. When dramatic changes to the product's components are required, having a limited number of suppliers may reduce the organization's reaction speed. This is especially true when a company needs to respond to competitor movement in radical innovations. Since a radical innovation involves dramatic changes to the existing approaches for product design, it requires a flexible supply chain to provide the necessary components or materials in time when needed [51]. Therefore, lean supply chain management is expected to reduce a company's responsiveness to radical innovations.

The supplier commitment, or the depth of the supply chain, may reduce the negative impact of buffer minimization on the responsiveness of an organization to radical innovations. The supplier commitment also includes communication between the firm and the supplier and the degree to which the suppliers are involved in new product development [37]. By doing so, the supplier can provide feedback to the company and reduce the variability of deliverables. The involvement in the new product design process promotes frequent contact with suppliers and may lead to a faster response speed. Incorporating a close relationship with suppliers may reduce the effects of eliminating additional vendors in the supply chain. It is expected that buffer minimization has a negative effect on a company's responsiveness to innovation and that the depth of the supply chain may moderate this level of negativity. Table 3.2 summarizes the key concepts of lean supply chain management and responsiveness to radical innovations.

Table 3.2 - Research Questions (Lean SCM vs. Responsiveness to Innovation) [40]

Lean Supply Chain Management vs. Responsiveness to Innovation	
Lean Supply Chain with limiting breadth: Minimize buffers in the system and limit number of vendors to eliminate waste and improve supply chain efficiency [37, 41]. *Supplier Commitment:* Commitment of supplier to continuous improvement and involvement in new product development to reduce supplier variability [37].	*Radical innovation:* Flexibility is required in the supply chain to respond quickly to unknown-unknown occurrences and/or necessary corrections [51].

The proposition and tested hypotheses created by the comparisons presented in the table are shown below.

Proposition 3: Lean supply chain management with limited breadth has a negative effect on a company's responsiveness to radical innovations and increasing supply chain depth will help to reduce such effect.

Hypothesis 3a: Lean supply chain management with limited breadth has a negative effect on a company's responsiveness to radical innovations.

Hypothesis 3b: The depth of lean supply chain management reduces the negative impact of buffer minimization and positively influences a company's responsiveness to radical innovations.

Figure 3.3 lists the independent variable (lean supply chain with limited breadth) and the dependent variable (responsiveness to radical innovation) along with the potential moderating factors to the overall relationship. Since the number of vendors measures the breadth of a supply chain, the independent variable is defined as "lean supply chain with limited breadth".

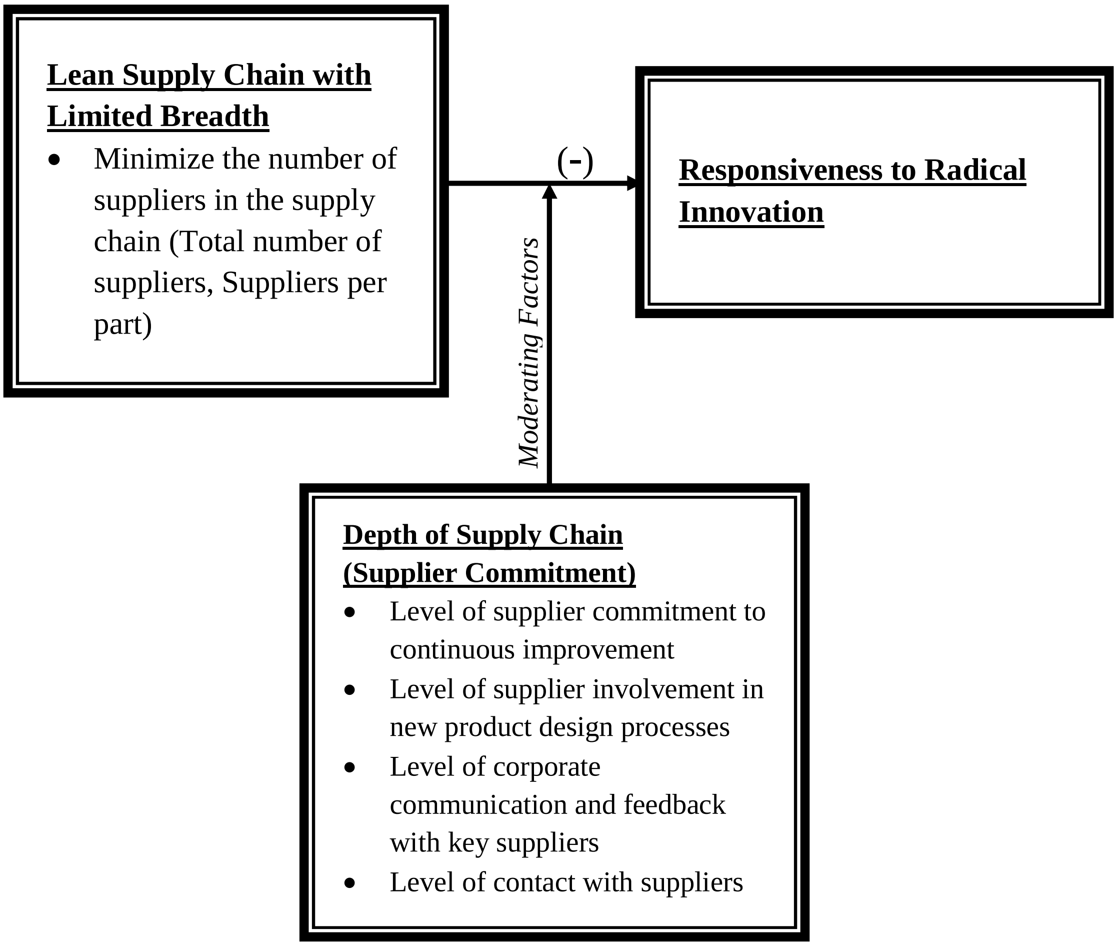

Figure 3.3 – Lean Supply Chain Management / Responsiveness to Innovation Relationship

4.0 Research Methods

To test the hypotheses, key measurements for lean design, lean supply chain management, innovation capability, and responsiveness to innovation were developed. Two online survey questionnaires were constructed accordingly; one addressing propositions 1 and 2, and the other addressing proposition 3. With lean design, measurements were developed based on the key characteristics of DFM, standardization, and value analysis. For lean supply chain management, measurements were based on the characteristics of buffer minimization and supplier commitment. The measurements of innovation capability and responsiveness to innovation were developed based on metrics defined in literature. The key metrics were then specified to each category of innovation.

4.1 Lean Measurements

4.1.1 Measuring the Variables of DFM and Standardization

To test the hypotheses of proposition 1, measurements for variables in DFM and standardization are developed. The main variables of DFM for lean design include: simplification, part integration, and compatibility between designs and manufacturing processes.

The first variable, simplification of the product design, is achieved by emphasizing design commonality and part reuse. Simplification introduces the concept of using common interfaces rather than creating an entirely new design [30, 31]. Design simplification is also achieved through the reuse of existing parts [30, 31]. The primary forms of measurement for part reuse include the overall emphasis within the organization and the level of existing parts reused in new product designs. Some organizations may have specific rules and guidelines for part reuse to achieve a certain level. This can also include the level of changes that a company allows in product designs from round-to-round. Table 4.1 presents the measurements and survey questions designed to measure the degree of product design simplification in DFM.

Table 4.1 - Simplification of the Product Design Measurements and Questions

1. Simplification of the product design [29-33]
Measurements / Questions: Emphasis of organization to simplify the product design through commonality. Emphasis of organization to simplify the product design by reusing existing parts. Level of existing parts that are reused in new products, designs. Level of allowable round-to-round changes to product design. 1.) In new product designs, you simplify designs as much as possible by emphasizing commonality. 2.) In your new product designs, the reuse of existing parts to simplify designs is emphasized. 3.) The design team uses existing parts as much as possible in new product designs. a. On average, ______% of existing parts are implemented in new product designs. b. If there are company rules or organizational goals to achieve a certain percentage of parts-reuse, please specify: ______% 4.) Your company discourages dramatic round-to-round changes to product designs. a. On average, ______% of changes are implemented in each round of new product designs. b. At maximum, the company allows for ______% of changes in each round.

DFM is also characterized by minimizing the parts count [29-31]. This translates to an emphasis of the organization to use part integration with its product designs. Part integration also includes introducing additional functions to an already existing part. The level of parts that are integrated to include multi-functionality is an additional measurement for the DFM practice in lean design. Table 4.2 lists the measurements and survey questions designed to measure the degree of part integration in DFM.

Table 4.2 - Part Integration Measurements and Questions

2. Part integration [29-31]
Measurements / Questions: Emphasis of organization to use part integration in new product designs. Level of parts that are integrated to include multiple functions. Level of part integration for new product designs. 1.) In your new product designs, part integration is emphasized. 2.) In your new product designs, designing integrated parts with multi-functionality is emphasized. 3.) There is strong implementation of part integration for new product designs in your company.

DFM is synonymous with constructing a product design that can be manufactured without changing the existing manufacturing processes and procedures [28, 29]. Compatibility can then be measured by the emphasis to elaborate the existing asset. This will cause an organization to avoid any form of designs that require changes to the existing manufacturing methods. The questions designed to measure the degree of compatibility of designs with existing processes are shown in Table 4.3.

Table 4.3 - Compatibility of Designs with Existing Processes Measurements and Questions

3. Compatibility of designs with existing manufacturing procedures and processes [28, 29]
Measurements / Questions: Emphasis on compatibility to elaborate the existing asset. Level of product designs that were avoided by the company due to required changes with the process to manufacture. Level of product designs that were compatible with the existing manufacturing methods. 1.) In your new product designs, compatibility of the product design with current manufacturing processes is emphasized. 2.) To design new products, you avoid designs that require changes to the existing process to manufacture. 3.) Designs of your products are compatible with the existing manufacturing methods in your company (no new equipment needed to be purchased to manufacture the new designs). a. On average, ______% of product designs are compatible with existing manufacturing methods.

Measurements for variables in standardization were also developed to test hypotheses 1a and 1c of proposition 1. Standardization is supported with product designs using standard parts, processes, and materials in order to reduce resources and costs [29]. All three forms of standardization are measured based on its organizational emphasis with new product designs. The purpose of using standardization is to reduce the levels of variability within the system [30]. A lean organization using DFM would trend towards discouraging any forms of variability. All three cases measure the levels of variability or change that are allowed in product designs. The frequency of part standardization and new Standard Operating Procedures are also measured. Standardization also requires the design team to emphasize on incorporating common parts and materials into new designs

[31]. Tables 4.4 through 4.6 summarize the measurements and survey questions for standard parts, processes, and materials.

Table 4.4 - Standard Parts Measurements and Questions

4. Use standardized parts (avoid special parts) to eliminate part dimensional and property variations [29-31]
Measurements / Questions: Emphasis of part standardization for new product designs. Level of part variability that is not suggested by the company. Frequency of part standardization. Emphasis of design team to use standard parts. 1.) In your new product designs, part standardization is emphasized. 2.) Part variability is not suggested in product design. (Part variability involves the use of special, or unique, parts that have not been applied to the specific type of products under design) 3.) Parts are frequently standardized within your firm. 4.) In your product designs, the design team uses as many standard parts as possible. a. On average, _____% of parts used in designs are standard.

Table 4.5 - Standard Processes Measurements and Questions

5. Use standardized processes of design with specific steps to eliminate variations [29, 31]
Measurements / Questions: Emphasis of Standard Operating Procedures and regulations in the design process. Frequency of new Standard Operating Procedures introduced in the design process. Level of allowable change to design processes. 1.) In your new product designs, it is emphasized that Standard Operating Procedures and regulations need to be followed. 2.) New Standard Operating Procedures are frequently introduced into the design process. 3.) Your company discourages changes to design processes. a. At maximum, the company allows for _____% of changes to the design processes.

Table 4.6 - Standard Materials Measurements and Questions

6. Use standardized materials in designing new products [30, 31]
Measurements / Questions: Emphasis of material standardization for new product designs. Level of new, or exotic, materials that are avoided by the company. Emphasis of design team to use standard materials. 1.) In your new product designs, standard materials are emphasized. 2.) In your new product designs, you avoid the use of new materials (existing or emerging materials that have not been used in the specific type of products under design). 3.) In your product designs, the design team uses standard materials as much as possible. a. On average, ______% of materials used in designs are standard.

The culmination of the aforementioned DFM and standardization practices can lead to quality products at a lower cost in efficient periods of time [29]. The levels of these practices, however, can be detrimental to an organization's innovation capabilities. An innovative organization requires variance, freedom, and other aspects that may be mitigated by these practices.

4.1.2 Measuring the Variable of Value Analysis

To test the hypotheses of proposition 2, measurements for value analysis are developed. The main measurements of value analysis consist of: matching customer requirements with the product design; rank-ordering product attributes valued by the customer; and defining the resource allocation based on its value to the final customer [2, 29, 39].

The general approach to value analysis is to match the requirements and needs of the customer with the necessary product features. This subsequently matches the requirements of the product design [2]. This practice can be measured by the firm's emphasis on meeting the needs of the customer and the level of features that were defined by the customers. Value analysis also considers anything that the customers do not require as waste and should be eliminated [39]. All specifications and criteria for a product design should be directed back to the customer requirements. However, the risk associated with identifying features outside of the mainstream customer requirements can lead to radical or disruptive innovations [15, 16, 21]. The measurements and survey questions designed to measure the degree of matching customer requirements with product designs are shown in Table 4.7.

Table 4.7 - Match Customer Requirements with Product Design Measurements and Questions

1. Match customer requirements with the necessary product features and subsequently product design requirements [2, 29, 39].
Measurements / Questions: Emphasis of organization to meet the current customer requirements. Ability of organization to allow features that are not required by current customers. Level of design specifications based on customer requirements. 1.) In new product designs, the firm emphasizes meeting the needs and requirements of the current customers. a. ______% (minimum) to ______% (maximum) of product/product features come directly from the requirements of current mainstream customers in your product designs. 2.) Your company discourages designs of products/product features that current customers do not require. 3.) Product design specifications are mapped back to customer requirements.

Value analysis is also concerned with the product attributes and the associated costs that are valued by the mainstream customer [2, 29, 38, 39]. The measurement for ranking product attributes, as shown in Table 4.8, are defined by three areas: attributes that meet the requirements of the customer; attributes based on the internal views of the organization; and attributes that are a response to the actions of its competitors. A lean environment would heavily weight the attributes that meet the requirements of the mainstream customers. The customer value can also be measured by the customer involvement in the ranking process; the level of direct input by the customer with the product attributes.

Customer value based resource allocation can also be measured and identified by determining the location of costs and resources [2, 21, 29, 39]. For value analysis, resources should primarily be directed towards improving products based on the requirements of the mainstream customer. An alternative approach would be to devote a certain level of resources towards new product attributes that are not required by the mainstream customer. This source of variability from the norm can support organizational innovation capabilities.

Table 4.8 - Rank-Ordering of Product Attributes Measurements and Questions

2. Rank-ordering of product attributes valued by customers [21, 38].
Measurements / Questions: Level of product attributes based on current customers' requirements. Level of product attributes based on internal beliefs. Level of product attributes based on a response to competitors' actions. Level of involvement of customers in the ranking process. 1.) a. When deciding on what attributes to be included in a product design, primary weight is given to attributes that meet the current customers' requirements. b. When deciding on what attributes to be included in a product design, primary weight is given to attributes that enhance technological superiority based on internal beliefs. c. When deciding on what attributes to be included in a product, primary weight is given to attributes that are a result of response to competitors' actions. 2.) In your new product designs, customers provide direct input for the ranking process of product attributes.

Table 4.9 – Customer Value Based Resource Allocation Measurements and Questions

3. Allocation of resources required to provide valued products to the customers [21, 29, 39].
Measurements / Questions: Level of resources that are devoted to exclusively following the future designs of the current customer requirements. Level of resources that are devoted to experimentation of future designs with differing attributes/features (not necessarily meeting current customer requirements). 1.) Your company allocates a high percentage of resources to improve the product along the dimensions of performance that the mainstream customers require. 2.) Your company allocates a high percentage of resources to design product attributes that are not valued by the current mainstream customers.

The primary goal of value analysis is to satisfy the needs and requirements of the final customer with specific capabilities and attributes at a certain price and time [39]. This is beneficial for the firm in terms of short-term improvements. Customers do not often view the long-term potential of new attributes or features. Innovation capabilities are required of an organization to venture beyond the short-term needs of the customer.

4.1.3 Measuring the Variables of Lean Supply Chain Management

To test the hypotheses of proposition 3, measurements for variables in lean supply chain management are developed. As mentioned in section 2.2.4, lean supply chain management has two important aspects: breadth and depth of the supplier relationship. In Table 4.10, the first four questions define the breadth of the supply chain while the remaining four refer to the depth of the supply chain. The objective of a lean supply chain with limited breadth is to minimize the buffers, or suppliers, in the system. The primary questions for this section are set to show if the organization tries to minimize or eliminate this supplier variability. As mentioned in section 3.0, supplier commitment may influence the impact of the breadth of the supply chain on the organization's responsiveness to radical innovations.

The main objective of lean in the supply chain is to minimize costs through the reduction and potential elimination of waste and variability. This may be acceptable if all products in the organization are functional. If, however, innovation is required to respond to competition, the organization requires a more agile system [44, 45]. Table 4.10 presents the survey questions designed to measure a company's approaches to lean supply chain management.

Table 4.10 - Lean Supply Chain Management Measurements and Questions

1. Lean Supply Chain Management [37, 44, 45]
Measurements / Questions:
Level of buffers in the supply chain.
Number of total suppliers in the supply chain.
Number of suppliers per part.
Level of supplier commitment to continuous improvement [37].
Level of supplier involvement in new product design processes [37].
Level of corporate communication and feedback on important issues with key suppliers [37].
Frequency of contact with suppliers [37].
1.) Your company tries to eliminate buffers, including additional suppliers and resources, in your supply chain.
2.) Your company tries to limit the number of suppliers as much as possible.
3.) Your company tries to limit the number of suppliers per part as much as possible.
a. Each part of our product has ______ to ______ suppliers.
b. ______% of the parts are solely outsourced, meaning only one supplier provides for those parts.
4.) Your company has successfully reduced the number of suppliers.
5.) Your suppliers are committed to continuous improvement through innovations.
6.) Your suppliers are highly involved in your new product design process.
7.) Your company performs frequent communications at the corporate level and provides feedback on important issues with your key suppliers.
8.) Your company is frequently in close contact with its suppliers.

4.2 Innovation Measurements

The capabilities of an organization to innovate are defined by its ability to manage the changes of the evolving markets while maintaining competitiveness [63]. In the literature reviewed there were several methods of measuring the capabilities and success of a company's innovations. Most cases involved measurement of inputs, or investments, into innovation as well as outputs received from these investments [17, 63-66]. This transition from innovation investments to generated outputs is known as the innovation-to-cash process. It is the measurement of steps taken by an organization from turning initial ideas into revenue. These levels of input and output are based on resources and knowledge within the organization. The knowledge of the organization can be defined by the level of understanding of the inputs and associated outputs for an innovation process [67]. The innovation metrics for multiple categories are displayed in Table 4.11 and discussed in the remainder of this section.

Table 4.11 - Innovation Measurements

Method of Measurement	Factors	Metrics
Innovation Input	Knowledge	• Level of internal learning [63, 64] • Level of training for new designs/processes [63, 64] • Emphasis on research and development [64, 65] • Emphasis on generating new ideas [17, 18]
	Resources	• Level of time spent on innovation projects [17, 63, 64, 66]
Innovation Output	Knowledge	• New competencies or knowledge for each type of innovation [63, 64, 68]
	Resources	• Number of new products developed (in a specific amount of time) [17, 18, 63, 64] • Percentage of revenue, or profits, generated from new products [17, 18, 63-65, 69, 70] • Research and development productivity [17, 18, 65, 68] • Number of patents [17, 64, 68-70]
Innovation Processes / Performance	Time	• Past performance (Revenue, level of worker knowledge) [17, 63, 70-72] • Present performance (Net present value, timely completion of new products) [17, 72] • Future performance (New innovative knowledge, continuous learning) [64, 72]
	Speed, Efficiency	• Time to market for new products [17, 19, 64, 70]
	Product Portfolio Mix	• Well-balanced new product developments [17, 65]
Cultural Tendency	Commitment	• Level of employee commitment to research and development [19]
	Uncertainty	• Level of tolerance for uncertainty or risks [73]
	Exploration, experimentation	• Level of allowable exploration and experimentation [73]

While most organizations are primarily concerned with the financial outputs generated by innovations, these metrics alone may lead to short-term investments and risk aversion [69]. Additional innovation metrics must be identified in terms of other intangible processes, or outputs, and innovation investments. The investments made for innovations can be measured based on either the resources or the knowledge within the organization. Inputs with regard to organizational knowledge include the levels of internal learning and the level of training for new or changed products and processes [63, 64]. Innovation investments can also be measured based on the emphasis of research and development for that particular organization [64, 65]. There must be a stressed importance on the research of new product designs in order to have sufficient innovation capabilities. The final and perhaps most important metric of knowledge for the investment of innovation is that of generating new ideas [17]. A new idea is considered the starting point for innovation in the overall innovation process pipeline. The generation of ideas as well as allowable experimentation and exploration in the workforce are key contributors to the emphasis on research and development.

Invested innovation metrics can also be based on the resources within an organization. In terms of employees, the amount of time spent on innovation projects can be determined [17, 63, 64, 66]. This level of time can be more specific by defining the frequency of utilization for each type of innovation. People are a key factor in innovation capability. How technical employees are being utilized can define a company's innovativeness.

The more common approach to measuring innovation is by identifying the returns generated from a particular innovation. In terms of knowledge, this includes new competencies that are obtained in support of innovation [63, 64, 68]. This metric can determine the employment growth in knowledge occupations and the introduction of new types of knowledge. Financial outputs from innovation have several metrics including: number of new products in a given time period; percentage of revenue generated from new products; research and development productivity; and the number of patents granted [17, 18, 63-65, 68-70]. It was determined that the number of patents would not be used as an innovation metric for this research. According to [74], patents are considered a flawed measure for the output of innovations because not all new innovations are patented and each patent varies in its impact on the economy. A different approach to measuring the output performance of innovation is by comparing each of the above output metrics for an organization with its competitors [17, 19]. This can determine the overall effectiveness of an organization's innovation capabilities in relation to the rest of the industry. This financial information may not be readily available for all organizations and therefore is not included as an innovation metric for this research.

In addition to input and output measurements, the performance of an organization's innovation processes is also of importance. This includes the measurements of time and speed. The innovation capabilities can be determined based on how the company has performed in the past, how it is currently performing, and how it may perform in the future [72]. Past innovation performance measurements include the revenue obtained from new technology over a given period of time and the level of knowledge of its workers [17, 63, 70-72]. Present performance involves level of timely completion of new developments and the net present value of new projects in development [17, 72]. While the net present value may be a suitable measure of current performance, it may not be an easily accessible measurement for all organizations. Future performance is based primarily on the ability of an organization to establish and support an innovative environment [64, 72]. This can be obtained through the creation of new innovative knowledge and continuous organizational learning. The time measurements can also be used to identify the speed, or efficiency, of a company's innovations. The level of time from completed design to the market identifies the speed at which a new product can be introduced [17, 19, 64, 70]. This innovation metric identifies the overall responsiveness of an organization to different types of innovation. The innovation processes can also be measured based on the product portfolio mix [17, 65]. The product portfolio measures the overall balance of new products between incremental and breakthrough innovations. This measurement of the portfolio mix is outside the scope of this research.

The cultural tendency of a firm is an additional source of measurement for innovation capabilities. An organization must be supportive of and allow for adequate freedom in exploring new, innovative designs and processes [19]. There must be an organizational emphasis on encouraging employee commitment to research and development. The organization must also be tolerant of certain levels of uncertainty and risk with new product designs and processes [73]. Measurements of allowable exploration and tolerance to uncertainty can give support to determining the innovative capabilities of an organization.

The measurement of an organization's capabilities is also based on the category, or type, of innovation. It was mentioned in section 2.1.1 that there is a wide variety of innovation categories. Frequently the literature reviewed defined the measured innovations as either incremental or radical (breakthrough). In this case the two extremes of the spectrum were compared and analyzed. There are several other types of innovation along this spectrum including: sustaining, regular, architectural, and disruptive. To obtain a more complete analysis of an organization's innovativeness, the two extreme levels of innovation should be selected as well as other distinguishable types with definite characteristics. Sustaining and regular innovations have a close resemblance to incremental innovation in terms of the gradual improvements to pre-existing technology. Architectural and disruptive innovations have distinguishable attributes that can be measured for an organization. Analyzing multiple types of innovation allows for the definition of an organization's tolerance of different levels of uncertainty.

Table 4.12 - Categories of Innovation

Innovation Category	Description
Incremental Innovation	A minor, or gradual, change from the existing practices of an organization; supports or strengthens the current technological capabilities [8].
Architectural Innovation	A change to the basic configurations of a product while maintaining the core design [13]. It involves changing the interactions and linkages between the core concepts and components [15].
Radical Innovation	A different technological or processing approach from the existing ones that creates a new functionality [8, 16]. It involves changing the core concepts and the linkages between them [15].
Disruptive Innovation	A new technology or process that is often initially worse in specific areas of performance than the established ones, but has new attractive attributes that are not currently valued by mainstream customers [21].

Each of the four categories of innovation involves different levels of change to a technology or process. This results in differing effects and outcomes for a lean organization.

4.2.1 Measuring an Organization's Innovation Capability

To test the hypotheses of propositions 1 and 2, measurements for variables relating to innovation capability are developed. Innovation capability is defined as the ability of an organization to improve or modify existing technologies to create new ones [71]. The extensiveness of the improvements is based on the type of innovation. In this regard there are a variety of measurements that contribute to innovation capability for each category of innovation.

The contributing factors to innovation capability are introduced to assess and analyze the culture of the organizations. It is assumed that if the contributing factors are positive in terms of the type of innovation, the innovation capability is also considered as positive for the organization. One of the contributing factors common to all four types of innovation is the organization's ability to apply new or reinforced knowledge to the pertinent changes [63, 64].

The main difference is the level of knowledge that is applied to an organization, which is determined by the type of innovation being created. For incremental innovation capability, an organization must be able to reinforce the existing knowledge of the components within a product. Architectural and radical innovation capabilities on the other hand require the establishment of new knowledge. Architectural innovation requires new knowledge on the integration and linking of components. Radical innovation goes a step further by establishing new knowledge on the core concepts as well as the linkages between them [15]. Disruptive innovation does not directly require new knowledge, but requires knowledge on the potential of new products that are outside of the current mainstream [21].

In addition to the establishment of new knowledge there are several other contributing factors for each of the four types of innovation capability. Tables are presented and discussed in the remaining portion of this section to present the measurements as well as the questions designed to identify a company's innovation capability.

Table 4.13 - Incremental Innovation Capability Measurements and Questions

1. Incremental Innovation Capability
Measurements / Questions: Emphasis of organization to change its product designs [18, 63, 64]. Level of support for generating new ideas [17, 18]. Emphasis on commitment to incremental innovations [19]. Level of time spent on incremental innovation projects [17, 63, 64, 66]. Emphasis on experimentation of incremental improvements to existing designs [73]. Ability of organization to reinforce current knowledge [63, 64]. Frequency of training for new product designs [63, 64]. 1.) Your company emphasizes on the need to gradually change and improve upon the existing product designs. 2.) Your company encourages generating new ideas that refine the existing product designs. 3.) In your new product designs, sustained development of core technological competencies is emphasized. 4.) The design team emphasizes the need for experimentation on minor components and concepts within the existing product designs. 5.) Your company is striving to reinforce knowledge of the core concepts and individual components of your products.

Incremental innovation refers to a marginal change to the existing technology or manufacturing process of a product [8, 16]. A capable organization for this type of innovation must emphasize the concept of continuous improvement with its product designs. This is achieved through supporting new ideas related to developing and enhancing existing products [17, 18]. Time is also of importance to defining an organization's innovation capabilities, as discussed previously. With incremental innovations, there must be time allotted to revisit existing designs and acknowledge the established settings. This time for research and development is a precursor to the level of commitment for the organization. The company must place an emphasis on refining and extending upon the existing designs for its new products [16]. The level of commitment can also be measured by the improvements made to the core technological competencies of the organization [19]. Continuous improvement also requires experimenting on potential changes to an existing design. The level of allowable experimentation to the minor components and concepts of an existing product is a contributing measurement to the organization's innovation capabilities [73]. A final measurement for incremental innovation is the amount of training allotted to the employees of an organization. To make improvements to a design, all members of the design team must experience frequent training in the field [63, 64]. This can be measured by the ability of the company to reinforce knowledge; the employees must be trained in order to receive this knowledge.

Table 4.14 presents the measurements and questions designed to measure an organization's architectural innovation capability.

Table 4.14 - Architectural Innovation Capability Measurements and Questions

2. Architectural Innovation Capability
Measurements / Questions: Emphasis of organization to change its product designs [18, 63, 64]. Level of support for generating new architectural ideas [17, 18]. Level of time spent on architectural innovation projects [17, 63, 64, 66]. Emphasis on experimentation of the interactions of components [73]. Ability of organization to establish new architectural knowledge [63, 64]. Frequency of training for new product designs [63, 64]. 1.) Your company emphasizes on the need to change the product design through modifying the ways in which components and concepts are integrated (the components may be reinforced if necessary). 2.) Your company encourages new ideas that re-organize existing (possibly reinforced) components of a product to create new designs. 3.) Your company frequently revisits the architecture of your product lines (The architecture may include the product platforms, the way products are modularized, or the interfaces of the modules). 4.) The design team frequently experiments on the re-organization of existing components for new product designs (the components may be reinforced if necessary). 5.) Your company is striving to create, store, and disseminate new architectural knowledge about the linkages among the core concepts/components of a product.

Each category of innovation requires the organization to emphasize on different areas of the product design. While incremental innovation was based on minor improvements to existing concepts, architectural innovation refers to changing the linkages between the core concepts and components while reinforcing the design of the components [13]. This different approach requires new levels of measurement for the contributing factors to define the organization’s architectural innovation capabilities. With the generation of new ideas, the measurement now refers to ideas that re-organize the current components of the product in order to construct a new design. The level of time is defined by the frequency of the company to revisit the platforms and modules of existing products. The level of additional time to experiment on the linkages and ways to re-organize the components are also measured.

Table 4.15 - Radical Innovation Capability Measurements and Questions

3. Radical Innovation Capability
Measurements / Questions: Emphasis of organization to change its product designs [18, 63, 64]. Emphasis of investments on radical changes [17, 63, 64, 66]. Emphasis on commitment to radical innovations [19]. Level of time spent on radical innovation projects [17, 63, 64, 66]. Level of organizational support for radical product design ideas with higher levels of uncertainty [73]. Emphasis on experimentation of radically new product designs [73]. Ability of organization to establish new knowledge on radical innovations [63, 64]. Frequency of training for new product designs [63, 64]. 1.) Your company emphasizes on the need to introduce radically new products to the market. 2.) Your company supports investing in the research and development of radically different technologies. 3.) Your company is committed to creating product designs with new core concepts and components that are integrated in a new way. 4.) Your company has a good tolerance of the increased uncertainty associated with new ideas that dramatically change the existing product designs. 5.) The design team frequently experiments on new product designs in which components and linkages are dramatically changed or overturned. 6.) Your company is striving to create, store, and disseminate new knowledge to radically change the ways in which the core concepts are embodied in the components and the linkages between them.

Table 4.15 presents the questions designed to measure an organization's radical innovation capability. Radical innovation is a breakthrough change to an existing product design so it requires significant levels of support to ensure the organization's innovation capabilities. First, the organization must understand and emphasize the need

for change to its products [18, 63, 64]. This involves dramatic changes to the core concepts and components as well as the way in which the components are integrated. Second, the organization must encourage new ideas that may strongly differ from the established product designs. The radical innovation capabilities are also measured by the organization's levels of time, commitment, and experimentation for new product designs that dramatically change or overturn the components of a product and the linkages between them. Due to the drastic changes involved in radical innovations the company must also be tolerant of uncertainty and be willing to invest in unpredictable projects.

Table 4.16 - Disruptive Innovation Capability Measurements and Questions

4. Disruptive Innovation Capability

Measurements / Questions:

Level of organizational support for new product designs [19, 63, 64].

- Level of assessment of potential product ideas [17, 18].
- Level of time spent on disruptive innovation projects [17, 63, 64, 66].

Emphasis on commitment to disruptive innovations [19].

- Ability of organization to realize the future potential of new product developments [21].
- Ability of company to identify a new market for new product designs [21].
- Level of support for products that initially have unsatisfying returns on investment [21].

Emphasis on experimentation of new technologies [73].

1.) Your company encourages a variety of new product design ideas.

2.1) Your company encourages the development and improvement of new products that may underperform in areas valued by mainstream customers but offer new areas of attractiveness.

2.2) Your company is good at identifying a new market for new product designs.

2.3) Your company is tolerant of supporting projects with unsatisfying returns on investment (ROI).

   i. From ______% to ______% of resources are allocated to projects that do not target the current needs of existing customers.

   ii. At maximum, ______ months are allowed for projects with an unsatisfying return on investment to be continued.

3.) The design team frequently experiments on new technologies that offer attributes not valued by mainstream customers.

Disruptive innovation refers to a product that initially may be worse in areas valued by mainstream customers, but has other attractive attributes and eventually dominates the market by improving the “worse” areas and the increased customer value to the other attractive attributes [21]. The level of innovation to the product design can vary in this situation from architectural changes to radical changes. The contributing factors for measuring this organization capability are based on the support and assessment of the future potential of projects [19, 63, 64]. This involves measuring the overall support and encouragement of a variety of new product designs. In doing so the company must evaluate all new ideas, regardless of its affiliation to mainstream customer requirements. The disruptive innovation capabilities of an organization are also measured by its emphasis of commitment [19]. This includes measuring the company's ability to encourage the development of new products, identify new markets for its new product designs, and support products with poor initial return on investments. The company must also be willing to experiment on all forms of new technologies and attributes, even if the mainstream customers do not require them [73]. Disruptive innovation capabilities are set by developing new attributes that are supported by a new market. With time these new attributes can transition from being an additional feature to a necessity in customer requirements.

The contributing characteristic factors discussed throughout this section are used to determine the innovation capabilities of an organization. The results of the innovation capabilities are then compared with the independent lean variables to analyze the overall impact of lean design on innovation capability.

4.2.2 Measuring an Organization's Responsiveness to Innovation

To test the hypotheses of proposition 3, measurements for an organization's responsiveness to radical innovations are developed. Table 4.17 presents the measurements used to identify an organization's responsiveness to innovation as well as the questions used in the survey.

Table 4.17 - Responsiveness to Innovation Measurements and Questions

5. Responsiveness to Radical Innovation
Measurements / Questions: Level of new products introduced as a result of responding to competitors' actions. Level of time to introduce the product to market once the design is complete (Reaction time to competitors' actions). Ability of suppliers to respond to competitor movement. Level of changes to suppliers in response to competitor movement. 1.) In your company, new products have been introduced to the market as a result of responding to competitors. a. ______% of product designs in your company are different from the designs adopted by your competitors. b. ______% of product designs in your company are similar to the designs adopted by your competitors, but differ in identifiable ways. c. ______% of product designs in your company are pure imitations of your competitors' designs. 2.) Your company is able to quickly react to events of product changes as a result of responding to competitor movement. a. It takes ______ months to ______ months to introduce the product to market once the design is complete. 3.) In events of product design changes as a result of response to competitor movement, the existing suppliers are able to manage a just-in-time delivery of the changed product components. 4.) In events of product design changes as a result of response to competitor movement, the company needs to switch to different suppliers for changed product components.

New product introductions can result from two possible scenarios: generate new ideas, experiment with the product designs, create a prototype, and introduce a new final product; or introduce a new product to the market as a response to the actions of the competitors. For this section the latter case is measured for each organization. New product designs as a result of competitors' actions can be measured as three different characteristics. These include: designs that are different from those by the competitors;

designs similar to the competitors' with noticeable differences; and designs that are imitations of those by the competitors. Another form of measurement is the reaction time of a company to the actions of its competitors [51]. This was determined by identifying the amount of time taken to introduce the product to market after completing the product design. Two final measurements involve the actions and abilities of the suppliers. The first is directed at the ability of the supplier to respond to competitor movement in terms of just-in-time [37, 41]. The final measurement involves the level of changes to different suppliers in response to competitor movement. This measurement would show if new suppliers were necessary when responding to competitors' actions.

The results obtained from these measurements of responsiveness to radical innovation are then compared to the results of the lean supply chain management measurements. An analysis is performed on the impact of lean supply chain management to the responsiveness of an organization to radical innovations made by its competitors.

4.3 Data Collection Process

The key measurements used to define an organization's levels of lean and innovation capability were questioned and analyzed using distributed online surveys. The survey was separated into two sections: "New Product Design Processes and Innovation Capability" and "Lean Supply Chain Management and Responsiveness to Radical Innovation". Identified respondents for the surveys consisted of firms located primarily in Minnesota that are involved in the design and/or manufacturing of products. A total of eleven different product type industries were included in this survey as shown in Table 4.18.

Table 4.18 - Participating Industries

SIC Code	Product Type
2400	Lumber and Wood Products
2600	Paper and Allied Products
2800	Chemicals and Allied Products
3000	Rubber and Miscellaneous Plastic Products
3300	Primary Metal Products
3400	Fabricated Metal Products
3500	Industrial and Commercial Machinery and Computer Equipment
3600	Electronic, Electrical Equipment and Components, except Computer Equipment
3700	Transportation Equipment
3800	Measuring/Analyzing/Control Instruments, Photo/Medical/Optical Goods
3900	Miscellaneous Manufacturing Products

4.3.1 Survey Questions

Each section of the online survey was compiled using the key measurements and questions presented in section 4.0. Respondents were asked to rank statements regarding their organization's attitude or practices on a seven-point Likert scale (1 = strongly disagree; 4 = neutral; 7 = strongly agree). This allowed the respondent to identify to what extent a specific statement describes the organization. One of two methods was used for direct measurements defining specific information (e.g. output levels or performance) about a company. The first was a five-point Likert scale with five different ranges of percentage values: 0-20%; 20-40%; 40-60%; 60-80%; and 80-100% for questions where only an approximate value was necessary. The respondent was then able to define the approximate level that the organization maintains based on the questioned measurement. For the remaining direct measurement questions, the method required the participant to input a value, often a minimum and/or maximum, with regards to the company's performance. To ensure bias was not involved in the responses, the types of innovation were not directly identified (only definitions) and the term "lean" was not used within the questions. For analysis, the questions related to an organization's practices were used in comparison to the innovation measurements. The direct measurements of performance were incorporated to either support or refute the practices of an organization.

In addition to the questions related to the key measurements of lean and innovation, the respondent was also required to provide information regarding his/her employment (e.g. years at current position and years employed with the company). This information was used to assess the results and significance of the responses. Three control factor questions were also acquired from the respondent: company product type, company size (number of employees), and company history (number of years). This helps further analysis on any significant impacts that these control factors may have on specific dependent variables.

4.3.2 Survey Distribution and Collection Process

The potential respondents were identified using two different approaches. The first approach selects participants through the University of Minnesota Duluth (UMD) network. This included contacting individuals that are: alumni of the engineering department at UMD; involved in an organization that supports the UMD engineering department; involved in the Senior Design programs at UMD; or personal contacts of the faculty committee members. The higher levels of involvement were believed to increase the overall response rate. The second approach was to select individuals from an online database using the product type and location as primary constraints. The product type was selected using the eleven industry types mentioned previously in Table 4.18. The inclusion of this second approach would allow for a wider range of responses.

After obtaining the sample for the survey, an initial letter was e-mailed to each of the individuals defining the two sections of the survey and ensuring that the individual's anonymity would be protected. If one of the sections was outside of the individual's expertise, he/she was asked to refer a suitable employee from the company that would be capable of completing the remaining section. A week following the initial letter a second e-mail was sent which distributed the website links for each section of the online survey. This one week time frame was set in place to allow the individuals to provide questions regarding the survey, provide referrals, or to decline participation. The timeline of the survey distribution included sending the initial e-mail in November 2009 with up to two reminder e-mails sent (one sent each month) to the participants regarding their progress of the surveys. Responses were collected until February 10, 2010 at which point the online surveys were closed.

After closing all responses were then collected and analyzed. Questions relating to a common variable or topic were assessed to determine overall consistency and unidimensionality of the responses. Surveys that were analyzed and found to have incomplete responses were discarded. After the initial assessment of the data, the final results were identified and then analyzed based on the model and hypotheses of this thesis.

5.0 Results

5.1 Sample

The sample frame for this research consisted of 450 people in eleven different industries defined in Table 4.18. Of the 450 potential participants, five were not in the supply chain management field resulting in 445 distributed surveys for the lean supply chain section. Of the distributed surveys, there were 84 initial responses for the "New Product Design Process" survey and 78 initial responses for the "Lean Supply Chain Management" survey. Eight of the "New Product Design Process" surveys and one of the "Lean Supply Chain Management" surveys was eliminated due to incomplete data. The final number of complete responses for the "New Product Design Process" and "Lean Supply Chain Management" surveys was 76 and 77, respectively. Of the respondents, approximately 80% were obtained from the UMD network. This yielded a response rate of 16.9% for the "New Product Design Process" survey and 17.3% for the "Lean Supply Chain Management" survey, shown in Table 5.1. While this response rate is not high, it exceeds the values of other studies in the field of new product design and similar research. On average, new product design studies have a response rate of approximately twelve percent [75-77]. The higher response rate achieved for this study is due in part to the networking pool approach.

Table 5.1 - Survey Distribution Results

	New Product Design Process Survey	Lean Supply Chain Management Survey
Number of Surveys Distributed	450	445
Number of Survey Responses	84	78
Response Rate for Initial Responses	18.67%	17.53%
Number of Complete Survey Responses	76	77
Final Response Rate	16.89%	17.30%

Tables 5.2 and 5.3 display the response rate of different company types. Of the responses obtained, approximately 73% of the results were from four product type companies: fabricated metal products; industrial and commercial machinery and computer equipment; electronic, electrical equipment and components; and measuring/analyzing/control instruments.

Table 5.2 - New Product Design Process - Product Type

Number	Product Type	Responses	% of Responses
1	Fabricated Metal Products	11	14.47%
2	Industrial and Commercial Machinery and Computer Equipment	12	15.79%
3	Electronic, Electrical Equipment and Components, except Computer Equipment	19	25.00%
4	Transportation Equipment	2	2.63%
5	Measuring/Analyzing/Control Instruments, Photo/Medical/Optical Goods	14	18.42%
6	Primary Metal Products	2	2.63%
7	Rubber and Miscellaneous Plastic Products	4	5.26%
8	Chemicals and Allied Products	0	0.00%
9	Lumber and Wood Products	3	3.95%
10	Paper and Allied Products	1	1.32%
11	Miscellaneous Manufacturing Products	8	10.53%

Table 5.3 - Lean Supply Chain Management - Product Type

Number	Product Type	Responses	% of Responses
1	Fabricated Metal Products	12	15.58%
2	Industrial and Commercial Machinery and Computer Equipment	10	12.99%
3	Electronic, Electrical Equipment and Components, except Computer Equipment	20	25.97%
4	Transportation Equipment	3	3.90%
5	Measuring/Analyzing/Control Instruments, Photo/Medical/Optical Goods	14	18.18%
6	Primary Metal Products	3	3.90%
7	Rubber and Miscellaneous Plastic Products	1	1.30%
8	Chemicals and Allied Products	1	1.30%
9	Lumber and Wood Products	5	6.49%
10	Paper and Allied Products	1	1.30%
11	Miscellaneous Manufacturing Products	7	9.09%

The second control factor identified from the responses was the company size measured by the number of employees. Tables 5.4 and 5.5 present the distribution of companies in terms of size. The results were well distributed with approximately 50% of the respondents in organizations with less than one thousand employees and approximately 50% with more than one thousand employees. This assisted in identifying if the size of the company affects its behaviors or performance.

Table 5.4 - New Product Design Process - Company Size

New Product Design Process Survey			
Number	**Company Size (# of Employees)**	**Responses**	**% of Responses**
1	Less than 50	8	10.53%
2	50-99	6	7.89%
3	100-249	6	7.89%
4	250-499	11	14.47%
5	500-999	6	7.89%
6	1,000-4,999	17	22.37%
7	5,000-9,999	4	5.26%
8	More than 10,000	18	23.68%

Table 5.5 - Lean Supply Chain Management - Company Size

Supply Chain Survey			
Number	**Company Size (# of Employees)**	**Responses**	**% of Responses**
1	Less than 50	7	9.09%
2	50-99	7	9.09%
3	100-249	6	7.79%
4	250-499	9	11.69%
5	500-999	7	9.09%
6	1,000-4,999	17	22.08%
7	5,000-9,999	7	9.09%
8	More than 10,000	17	22.08%

The final control factor was the company history. Of the respondents the majority were from companies greater than twenty years old. The data from Tables 5.6 and 5.7 were then used to test the significance of company history to the dependent variables of the research model.

Table 5.6 - New Product Design Process - Company History

New Product Design Process Survey			
Number	**Company History (Number of Years)**	**Responses**	**% of Responses**
1	Less than 5 Years	5	6.58%
2	5-9 Years	2	2.63%
3	10-19 Years	7	9.21%
4	20-39 Years	17	22.37%
5	40-49 Years	9	11.84%
6	More than 50 Years	36	47.37%

Table 5.7 – Lean Supply Chain Management - Company History

Supply Chain Survey			
Number	**Company History (Number of Years)**	**Responses**	**% of Responses**
1	Less than 5 Years	4	5.19%
2	5-9 Years	2	2.60%
3	10-19 Years	10	12.99%
4	20-39 Years	18	23.38%
5	40-49 Years	7	9.09%
6	More than 50 Years	36	46.75%

5.2 Reliability and Unidimensionality Tests

5.2.1 Lean Variable Measurements

For each of the variables, tests must be used to ensure that all scale measurements are reliable and unidimensional. A pool of scale items was generated for measuring each of the constructs based on the review of the literature for lean and innovation. Each of the individual scale measurements is identified in the section 4.0 of this thesis. The scale items for each standardization and design for manufacturability variable are displayed in Table 5.8. The mean and standard deviation for each item are defined, as well as the item-to-total correlation. The six variables for standardization and DFM are: simplification of product design; part integration; the use of standardized parts, standardized processes, and standardized materials; and compatibility of designs with existing processes and procedures. For each multi-item variable, the Cronbach's alpha coefficient value was determined along with the overall mean and standard deviation values. The values for each measurement were ranked on a 7 point Likert scale (1 = strongly disagree; 4 = neutral; 7 = strongly agree).

Table 5.8 - Variable Measures - Standardization and DFM

Variable Name	Measurement	Mean (S.D.)	Item-to-Total Correlation
Simplification of Product Design	S1	5.26 (1.33)	0.592
Alpha: 0.847[c]	S2	5.07 (1.50)	0.671
Mean: 5.09[c]	S3	4.93 (1.48)	0.690
S.D.: 1.26[c]	S4[a]	4.32 (1.66)	0.233
Part Integration	PI1[b]	5.04 (1.23)	0.519
Alpha: 0.824[c]	PI2	4.30 (1.45)	0.644
Mean: 4.41[c]	PI3	4.53 (1.30)	0.750
S.D.: 1.27[c]			
Use Standardized Parts	SP1	4.97 (1.46)	0.627
Alpha: 0.833[c]	SP2[a]	3.95 (1.50)	0.250
Mean: 4.85[c]	SP3	4.58 (1.51)	0.698
S.D.: 1.29[c]	SP4	5.00 (1.50)	0.618
Use Standardized Processes	PROC1	5.59 (1.25)	
Alpha: 0.315[d]	PROC2	4.51 (1.49)	
	PROC3	3.80 (1.44)	
Use Standardized Materials	SM1	5.11 (1.31)	0.633
Alpha: 0.844[c]	SM2[b]	4.04 (1.66)	0.406
Mean: 5.26[c]	SM3	5.41 (1.16)	0.639
S.D.: 1.15[c]			
Compatibility of Designs with Existing Procedures/Processes	C1	5.26 (1.45)	0.526
Alpha: 0.706	C2	3.89 (1.61)	0.505
Mean: 4.56	C3	4.53 (1.64)	0.544
S.D.: 1.21			

a: Measurements "S4" and "SP2" were suppressed (Item-to-total correlation lower than 0.35)
b: Measurement "PI1" and "SM2" were suppressed (to improve reliability)
c: Values for Alpha, Mean, and Standard Deviation are calculated after suppressing items
d: Due to its low Alpha value, measurement "PROC3" was selected to represent the "Standardized Processes" variable based on its key definition.

The unidimensionality for the multi-item variables was obtained using the item-to-total correlation values. The scale measurements with correlation values lower than 0.35 were suppressed because this resulting correlation translates to an item that is not consistent with the rest of the items for the given variable [75, 78]. For example, measurement “S4” for the simplification variable had an item-to-total correlation value of 0.233, signifying that this question may not be consistent with the remaining scale measurements. Therefore, this item was suppressed to ensure that the scale for the simplification variable was indeed unidimensional. The Cronbach’s alpha coefficient values were also calculated to determine the overall reliability of the unidimensional scale items to the latent construct. An alpha coefficient value greater than or equal to 0.70 is often deemed as acceptable in terms of indicating good reliability [75]. For each multi-item variable the alpha values were all greater than 0.70, indicating that the scale items have a relatively high level of consistency and reliability towards the latent constructs (with the exception of “Standardized Processes”). The two calculated tests showed that the multi-item standardization and DFM variables in this research have acceptable levels of unidimensionality and reliability.

The descriptive data for the value analysis variables are presented in Table 5.9. The constructs used to measure value analysis include matching customer requirements with new product design processes; rank-ordering product attributes; and the customer value based resource allocation of the organization. To ensure unidimensionality and reliability for the “matching customer requirements” variable, measurement “MCR2” was suppressed due to its low item-to-total correlation value (0.197). For the rank-ordering of product attributes, a single item was used to determine the level of weight an organization gives to attributes that meet the current customers’ requirements. Additional questions were included in the survey relating to other areas for defining weight to ensure consistency of an individual’s responses. The same approach was used for the resource allocation measurement. The purpose of this variable was to identify the level of allocated resources that a company provides for design product attributes not valued by its current mainstream customers. An additional question was provided to determine the opposing spectrum for allocating company resources.

Table 5.9 - Variable Measures - Value Analysis

Variable Name	Measurement	Mean (S.D.)	Item-to-Total Correlation
Match Customer Rqmts. w/ NPD	MCR1	6.08 (1.39)	0.493
Alpha: 0.803[b]	MCR2[a]	4.32 (1.63)	0.197
Mean: 5.88[b]	MCR3	5.67 (1.43)	0.569
S.D.: 1.29[b]			
Rank-Ordering of Product Attributes	RO1a	4.71 (1.41)	
	RO1b	4.53 (1.37)	
	RO1c	4.84 (1.66)	
Customer Value Based Resource Allocation	RA1	4.89 (1.64)	
	RA2	3.11 (1.50)	

a: Measurement "MCR2" was suppressed (Item-to-total correlation lower than 0.35)
b: Values for Alpha, Mean, and Standard Deviation are calculated after suppressing "MCR2"

The final set of lean variables for this research involved those related to supply chain management. Four scale item measurements were used to define each aspect of the supply chain. Measurements with regards to the breadth of the supply chain related to the company's preferences and practices in terms of minimizing buffers (suppliers) within its system. The depth of the supply chain involved items related to the supplier commitment within the organization. Table 5.10 shows that there is sufficient reliability and unidimensionality for the scale items of each variable.

Table 5.10 - Variable Measures - Lean Supply Chain Management

Variable Name	Measurement	Mean (S.D.)	Item-to-Total Correlation
Lean Supply Chain with Limited Breadth	BSC1	5.13 (1.33)	0.389
Alpha: 0.746	BSC2	4.87 (1.54)	0.670
Mean: 4.95	BSC3	4.73 (1.42)	0.595
S.D.: 1.10	BSC4	5.06 (1.55)	0.520
Depth of Supply Chain	DSC1	4.79 (1.14)	0.489
Alpha: 0.748	DSC2	4.29 (1.44)	0.544
Mean: 4.84	DSC3	4.65 (1.45)	0.548
S.D.: 0.97	DSC4	5.65 (1.07)	0.628

5.2.2 Innovation Measurements

The unidimensionality and reliability tests were also performed for the innovation variables, as shown in Table 5.11. Item-to-total correlation values were all greater than 0.35 and the Cronbach's alpha coefficient values were greater than 0.70 for architectural and radical innovation capability. The scale items for disruptive innovation capability were measured and analyzed individually due to the differing approaches for each measurement. For disruptive innovation to be successful the following must be true with regards to a company: encouragement of new products that may underperform in areas valued by mainstream customers but offer new areas of attractiveness (DI1); tolerant of projects with unsatisfying returns of investment (DI2); frequent experimentation on new technologies that may not be valued by mainstream customers (DI3); encouragement of new product design ideas (DI4); and ability to identify new markets (DI5). Each of these measurements is therefore analyzed individually to identify the impact that lean value analysis has on each aspect required for disruptive innovation.

Table 5.11 - Variable Measures - Innovation Capability

Variable Name	Measurement	Mean (S.D.)	Item-to-Total Correlation
Incremental Innovation	II1	5.41 (1.44)	0.426
Alpha: 0.788	II2	5.43 (1.43)	0.672
Mean: 4.99	II3	5.12 (1.45)	0.561
S.D.: 1.02	II4	4.55 (1.26)	0.457
	II5	4.49 (1.35)	0.735
Architectural Innovation	AI1	4.70 (1.15)	0.357
Alpha: 0.700	AI2	4.66 (1.35)	0.484
Mean: 4.39	AI3	4.43 (1.61)	0.513
S.D.: 0.92	AI4	4.14 (1.21)	0.406
	AI5	4.04 (1.51)	0.497
Radical Innovation	RI1	4.39 (1.60)	0.425
Alpha: 0.819	RI2	4.47 (1.84)	0.690
Mean: 4.32	RI3	4.57 (1.52)	0.652
S.D.: 1.13	RI4	4.25 (1.39)	0.531
	RI5	4.24 (1.47)	0.583
	RI6	4.00 (1.53)	0.638
Disruptive Innovation	DI1	4.14 (1.56)	
	DI2	3.18 (1.64)	
	DI3	3.42 (1.39)	
	DI4	5.24 (1.55)	
	DI5	4.42 (1.50)	

Similar to the approach for disruptive innovation, the individual scale measurements for a company's responsiveness to radical innovation was also measured individually. The items for this construct involve analyzing a company based on its response to competitor movement. To analyze a company's responsiveness to innovation the following measurements were collected: the level of introduction of new products to the market as a result of competitor movement (RtoI1); the ability to quickly react to events of product changes (RtoI2); the ability to manage just-in-time delivery of changed product components (RtoI3); and the need to switch to different suppliers for changed product components (RtoI4). The collection of these scale items can be used to identify a company's actions with regards to product design changes as a result of response to competitor movement.

Table 5.12 - Variable Measures - Responsiveness to Innovation

Variable Name	Measurement	Mean (S.D.)
Responsiveness to Innovation	RtoI1	4.95 (1.51)
	RtoI2	4.35 (1.57)
	RtoI3	4.20 (1.35)
	RtoI4	4.00 (1.37)

The direct measurement results were collected for multiple constructs as well. The results of these measurements along with the scale items mentioned in this sub-section are discussed in detail in the next section.

5.3 Correlation Matrix

The final step prior to the statistical analysis is to construct a correlation matrix of the lean and innovation concepts as shown in Table 5.13 through Table 5.15. For each variable the individual correlation is identified in relation to each of the remaining variables. This zero-order correlation coefficient defines the relationship of two variables and ignores the influence of all other variables. The correlation coefficient, denoted by "r", ranges between -1.0 (perfect negative relationship) and +1.0 (perfect positive relationship) and is given a specific significance level for each identified relationship [79]. This initial testing can be used to identify if there is any statistically significant relationship between individual lean variables and innovation capability variables. In Table 5.13 through Table 5.15 a correlation coefficient value without any asterisks has no statistical significance. Table 5.13 shows the correlation matrix for the first proposition relating to standardization and DFM versus innovation capability.

Table 5.13 - Correlation Matrix: Standardization and DFM vs. Innovation Capability

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. Simplification	1.0							
2. Part Integration	0.342***	1.0						
3. Standardized Parts	0.811****	0.375***	1.0					
4. Standardized Processes	0.090	0.056	0.010	1.0				
5. Standardized Materials	0.431****	0.118	0.552****	0.103	1.0			
6. Compatibility	0.342***	0.128	0.387***	0.305***	0.480****	1.0		
7. Radical Innovation	-0.164	0.244**	-0.194*	-0.200*	-0.116	-0.198*	1.0	
8. Architectural Innovation	0.298***	0.494****	0.209*	-0.109	0.078	0.076	0.633****	1.0

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

Proposition 1 states that standardization and DFM have a negative effect on an organization's innovation capability. Sub-dividing this proposition to the lower level, the individual lean aspects should have a negative effect on each type of innovation capability. The matrix shows that all individual lean aspects have a negative effect on radical innovation capability, with the exception of part integration. For architectural innovation capability, there are instances where the individual concepts have a significant positive effect.

The correlation matrix for proposition 2 is presented in Table 5.14, identifying individual statistically significant relationships between the independent and dependent variables. In addition, the matrix was also used to verify that there is a statistically significant positive correlation between each of the three aspects of value analysis.

Table 5.14 - Correlation Matrix: Value Analysis vs. Innovation Capability

	1	2	3	4	5	6	7	8
1. Match Customer Rqmts. w/ NPD	1.0							
2. Rank Ordering	0.464****	1.0						
3. Resource Allocation	0.403****	0.405****	1.0					
4. Disruptive Innovation (DI1)	-0.044	-0.195*	-0.250**	1.0				
5. Disruptive Innovation (DI2)	-0.188*	-0.129	-0.339***	0.073	1.0			
6. Disruptive Innovation (DI3)	-0.011	-0.243**	-0.177	0.225*	0.305***	1.0		
7. Disruptive Innovation (DI4)	0.175	-0.009	0.074	0.390***	-0.028	0.238**	1.0	
8. Disruptive Innovation (DI5)	0.314***	0.256**	0.061	0.145	0.028	0.138	0.364***	1.0

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

Table 5.15 presents the correlation matrix of the lean supply chain management variables and the four measurements relating to an organization's responsiveness to innovations. These four measurements are analyzed individually because each presents a differing aspect to responding to competitor movement. Therefore each may be affected differently by the levels of breadth and depth in the supply chain.

Table 5.15 - Correlation Matrix: Lean Supply Chain Management vs. Responsiveness to Innovation

	1	2	3	4	5	6
1. Lean supply chain w/ limited breadth	1.0					
2. Depth of Supply Chain	0.431****	1.0				
3. Responsiveness to Innovation (RtoI1)	0.079	0.272**	1.0			
4. Responsiveness to Innovation (RtoI2)	0.073	0.308***	0.185	1.0		
5. Responsiveness to Innovation (RtoI3)	0.156	0.270**	0.052	0.626****	1.0	
6. Responsiveness to Innovation (RtoI4)	0.168	0.272**	0.191*	0.208*	0.059	1.0

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

In terms of individual analyses, the correlation matrix showed that the depth of the supply chain (supplier commitment) has a positive effect on all aspects of responsiveness to innovation, whereas the lean supply chain with limited breadth (buffer minimization) has no statistically significant influence. These findings for each of the three propositions will be analyzed more thoroughly using the regression analysis methods in section 6.0.

6.0 Data Analysis

6.1 Standardization and DFM vs. Innovation Capability

The first proposition defined in this research was set in place to define the relationship between the standardization and design for manufacturability aspects of lean design with the innovation capability of an organization. The lean design aspects were separated into seven primary constructs with each having an influence on the standardization and DFM levels of an organization. The innovation capability levels were tested in terms of radical and architectural innovation. The first proposition states that standardization and DFM has a negative effect on a company's radical and architectural innovation capability. The proposition is tested by four hypotheses, separated by categories of lean design and innovation capability. The process and results of the data analysis are described in detail in the remaining portion of this section.

Table 6.1 - Proposition 1: Standardization and DFM vs. Innovation Capability

Proposition 1	Standardization and DFM in lean design has a negative effect on a company's radical innovation capability and architectural innovation capability.
Hypothesis 1a	Standardization in lean design has a negative effect on a company's radical innovation capability.
Hypothesis 1b	DFM in lean design has a negative effect on a company's radical innovation capability.
Hypothesis 1c	Standardization in lean design has a negative effect on a company's architectural innovation capability.
Hypothesis 1d	DFM in lean design has a negative effect on a company's architectural innovation capability.

The data analysis used to test each hypothesis of the propositions is based on multiple regression analysis. Multiple regression analysis is used to determine the variance of a dependent variable based on combinations of multiple independent variables [80-82]. Multiple regression can identify how a specific set of independent variables accounts for a proportion of the variance in a dependent variable through the identification of the R-squared value (coefficient of multiple determination). The R-squared value indicates how well the model fits the overall data by identifying the percent of variance in the dependent variable explained by the independent variables [80, 82]. The greater the R-squared value the greater the level of variability accounted for with the items defined in the given model. R-squared defines the error reduction for estimating the dependent variable using the specified independent variables. The F-values (obtained from the F test) define the significance of the R-squared value, or the overall significance of the regression model [80, 82].

The analysis can also be used to suggest the statistically significant predictive importance of independent variables by analyzing the regression (b) or beta coefficients [80]. The regression coefficient is the level by which the dependent variable increases, provided the given independent variable increases by one unit and all other independent variables remain constant. This un-standardized coefficient is used when the scales for each variable are the same. In cases where the scales are different among the variables, a standardized regression coefficient (beta) is used. Common for testing the relative strength of independent variables within a regression model, the beta coefficients are measured in terms of standard deviations instead of individual units. Therefore the beta coefficient identifies the amount the standard deviation of the dependent variable increases provided the standard deviation of a given independent variable increases by one and all others are held constant.

Hierarchical multiple regression was included in this analysis to test the relative importance of introducing each independent variable to the given model [80, 82]. This will suggest the level at which each independent variable contributes to explaining the overall variance of the model. The F-values in this case define the significance of the input of an additional variable based on the R-squared value. The stepwise multiple regression approach is introduced into this analysis to identify the entry order for the independent variables into each model. This order is determined by the independent variable that results in the greatest increase in the R-squared value, or the variable with the greatest impact on the overall model. With the stepwise approach, the R-squared values are analyzed by the level at which it increases when a new independent variable is added to the model. The incremental change in the R-squared value defines the predictive power that a new variable provides to the multiple regression analysis. The use of correlation matrices, and hierarchical and stepwise multiple regression analyses are used in all sections of this research to show the statistical significance of lean concepts on an organization's innovation capability and responsiveness to radical innovation.

Hypotheses 1a and 1b were first tested to show the relationship between standardization and DFM in lean design with an organization's radical innovation capability. To analyze the relationship at a higher level, the three standardization constructs (standardized parts, standardized processes, and standardized materials) were analyzed as one collective construct entitled "standardization" (alpha = 0.771). This approach led to a clearer definition for relating the results to the initial proposition. The stepwise approach to multiple regression analysis was used in Table 6.2 to identify the entry order of lean variables to radical innovation capability.

Table 6.2 - Radical Innovation Capability - Hypothesis Testing

	Model 1	Model 2	Model 3
Simplification		-0.103	-0.101
Part Integration	0.277***	0.302***	0.303***
Standardization	-0.477****	-0.400**	-0.365*
Compatibility			-0.045
R-Squared (F-Value)	0.184 (8.223)	0.192 (5.708)	0.194 (4.268)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

The final model for this analysis, Model 3, explained approximately twenty percent of the variance of radical innovation capability ($F = 4.268$). The stepwise approach identified standardization and part integration as having the greatest impact on the R-squared value. Neither simplification nor compatibility accounted for a significant level of the variability in the model. As predicted in hypothesis 1a, standardization has a negative effect on an organization's radical innovation capability ($b = -0.365$, $p < 0.10$). The formalization of the design procedure encountered using standardization may deter dramatic or radical changes to the product design.

Contrary to original expectations of hypothesis 1b, part integration was deemed to have a positive effect on radical innovation capability ($b = 0.303$, $p < 0.01$). One possible explanation for this result is due to unexpected interpretation of the part integration questions in the survey. It was originally hypothesized that part integration has a negative effect on an organization's innovation capability. Incremental improvements would occur but significant changes would be deterred. However, depending on the level of integration and the type of parts or components used in the integration, the innovation level may change. If new integrated parts are created and used, it may translate to a higher level of innovation [83]. Since this differentiation was not identified specifically in the part integration questions, the respondents may have interpreted them differently than was originally assumed. (Additional testing did confirm that incremental innovations would be positively influenced by part integration and was shown by its statistically significant positive correlation ($r = 0.320$, $p < 0.01$).)

Simplification and compatibility of designs with existing procedures in Model 3 were shown to have no statistical significance on the impact of radical innovation capability. This result also rejected hypothesis 1b. At the individual level (using the correlation matrix), emphasizing compatibility of product designs with existing manufacturing processes was found to have a statistically significant negative correlation to radical innovation capability ($r = -0.198$, $p < 0.10$). Simplification of product designs also had a negative correlation to radical innovation capability but was not deemed statistically significant.

To further define this analysis, each of the standardization constructs was then separated and the regression model was re-analyzed to identify each construct's significance. Table 6.3 shows that Model 5 explains about twenty-one percent of the variance for radical innovation capability ($F = 3.089$).

Table 6.3 - Radical Innovation - Hypothesis Testing (2)

	Model 1	Model 2	Model 3	Model 4	Model 5
Simplification					-0.002
Part Integration	0.329***	0.341***	0.338***	0.348***	0.348***
Standardized Parts	-0.292***	-0.295***	-0.271**	-0.314**	-0.312*
Standardized Processes		-0.171**	-0.156*	-0.156*	-0.156*
Standardized Materials				0.102	0.102
Compatibility			-0.060	-0.089	-0.089
R-Squared (F-Value)	0.155 (6.672)	0.202 (6.073)	0.205 (4.585)	0.212 (3.760)	0.212 (3.089)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

Of the three standardization constructs, the use of standardized parts (b = -0.312, p < 0.10) and processes (b = -0.156, p < 0.10) were deemed to be statistically significant in terms of having a negative effect on an organization’s radical innovation capability. The stepwise approach shows that part integration, standardized parts, and standardized processes accounted for a majority of the explained variance for radical innovation capability.

Based on the analysis, hypothesis 1a was supported by the regression analysis. Standardization has a negative effect on an organization’s radical innovation capability. Hypothesis 1b was rejected by the analysis. Individually, the correlation matrix shows that compatibility of design with existing procedures has a negative effect on radical innovation capability. While negatively correlated, simplification was not found to be statistically significant. Part integration was shown to have a positive influence on radical innovation capability. This result though could be due to the respondent’s interpretation.

A similar multiple regression approach was used to analyze the impact of standardization and DFM on an organization’s architectural innovation capability. The standardization constructs were initially analyzed collectively and were then separated to identify any significance at the individual levels. Table 6.4 shows that Model 3 of the lean design concepts explains approximately thirty-two percent of the variance for architectural innovation capability (F = 8.307).

Table 6.4 - Architectural Innovation Capability - Hypothesis Testing

	Model 1	**Model 2**	**Model 3**
Simplification	0.107	0.215**	0.212**
Part Integration	0.323****	0.322****	0.321****
Standardization		-0.288**	-0.344**
Compatibility			0.073
R-Squared (F-Value)	0.263 (13.042)	0.312 (10.893)	0.319 (8.307)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

The stepwise approach suggested that simplification, part integration, and standardization accounted for a primary level of the explained variance in the model. Each of these constructs was also found to be statistically significant. As predicted in hypothesis 1c, standardization was negatively associated with architectural innovation capability ($b = -0.344$, $p < 0.05$). Hypothesis 1d was refuted ($b = 0.321$, $p < 0.001$) which could again be contributed to respondent interpretation of the questions, similar to the results shown for hypothesis 1b.

Contrary to hypothesis 1d, simplification of product designs was also shown to have a statistically significant positive effect on architectural innovation capability ($b = 0.212$, $p < 0.05$). Rationale behind this can be that the desire of the organization to simplify the product design encourages the changing of the linkages and interactions of a product's components and thus promotes architectural innovation. Compatibility of designs to existing procedures was shown to have no statistical significance on the effect of architectural innovation capability using regression analysis or the correlation matrix.

Table 6.5 shows the impact of the individual standardization constructs on an organization's architectural innovation capability.

Table 6.5 - Architectural Innovation - Hypothesis Testing (2)

	Model 1	Model 2	Model 3	Model 4	Model 5
Simplification	0.107	0.116	0.267**	0.266**	0.268**
Part Integration	0.323****	0.326****	0.348****	0.349****	0.351****
Standardized Parts			-0.190	-0.205	-0.214
Standardized Processes		-0.095	-0.106	-0.117*	-0.118*
Standardized Materials					0.019
Compatibility				0.043	0.037
R-Squared (F-Value)	0.263 (13.042)	0.285 (9.568)	0.308 (7.894)	0.310 (6.299)	0.311 (5.183)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

Of the standardization constructs, standardized processes was the only variable to have a statistically significant negative effect on architectural innovation capability (b = -0.118, p < 0.10). While standardized parts accounted for some of the explained variance in the model, it was not deemed statistically significant.

Hypothesis 1c of proposition 1 was supported based on the data analysis results. This suggested that standardization negatively affects an organization's architectural innovation capability. All other results obtained were found to reject hypothesis 1d of the proposition. Part integration and simplification of product designs had a positive impact on architectural innovation capability while compatibility of designs with existing processes was not significant.

To further analyze the models for both levels of innovation capability, the three control factors (product type, company size, and company history) were introduced.

Table 6.6 shows that company size was the only statistically significant factor in either case. According to the data analysis, the size of the company had a positive effect on both radical innovation capability ($\beta = 0.276$, $p < 0.05$) and architectural innovation capability ($\beta = 0.288$, $p < 0.01$). This could be explained by the significant levels of financial and technical capabilities of a larger company. Larger companies may also have the economies of scope and sales volume to account for risks of new product designs and for research and development [84]. This result could also be slightly skewed because of the relatively small sample size for each level of the company size scale.

Table 6.6 - Innovation Capability with Control Factors – Regression Analysis

	Radical	Architectural
Simplification	0.039	0.402**
Part Integration	0.347***	0.444****
Standardized Parts	-0.354*	-0.291
Standardized Processes	-0.176	-0.171
Standardized Materials	0.160	0.051
Compatibility	-0.109	0.031
Product Type	0.167	0.093
Company Size	0.276**	0.288***
Company History	-0.188	-0.112
R-Squared (F-Value)	0.310 (3.292)	0.389 (4.666)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

In addition to the data analysis performed on the lean measurements related to an organization’s attitudes and practices, results were also obtained on direct measurements related to an organization’s output levels and performance. For each of the direct measurements, the mean and standard deviation values were calculated as well as the correlation coefficient in relation to each type of innovation capability.

Table 6.7 - Analysis of Direct Measurements (Innovation Capability)

	Mean	Standard Deviation	Radical Innovation	Architectural Innovation
1a: Simplification (S3a) *(N=76)*	2.92	1.20	-0.207*	0.029
1b: Simplification (S3b) *(N=46)*	2.02	1.26	-0.020	0.318**
1c: Simplification (S4a) *(N=72)*	2.51	1.06	0.234**	0.113
1d: Simplification (S4b) *(N=67)*	3.42	1.41	0.186	0.102
2a: Standardized Parts (SP4a) *(N=76)*	2.80	1.23	-0.190*	0.067
3a: Standardized Proc. (PROC3a) *(N=68)*	2.91	1.25	0.214*	0.292**
4a: Standardized Matl. (SM3a) *(N=76)*	3.97	1.05	0.054	-0.039
5a: Compatibility (C3a) *(N=74)*	3.96	0.91	-0.256**	-0.211*

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

In Model 1a, the simplification question relates to the average percentage of existing parts implemented in new product designs. As this percentage of existing parts increased, the level of radical innovation capability decreased (r = -0.207, p < 0.10), supporting hypothesis 1b. This could be because the designs of radical innovations cannot be dependent on existing technologies. There was no significant correlation between this level of simplification and architectural innovation capability.

Model 1b related to company rules or organizational goals to achieve a certain percentage of parts-reuse. The data shows that approximately 60% of respondents had these specific goals or rules. For companies with these rules, as the percentage of parts-reuse is increased, the level of architectural innovation capability also increased (r = 0.318, p < 0.05). There was no significant correlation between parts-reuse and radical innovation capability. These results are closely related to those obtained in the multiple regression analysis.

Model 1c and 1d relate to the average and maximum percentage of changes implemented in each round of new product designs. As the percentage of changes in each round increases, the radical innovation capability for an organization also increases

($r = 0.234$, $p < 0.05$). This supports the prediction that dramatic changes are required for radical innovation to be successful. The maximum levels for percentage of round changes were found to not be of statistical significance to radical or architectural innovation capability.

Model 2a relates to the average percentage of standard parts used in product designs. Similar to the results of the regression analysis, this aspect of standardization has a statistically significant negative effect on radical innovation capability ($r = -0.190$, $p < 0.10$). Model 3a relates to the percentage of changes allowed to the design processes. An increase in the level of changes was shown to have a positive effect on both categories of innovation capability. This result of the direct measurement for standard processes supports the results obtained in the multiple regression analysis. Model 4a shows that the percentage of standard materials used in designs does not impact the level of innovation capability. This finding could be explained by the relatively short time frame for this research. There are often industry standards for using specific materials on a given product design and significant periods of time are needed to show a dramatic change in the materials used.

Model 5a relates to the average percentage of designs that are compatible with existing manufacturing methods. The results of this direct measurement show that compatibility has a negative effect on radical and architectural innovation capability. This could be related to the prediction that innovations require changes to any aspect of the design, which has noticeable discrepancies with the compatibility approach.

In summary, it can be concluded that hypotheses 1a and 1c of proposition 1 are accepted while hypotheses 1b and 1d are rejected. Standardization was found to have a negative impact on both levels of innovation capability. Compatibility, in terms of the direct measurements, showed a significant negative correlation against radical and architectural innovation capability. The aspects that contradicted hypotheses 1b and 1d related to part integration and simplification of product designs. Simplification had a positive effect on architectural innovation capability while part integration was found to have a positive effect on both levels of innovation capability. The respondents' interpretations of these questions may have contributed to these findings for hypotheses 1b and 1d.

6.2 Value Analysis vs. Innovation Capability

The third component of lean design, value analysis, is based on closely following the needs and requirements of the customer in terms of product design and manufacturing [29]. This is accomplished through three main steps: matching the customer requirements with new product designs; rank-ordering product attributes with primary weight given to current customer requirements; and creating a cost framework in which resources are not highly allocated to concepts that are not valued by the current customer [21, 38]. Disruptive innovation capability is based on achieving all of the following aspects [21]. The values in parentheses following each of the aspects denote the variable measurements for the disruptive innovation capability:

- Encouragement of the development and improvement of new products that may underperform in certain areas but offer new areas of attractiveness. (DI1)

- Tolerance of supporting projects with unsatisfying returns on investment. (DI2)
- Frequent experimentation on new technologies that offer new attributes not originally valued by mainstream customers. (DI3)
- Encouragement of a variety of new product design ideas. (DI4)
- Ability to identify new markets for new product designs. (DI5)

It is the culmination of these five aspects that supports an organization's disruptive innovation capability. The hypotheses were defined using DI1 – DI3; the remaining aspects were assumed to not have a significant relationship with disruptive innovation capability. This is because measurements "DI4" and "DI5" may be attributed to factors other than disruptive innovation capability.

Table 6.8 - Proposition 2: Value Analysis vs. Innovation Capability

Proposition 2	The value analysis in lean design has a negative effect on a company's capability to successfully deal with disruptive innovations.
Hypothesis 2a	The value analysis in lean design has a negative effect on a company's capability to encourage the development of new products that may underperform in certain areas but offer new areas of attractiveness.
Hypothesis 2b	The value analysis in lean design has a negative effect on a company's capability to tolerate projects with unsatisfying returns on investment.
Hypothesis 2c	The value analysis in lean design has a negative effect on a company's capability to frequently experiment on new technologies that offer attributes not valued by mainstream customers.

Each of the five variables for disruptive innovation capability represents a different required condition. In order for disruptive innovation to be successful in an organization, all five variables must be promoted. Therefore multiple regression analysis was performed to all of the variables to show the impact created by value analysis. The stepwise multiple regression analysis approach was used to show the order of entry for the value analysis variables.

Table 6.9 presents the results of this analysis for the first variable of disruptive innovation capability (DI1). The encouragement of new products that may initially underperform in certain areas that are valued by the mainstream customers, but offer new areas of attractiveness is a key contributor to disruptive innovation.

Table 6.9 - Disruptive Innovation Capability - Hypothesis Testing (DI1)

	Model 1	**Model 2**
Matching Customer Requirements		0.150
Rank Ordering	-0.133	-0.186
Customer Value Based Resource Allocation	-0.212	-0.245*
R-Squared (F-Value)	0.073 (2.881)	0.084 (2.212)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

The final model of this analysis, Model 2, shows that the customer value based resource allocation of value analysis has a negative effect on this aspect of disruptive innovation capability ($b = -0.245$, $p < 0.10$). As predicted by hypothesis 2a, a structure that does not allocate resources to areas outside the requirements of one’s mainstream customers translates to a negative influence on this aspect of disruptive innovation. While rank-ordering of product attributes accounted for a high level of the total variance, it was not deemed to be statistically significant for the overall model thereby refuting hypotheses 2a. The correlation matrix, however, suggested that the rank-ordering of product attributes in terms of customer requirements was negatively correlated to this aspect of disruptive innovation capability ($r = -0.195$, $p < 0.10$).

Table 6.10 - Disruptive Innovation Capability - Hypothesis Testing (DI2)

	Model 1	Model 2
Matching Customer Requirements	-0.078	-0.095
Rank Ordering		0.046
Customer Value Based Resource Allocation	-0.343**	-0.353**
R-Squared (F-Value)	0.118 (4.878)	0.119 (3.238)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

Table 6.10 shows the hierarchical regression analysis for the disruptive innovation measurement “DI2”. This variable is based on the tolerance of an organization to support projects that have unsatisfying returns on investment. The final model of this analysis, Model 2, explained approximately twelve percent of the total variance for tolerating unsatisfying projects (F = 3.238). Neither matching customer requirements nor rank-ordering attributed significantly to this total variability for the model. As predicted by hypothesis 2b, customer value based resource allocation had a negative effect on an organization’s tolerance to supporting projects with unsatisfying returns ($b = -0.353$, $p < 0.05$). An organization that is unwilling to allocate resources to areas outside the requirements of its current customers is generally risk-averse. A risk-averse organization would in turn not be as willing to support projects that do not provide an immediate return on investment. Given the necessary time and space to develop, a disruptive innovation will eventually dominate the market [21].

Table 6.11 - Disruptive Innovation Capability - Hypothesis Testing (DI3)

	Model 1	Model 2
Matching Customer Requirements	0.139	0.180
Rank Ordering	-0.319**	-0.279**
Customer Value Based Resource Allocation		-0.126
R-Squared (F-Value)	0.072 (2.830)	0.086 (2.271)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

The third variable of disruptive innovation "DI3" relates to the frequent experimentation on new technologies with attributes that are not valued by the mainstream customers. The results of the rank-ordering of product attributes, as shown in Table 6.11, supported hypothesis 1c because there was a significantly negative effect on this type of experimentation (b = -0.279, p <0.05). If an organization places primary weight on attributes by customer requirements, the design team will not be allowed to experiment on external technologies. Neither matching customer requirements nor customer value based resource allocation were shown to be significant in this model, refuting the hypothesis. Individually the correlation matrix suggested that matching customer requirements with new product designs has a negative correlation on this level of experimentation (r = -0.188, p < 0.10).

The final two aspects of disruptive innovation capability (DI4 and DI5) were not hypothesized because it was assumed that there was no direct relationship with value analysis. There is the possibility that other factors could influence this type of behavior. While not part of the final results, a regression analysis was performed to these aspects to test for any significance. Table 6.12 presents the results for the variable "DI4".

Table 6.12 - Disruptive Innovation Capability – Regression Analysis (DI4)

	Model 1	**Model 2**
Matching Customer Requirements	0.275*	0.263
Rank Ordering	-0.136	-0.148
Customer Value Based Resource Allocation		0.038
R-Squared (F-Value)	0.041 (1.568)	0.042 (1.058)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

Variable "DI4" represents an organization's encouragement of a variety of new product design ideas. The final model, Model 2, explained only 4.2% of the total variance of disruptive innovation capability (F = 1.058). As expected, this low level along with the insignificant results of the regression coefficient shows that value analysis does not influence this aspect of disruptive innovation capability. The correlation matrix also shows that the individual aspects of value analysis are not correlated to the encouragement of a variety of new ideas. This can be explained by the fact that many other factors of an organization can influence new product design ideas. This is not specifically related to disruptive innovation capability so other areas could be determinants of this concept.

The measurement "DI5" is similar to "DI4" in the fact that it is not exclusively associated with disruptive innovation capability. The ability to identify a new market for a new product design could be attributed to other aspects of an organization, as well as other levels of innovation.

Table 6.13 - Disruptive Innovation Capability – Regression Analysis (DI5)

	Model 1	**Model 2**
Matching Customer Requirements	0.290**	0.329**
Rank Ordering	0.160	0.199
Customer Value Based Resource Allocation		-0.123
R-Squared (F-Value)	0.114 (4.696)	0.126 (3.454)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

As shown in Table 6.13, model 2 of this stepwise regression analysis explained approximately thirteen percent of the total variance for identifying new markets (F = 3.454). The aspect of matching customer requirements with new product designs was shown to have a statistically significant positive effect on the ability to identify new markets (b = 0.329, $p < 0.05$). This could be explained by the variable not being exclusive to disruptive innovation capability. Gradual improvements and changes of a customer's requirements could result in incremental changes to the market used for new product designs. This is shown by the statistically significant positive influence of matching customer requirements on incremental innovations (b = 0.275, $p < 0.01$). Therefore the interpretation of the question in terms of the level of innovation impacting the identification of new markets could influence this final result.

Table 6.14 - Disruptive Innovation with Control Factors – Regression Analysis

	DI1	**DI2**	**DI3**	**DI4**	**DI5**
Matching Customer Requirements	0.090	-0.104	0.122	0.196	0.255*
Rank Ordering	-0.150	0.051	-0.290**	-0.138	0.182
Resource Allocation	-0.242*	-0.325**	-0.084	0.061	-0.099
Product Type	0.138	0.150	0.031	0.019	0.111
Company Size	-0.015	-0.006	0.257**	0.123	0.107
Company History	0.045	-0.015	-0.010	0.000	-0.087
R-Squared (F-Value)	0.103 (1.326)	0.141 (1.891)	0.149 (2.007)	0.057 (0.693)	0.151 (2.040)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

Each of the variables of disruptive innovation capability was also tested against the three control factors to identify any significant relationships. As shown in Table 6.14, the only statistically significant relationship is the positive effect of company size on the frequent experimentation of new technologies ($\beta = 0.257$, $p < 0.05$). This can be explained by the increased level of available resources at these particular companies. The greater the overall size of the company, the greater the size of the research and development teams. This increase in team size can lead to a greater amount of time and resources allocated to experimenting on new technologies that are outside of the mainstream customers' requirements. The other control factors were not shown to be statistically significant in influencing disruptive innovations.

Direct measurements of value analysis and disruptive innovation capability were also included to analyze actual performance and output levels for individual companies.

Table 6.15 - Analysis of Direct Measurements - Disruptive Innovation (DI2i)

	Disruptive Innovation Capability (DI2i)
Matching Customer Requirements (MCR1a)	-0.322***

The first direct measurement analysis tested the level of correlation between matching customer requirements and disruptive innovation capability. Variable "MCR1a" related to the minimum and maximum percentages of products or features that come directly from the requirements of current mainstream customers. Variable "DI2i" related to the minimum and maximum percentages of resources allocated to projects not targeting the current needs of the customers. The values were input by the respondents but were then modified to an 11-point Likert scale (ranging from 1 = 0% to 11 = 100%). To analyze based on the organization's highest levels of lean concepts, the correlation was tested based on the maximum MCR value and the minimum disruptive innovation value. Matching customer requirements has a negative effect on the resource allocation aspect of disruptive innovation ($r = -0.322$, $p < 0.01$). This supports hypothesis 2b because an organization that places more emphasis on matching its current customers' needs and requirements results in less emphasis on allocating resources to projects with lower initial returns on investment. This tolerance is required for successful disruptive innovations within an organization.

Table 6.16 - Analysis of Direct Measurements - Disruptive Innovation (DI2ii)

	Model 1	Model 2
Matching Customer Requirements	-0.162	-0.139
Rank Ordering	-0.145	-0.118
Customer Value Based Resource Allocation		-0.090
R-Squared (F-Value)	0.069 (2.564)	0.075 (1.850)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10. (N=72)*

Measurement "DI2ii" related to the maximum number of months that were allowed for a project to be continued with an unsatisfying return on investment. A multiple regression analysis was used to show any relationships between the three aspects of value analysis with this direct measurement. The values for "DI2ii" were input by the respondents and then modified to a 10-point Likert scale (ranging from 1 = 0 months to 10 = greater than 24 months). Table 6.16 shows that all aspects of value analysis are negatively related to this aspect of disruptive innovation but are not statistically significant, refuting hypothesis 2b. Based on the correlation matrix, all three aspects individually are negatively correlated to the maximum number of months allowed for low ROIs ($p < 0.10$). This support of risk in terms of ROI is necessary in order for an organization to be successful with disruptive innovation.

Based on the final analyses, there is not enough evidence to completely accept hypotheses 2a through 2c of proposition 2. All aspects of value analysis did not have a significant negative effect on an organization's disruptive innovation capability. The resulting relationships were dependent on the aspect of disruptive innovation that was analyzed. The aspects exclusively related to disruptive innovation (DI1 through DI3) were found to be negatively influenced by customer value based resource allocation and the rank-ordering of product attributes thereby supporting all three hypotheses. These exclusive aspects were developing new areas of attractiveness, tolerating low ROIs, and frequently experimenting on new technologies. These results were further supported by the negative relationships identified with the direct performance measurements. The correlation matrix suggested that matching customer requirements was negatively correlated with the level of experimentation on new technologies. However, the regression analysis showed no statistical significance between matching customer requirements and disruptive innovation capability, refuting the three hypotheses. The overall results showed that the actual actions of a company (rank-ordering and resource allocation) may have a greater influence on disruptive innovation capability than the preferences of an organization to match the customers' requirements with its new product designs. While there is not enough evidence to support the hypotheses, the results suggest that proposition 2 can be accepted. This is the case because disruptive innovation requires all five aspects to be successful; any negative relationship can result in an environment that may stumble over disruptive innovations. If an organization wishes to be successful in terms of disruptive innovation capability, it must properly manage its value analysis techniques.

6.3 Lean Supply Chain Management vs. Responsiveness to Radical Innovation

The lean concepts applied to supply chain management were proposed to influence an organization's responsiveness to radical innovations, or reaction time to product changes due to competitor movement. The lean supply chain is based on two aspects: breadth and depth. The lean supply chain with limited breadth attempts to eliminate waste by minimizing the number of buffers (or suppliers) in the system to improve efficiency [37, 41]. This approach however may prevent the necessary flexibility of the supply chain when an organization is required to respond to dramatic or radical changes by its competitors. The depth level of lean supply chain management is based on the levels of supplier commitment and involvement. Proposition 3 states that lean supply chain management has a negative effect on a company's responsiveness to radical innovations. This proposition is tested by two hypotheses as displayed in Table 6.17. It is hypothesized that lean supply chain management with limited breadth will have a negative effect and the depth will serve as a moderating factor. The depth will reduce the level of the negative influence of supply chain breadth by having a positive effect on responsiveness to competitor movement.

Table 6.17 - Proposition 3: Lean Supply Chain Management vs. Responsiveness to Innovation

Proposition 3	Lean supply chain management with limited breadth has a negative effect on a company's responsiveness to radical innovations and increasing supply chain depth will help to reduce such effect.
Hypothesis 3a	Lean supply chain management with limited breadth has a negative effect on a company's responsiveness to radical innovations.
Hypothesis 3b	The depth of lean supply chain management reduces the negative impact of buffer minimization and positively influences a company's responsiveness to radical innovations.

Hierarchical regression analysis was performed to analyze the relationship of the depth of the supply chain serving as a moderating factor to the overall model. In this case, the stepwise approach is not necessary because the order of entry is based on the propositions made by research. The collected data was standardized for each of the regression analyses tests. Model 2 in each of the following cases presents the introduction of the depth of the supply chain to the overall system. Model 3 was presented to test the interaction, or moderating, effect by observing "Limited Breadth X Depth".

Table 6.18 - Responsiveness to Innovation - Hypothesis Testing (RtoI1)

	Model 1	Model 2	Model 3
Lean Supply Chain with Limited Breadth	0.079	-0.047	-0.081
Depth of Supply Chain		0.292**	0.268**
Limited Breadth X Depth			-0.126
R-Squared (F Value)	0.006 (0.474)	0.076 (3.039)	0.089 (2.383)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

The first variable "RtoI1" is related to the level of new product introduction to market based on responding to competitors. The change in R-squared by introducing supplier commitment was found to be 0.070 and was deemed significant ($p < 0.05$). Contrary to original expectations of hypothesis 3a, the final model suggested that the breadth has no significant effect on the level of new product introduction as a result of responding to competitors. The depth on the other hand was found to have a statistically significant positive effect on this aspect on responsiveness to radical innovations, supporting hypothesis 3b ($\beta = 0.292$, $p < 0.05$). This shows that the level of buffers in the supply chain does not significantly impact the responsiveness to innovation, but the supplier commitment level does have a strong influence. The change in R-squared by introducing the interaction effect, as shown in Model 3, was found to be 0.013 and was deemed not significant. This signifies that there is no moderating effect in this case.

Table 6.19 - Responsiveness to Innovation - Hypothesis Testing (RtoI2)

	Model 1	Model 2	Model 3
Lean Supply Chain with Limited Breadth	0.073	-0.073	-0.067
Depth of Supply Chain		0.340***	0.344***
Limited Breadth X Depth			0.022
R-Squared (F Value)	0.005 (0.405)	0.099 (4.077)	0.100 (2.694)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

The variable "RtoI2" defines the ability of an organization to quickly react to product changes as a result of responding to competitor movement. The R-squared change of introducing supplier commitment in this case is 0.094 and is significant ($p < 0.01$). This shows that the depth of the supply chain does have a significant impact on the overall model. This is supported by the standardized coefficient ($\beta = 0.340$, $p < 0.01$) signifying that the supplier commitment level has a positive influence on reaction time to product changes. The breadth of the supply chain was again shown to have no statistical significance, refuting hypothesis 3a. The moderating effect was also shown to have no statistical significance as shown in Model 3.

A similar result was also identified for "RtoI3". This variable is related to the ability of existing suppliers to manage a just-in-time delivery of changed product components during events of product design changes as a result of competitor movement. Suppliers that are committed to continuous improvements, highly involved in NPD, perform frequent communications and provide feedback, and have a close contact relationship showed a positive effect on just-in-time delivery ($\beta = 0.248$, $p < 0.05$). The minimization of buffers and suppliers was shown to not have a significant impact on this just-in-time delivery. Model 3 also showed that there is no significant moderating effect.

Table 6.20 - Responsiveness to Innovation - Hypothesis Testing (RtoI3)

	Model 1	Model 2	Model 3
Lean Supply Chain with Limited Breadth	0.156	0.049	0.055
Depth of Supply Chain		0.248**	0.253*
Limited Breadth X Depth			0.022
R-Squared (F Value)	0.024 (1.856)	0.075 (2.948)	0.075 (1.949)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

The final variable "RtoI4" defines the need of an organization to switch suppliers for changed product components in the event of responding to competitor movement. Table 6.21 shows that neither breadth nor depth of the supply chain has a significant effect on this aspect of responsiveness to radical innovation, countering both hypotheses. The change in R-squared, 0.025, was also found not to be significant which means that the depth of the supply chain did not significantly impact the overall model. The change in R-squared by introducing the interaction effect, as shown in Model 3, in this case is 0.075 and is significant ($p < 0.10$). This shows that there is a significant moderating effect in terms of an organization's need to switch suppliers in the event of responding to competitor movement ($\beta = 0.239$, $p < 0.10$).

Table 6.21 - Responsiveness to Innovation - Hypothesis Testing (RtoI4)

	Model 1	Model 2	Model 3
Lean Supply Chain with Limited Breadth	0.196*	0.121	0.186
Depth of Supply Chain		0.176	0.222*
Limited Breadth X Depth			0.239*
R-Squared (F Value)	0.039 (3.009)	0.064 (2.523)	0.112 (3.064)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

Each of the aspects for responsiveness to radical innovation was then re-analyzed with the inclusion of the three control factors. The results of this regression analysis are displayed in Table 6.22.

Table 6.22 - Responsiveness to Innovation with Control Factors - Hypothesis Testing

	RtoI1	RtoI2	RtoI3	RtoI4
Breadth of Supply Chain	-0.058	-0.048	0.133	0.114
Depth of Supply Chain	0.262**	0.637***	0.280**	0.205
Product Type	0.063	-0.102	-0.265**	-0.130
Company Size	0.159	-0.316**	-0.222*	0.002
Company History	-0.068	0.109	-0.019	0.111
R-Squared (F-Value)	0.100 (1.578)	0.190 (3.329)	0.194 (3.372)	0.094 (1.482)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

The regression analysis suggested that company size has a statistically significant negative effect on reaction time to product changes ($\beta = -0.316$, $p < 0.05$) and on a supplier's ability to manage just-in-time delivery during events where changes occur due to competitor movement ($\beta = -0.222$, $p < 0.10$). This could be explained by the theory of inertia [84, 85]. This bureaucratic inertia refers to a slower response to accomplishing specific tasks or goals, specifically in terms of dramatic or radical changes. New radical ideas must travel through several administration layers before it can be approved. This could translate to a slower reaction time and an improbable just-in-time atmosphere.

The type of product was also shown to have a significant influence on the ability of a supplier to manage a just-in-time delivery during product changes. This could be explained by the differing development times and lead times required of different product types. Suppliers may become more susceptible to problems during competitor movement depending on the type of products that are developed.

Direct measurements were also analyzed using multiple regression analyses and the correlation matrix to support the results based on an organization's performance. The measurements "RtoI1a", "RtoI1b", and "RtoI1c" are related to the percentage of product designs that are created in an organization. The questions were based on a five-point Likert scale (1 = 0-20%, 2 = 20-40%, 3 = 40-60%, 4 = 60-80%, 5 = 80-100%).

- RtoI1a – the percentage of product designs in an organization that are different from designs adopted by competitors (radical innovation).
- RtoI1b – the percentage of product designs in an organization that are similar to designs adopted by competitors but differ in identifiable ways.

- RtoI1c – the percentage of product designs in an organization that are pure imitations of competitors' designs.

This analysis was set in place to show that radical innovations (RtoI1a) would be impacted the most by lean supply chain management. This is the case because higher levels of flexibility are required in the system to respond to dramatic changes in the system. The results of the three measurements are displayed in Table 6.23 through Table 6.25.

Table 6.23 - Analysis of Direct Measurements - Responsiveness to Innovation (RtoI1a)

	Model 1	Model 2
Lean Supply Chain with Limited Breadth	0.142	0.047
Depth of Supply Chain		0.225*
R-Squared (F Value)	0.020 (1.525)	0.062 (2.410)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*
Rto1a: Mean = 2.92, S.D. = 1.25 (on a 5-point Likert scale)

Table 6.24 - Analysis of Direct Measurements - Responsiveness to Innovation (RtoI1b)

	Model 1	Model 2
Lean Supply Chain with Limited Breadth	-0.041	-0.001
Depth of Supply Chain		-0.094
R-Squared (F Value)	0.002 (0.124)	0.009 (0.332)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*
Rto1b: Mean = 3.00, S.D. = 1.12 (on a 5-point Likert scale)

Table 6.25 - Analysis of Direct Measurements - Responsiveness to Innovation (RtoI1c)

	Model 1	Model 2
Lean Supply Chain with Limited Breadth	0.031	0.014
Depth of Supply Chain		0.041
R-Squared (F Value)	0.001 (0.072)	0.002 (0.085)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*
Rto1c: Mean = 1.49, S.D. = 0.83 (on a 5-point Likert scale)

Table 6.23 shows that the lean supply chain management aspects have the greatest impact on responsiveness to radical innovations, or product designs that are different from one's competitors. Supporting the previous results, the depth of the lean supply chain has a significant positive effect on radical innovations ($\beta = 0.225$, $p < 0.10$) whereas the breadth is not deemed to be significant. Tables 6.24 and 6.25 suggested that innovations that were not dramatically different from competitors' designs were not significantly impacted by lean supply chain management. This is explained by the vastly different concepts of lean supply chain management and radical innovation, primarily in terms of flexibility. The lack of significance could also be due to the nature of the questions. It would be extremely difficult to provide a precise answer to these three questions; an educated approximation is the best approach and could sway the results depending on the viewpoint of the respondent.

Correlation tests were also performed to analyze the direct measurements where an exact value was required from the respondent. Table 6.26 presents the analysis between the number of suppliers per part (BSC4a) and the number of months to introduce the product to market once the design is complete (RtoI2a). The correlation values were tested against all possible combinations of minimum and maximum values for each variable. This was done to test the lowest and highest levels of the lean supply chain in terms of limiting breadth.

Table 6.26 - Analysis of Direct Measurements - Responsiveness to Innovation (RtoI2a)

	RtoI2a (Minimum value)	**RtoI2a (Maximum value)**
BSC4a (Minimum value)	-0.044	-0.102
BSC4a (Maximum value)	-0.119	-0.106

BSC4a(MIN): Mean = 1.16, S.D. = 0.65 *BSC4a (MAX): Mean = 3.55, S.D. = 2.12*
RtoI2a(MIN): Mean = 4.96, S.D. = 5.02 *RtoI2a(MAX): Mean = 14.82, S.D. = 14.17*

The results in this case are similar to the previous results in that the breadth of the lean supply chain does not have a significant influence on the responsiveness to innovation. This result could also be due to the high level of variability associated with inputting direct measurement values. The respondent may not be fully aware of the exact number of suppliers per part or the length of time to introduce a product to market.

The final direct measurement "BSC4b" is related to the percentage of parts that are solely outsourced. This means that only one supplier provides for those particular parts. A correlation test was analyzed against each aspect of the responsiveness to radical innovation and is shown in Table 6.27.

Table 6.27 - Analysis of Direct Measurements - Responsiveness to Innovation (BSC4b)

	RtoI1	RtoI2	RtoI3	RtoI4
Breadth of Supply Chain (BSC4b)	0.070	-0.239**	-0.124	-0.120

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*
BSC4b: Mean = 2.88, SD = 1.31 (on a 5-point Likert scale)

The analysis suggested that higher percentages of solely outsourced parts have a negative effect on a company's ability to quickly react to events of product changes as a result of competitor movement. This limited breadth variable had no significance on all of the remaining responsive to radical innovation variables. The results for "RtoI2" were then further analyzed by introducing the moderating factor of the supply chain depth. The analysis is shown in Table 6.28.

Table 6.28 - Analysis of Direct Measurements - RtoI2 with BSC4b

	Model 1	Model 2	Model 3
Lean Supply Chain with Limited Breadth	-0.239**	-0.216*	-0.241**
Depth of Supply Chain		0.289***	0.326***
Limited Breadth X Depth			-0.168
R-Squared (F Value)	0.057 (4.440)	0.140 (5.862)	0.166 (4.711)

*Significance Levels: ****p<0.001, ***p<0.01, **p<0.05, *p<0.10.*

Model 2 of the analysis explained approximately fourteen percent of the total variance of this aspect of responsiveness to radical innovation ($F = 5.862$). The R-squared change was found to be 0.083 and was significant ($p < 0.01$). The results of this measurement supported hypothesis 3a and partially supported hypothesis 3b. A lean supply chain with limited breadth has a negative effect on the reaction time of a company to competitor movement when the extreme level of buffer minimization is incorporated (one supplier per part). The depth on the other hand has a positive effect ($\beta = 0.289$, $p < 0.01$) on the reaction time. Model 3, however, shows that there is not a significant moderating effect on this system. The change in R-squared was 0.026 and was not significant.

The data analysis results suggest that hypothesis 3a of proposition 3 was rejected and there was not enough evidence to completely accept hypothesis 3b. It was shown that lean supply chain management with limited breadth (buffer minimization) had no significant effect on responsiveness to innovation. Hypothesis 3b was correct in identifying that the depth of the supply chain (supplier commitment) has a positive influence on an organization's responsiveness. There was, however, not enough evidence to support the moderating effect on buffer minimization. The results suggest that the number of suppliers, or vendors, in a supply chain is not as influential on responsiveness to product change as is the commitment and involvement levels of all the suppliers. This showed that lean supply chain management did not negatively affect responsiveness to radical innovation, but the depth of the supply chain served as a positive factor. Hypothesis 3a was correctly predicted in one case of organizational responsiveness: the effect of solely outsourcing parts on reaction time to product changes. This is the extreme case of lean supply chain management in which there are no buffers in the system. Hypothesis 3b was also partially correct in terms of lean supply chain depth having a positive impact on reaction time to competitor movement. The results in this case support the potential pitfalls of going "too lean" as noted in [50]. The analysis suggested that a high level of solely outsourced parts has a negative effect on reaction time but the depth of the supply chain has a positive effect on the organization's responsiveness.

7.0 Conclusions and Recommendations

7.1 Research Findings

Hypothesis tests in the previous section led to a research framework summarized in Figure 7.1. Negative relationships suggested by the research findings are presented with a dashed red line; a dash-dot blue line represents a positive relationship. The solid lines to disruptive innovation and responsiveness to innovation represent a relationship suggested by literature and research. No statistical significance is represented by a black dotted line.

Legend for Figure 7.1:

Negative Relationship

Positive Relationship

Positive Relationship supported by literature

No statistical significance

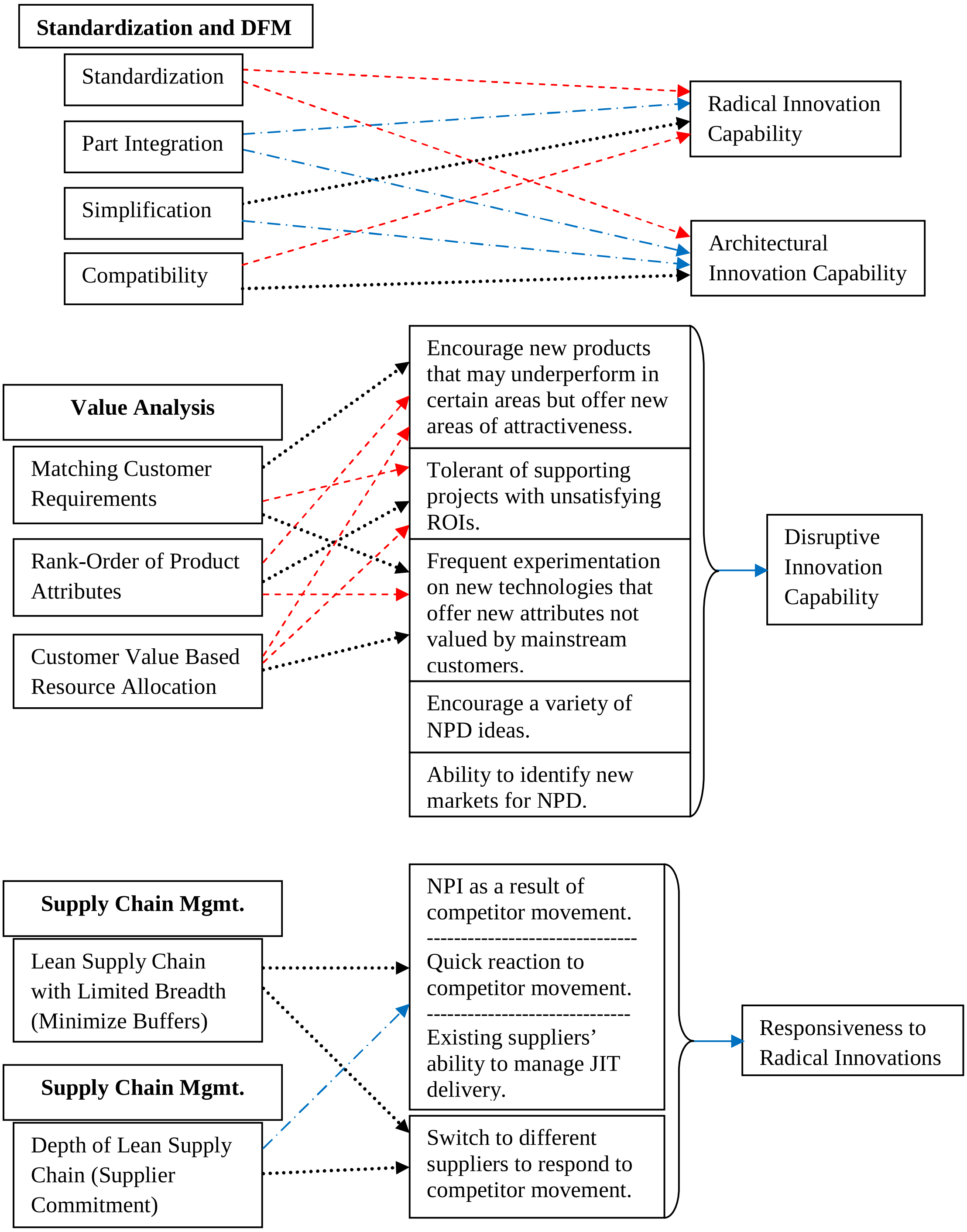

Figure 7.1 - Research Framework

Table 7.1 summarizes the overall findings for the relationships between standardization and DFM in the lean design concept on a company's radical and architectural innovation capability.

Table 7.1 - Research Findings - Standardization and DFM vs. Innovation Capability

Standardization and Design for Manufacturability (DFM)	Radical Innovation	Architectural Innovation
Standardization	Negative++	Negative++
Part Integration	Positive++	Positive++
Simplification	None	Positive++
Compatibility	Negative+	None

++: Relationship tested by multiple regression analysis
+: Relationship tested by correlation matrix

In accordance with the proposition and hypotheses, the study showed a negative relationship between standardization and both radical and architectural innovation capability. Compatibility of designs with existing procedures was found to have a negative effect on radical innovation capability. A company must identify the beneficial trade-off between improving its efficiencies and remaining flexible to changes. Too much structure can reduce an organization's flexibility in its new product design processes thereby stifling its creativity and innovativeness. No structure in the process though may cause the system to become inefficient. A proper balance must be determined in an organization to ensure that any structure in the system, through standardization or ensuring compatible designs with existing procedures, does not prevent innovative ideas in the design environment.

Contrary to hypotheses 1b and 1d, part integration has a positive effect on radical and architectural innovation. Simplification also showed a positive effect on architectural innovation. As mentioned previously this result may be due to the interpretation of the questions by the respondents. A possible explanation for the relationship with part integration is that the components may be new to the firm, resulting in a more innovative product. The relationship with simplification could be explained that the architectural innovations are performed by the organization to simplify the product design. Part integration and simplification of product designs may be beneficial to an organization as long as the approaches are not detrimental to the creative environment that is necessary for innovative ideas. A company must ensure that these aspects are not implemented with the sole purpose of improving efficiency and minimizing costs but also to improve the overall quality of the product designs.

As another important aspect of lean design, value analysis incorporated customers' perspective and requirements in product designs and cost settings. As predicted, this approach showed a negative effect on disruptive innovation which requires companies to identify new areas of attractiveness that the mainstream customer may not require. Table 7.2 presents the overall findings for this relationship.

Table 7.2 - Research Findings - Value Analysis vs. Innovation Capability

Value Analysis	**DI1**	**DI2**	**DI3**	**DI4**	**DI5**
Matching Customer Requirements w/ NPD	None	Negative+	None	None	Positive++
Rank-Order of Product Attributes	Negative+	None	Negative++	None	Positive+
Customer Value Based Resource Allocation	Negative++	Negative++	None	None	None

++: Relationship tested by multiple regression analysis
+: Relationship tested by correlation matrix

For a company to be successful with disruptive innovations, five different factors need to be present. The results suggested that certain aspects of value analysis have negative effects on some of these factors. As shown in Table 7.2, the rank-ordering of product attributes and the customer value based resource allocation of an organization have the most significant impact on the success of disruptive innovation. While there was not enough evidence to support hypotheses 2a to 2c, it was found that the higher the percentage of matching customer requirements with new product designs is, the less likely a company is going to allocate resources to new designs that do not meet the mainstream market requirements.

For disruptive innovations, an organization must be willing to allocate time and resources to new ideas that may be outside of their current customers' needs or requirements. While matching customer requirements with designs is an important management technique for incremental and sustaining technologies, it may cause one to stumble over disruptive ones. An organization must also be sure to treat each category of innovation differently. Incremental improvements to an existing technology require a different approach than disruptive technologies involved in creating a new strategy for a new market. Managers within an organization must be able to identify the differing demands for sustaining and disruptive technologies [21]. For disruptive innovations, an organization must identify the potential long-term competitive advantages and become flexible with the experimentations and risks that are involved. One must plan for failure and respond to change as new information is identified. It must be made clear in an organization that the traditional approaches for managing successful sustaining technologies often leads to failures for disruptive technologies [21].

Table 7.3 - Research Findings - Lean Supply Chain Management vs. Responsiveness to Innovation

Lean Supply Chain Management	RtoI1	RtoI2	RtoI3	RtoI4	RtoI2 w/ BSC4b
Lean Supply Chain with Limited Breadth	None	None	None	None	Negative++
Depth of Supply Chain	Positive++	Positive++	Positive++	None	Positive++

++: Relationship tested by multiple regression analysis

Table 7.3 shows the overall findings of the impact of the breadth and the depth of a supply chain on its company's responsiveness to radical innovations. Contrary to the original prediction, lean supply chain management with limited breadth, or buffer minimization, showed no significant impact. The depth of the supply chain showed a positive relationship with responsiveness. This means that an organization with a higher level of supplier commitment and involvement has a more significant impact on responsiveness than the number of suppliers in the chain. There was also not enough evidence for the moderating effect to be supported. The findings showed the overall importance of supplier commitment for an organization. Ensuring that suppliers are committed to and involved in the new product design process can support quick responsiveness to radical changes brought on by competitors. Management should support open communication with its suppliers and encourage feedback on its design processes. This could help to promote the relationship between the organization and its suppliers and create a more responsive environment.

It should also be noted that a direct measurement used for supply chain breadth at the extreme lean case showed a negative effect on a company's reaction time to product changes. If a higher percentage of parts were solely outsourced it would result in a lower reaction time to competitor movement. The depth of the lean supply chain, on the other hand, showed a positive effect on a company's responsiveness. The extreme level of rigidity in the supply chain caused by the buffer reduction can lead to insufficient flexibility to respond to competitor movement. While lean supply chain emphasizes solely outsourcing to improve an organization's efficiencies and to minimize costs, it may come at the expense of responsiveness. Solely outsourcing should be avoided because it may prevent the quick responsiveness and flexibility that is necessary if radical changes occur. The results also showed no moderating effect with the lean supply chain aspects. Regardless of the level of supplier commitment and involvement in the new product design process, it will not moderate the negative effects of limited breadth if there are no buffers in the system. This is a result of the limited capacities and capabilities of a sole supplier. A strong commitment is not sufficient if the supplier does not have the capacity and flexibility to quickly respond to changes brought on by competitors. This result involving the direct measurement, however, only used a single-item variable for the breadth aspect as compared to four items in the previous findings, and was confirmed with only the "RtoI2" measurement. All other responsiveness measurements using this direct measurement had a similar result to the findings in Table 7.3.

In conclusion the final results and analyses have shown that certain aspects of the lean design and lean supply chain have a negative effect on innovation capability and responsiveness to innovation. An organization should be aware of the disagreeing objectives of lean management and innovation management concepts, especially the ones that showed negative relationships in this research.

7.2 Contributions

In this study, literature review identified visible discrepancies between the objectives of lean and innovation management concepts. Lean is dedicated to efficiency and minimizing waste through risk reduction. Innovation requires organizational support for risk taking activities and numerous experiments that may not yield any productivity. While the importance and benefits of both concepts have been studied by numerous researchers, no study has investigated the impact that certain lean management concepts may have on an organization's innovation capabilities. To bridge this gap, three groups of hypotheses were tested through statistical analysis based on survey results. It presented evidence from several different types of engineering firms of varying sizes and histories to ensure the generality of the results.

With a focus on lean design and lean supply chain, the study provides insights and calls for attentions on the possible negative effects that these lean practices have on a company's capability to successfully deal with different levels of innovations. With these insights in hand, an organization will be able to better decide where and how much it should apply the lean management concepts to achieve overall success.

While some of the results were not in line with the original hypotheses, interesting issues have emerged and call for further investigation.

7.3 Limitations and Future Work

A major limitation of this research is associated with the number of respondents for the online surveys. While the response rate is relatively higher than the average in the field of engineering management studies, the sample size is limited. A larger sample with more responses would lead to higher confidence in the research results.

An additional limitation of this research is associated with the measurements for the innovation variables. Rather than using direct measurements based on the number of successful innovations or the financial performance for each category of innovation, contributing factors were used to identify an organization's innovation capability. The contributing factors, suggested by literature, were based on an organization's practices and attitudes towards certain activities contributing to different levels of innovation. The factors were then used to identify an organization's innovation capabilities.

The questionnaire design could also be improved. For example, part integration was revealed to have a positive effect on a company's radical and architectural innovation capability, countering the original proposition. This could be a result of different interpretations of the survey questions. Future work could be done to improve the questions related to part integration to ensure they are interpreted as expected. This can lead to a better understanding of the effect of part integration on a company's radical and architectural innovation capability.

The results of this research have opened other areas of future work. While studying the impact of a supply chain's breadth on a company's responsiveness to innovation, it was identified that solely outsourcing parts, a key characteristic of a lean supply chain, has a negative effect on the company's reaction to product changes. However, since this result is based on one survey question only, future work can introduce a multi-item construct to further confirm this relationship. It will also be interesting to identify the "sufficient" level of buffers needed in a supply chain to avoid response delays. The results also found that company size was statistically significant in multiple areas of innovation capability and responsiveness to innovation. As discussed previously, this is an often debated topic due to its conflicting nature. A larger firm has the economies of scale and the financial standing to support different levels of research and development. However, it may also tend to follow the “sacred cow” mentality, or the theory of inertia [84, 85]. A more significant range of engineering firms of small, medium, and large sizes could be tested in future work to further investigate this relationship.

Future work can also investigate different strategies to achieve a balance between lean and innovation. In [40], four strategies are introduced to allow organizations to incorporate both lean and innovation concepts: outsource innovation, temporal think tank™, lean innovation system, and the innovative product development process (IPDP). Their effectiveness can be evaluated through detailed analysis.

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