Innovation in Lean Manufacturing Through Data Analysis

by

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Abstract

Two business strategies that are becoming more commonly implemented are innovative activities and Lean principles. Each can provide a firm with competitive advantages, but to implement the two contradicting strategies simultaneously has proven difficult, as shown in previous research. This research will propose a model to maintain a culture of innovation within a Lean manufacturing system through the use of a manufacturing execution system. Firms can utilize a manufacturing execution system to implement product innovation, process innovation, and customer innovation into an existing manufacturing process. The model will be constructed from previous research and a theory-building approach using existing case studies.

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Introduction

Traditionally, Lean principles are implemented in a process to remove wasteful steps and create value. After removing wasteful steps and excessive inputs from a process, what remains should be only value-added, critical steps from beginning to end, commonly called the value stream (Cottyn, Van Landeghem, Stockman, & Derammelaere, 2011). Lean activities tend to reduce variation and changes in processes to ensure stability (Schuh, Lenders, & Hieber, 2011). A Lean manufacturing system should be reviewed continually to ensure that the process remains effective and efficient. As a business strategy, Lean can be a very cost-effective way for a firm to maintain a competitive advantage; however, the firm may not be able to sustain relevance in the market without the introduction of new products.

Innovation can be described as the creation of ideas, products, or services that bring value to both the firm and the customer (Chapman & Hyland, 2004; Leiponen, 2012). The development of ideas can help firms create better products or services for customers. Innovative activities tend to allow high numbers of variants with minimal process change to determine the optimal input (Schuh et al., 2011). Within an open market, however, innovative activities have the potential to be very costly, as a firm's competition is also trying to create new products; ideas and focuses may change quickly due to responses from others in the industry.

For a firm to implement and benefit from both Lean principles and innovation, the consequences derived from each strategy must be balanced. Whereas innovative activities build a process through trial and error, Lean activities attempt to remove excess inputs and steps in a process. If innovation and Lean principles are implemented without balance, the benefits of one will negate the other.

Background of Study

Research in the areas of innovation and Lean is increasing, as firms are experiencing more competition, both domestically and internationally. Firms are implementing innovative strategies in varying capacities to provide stability and to ensure future growth. Lean systems are also being implemented in firms to reduce excess spending and to help focus manufacturing activities to maximize profitability. Implementing and maintaining both strategies concurrently, however, has not been as common due to the inherent focus of each strategy.

Purpose of the Study

The purpose of this study is to attempt to offer a strategy to introduce innovative practices in a business setting that has already implemented Lean principles and practices. By understanding the key characteristics of innovation and Lean principles, a model will be proposed that may allow a firm to balance and benefit from both business strategies.

Prior research that combines innovation and Lean practices is minimal, although research in the individual areas is expansive. Due to the nature of each practice, innovation and Lean may be considered conflicting strategies, as one builds a process and the other removes wasteful aspects of a process. This qualitative and theoretical research will attempt to provide a business tool that may be used to allow both strategies to function concurrently. Rather than focusing on only one of these two business strategies, this research may allow firms to benefit from both, through the use of data analysis.

Statement of the Research Question

The purpose of this qualitative research is to examine the dichotomous relationship of innovation and Lean principles within a single firm. The paper proposes to address the following research question: How can a culture of innovation be maintained within a Lean manufacturing system? This research presents an overview of the topics as well as a model that allows organizations to benefit from both innovation and Lean principles through data analysis.

Rationale

Previous research in Lean principles and innovation details much of the theoretical background and principles related to the topics. Many of the research conclusions relate to organizational principles, providing generic guidelines to properly implement and maintain these business strategies. Minimal research, however, has been done to understand the implementation tools required to make these strategies successful. This study will review the critical features of Lean systems and innovative practices to provide a tool that a firm can use to begin implementing and integrating these business strategies. Future research should focus on how the two systems work together in firms that have implemented both and give a quantitative, as well as a qualitative, foundation to this theoretical research.

Significance of the Study

To support an environment that can maintain both innovation and Lean principles, the use of a manufacturing execution system will be examined in order to fully understand the intricacies, timing, and relationships within a manufacturing process that may help firms to discover where value can be found. Firms can then use this information to create value through the back end of the manufacturing process via customer innovation, through the middle of the process in determining where steps of the process can be altered to meet demands, and prior to the start of the manufacturing process by understanding the resources used.

Currently manufacturing execution systems are used within Lean systems to collect manufacturing data on a real-time basis and store the data in the firm's centralized server or database. The documentation of the process is used to monitor both the quality of a product moving through the manufacturing process and the status of the tools within the process. Beyond the direct analysis of the product and process, correlations can be mapped using data analysis to help a firm understand underlying relationships that two random aspects of the process may share.

Literature Review

Innovation

In business, the term innovation is generally considered to be the creation of ideas, products, or services that bring value to both the firm and the customer (Chapman & Hyland, 2004; Johnstone, Pairaudeau, & Pettersson, 2011). A firm may have many influences that drive innovation, such as customer needs or a need to reduce internal costs (Chapman & Hyland, 2004; Johnstone et al., 2011; Leiponen, 2012; Marion & Friar, 2012). Depending on the industry and type of market, firms will often invest resources into innovative practices because the value creation can manifest into competitive advantages within the industry (Johnstone et al., 2011; Ngo & O'Cass, 2013).

Customer-driven innovation.

In customer-driven innovation, an important cycle exists between the customer and the firm, starting with the needs of the customers. Firms can focus on the current products or services available to customers and enter an ideation or creativity stage, in which ideas for new and improved products are created. Once the idea is refined to a product that is acceptable to customers, the firm can scale up production and provide to the market (Johnstone et al., 2011). The customer benefits from being able to provide input specific to optimizing the product, and the firm benefits by creating a product that consumers want (Ngo & O'Cass, 2013).

In certain markets, responsibility for product design has shifted away from staff designers and toward ideas and designs generated by the end-user, the customer. This shift allows customers to have more influence in how the product is made, which ultimately, allows them to become more invested in the product. Some firms have started marketing the customer-generated designs as well. Firms have benefitted from this approach by receiving a vast number of diverse ideas from many consumers. The firm can also promote the fact that the product was designed by an actual user with a vested interest in the quality and design (Schreier, Fuchs, & Dahl, 2012).

Although most innovation research is focused on product innovation, another important aspect open to innovation is service quality (Kastalli, Looy, & Neely, 2013; Ngo & O'Cass, 2013). Services can be described as the interaction that accompanies the sale of an actual product. These services can include product support, knowledge, and an ability to provide feedback on current products. Research has shown that customers create a stronger relationship with, and tend to be more loyal to, firms that provide good service quality (Kastalli et al., 2013). Firms that allow customer interaction within development processes can be rewarded with increased market share and more revenue (Kastalli et al., 2013; Ngo & O'Cass, 2013).

Manufacturing firms can also benefit from strong service quality. Aside from creating products specific to consumer needs, value can be created through the servicing of current products to improve customer perception. Research by Kastalli et al. (2013) showed firms that maintained records of customer interaction had a competitive advantage over those that did not. In creating a performance management system, firms gained insight from successful and non-successful tactics, and used these tactics to guide future interactions with specific consumers (Kastalli et al., 2013).

Research and development.

Innovation is not always driven by direct customer input, although the end goal of creating a desired product is still most important. Firms can innovate an existing product or process in a way that reduces costs (Chapman & Hyland, 2004; Johnstone et al., 2011; Marion & Friar, 2012). Since profit is related to costs incurred during the creation of the product, firms often look to research and development groups to reduce costs by using alternate inputs (Marion & Friar, 2012) or by finding more effective ways of creating the same product (Johnstone et al., 2011).

Multiple studies have found that research and development activities are very important to the success of businesses (Chapman & Hyland, 2004; Leiponen, 2012; Srinivasan, 2010). By tasking a division of a company to focus primarily (or exclusively) on developing the next generation of product, the company can ensure future growth. This research and development group should understand the company's strategic goals in order to prioritize various projects. The group should also manage the knowledge within the company and utilize past experiences as well as market research to effectively create new products (Chapman & Hyland, 2004). Possible research and development groups may consist of internal product development, applied research, and domain-specific product research groups that allow employees to focus on various stages of a product's life-cycle (Srinivasan, 2010; Terziovski, 2010).

For example, open innovation has helped Rockwell Collins, an aviation electronics and communication systems firm, maintain a high level of success. The company created an internal open innovation competition by which employees were invited to submit their own ideas to better the products and processes within the company. In addition to company-wide recognition, the winners of the competition received a chance to be part of the project implementation team. The perceived benefit for Rockwell Collins was an entire workforce investing time and effort back into the company to improve products (Srinivasan, 2010). Internal innovation can be a powerful tool, and has been proven to be a successful innovation strategy (Oke, 2013).

If a firm can't afford to create or maintain an internal research and development group, it can investigated the possibility of outsourcing the task. Marion and Friar (2012) found that firms could benefit from outsourcing by adding expertise at certain phases of product development. Although the outsourced group did incur costs, these costs were not permanently fixed. Firms that successfully outsourced chose partners with similar goals, used rapid product prototyping to reduce time and money, and were able to test the target market with small batch manufacturing runs prior to scaling up processes (Marion & Friar, 2012). Although this approach may not be ideal in all cases, it may be an effective way to reduce costs for a small firm that can't maintain a full, effective innovation group.

Lean Manufacturing

The concept of a Lean system was made popular through research of Toyota's manufacturing procedures (Womack, Jones, & Roos, 1990). Rather than focusing only on the end product as the basis of a successful business, Toyota practitioners continually reviewed each step of the manufacturing process to ensure the process followed what are now referred to as Lean principles. The basis of Lean manufacturing suggests reviewing an entire production process and understanding the specific, necessary value-adding steps. The grouping of these critical steps is often called the value stream and is crucial to make the process run successfully. Once these value streams are identified, firms can begin eliminating all non-value adding activities that exist within the process but don't impact the value stream. The ultimate goal in creating a fully Lean process is to have only value-adding steps from beginning to end (Womack et al., 1990).

The benefits of a Lean manufacturing process can be realized through improved manufacturing speed, improved quality of products, and lowered costs of manufacturing (Hoppmann, Rebentisch, Dombrowski, & Zahn, 2011; Johnstone et al., 2011; Vinodh & Joy, 2012). A well-defined value stream without excessive process steps saves time and resources, yet maintains a strong focus on product quality. For a firm to successfully implement a Lean system that balances speed, resources, and quality, it is important for the firm to fully accept the Lean culture and the continual changes that may be required (Vinodh & Joy, 2012).

The implementation of Lean principles in a manufacturing setting can be separated into multiple stages (Browning & Sanders, 2011; Deming, 2000; Green, Lee, & Kozman, 2010; Schuch, Lenders, & Hieber, 2011). Research has found that successful implementation generally follows a Plan, Do, Check, and Act (PDCA) change management structure (Figure 1). An initial planning stage is used to gather all necessary information about a given process. After the planning is complete, a small-scale active analysis of the process is done to understand the intricacies of the plan. The check stage allows changes and alterations to be made to optimize the process. Once the process is ready, the firm can begin full-scale implementation across all facets of the standardized process in the act stage. Upon completion, it is important restart the PDCA process to analyze the most current process and continually improve the manufacturing process. Research has shown that successful implementation and use of these stages is related to better performance (Jones, Parast, & Adams, 2010).

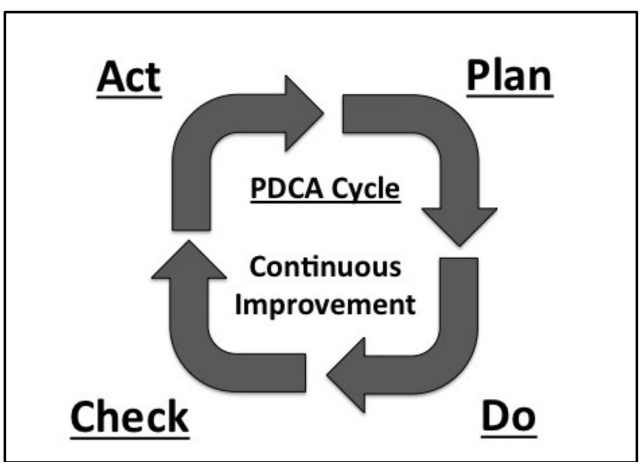

Figure 1. PDCA Cycle. Four stages of continuous improvement cycle include planning, doing, checking, and acting. When cycle completes, the cycle should begin again to analyze the most current process. Adapted from "Out of Crisis" by W.E. Deming, 2000, Cambridge, MA: MIT Press. Copyright 1982, 1986 by The W. Edwards Deming Institute.

Many researchers describe the planning stage as a critical aspect of successful Lean implementation (Browning & Sanders, 2011; Green et al., 2010; Schuch et al, 2011). Schuch et al. (2011) state "the early structuring of value, product, and process is a key factor for development projects" (p. 43). In this stage, the firm should gather all necessary information related to the process, including inputs, outputs, process steps, and customer requirements. This information should help implementers understand the complexity of the process, as well as any possible relationships between the specific process and other aspects of the manufacturing plant (Browning & Sanders, 2012; Green et al., 2010). Once the information is compiled, an action plan should be proposed with a focus that remains in accordance with organizational goals (Green et al., 2010).

The planning stage of Lean implementation should also include communication with the firm's management. Research shows that Lean programs are more successful when management is in agreement with the plan (Green et al., 2010). To be successful, a culture supporting Lean initiatives should be created to help drive projects toward completion. Schuh et al. (2011) found that "to implement lean innovation successfully, a rethinking has to be achieved: a culture which identifies needs for change and is prepared for constant change is essential" (p. 53). This finding is common to change management strategies, in that a constant reinforcement is needed to sustain progress (Johnstone, et al., 2011; Scott, Swan, Wilson, & Roberts, 1986).

Once a process plan has been fully constructed, implementation can occur. The doing stage enacts the plan to gather necessary data. Once the data has been compiled, the data is analyzed and compared to the original plan in the check stage. Depending on the outcome of the check stage, the plan is either implemented or revised, and the cycle repeats (Jones et al., 2010).

Throughout much of the research related to Lean manufacturing, a common theme related to successful implementation is continuous improvement (Chapman & Hyland, 2004; Johnstone et al., 2010; Jones et al., 2010; Lewis, 2000). The PDCA strategy is presented as a cycle that continues to repeat to be most effective (Jones et al., 2010). When a process is improved, it should be controlled and reviewed constantly so that it does not deviate from the intended target (Green et al., 2010). Although processes should be controlled to prevent deviation, firms should be continually searching for new or better ways to maintain relevance in the market and provide competitive advantages.

The need to constantly review processes will likely cause inputs and outputs of processes to be in constant flux, so continual review may be necessary (Vinodh & Joy, 2012). When creating a product from an innovative process, research suggests that, in order to maintain Lean principles within the process, there should be multiple design sets to account for all relevant solutions as a process grows. Research shows that by including all possible design pathways in the planning, the product cannot be limited by narrowed thinking or iterations (Schuch et al, 2011). Browning and Sanders' (2010) research of Lockheed Martin concluded, similarly, that a process should not be improved in isolation, as other aspects of the process may visibly or invisibly affect or be affected by that process. A continual and holistic review of processes should help keep a process functioning over a long period of time.

Manufacturing Execution Systems

In manufacturing settings, an important aspect of understanding how a process is performing can come from data analysis of that process. This analysis may identify problems, critical aspects, and potential improvements that may not be apparent or visible by other means (Banerjee, Bandyopadhyay, & Acharya, 2013). New technology, such as radio frequency identification (RFID) tagging (Modrak & Moskvich, 2012), and real-time data acquisition programs should help manufacturing firms improve performance over time, especially in Lean process improvement activities (Cottyn et al., 2011; Lee, Hong, Katerattanakul, & Kim, 2012).

The analysis of large amounts of data, commonly referred to as data analytics, is becoming more prevalent in business due to "the advent of technology that can compile data in a form that is amenable to analysis leading to decision-making" (Banerjee et al., 2013, p. 3). Depending on the approach used, data analytics can identify a number of solutions for various business activities. The data can determine what may have happened in a specific situation (descriptive analytics), why something happened, (diagnostic analytics), what is likely to happen in the future (predictive analytics), and what should be done about it (prescriptive analytics) (Banerjee et al., 2013). Within manufacturing firms, data gathered from a manufacturing execution system can be used in all of these data analytic approaches to improve processes.

A manufacturing execution system is a data collection tool that can provide real-time information from the manufacturing process (Lee et al., 2012). The manufacturing execution system is a management system that can gather information from multiple point systems (e.g., machines) that may not have similar software and display it in a single, integrated format. This format can provide a general user interface to all employees and a single data management system for the entire process (Cottyn et al., 2011).

Because the manufacturing execution system is continually providing data to users, the analysis of the data is also continually occurring. In manufacturing settings, manufacturing execution systems are commonly paired with statistical process control data management systems to create an initial analysis of all of the acquired data. The statistical process control system can be configured to notify engineers if any abnormal results are found within a process

(Lee et al., 2012). This allows engineers and managers to quickly retrieve the relevant data to understand the specifics of a problem and determine the best course of action to remedy the situation. Research has found that information timeliness, information completeness, and quality of the manufacturing execution system are key factors in determining user satisfaction, and are also strongly correlated to production performance (Lee et al., 2012). These descriptive and diagnostic analytics help to maintain the quality of manufacturing line performing at a high level.

Beyond the specifics of each process within the manufacturing line, the manufacturing execution system can also provide useful data to enterprise resource planning and supply chain management groups (Lee et al., 2012). These organizational-level groups are able to monitor manufacturing productivity and production data that is "critical for effective operational decision-making" (Lee et al., 2012, p. 1951). A manufacturing execution system can also provide enterprise resource data related to the usage and purchasing needs of raw materials while supply chain management data can provide "visibility across partner firms in the strategic alliance" (Lee et al., 2012, p. 1951) of the supply chain. A study by Vinodh and Joy (2012) found that a necessary trait of Lean manufacturing firms was "internal integration of operations with suppliers and customers" (p. 1606). The manufacturing execution system can act as a tool to keep all necessary parties informed and continuously integrated.

Methodology

The purpose of this theoretical research is to create a new business strategy that will allow a firm to implement innovative practices while practicing Lean principles. This research will help a firm understand that innovation can exist within a Lean manufacturing setting and that the firm does not need to choose one strategy over the other. The design of the research solution will incorporate a method proposed by Eisenhardt (1989) to analyze case studies as a means to build a theory based upon similarities between the case studies and prior research. From there, important aspects of manufacturing execution system research will be discussed. The research will show how data analysis using data from a manufacturing system can benefit the connection between innovation and Lean manufacturing. Finally, a new model and potential future research studies will be proposed to relate these topics. The model will illustrate various paths along which innovative activities can be implemented in a manufacturing setting. Continuous improvement and revision will also be discussed to ensure the integrated system continues to function. Due to the constraints of this research project, future research will be proposed.

Research Design

The research question will be investigated through careful analysis of existing case studies in combination with a comparison to existing research. Eisenhardt (1989) proposes that analysis of multiple case studies can be used to provide "stronger substantiation of constructs and hypotheses" (p. 538). Several case studies exist (Browning & Sanders, 2012; Lewis, 2000; Srinivasan, 2010) in which Lean principles and innovation are analyzed in depth, but little research has been done in connecting the two concepts with the implementation or use of a manufacturing execution system. This study will attempt to describe the relationships of Lean and innovative environments. A model utilizing data analysis through a manufacturing execution system will be proposed.

Research Procedure

Three case studies were chosen for analysis using the theory-building method described by Eisenhardt (1989). Rather than selecting cases that are statistically comparable (such as case studies of firms within the same business sector to control environmental variability), the studies used within this research are based on similar business strategy, (i.e., Lean and innovation implementation). Eisenhardt (1989) believes "the cases may be chosen to replicate previous cases or extend emergent theory, or they may be chosen to fill theoretical categories and provide examples of polar types" (p. 537). The case studies within this research are all related to manufacturing, but the companies are not in the same market.

The case studies used within this research approach innovation and Lean systems using different viewpoints, but each highlights the successes and failures experienced from implementing Lean and innovative programs. Through comparison of each firm, cross-study similarities and deficiencies will emerge to help build a theory that will attempt to answer the research question.

Data collection

Three case studies were chosen for analysis within this study. Srinivasan (2010) analyzed the successes of aviation electronics firm Rockwell Collins and, more specifically, its innovation practices. Browning and Sanders (2012) researched the aerospace engineering firm Lockheed Martin. The company was strongly urged to implement a Lean manufacturing program during the building of its F-22 Raptor airplane. Lewis (2000) examined three small manufacturing firms in Europe, but only one will be used within this research. The firm implemented a process control using a manufacturing execution system that helped isolate a customer's quality issue. The successes of the Lean and innovation processes are compared in terms of maintaining competitive advantages in each respective market. Although the research spreads across multiple manufacturing fields, the successes and failures of the companies represented will help to illustrate the major aspects of the proposed model.

Delimitations and Limitations

A delimitation of this qualitative research comes from the purpose of the study, in that the goal of the study is to attempt to bridge a theoretical knowledge gap between two seemingly opposing business models, innovation and Lean. The purpose of the study is not to provide a firm with roadmap to success, but rather to show connections between the two strategies so that a firm may begin to understand and work toward implementing both successfully. Future research should be performed to confirm this qualitative research with more qualitative and quantitative studies.

A limitation of this study can be found within the methodology of this research, which is an analysis of existing case studies. By using the analysis of another individual or group, this research will be confined to the extent of the original reporting of initial research. With no direct access to the raw data collected during the primary qualitative research, an attempt to control any bias will be done through the analysis of multiple case studies. This limitation is due to the scope and time constraint of the research project.

Another limitation of this study is the use of only five case studies to build a theory. Some bias may exist within each part of the model, as the number of case studies is small; only three case studies were used to build the theoretical model. Although Eisenhardt (1989) utilized multiple case studies to build theory, the proposed model utilizes past research to confirm the validity of each potential area of innovation. This limitation is due to the scope and time constraint of the research project.

Solution

Analysis and Interpretation

Rockwell Collins, United States.

Srinivasan (2010) studied an aviation electronics and communication systems firm, Rockwell Collins. The focus of the research was to understand the methods Rockwell Collins used to implement a strong innovation environment for sustained growth. The company had previously instituted a Lean Electronics program that had helped maintain operational stability. For Rockwell Collins to grow and maintain relevance in their market, the innovative areas within the company needed to be improved (Srinivasan, 2010).

Rather than focusing on one area of innovative activities, Rockwell Collins split innovation resources into three groups. The research and development (R&D) employees were split between an internal R&D group for basic research, an applied research group for next-generation products and services, and domain-specific product research groups focusing on and improving various aspects of an existing product's life cycle. The dispersion of talent allowed Rockwell Collins to have innovative diversification as well as stability if a specific project turned out to be unsuccessful (Srinivasan, 2010).

Additional incentives garnering employee support and innovation were also implemented to boost internal creativity. One improvement program was created to give employees with big ideas a chance to be heard. The program accepted high-risk ideas that would result in a significant improvement in cost, size, or power. If management accepted the idea, the employee who submitted it would get a chance to be part of the implementation team and see the project through implementation for the next year. Due to the popularity and significance of the program, the funding in the second year was raised from $500,000 to $1,000,000. The impact of the open innovation effort within Rockwell Collins has helped the firm maintain a strong position in its market (Srinivasan, 2010).

Lockheed Martin, United States.

A case study was performed on the implementation of Lean principles into the production system of Lockheed Martin's F-22 Raptor airplane (Browning & Sanders, 2012). The F-22 Raptor program was subjected to implementation of Lean principles throughout production in order to potentially reduce costs. The authors were able to interview many Lockheed Martin employees at various levels of operation and management, as well as review company documents while on-site. These interviews and documents were critical in determining the success of the program (Browning & Sanders, 2012).

The tools that Lockheed Martin used to implement Lean systems were primarily documentation and resource based. The leaders of the F-22 Raptor program emphasized documentation and standardization of work through "6S (sort, straighten, shine, standardize, safety, and sustain), visual management, and mistake-proofing" (Browning & Sanders, 2012, p. 11). However, the researchers note that standardization may have been done prematurely, before the process was stable and finalized. Since the process was formally documented after each change, multiple revisions of documentation were required and a substantial amount of time was wasted (Browning & Sanders, 2012). Once a process is stable and controlled, it can be more easily documented.

In addition to the enhancement of documentation practices, non-value-adding activities were minimized, as is typical in Lean practices. To help reduce wasteful costs, tool capacity buffers were minimized and on-hand inventory was reduced. These measures were successful by Lean metrics, but the reduction implementation was isolated to specific areas of the process. By eliminating these resources, Lockheed Martin had less margin for error in production and eventually spent time waiting for replacement parts to arrive. These practices resulted in short-term benefits, but were detrimental in the long-term scope of the project (Browning & Sanders, 2012).

Browning and Sanders (2012) concluded that the inputs of the process were crucial to the success of the product; in order to have a high-quality product, the inputs used to create the product must be of high quality. The inputs in a process, like the F-22 Raptor production project, can be either raw materials or information. As Lockheed Martin was removing waste, the understanding of crucial aspects of the process was not clear, so many important tools and steps were removed and quality quickly diminished. The authors summarized the critical nature of understanding an entire process before making any changes:

> It is essential to measure the value of a process as a whole, rather than merely as the sum of the values provided by its constituent activities, because the value of a system is different than the sum of its parts. (Browning & Sanders, 2012, p. 14)

Depending on the complexity and novelty of the process, gathering enough information to fully understand the intricacies of a process may be the most important aspect of creating a successful Lean process.

Manufacturing Company C, France

Three European manufacturers were researched and compared in terms of sustainable competitive advantage (Lewis, 2000). For anonymity, the researcher assigned only letters A, B, and C to each of the firms. For the purpose of this research, only Company C will be discussed in depth.

Company C was a manufacturing firm located in France that produced electronic components (Lewis, 2000). Company C was pressured by customers to improve quality and lower costs. An analysis of the manufacturing process revealed a significant issue that greatly impacted quality. The firm instituted a system of statistical process control to monitor the process and improved quality. This success motivated the company to continue analyzing other areas within the manufacturing line and to utilize other Lean tools. Due to Company C's implementation of Lean tools, profits and sales volumes have increased. The company was also able to focus more resources on the introduction of one completely new product and new versions of two existing products (Lewis, 2000).

Discussion

Using the case studies and previous research in the fields of innovation and Lean practices, a model was created to illustrate the three key areas in a manufacturing process in which a firm can innovate. Figure 2 describes a manufacturing process flow and how the following types of innovation can be realized through the use of a manufacturing execution system:

1. Product Innovation. This type of innovation begins with the raw materials that go into creating the product. Information related to the inputs should be stored in the manufacturing execution system so that future analysis can be done on the effectiveness of each input. Product innovation is closely associated to research and development activities.
2. Process Innovation. As a product moves through the manufacturing process, data should be collected regarding all critical measurements and events related to the product. As the data is captured in the manufacturing execution system, engineers are able to analyze and make changes to improve the process.
3. Customer Innovation. Feedback from the customer should be a critical source of information to help improve a manufacturing process. The documentation of customer requirements should be readily available to all employees working with a specific process to ensure high quality is maintained. Storing customer feedback in the manufacturing execution system can also allow for easier access for those making process changes.

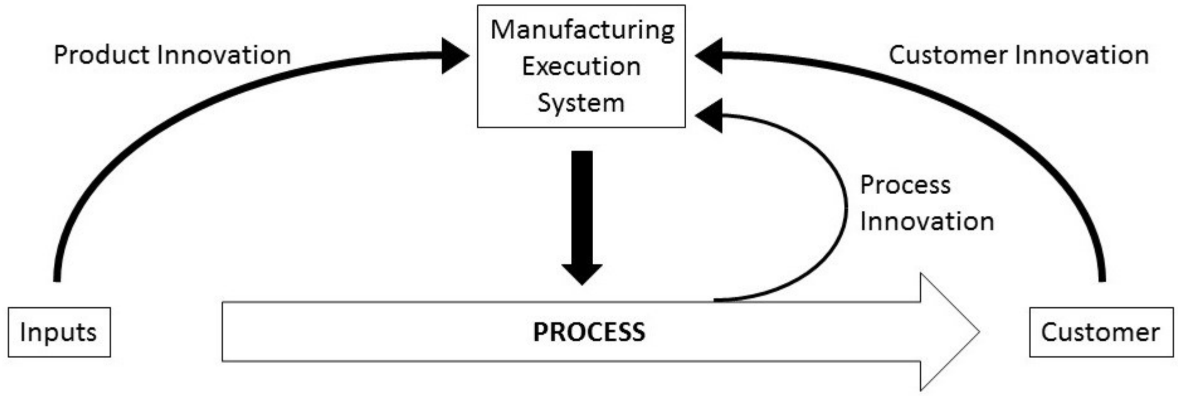

Figure 2. Manufacturing process flow diagram, describing three proposed innovative practices. Data should be collected from three major points within the manufacturing process and maintained in the manufacturing execution system to promote innovative activities.

The model in Figure 2 represents a manufacturing process, starting with the raw material inputs and finishing with the final product reaching the customer. Data should be collected throughout all aspects of the process, including full documentation of raw materials, all steps within the process, and any customer feedback that can eventually be correlated back to a step within the process. A manufacturing execution system can collect and store all of the relevant data so that it can be recalled for future data analysis.

The first type of innovation that could be realized within a Lean manufacturing process is product innovation, which is associated with raw material inputs and product design. This innovation is similar to typical research and development, in that the starting materials and design are analyzed to create a better product. Research and development within an organization has been proven to be a successful aspect of innovation within a firm and should be included in the Lean innovation model in Figure 2.

Product innovation in a Lean manufacturing setting would benefit from the use of a manufacturing execution system because such a system would facilitate the feedback necessary to make improvements. Many research and development activities are done by trial and error methodologies, resulting in numerous failed attempts. Because Lean methodologies are generally focused on reducing any wasted steps and materials, the innovative activities would seem wasteful. By having a system that would be able to give feedback to the research and development teams, the number of trials could be minimized if the data were to show a specific aspect of the product that failed. The development team would then have a more precise plan to fix the issue and improve the product. With the manufacturing execution system, product development activities would become more focused after each development attempt and wasteful trials would be reduced.

Rockwell Collins created a culture that promoted innovation in multiple ways (Srinivasan, 2010). The firm created three distinct innovation groups focused on improving products: Basic research and development, applied research, and specific product life-cycle research. The innovative functions of each group were separated in order to diversify and stabilize the company. The applied research group was focused on new product innovation, including finding the next big product or service that Rockwell Collins could provide customers. This group would be considered working within the product innovation section of the model in Figure 2.

In addition to creating the three development groups, Rockwell Collins was able to benefit from a plethora of ideas to improve the process and products through the employee-driven innovation programs. The study did not specifically state the selection process for the idea contest, nor what was done with the non-winning submissions, but because the company defined a budget, the study did state that not all submissions were implemented. This would mean that there might have been some ideas submitted that may have benefitted the company, but did not meet contest rules of guaranteeing an improvement of at least ten times the current status.

If Rockwell Collins were to utilize a manufacturing execution database, it is possible that many more innovative ideas could have been applied to the process. By having a Lean process and value stream fully mapped out, the firm could potentially have even used partial aspects of employee suggestions to improve the process or products. Data from the manufacturing execution system could have been analyzed with various process changes to determine whether the suggestions were valid, resulting in many more beneficial process updates.

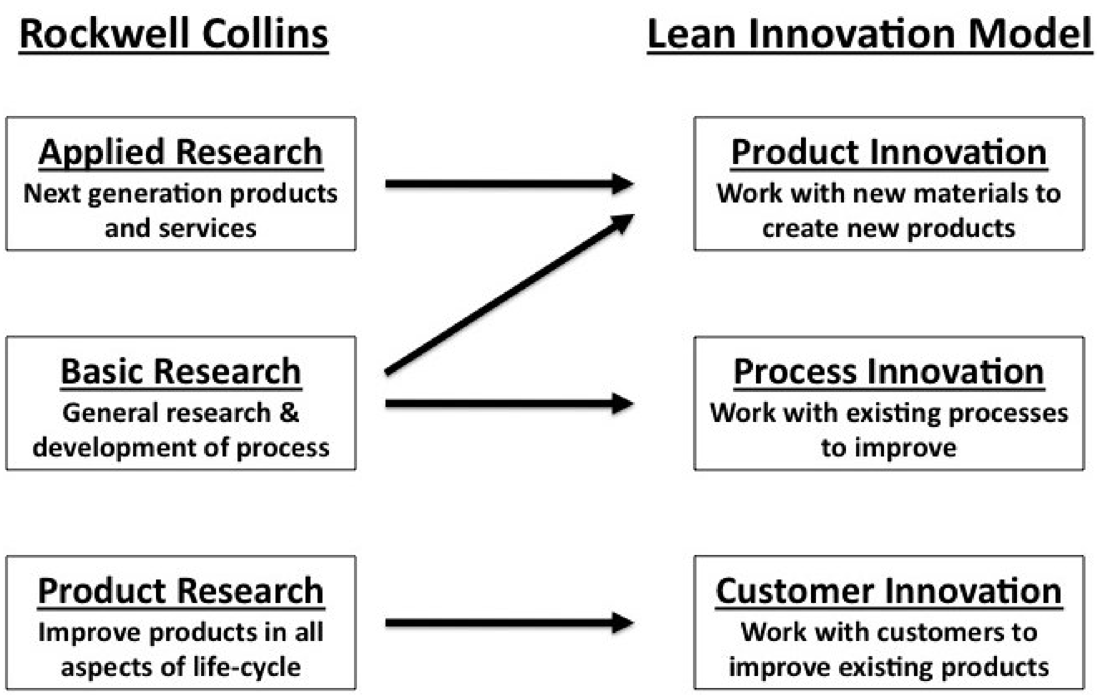

Figure 3. A comparison of the innovative research activities to the proposed Lean innovation model. Rockwell Collins' applied research correlates to product innovation, basic research correlates to both product and process innovation, and Rockwell Collins' product research correlates to customer innovation.

Traditionally, in a Lean manufacturing process, much work is done to understand and solidify the value stream. This analysis can be done using the inline data that is collected within a manufacturing execution system, as the product is moving through the manufacturing process. Any improvements made to the process as a result of the analysis of data can be considered process innovation, as shown in Figure 2.

In the Lockheed Martin case study, the F-22 Raptor program attempted to utilize Lean principles as tools to improve the product and cut costs (Browning & Sanders, 2012). According to the case study, however, the areas where Lean tools were applied to the manufacturing process were isolated from one another and wastes were removed independently, without regard to other areas of the process. Rather than cutting costs, the isolated Lean areas needed more resources than originally planned.

By applying the proposed model to the situation at Lockheed Martin, the firm may have been able to have a better understanding of the process as a whole. Any changes made to the process should have been documented and data from the manufacturing execution system should have been analyzed to ensure no other areas were affected negatively. The data collected would have also helped the firm realize if its process was stable enough to document and standardize, which was one of Lockheed Martin's other downfalls in Lean implementation.

The basic research and development group of Rockwell Collins was likely tasked to improve the current processes and determine if any new raw materials or processes could be used to create a better product. This group would likely be classified in both the product innovation section and the process innovation section described in Figure 2, due to the broad range of tasks within the group. This group would likely work to improve the current process activities as well as add new materials to improve processing, which would include the group in product innovation, shown in Figure 3. The benefit of a manufacturing execution system to this group would have been similar to the Rockwell Collins applied research group, in that trial and error innovation activities would have been minimized because the group would have received feedback prior to attempting the next trial.

Customer innovation is the final type of innovation that could be included within a Lean manufacturing process. This type of innovation is based on the customer's needs to optimize the product and to improve product quality. The firm should request as much feedback from the customer as possible in order to improve the products and services provided. This information should be stored within the manufacturing execution system so that the customer can feel confident that issues are being reviewed. For quality purposes, it would also be beneficial for the firm to use the data within the manufacturing execution system to correlate any issues to specific events in the line and then make improvements accordingly.

The case study of the European manufacturing firm showed a successful transaction between customer and firm to improve a process (Lewis, 2000). The customer was pressuring the firm for better quality and the firm responded by implementing more quality control measures. The manufacturer utilized data from its existing manufacturing execution system and was able to find the root cause of the issue. A statistical process control system was also implemented, which gave the manufacturer a chance to stop any products with potential quality issues before those products got all the way through the manufacturing line. Although quality isn't necessarily a physical attribute of the product, in terms of customer product innovation, the case study implies that data was analyzed through the data collection system that was in place to determine the source of quality issues. By using the system, the customer's requests were satisfied and the business relationship was maintained (Lewis, 2000). If the manufacturing execution system was not in place, the amount of time spent to understand the problem would have been much longer and prevention of the issue would not have been possible.

The product research group at Rockwell Collins was in charge of innovating current products, likely using customer feedback, to keep the current products relevant and useful to customers. The group was in charge of improving products in various stages of the product life cycle: introduction, growth, maturity, and decline. Most profits are made in the growth and maturity stages, so the goal of the product research group was likely to discuss product needs with the customer and modify and innovate the current product to keep it in those two stages. A manufacturing execution system would likely help the product research group understand what changes could be made and what effect each change would have on the product, as well as the process.

An aspect of this model that will be important during its implementation in a manufacturing setting is the Lean practice of continuous improvement. The model in Figure 2 represents a continuous improvement cycle, much like the PDCA cycle does in Figure 1. The manufacturing execution system is a tool that can help in the planning and the checking stages of an innovative improvement project. The data gathered from the system can show areas in need of improvement and help prioritize projects. Once a project is chosen and tested, the data collected can be used to determine the level of success related to the proposed change.

Continuous improvement can also apply to customer interaction, in that all feedback should be constantly reviewed. Customer satisfaction does affect sales, so effort should be invested in understanding and addressing the customer's needs (Kastalli et al., 2013). Implementing a manufacturing execution system that can record customer feedback, as well as quickly respond to any issues using the system, could be crucial to improving customer satisfaction.

Product innovation activities would likely also benefit from a continuously updating manufacturing execution system, as the system would provide feedback to help improve developmental activities. Real-time information should help research and development groups diagnose issues more quickly as the product moves through the manufacturing line, rather than waiting for a quality check of the final product. The data could also be used to analyze the success of various development projects, which could help the firm save money if non-value adding projects were stopped earlier in the process.

It is critical to understand that one change within an entire process will affect other areas within the process, as shown in case studies (Browning & Sanders, 2012) and research (Womack et al., 1990). For example, at Lockheed Martin, changes were made in one area of the process, but were not applied or compared to any other area of the process. This caused problems with the F-22 Raptor program and lean implementation failed (Browning & Sanders, 2012). Therefore, not only is continuous improvement necessary in each area within Figure 2 to improve a process or product, continuous improvement is required for each aspect of innovative or Lean activities to compensate for changes made in other areas. This idea can be generally described in Figure 4, showing that all aspects of innovation within a process are interconnected.

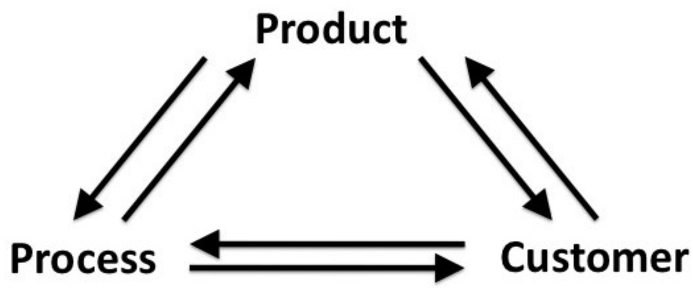

Figure 4. All innovation strategies within a manufacturing process are related. If an innovative change is made to one aspect of the manufacturing process, there will be an effect on the other two areas and should be stabilized before another change is made.

To benefit fully from any innovative activities within a Lean manufacturing process without experiencing any isolation issues, as seen with Lockheed Martin, the manufacturing process should be in a stable state. If a change is made to the process through any aspect of the innovative avenues, the consequences of the change should be fully realized and the process stabilized again before another change is made. By waiting for a stable process, the proposed change should be the only variable within the process and the result of the change should be the only outcome, rather than possibly being masked by the effect of a different innovative change (Browning & Sanders, 2012).

Conclusion

This research was intended to be a theoretical investigation to create a method in which a manufacturing firm that uses Lean principles could also implement innovative activities. Past research showed the importance of customer innovation and research and development innovation to the sustained success of a firm. Research has also shown that implementing Lean principles in manufacturing is beneficial in terms of reducing costs and non-value adding steps within a process. This research proposes a model in which the use of a manufacturing execution system that can gather and hold various sources of data can be an extremely valuable tool for innovation implementation within a manufacturing process.

This research proposes three areas of innovation that can be inserted into a Lean manufacturing system with the use of the manufacturing execution system: product innovation, process innovation, and customer innovation. The product innovation relates to the research and development that exists to create new products for the manufacturing line to run. The process innovation encompasses the improvement of all process steps used to manufacture a product. The customer innovation aspect includes the customer input on potential improvements that could be made to a product, including quality. By implementing data collection of every part of the manufacturing process, including information from inputs and final products, data analysis can be performed to improve the process and help the firm to become more successful.

Future research on this topic should be conducted, as combining innovation and Lean principles is a viable business strategy to reduce costs and improve quality. Although this research is mostly theoretical, it is likely that there are companies, such as Rockwell

Collins, that incorporate innovation programs and Lean programs, simultaneously. It would be beneficial to understand how companies that have implemented Lean principles view and attempt innovation activities. Quantitative and qualitative research should also be done to determine if implementing both strategies is financially beneficial.

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