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Development of an Optimal Lean Six Sigma Model

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DEVELOPMENT OF AN OPTIMAL LEAN SIX SIGMA MODEL

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ABSTRACT

Lean six sigma is a hybrid continuous improvement methodology that is not standardized and is not well understood. A review of literature found that the spectrum of lean six sigma approaches extends from those that are lean dominant to those that are six sigma dominant. This research illuminated the lean six sigma methodology by methodically assessing the literature via text mining and cluster analysis. Text mining was used to establish the degree to which lean six sigma models, as described in articles published in the International Journal of Lean Six Sigma, are lean dominant versus six sigma dominant. The iterative cluster analysis was used to identify clusters of articles that were interpretable. A cluster of lean dominant lean six sigma articles was identified and statistically validated as being distinct from other models. It was determined that characteristics of a lean dominant lean six sigma include the text mining key words “waste”, “value”, and “kaizen.” The research also found that these lean dominant lean six sigma articles ascertain lean as the dominant philosophy and six sigma as a subordinate tool used in achieving the lean objectives. The findings of the research as well extrapolation of the literature informed a recommended lean six sigma model. The recommended model is lean dominant and consists of two subordinate methods – six sigma and statistical process control. The three synergistic approaches not only each serve in their own way to manifest process improvements, they also all contribute to organizational learning which is considered a chief contributor to competitive advantage.

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INTRODUCTION

The objective of chapter one was to delineate an abbreviated background against which the research was assessed for suitability. The continuous improvement methods being discussed were reviewed. The lean six sigma hybrid was introduced and the recognition that a standard model definition is lacking was established. The essence of the research was defined by way of problem statements and research questions supported by statement of need. The methodology that was utilized in the research was summarized.

Background

Lean and six sigma respectively are widely popular process improvement approaches used around the world (Snee, 2010). In recent years lean and six sigma are being integrated into what is commonly called lean six sigma (Snee, 2010). The integration of six sigma (Corbett, 2011), which focuses on processes, with lean, which focuses on the connection between process steps (Antony, 2010, p. 186), is supported by both practitioners and scholars. The purpose of this research was to explore the theory and definition of this integration. Currently, a standard framework for lean six sigma is lacking (Pepper & Spedding, 2006). Until lean six sigma is adequately defined as a distinct approach, it cannot be compared and contrasted with other continuous improvement methodologies, including lean and six sigma respectively, from which the integration is derived.

The central problem of management is to understand and to reduce variation (Deming, 1996). Process variation contributes to uncertain outcomes. Various technologies contribute to the reduction in outcomes uncertainty (Rogers, 2003). Technologies may consist of hardware and/or software components (Rogers, 2003). Lean six sigma as such, is a software system in that it consists of information, procedures, and principles derived for the purpose of understanding and reducing uncertainty aspects of processes (Rogers, 2003).

The term lean is a truncated version of what is alternatively called lean manufacturing, lean production, or lean thinking (de Koning, Verver, van den Heuvel, Bisgaard, & Does, 2006). Lean is derived from the Toyota Production System (Pepper & Spedding, 2010). The popularity of lean outside of Toyota was first extensively documented in the book *Lean Thinking* (Womack & Jones, 1996b). Lean thinking is based upon five principles (Womack & Jones, 1996b). The first principle is to specify *value* for the customer. Secondly, the *value stream* is identified. Thirdly, the value is made to *flow*, as Ford prescribed so many years ago (Zarbo & D'Angelo, 2006). The fourth principle is to arrange for processes to trigger production based upon the *pull* of subsequent processes in which production planning is a matter of replenishment. The final principle is *perfection.* From the Toyota Production System perspective, two key characteristics are just-in-time (JIT) and zero defects, or built-in quality (Liker, 2004). The JIT principle is realized by delivering the right product at the right time in the right quantity, which is a corollary to flow and pull. Resources are not expended until they are required. Furthermore, resources are not expended to produce product which will not be immediately consumed. Zero defects are facilitated by detecting problems at the source and preventing them from being passed along to the next point in the process (Arnheiter & Maleyeff, 2010, p. 10). Defects are considered waste and a drag on profitability. Lean consists of a number of techniques that are used to realize just-in-time, to reduce defects, and to generally stabilize chaotic processes. Despite these definitions, lean continues to be a management approach which defies common definition (Hopp & Spearman, 2004; Shah & Ward, 2007). Part of the confusion is attributable to disparate evolution of the methodology over a vast period of time (Lee & Jo, 2007; Shah & Ward, 2007).

Six sigma, originating in the quality field (Bisgaard, 2008), is a methodical approach for understanding and reducing process variation (Andersson, Eriksson, & Torstensson, 2006). Process variation is the source of defects. Taguchi formulated a model which demonstrates the importance of uniformity, "working for less and less variation about the nominal value" (Deming, 1986, p. 49). The six sigma methodology takes the form of a roadmap consisting of five phases: define, measure, analyze, improve, and control (DMAIC) (de Koning *et al*, 2006). In the define phase, the problem is selected, quantified and assessed a financial value. The problem is translated into a measurable form in the measure phase. Baseline performance is established using measurements that are validated. Causal relationships that determine process performance are identified and explored in the analyze phase. In the improve phase modifications are made to the process in order to improve performance. A control system, which secures that improvements are sustained, is implemented in the control phase. The DMAIC model is a form of the plan-do-check-act (PDCA) cycle of problem solving invented by Walter Shewhart and advanced by W. Edwards Deming (Best & Neuhauser, 2006).

Both lean and six sigma are subordinate to the objectives of excellence and continuous improvement (Pepper & Spedding, 2010). Some organizations utilize both lean and six sigma but do not combine them in any way (Jing, 2009). Synergies achieved by integrating lean and six sigma are expected to contribute to continuous improvement that is superior to the sum of the individual methods (Cheng, 2010; Hoerl & Snee, 2010; Patterson, 2009). Exclusive use of either lean or six sigma would facilitate most process improvements (Nave, 2002, p. 78), however it is argued that superior efficiency and effectiveness is realized by a lean six sigma model (Jing, 2009). There is no consensus on how to define lean six sigma (Gershton & Rajashekharaiah, 2011). There are a myriad of ways to combine lean and six sigma (Pepper & Spedding, 2010). Salah, Rahim and Carretero (2010) categorize five basic methods of combining lean and six sigma and propose a sixth model which they claim to be more balanced and holistic.

One common lean six sigma model consists of lean as an overriding production philosophy (Pepper & Spedding 2010). As obstacles are encountered along the lean journey, six sigma is deployed as a tactic to tackle complex obstacles (Pepper & Spedding, 2010). Lean thinking establishes a target condition whereas six sigma is used to address deviations from the target (Cheng, 2010). This lean dominant approach benefits from the problem solving methodology that six sigma brings to bear (Pepper & Spedding, 2010). With such a lean six sigma hybrid, six sigma is a subordinate component that is absorbed into lean as the dominant model (Salah *et al*, 2010). Pepper and Spedding (2010) propose such a lean dominant model. Lean thinking establishes the business case and the direction for the organization. As the objectives are pursued, obstacles identified as “hot spots” are encountered. Six sigma provides a focused problem solving approach for dealing with these “hot spots” (Pepper & Spedding, 2010), which propels the organization forward.

Alternative is the model wherein lean is subordinate to six sigma. This lean six sigma model originates from and is driven by the six sigma community (Hill & Kearney, 2003; Jing, 2009; Smith, 2003). For many practitioners, lean six sigma is essentially six sigma with lean tools incorporated (Bendell 2006; Chiarini, 2011; de Koning *et al*, 2006; Gershton & Rajashekharaiah, 2011). This lack of true integration of the systems is further reflected in that six sigma oriented authors use the term *lean six sigma* interchangeably with s*ix sigma* (Snee, 2010). Snee even goes on to discuss the integration of lean manufacturing with lean six sigma, implying that lean six sigma is simply six sigma reconstituted.

Snee (2010) proposes that business and process performance goals establish the business case and that deviations from goals lead directly to six sigma projects, or indirectly by way of value stream mapping analysis. Depending upon targets that are derived from value stream mapping, a six sigma project, a kaizen event, or a quick hits action is selected. These three options are the means by which to address the performance gaps, and they may also inform and lead to each other (Snee 2010). The objective overall is to achieve business excellence by continuously making improvements (Bhuihan & Baghel, 2005).

Thus far academia has paid scant attention to lean six sigma (Hoerl & Snee, 2010a; Ngo, 2010, p. 18). Lean six sigma methods need to be supported by sound theory that is scientifically underpinned (Pepper & Spedding, 2010) and theory needs to be continually challenged and enhanced (Snee 2010).

Statement of the Problem

The problem for this study was to develop an optimal lean six sigma model system based on the assessment of characteristics, differences and dominance.

Research Questions

1. Is lean six sigma different from lean?
2. Is lean six sigma different from six sigma?
3. What are the characteristics of a lean dominant lean six sigma model?
4. What are the characteristics of a six sigma dominant lean six sigma model?
5. What is the best derived model for lean six sigma?

The associated hypothesis statements were as follows:

1. There is no significant inverse relationship between lean dominance and six sigma dominance as described in the lean six sigma literature.
2. The distribution of lean six sigma models, as described in the lean six sigma literature, are not clustered into two distinct lean dominant and six sigma dominant versions.
3. There is no significant difference between the ratios of lean key words to six sigma key words among identified clusters of articles/models.

Statement of Need

A system is a set of two or more interrelated elements that interact with each other so as to have an effect on the whole system in ways that are not achievable with the individual elements (Ackoff, 1997). According to Snee (2009) "holistic improvement is defined as: 'An improvement system that can create and sustain significant improvements of any type, in any culture for any business'" (p. 52). A holistic lean six sigma approach would satisfy Ackoff's definition of a system. For instance, one firm uses a lean based daily continuous improvement process as a countermeasure to the decline in performance which reportedly occurs after some six sigma projects are completed (Assarlind, Gremyr & Backman, 2012).

There have been limited scholarly studies of lean six sigma models (Corbett, 2011). The target of Corbett's study (2011) was an armament research, development and engineering company as well as an aluminum ingot manufacturer, located in the United States and New Zealand respectively. Corbett (2011) recommends that future research will expand the number of companies and industries studied. Chairini (2011) suggests that case studies will augment literature review based research such as his own.

This study contributed to the convergence in lean six sigma methodologies thereby leveraging the synergies that are expected. Such a hybrid should not compromise on the principles of the underlying independent methodologies. Some theories that support the practice of lean six sigma exist, but need to be examined and improved (Snee, 2010).

There is a need for holistic improvement systems (Bendell, 2006; Pepper & Spedding, 2010; Salah *et al*, 2010; Snee, 2010). This could be manifest in a lean six sigma transition from project based improvements to a culture of continuous improvement (Snee, 2010) such as embodied by Toyota's system of continuous improvement and adaption (Rother, 2010). A holistic hybrid should not abandon the common desirable aspects of lean and six sigma respectively (Bendell, 2006).

Statement of Assumptions

The following assumptions were applied to this study.

1. It is assumed that the Toyota Production System as developed and used at Toyota is the prototypical representation of lean.
2. It is assumed that organizations and the processes therein are complex systems for which prescriptive results based upon small data sets are inconclusive but that knowledge gained is cumulative in nature leading to an increased understanding.
3. It is assumed that data mining analysis of the literature are accurate representations of lean six sigma systems in practice.

Statement of Limitations

Given that there are a multitude of clustering algorithms, the clusters that resulted were dependent upon the algorithm deployed and may differ from clusters resulting for differing algorithms (Duarte *et al*, 2012, p. 201). The hierarchical method of cluster analysis is an exploratory method which may prescribe further a non-hierarchical method as a means of complementary corroboration (Sharma, 1996). The target journal, *International Journal of Lean Six Sigma*, has been in existence only since 2010, which is consistent with the recency of the lean six sigma methodology.

Statement of Methodology

The research focused on quantitizing the qualitative data via a data mining scheme. The analysis investigated for the presence of both lean dominant and six sigma dominant variants of lean six sigma. Word counts were utilized for determining content and attributes for each category. Key words associated with lean and six sigma respectively were identified and mined from the *International Journal of Lean Six Sigma*. Each article/segment was a sample and was mined for the frequencies of key words, leading to the creating of a lean and six sigma index respectively. Descriptive statistics were calculated for the lean and six sigma indices. A regression analysis was conducted on the pairs of indices, to determine if an inverse relationship exists, which is what was expected if the literature samples were primarily stratified into lean dominant and six sigma dominant variants respectively. A cluster analysis (Sharma, 1996) was performed on the frequency of key words, to see if the samples fall into two distinct clusters, lean and six sigma dominant models respectively. As the data fell into distinct lean and six sigma dominant clusters, a one-way ANOVA was performed on the mean frequency of lean key words for each cluster. The one-way ANOVA was repeated for the mean frequency of six sigma key words.

Definition of Terms

Holisticity is the degree to which the whole system is emphasized, and in recognition that the parts "are equally interrelated" (Pepper & Spedding, 2010, p. 144.

Lean production is the execution of processes employing teams of multi-skilled workers using highly flexible machines to facilitate large variety of outputs which are highly conforming and use much fewer resources in the pursuit of perfection (Womack, J. P., Jones, D. T., & Roos, D. 1990).

Lean thinking is the principles for action for pursuing lean production, and are: specify the meaning of value in the eyes of the customer, identify the value stream within which value is created, make the value flow without interruption, schedule production based upon the pull of the next customer/process, and pursue perfection (Womack & Jones, 1996).

Six sigma is an improvement methodology, a system of management, a measure to define capability, and a goal of near perfection (George, 2002).

Summary

In chapter one, a mini review of literature provided the necessary background against which the research project was assessed. Lean and six sigma, as separate initiatives, were briefly reviewed. The lean six sigma hybrid model was briefly introduced. An important statement of need delineated that there was no standard definition for lean six sigma. The problem statement and research questions set the stage for the research that was described herein. A brief review of the research methodology was summarized. The next chapter presents a review of literature as relates to the topics of lean, six sigma, and lean six sigma.

CHAPTER 2

REVIEW OF LITERATURE

This chapter was expressed in six parts. The first two parts provide a review of lean and six sigma as current continuous improvement approaches. The third section expounds on the research that is available as pertains to the subject of this research, lean six sigma. There are several distinct methods of lean six sigma that were explored. The fourth part relates to the theory, or lack thereof, for the practice of lean six sigma. The fifth section describes the need for lean six sigma as an important contribution to the continuous improvement field. The sixth and final section of this chapter briefly identifies research needs as stated in the literature reviewed.

Lean

Defies Common Definition

As compared to six sigma DMAIC, the framework of the lean methodology is less prescriptive (Ngo, 2010, p. 14). Within Toyota, the concept of lean – as the Toyota Production System is known outside of Toyota – has been characterized as a "formalization and codification of experience and judgment" (Goh as reported in Antony, 2011, p. 186). Now, many years later than the inception of lean at Toyota, the lean methodology is being broadly practiced, yet there remains disconnects between the many differing definitional viewpoints (Ngo, 2010, pp. 14-15). As with six sigma, lean is a methodology for bettering business processes (Gershon *et* a, 2011, p. 26). For many practitioners, lean embodies a tool set used for the purpose of finding and removing all waste (Gershon *et* a, 2011, p. 26). For a period of time, lean was held to be synonymous with the just-in-time philosophy (Ngo, 2010, p. 15). Others perceive value stream mapping (VSM) as being synonymous with lean (Pepper & Spedding, 2010, p. 139). Still others stress that the lean philosophy is a holistic approach (Mayeleff *et* al, 2012, p. 543; Pepper & Spedding, 2010, p. 139).

Derived from TPS

The Toyota Production System was developed at Toyota Motor Manufacturing as far back as the middle of the last century, with Taiichi Ohno as the chief architect (Mayeleff *et* al, 2012, p. 543). The mantel within Toyota was to eradicate all waste (Pepper & Spedding, 2010, p. 138), which leads to improved quality, which furthermore leads to reduced costs and increased productivity, in accordance with the Deming Chain Reaction (Deming, 1986, p. 3; Gershon *et al*, 2011, p. 26). The Toyota Production System (TPS) was the forerunner for what is known today as lean (Ngo, 2010, p. 14; Pepper & Spedding, 2010, p. 138). Prior to the assignment of the name lean, the Toyota Production System was becoming more broadly studied and practiced as a methodology entitled simply as just-in-time (JIT) " (Gershon *et* a, 2011, p. 26).

JIT & Zero Defects

The Toyota Production System (TPS), using the analogy of a house in order facilitate ease of understanding,   consists of two key pillars (Smalley, n.d., p. 6). The first pillar is known by its Japanese name 'jidoka' which refers to the principle of designing process so as to maximizing inherent quality (Smalley, n.d., p. 3). One of the oldest precepts is that of designing production equipment that will automatically shut down in the presence of defects (Smalley, n.d., p. 3). This precept further enables production personnel to operate multiple machines (Smalley, n.d., p. 3). This disengagement of people from machines brings about a flexibility that frees operators to also work on higher level activities (Smalley, n.d., p. 6).

The second principle of the Toyota Production System is the just-in-time (JIT) pillar (Smalley, n.d., p. 3). Other components were added later to this JIT principle, including takt time, supermarkets, and kanban (Smalley, n.d., p. 3). The JIT pillar has two underlying objectives, the first being more intuitive than the second. The first objective is to ensure the manufacturing and distribution of "the right parts, in the right amount, at the right time" and doing this in the most efficient manner possible using the minimum resources (Smalley, n.d., p. 6). The promise of this system is one of lesser inventories leading to reduced costs on several fronts, including the cost of money to carry the inventory, the cost to transport and store the inventory, and the occasional cost of dealing with obsolete or damaged inventory. A second, less obvious objective of the JIT system is that it creates a system which exposes problems which might otherwise be generally shielded by extra inventory, sometimes referred to as safety stock; the security of ongoing production is protected by backup inventories (Smalley, n.d., p. 6). If extra inventories are not being kept aside, then any disruption – related to quality problems, supply problems, equipment reliability, etc. – puts the supply of production at great risk. The philosophy of this second objective is that the urgency that a threatened shut down might incur creates an even greater urgency for addressing and fixing the underlying problem, both thoroughly and permanently (Smalley, n.d., p. 6). The concept of making problems visible and addressing them as a top priority is a high level priority throughout the Toyota Production System (Chiarini, 2011, p. 347; Smalley, n.d., p. 6).

Many, if not most, TPS methodologies will not be successful unless prerequisite conditions are satisfied. These foundational prerequisites include level production and reliable production systems (Smalley, n.d., p. 7). Level production, created by smoothed demand, facilitates a predictability that is the necessary foundation for the various JIT methodologies (Smalley, n.d., p. 7). Level production cannot be guaranteed unless the production and manufacturing systems upon which it depends are reliable (Smalley, n.d., p. 7).

Lean Thinking

Upon studying practitioners of lean, Womack & Jones (1996b) concluded that there were five principles which comprise the practice of lean thinking, the idea of "doing more and more with less and less" (pp. 9-10). The first of the principles is to establish value by product line, from the perspective of the customer (Womack & Jones, 1996b, pp. 9-10). The second is to establish the value stream for each product line (Womack & Jones, 1996b, pp. 9-10). In doing so, the emphasis of lean thinking is on distinguishing value from non-value added activities. Non-value added activities are associated with waste, which must be removed by scrutinizing the value stream processes (Akbulut-Bailey *et al*, 2012, p. 19; Antony, 2010, p. 185; Assarlind *et al*, 2012, p. 22). The third step is to design the processes so as to hasten the value flows, without ceasing (Chiarini, 2011, p. 340; Womack & Jones, 1996b, pp. 9-10). The objective is to minimize the overall product/service delivery timeline, as measured from point of order until actual delivery (Assarlind *et al*, 2012, p. 22; Smalley, n.d., p. 6). The fourth principle is to use customer demand to initiate the flow of value-added product (Womack & Jones, 1996b, pp. 9-10). The fifth and final step is to endlessly seek to attain perfection via a philosophy of continuous improvement (Assarlind *et al*, 2012, p. 22; Womack & Jones, 1996b, pp. 9-10). Delivering products or services that flow interrupted with minimal waste makes for an efficient process with residual quality benefits (Antony, 2011, p. 185; Corbett, 2011, p. 120). Wastes which work in opposition to lean include long lead times, large inventories, long set up times, equipment breakdowns, and quality problems leading to scrap and rework (Antony, 2010, p. 185). Tools and techniques have been developed and affirmed to this end (Antony, 2010, p. 185; Assarlind *et al*, 2012, p. 22; Chiarini, 2011, p. 344).

Comprehensive and Various Descriptions

Many lean practicing companies conduct problem solving exercises in the form of organized projects, often referred to as kaizen events, wherein teams dedicate an uninterrupted period of time to the cause (Mayeleff *et al*, 2012, p. 543). Kaizen events typically lead to quick gains, often with little data acquisition required (Hoerl & Gardner, 2010, p. 32).

Human and Cultural Aspects

A key aspect of the Toyota Production System (TPS) is the principle of "respect for humanity" (Chiarini, 2011, p. 344). The heart of TPS is the employees, by whom lean objectives are realized, under the coaching of management (Assarlind *et al*, 2012, p. 22; Shah *et al,* 2008, p. 6683; Smalley, n.d., p. 8). As contrasted with six sigma, employees do not need access to high level statistical methods (Chiarini, 2011, p. 341). While complex problems may be typically addressed with the six sigma methodology, lean initiatives more frequently address "every day waste" which draws upon the participation of the broader base of employees (Corbett, 2011, p. 125). Such am emphasis on full employee involvement reflects lean as a culture (Smalley, n.d., p. 6), rather than simply a collection of tools and techniques.

Six Sigma

Improvement Methodology/Strategy

Six sigma was invented at Motorola and further advanced by General Electric (Akbulut-Bailey *et al*, 2012, p. 21; Corbett, 2011, p. 121). The impetus for the six sigma methodology was the need to reverse poor product quality trends, in order to assure organizational sustainability in the face of stiffening competition (Corbett, 2011, p. 121; Goh, 2012, p. 20). The six sigma methodology offers a quality enhancement and customer satisfaction plan (Antony, 2010, p. 185; Chairini, 2011, p. 342; Goh, 2012, p.23) whose application has been broadened to cover all manner of business outcome (Corbett, 2011, p. 121; Dumitrescu & Dumitrache, 2011, p. 536; Goh, 2010, pp. 304-305; Montgomery, 2010, p. 62), with the superordinate goal of "bottom-line results" (Antony, 2010, p. 186). Six sigma, as a name, not only represents the overall business methodology, but also represents a performance metric – sigma level - by which project success is measured (Chiarini, 2011, p. 345), and by which a portfolio of future projects can be tracked and prioritized for improvement (Goh, 2010, p. 300). A six sigma process is one in which the nearest specification limit is six standard deviation away from the process mean, at least in the short run (Montgomery, 2010, p. 61).

Y=f(X) Problem Solving

The six sigma method of process improvement is realized by finding latent solutions to the causes of process errors (Antony, 2010, p. 185; Hoerl & Gardner, 2010, p. 31). Utilizing a statistical, data-based scheme (Chiarini, 2011, p. 343; Duarte *et* al, 2012, p. 188; Goh, 2010, pp. 304-305; Hahn *et al*, 1999, p. 208), the six sigma approach optimizes processes by determining the relationship between critical process inputs and the essential process outputs, and resetting the inputs accordingly (Oguz, Kim, Hutchinson, & Han, 2012, p. 3). The theoretical equation that represents the essence of the six sigma problem solving method is *Y=f(X)* (Oguz, Kim, Hutchinson, & Han, 2012, p. 3). The *Y* represents the process output and the *X* represents the critical inputs which drive the performance of the output (Oguz, Kim, Hutchinson, & Han, 2012, p. 3). Understanding and controlling the pertinent inputs facilitate solutions which optimize process outputs (Oguz, Kim, Hutchinson, & Han, 2012, p. 3).

Understand and Reduce Variation

The six sigma methods have a considerable overlap with the quality engineering body of knowledge (Chiarini, 2011, p. 344). Six sigma originated as a quality focus for reducing process variation (Assarlind *et al*, 2012, p. 22; Chiarini, 2011, p. 344), leading to near zero breaches of specification limits, and thereby, near zero defects (Corbett, 2011, p. 121; Mayeleff *et al*, 2012, p. 543; Montgomery, 2010, p. 61; Oguz, Kim, Hutchinson, & Han, 2012, p. 2). The six sigma approach can be used to reduce variation about the target, realign the process center with the target, or both (Antony, 2010, pp. 185-186; Dumitrescu & Dumitrache, 2011, p. 536). Because process variation creates defects, it is considered as waste, from a lean perspective (Chiarini, 2011, p 343). Taguchi formulated a model which demonstrates the importance of uniformity, "working for less and less variation about the nominal value" (Deming, 1986, p. 49).

DMAIC

The six sigma strategy is executed by means of improvement projects (Corbett, 2011, p. 121; Goh, 2012, p. 21). Projects are chosen based upon their linkage to organizational strategy and bottom line contribution (Corbett, 2011, p. 121). The six sigma methodology follows a meticulous project management framework consisting of five phases: define, measure, analyze, improve, and control (DMAIC) (Corbett, 2011, p. 121; Duarte *et* al, 2012, p. 188; Gibbons *et al*, p. 317, 2012). The "linear and sequential" DMAIC protocol (Gibbons *et al*, p. 317, 2012), consisting of a systemic integration of tools and techniques (Goh, 2010, p. 301), is the basis for the six sigma problem solving methodology (Chiarini, 2011, p. 347; Hoerl & Snee, 2010b, p. 128). Such integration exemplifies that the "whole [of the DMAIC deployment] is larger than the sum of the parts" (Goh, 2010, p. 301). The DMAIC roadmap is an original collection of statistical and quality related tools and techniques which can be generally applied to any problem solving effort

(Chiarini, 2011, p. 343; Hoerl & Snee, 2010b, p. 123). The DMAIC roadmap is often described as being akin to the plan-do-check-act (PDCA) cycle of improvement as invented by Walter Shewhart and further advanced by Edwards Deming (Duarte *et* al, 2012, p. 188; Gibbons *et al*, 2012, pp. 316-317).

The define phase consists of designating the process that warrants transformation (Akbulut-Bailey *et al*, 2012, p.20). The measure phase amounts to depicting the process in a visual map and measuring the current state of the process which establishes a baseline against which improvement can be measured (Akbulut-Bailey *et al*, 2012, p. 20; Oguz, Kim, Hutchinson, & Han, 2012, p. 2). The measurement device by which the process is measured is also validated. During the analyze phase potential causes for poor performance, as designated in the *Y=f(X)* equation, are postulated. Pertinent data are collected and analyzed, statistically and otherwise, with the intent of determining the strength of relationship of the hypothesized *Y=f(X)* relationships, thereby exacting the root causes of the process trouble (Oguz, Kim, Hutchinson, & Han, 2012, p. 2). The improve phase entails the actual transformation of the process, so as to resolve a problem and/or improve process performance, based upon the findings of the analyze phase (Akbulut-Bailey *et al*, 2012, p. 20; Oguz, Kim, Hutchinson, & Han, 2012, p. 2). In the control phase the sustainment of the improvements installed in the improve phase are assured by means of documentation, including process controlling and monitoring plans (Akbulut-Bailey *et al*, 2012, p. 20; Oguz, Kim, Hutchinson, & Han, 2012, p. 2). The DMAIC disposition of projects is confirmed stage-by-stage with intervening tollgates (Chiarini, 2011, p. 343).

Roles and Culture

The appeal of six sigma lies in the resultant cultural change more so than the application of statistical tools (Chiarini, 2011, p. 341; Goh, 2012, p. 20). To ensure six sigma success, participation is expected from throughout the organization, particularly from upper management (Dumitrescu & Dumitrache, 2011, p. 536; Goh, 2010, p. 301).). The six sigma methodology is deployed by teams, under the direction of management and led by skilled professionals (Chiarini, 2011, p. 342; Shah *et al,* 2008, p. 6683). However, a key role in the structure is the project leader, in the form a highly trained six sigma expert called a black belt (Chiarini, 2011, p.342; Corbett, 2011, p. 121). Other roles in the six sigma structure are champion (project owner/ supervisor), master black belt (six sigma consultant), and green belt (lesser trained project leaders) (Goh, 2010, p. 301). Holding the six sigma leadership responsible for quality improvements abandons the concept that quality is the responsibility of everybody, which can regress into quality being the responsibility of nobody (Goh, 2010, p. 301).

Lean Six Sigma

Lean Six Sigma Introduction

Lean six sigma is the most recent improvement system that traces its roots to the instruction of W. Edwards Deming (Mayeleff *et al*, 2012, pp. 542-543). Lean six sigma (LSS) is an extensively utilized method for process improvement (Duarte *et* al, 2012, p. 189; Mayeleff, Arnheiter & Venkateswaran, 2012, p. 542). LSS is applicable to all manner of processes, including both service and manufacturing types (Duarte *et* al, 2012, p. 189).

Distinctions between Lean and Six Sigma

Lean and six sigma have much mutuality (Akbulut-Bailey *et al*, 2012, p. 19; Ngo, 2010, p. 20). For instance, they both emphasize a customer orientation (Chiarini, 2011, p. 344). Nonetheless, there remain significant distinctions (Ngo, 2010, p. 20). Arguably the most important distinction pertains to the breadth of employee participation (Ngo, 2010, p. 20). Six sigma deployments are predominantly limited to the few highly trained professionals while "lean is shop floor driven" (Ngo, 2010, p. 20).

Standard definition is lacking

Lean six sigma, while be widely utilized, carries different meanings to different practitioners (Gershon, 2011, p. 27). These differing expressions of LSS do not lend itself to coalescence about a standard definition (Assarlind *et al*, 2012, p. 23; Gershon, 2011, p. 27). It remains unanswered as to if there should "be many types of [lean six sigma] combinations depending upon organizational context or can a universal model be developed" (Ngo, 2010, p. 22).

Integration of Lean and Six Sigma

It is generally inferred that lean six sigma consists of an integration of the two independent methodologies (Assarlind *et al*, 2012, p. 23; Corbett, 2011, p. 123; Gershon, 2011, p. 27). Carreira and Trudell (2006) describe lean six sigma as any combination of the tools and techniques of lean and six sigma which contribute to the superordinate goal of continuous improvement (p. XV). The expectation is that the merging of the two results in a magnified advantage. There are a number of different ways in which the integration is manifest however Salah *et al* (2010) states insightfully that "the integration needs to achieve a full fusion of the lean philosophy of waste elimination with the six sigma mentality of perfection" (p. 256). LSS blends the focus on process flow by lean with the six sigma spotlight on improved capability by virtue of diminished variation (Chiarini, 2011, p. 343; Oguz *et al*, 2012, p. 2). Integration is not achieved when lean and six sigma are alternatively deployed, as per menu options (Salah *et al*, 2010, p. 251).

Six Sigma Dominant Models

Six sigma has evolved so as to incorporate lean tools and techniques (Gershon *et al*, 2011, p. 26). Several researchers of lean six sigma conclude that lean six sigma and six sigma are one and the same (Duarte *et al*, 2012, pp. 189-190; Dumitrescu & Dumitrache, 2011, pp. 539-542). Snee (2010) uses the terms six sigma and lean six sigma interchangeably. The adding of the term lean, as Snee implies, simply recognizes that lean concepts have been added to the six sigma tool portfolio. Most references in the literature and texts imply that LSS is simply six sigma reformulated with lean tools and phrase intermingled (Chiarini, 2011, p. 343; Gershon *et al*, 2011, p. 26; Hoerl & Snee, 2010a, p. 5). Many sources of LSS training offer black belt certificates based upon training that is not far afield from the traditional DMAIC based six sigma curriculum (Chiarini, 2011, p. 348). The essence of the LSS methodology remains underpinned by the six sigma DMAIC roadmap (Gershon *et al*, 2011, p. 26). Lean tools and techniques are part of the American Society for Quality (ASQ) Six Sigma body of knowledge, further indicating the breadth of the implication that a major form of LSS identifies lean as a subset of six sigma (Arnheiter, Maleyeff, & Venkateswaran, 2010). LSS is frequently an evolved rendition of six sigma, with lean tools and techniques interwoven into the six sigma methodology (Gershon, 2011, p. 27). According to Hoerl & Gardner (2010), LSS, when defined as six sigma plus lean tools, “is not a holistic business improvement system” (Hoerl & Gardner, 2010, p. 35).

Assarlind et al Study (Balanced Application)

In a large firm in Sweden, a version of lean was introduced subsequently to the introduction of six sigma (Assarlind *et al*, 2012, p. 24). Not an overt practitioner of LSS, this company has inventively cherry picked those components of lean and six sigma that enhance their cohesive production system (Assarlind *et al*, 2012, p. 28). The two methodologies have since become integrated into a single system (Assarlind *et al*, 2012, p. 24). Within this unified system, the DMAIC framework is utilized for every form of improvement activity (Assarlind *et al*, 2012, p. 24). Montgomery (2010) argues that lean initiatives can be executed via the DMAIC project management scheme (p. 63). In the case study firm, black belts are qualified in both six sigma and lean (Assarlind *et al*, 2012, p. 24). Tools from both methodologies are selectively incorporated, depending upon the dictates of the respective projects (Assarlind *et al*, 2012, p. 25; Hoerl & Gardner, 2010, p. 33; Salah *et al*, 2010, p. 251). The characterization of lean six sigma does not fit a neat definition, even amongst employees within this case study firm (Assarlind *et al*, 2012, p. 27). LSS, as deployed, is versatile and adaptable, contingent upon the requirements of the activity (Assarlind *et al*, 2012, p. 27). There is some contention as to if this version of lean six sigma is a true assimilation or a parallel deployment of lean and six sigma (Assarlind *et al*, 2012, p. 25). These varying views are not necessarily a contradiction but instead are a “matter of perspectives” (Assarlind *et al*, 2012, p. 27). This firm’s improvement teams consider lean to be the blueprint for routine continuous improvement while six sigma is reserved for major obstacles requiring a more sophisticated approach (Assarlind *et al*, 2012, p. 27). When a larger project is assigned to a black belt, the six sigma approach is used, readily incorporating lean tools and ideas (Assarlind *et al*, 2012, pp. 27-28). The black belt improvement professional is afforded this level of discretion (Assarlind *et al*, 2012, p. 28). While the DMAIC framework is used for the improvement team’s daily improvements, the influence of lean is clearly apparent (Assarlind *et al*, 2012, p. 28). The lean philosophy can dictate project priorities, often subsequent to value stream mapping exercises (Assarlind *et al*, 2012, p. 28). Assarlind *et al* (2012) contend that a single universal method cannot be equally effective for shop floor level improvement projects and complex projects requiring sophisticated analytics, which rely upon divergent tools and techniques (p. 28). Assarlind *et al* (2012) conclude that the advantages of lean and six sigma can be realized without the adherence to a blended lean six sigma model prescription (Assarlind *et al*, 2012, p. 28).

Johnson Technologies (Lean Dominant)

Johnson Technologies Inc. is a manufacturing company that adopted lean manufacturing in the early 1990s, in order to improve their competitiveness (Akbulut-Bailey *et al*, 2012, p. 24). In 1997, Johnson Technologies was acquired by General Electric, an early and major practitioner of six sigma. At this time the lean six sigma hybrid was born at Johnson Technologies (Akbulut-Bailey *et al*, 2012, p. 24). Johnson Technology management was proficient in both lean and six sigma (Akbulut-Bailey *et al*, 2012, p. 25). Despite this declaration of a lean six sigma integration, much of this study focused on the lean aspects of lean six sigma such as one piece flow, standard work, kanban, and jidoka; there was very little mention of six sigma details. This reflects the likelihood that at Johnson Technologies Inc., lean six sigma takes a lean dominant form.

Corbett Study (Balanced Application)

In the case companies observed by Corbett (2011) “there was little evidence of the dominance of one component [lean or six sigma] over the other… the choice of tools to be used in the identified projects was left to the teams” regarding lean six sigma (LSS) as more akin to being tool sets rather than a holistic integration (p. 125). The improvement practitioners determined which tools to execute, depending upon the nature and need of the project (Corbett, 2011, p. 129).

Pepper & Spedding Model (Lean Dominant)

Pepper and Spedding (2010) develop a LSS integration model which reflects that lean is the dominant methodology and that six sigma is used in a subordinate role. This model constitutes a comprehensive management approach addressing all manner of business process improvement (Pepper & Spedding, 2010, p. 150). Figure 1 depicts this integration model. The lean ideology represents the key foundation of the improvement model, not unlike what has been demonstrated at exemplary firms such as Toyota (Pepper & Spedding, 2010, p. 150). In the pursuit of the lean ideal state, obstacles, referred to as "hot spots," are encountered (Pepper & Spedding, 2010, p. 150). Tactically, six sigma is deployed at these hot spots "driv[ing] the system towards the desired future state" (Pepper & Spedding, 2010, p. 150). These hot spot

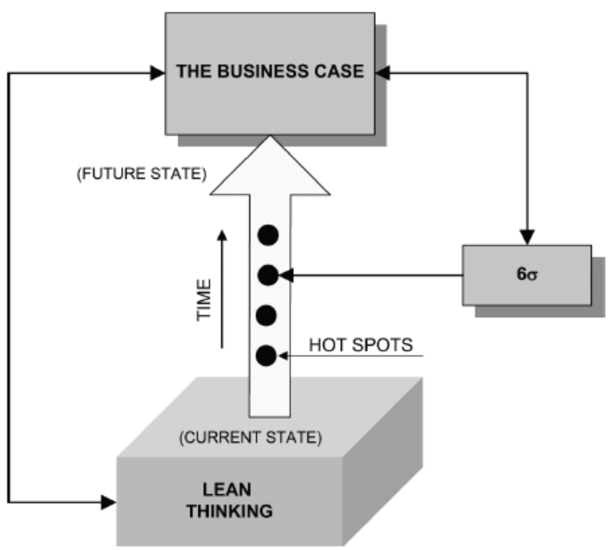

Figure 1. Conceptual Model for lean Six Sigma (Pepper & Spedding, 2010, p. 150)

obstacles may be more effectively addressed with six sigma due to the analytical superiority of the six sigma system, enabling the process to gain progression towards a goal of true lean existence (Pepper & Spedding, 2010, p. 149). This model is not completely novel in that many firms deploy an integrated LSS approach by "apply[ing] basic lean tools and techniques at the starting phase of their program such as a current state [value stream] map, basic housekeeping using 5S practice, standardized work" (Antony, 2011, p. 190). The simpler Lean approaches used at the vanguard of the roll out remove many of the ground level wastes, leaving and often further revealing the more complex, and often persistent, "hot spots" that can be effectively tackled with the six sigma approach (Antony, 2011, p. 190; Pepper & Spedding, 2010, p. 148).

Salah et al Model (Balanced Application)

According to Salah *et al* (2010), the five lean thinking principles, as defined by Womack and Jones (1996), closely maps to the DMAIC steps of six sigma (Salah *et al*, 2010, p. 256). Figure 2 depicts this relational delineation in the form of a lean six sigma integrated model (Salah *et al*, 2010, p. 256). The system uses the prevalent DMAIC framework as a basis for project execution, providing both the necessary organization and adaptability (Salah *et al*, 2010, pp. 256, 265). Lean tools are used throughout this modified DMAIC framework, gaining

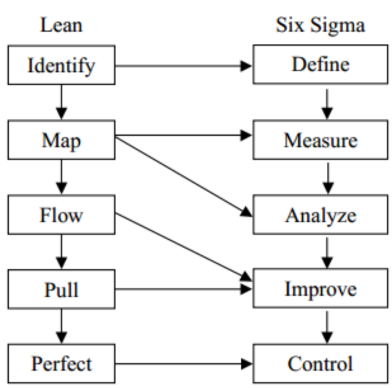

Figure 2. Lean and Six Sigma phases relationship (Salah *et al*, 2010, p. 265)

equal standing with six sigma methods, depending upon fitness of use towards the respective project (Salah *et al*, 2010, p. 265). In this integrated model, the distinction of the DMAIC phases is diminished, yet the holistic nature of the model is enhanced (Salah *et al*, 2010, p. 265). In the define phase, value as defined by the customer is established (Salah *et al*, 2010, p. 256). The value stream as mapped is consistent with the objectives of the six sigma measure and analyze phases (Salah *et al*, 2010, p. 256). The current state is established, relevant data are collected, and process understanding begins to be revealed. Improvements are manifest in the improved flow of the process, ultimately at the behest of the pull of the customer demand (Salah *et al*, 2010, p. 256). In the six sigma control phase, the improved process is standardized and a monitoring plan is introduced creating opportunities for continual pursuit of perfection (Salah *et al*, 2010, p. 256).

Snee Model

It is common for value stream mapping (VSM) to be conducted early in an improvement project initiative (Oguz *et al*, 2012, p. 6). VSM, an important lean technique, identifies deviations from ideal state, often forming the basis for six sigma projects (Oguz *et al*, 2012, p. 6). It may be inefficient to utilize the arduous six sigma methodology to solve simple problems however complex operational conundrums that result from VSM create the kind of holistic integration that accentuates lean six sigma (Snee, 2010, p. 14). As identified by other LSS researchers, the interchangeability and dominance of lean versus six sigma tools are project dependent (Snee, 2010, p. 14). In describing LSS, Snee (2010) reinforces the interplay between lean and six sigma, and the flexible utilization of the juxtaposed tools respectively. Curiously Snee (2010), after describing how lean and six sigma should be used concurrently, accentuating the particular method and its respective tools depending upon the type of problem, he later interjects the possibility of integrating lean manufacturing and lean six sigma, further validating the premise that lean six sigma, as he presents it, is simply a derivation of six sigma (p. 17). The model for integrating lean manufacturing and lean six sigma, as proposed by Snee (2010), is shown in Figure 3 (p. 18). When LSS is interpreted in this more narrow way, it can be accurately judged that, alone, it is not a holistic method (Hoerl & Snee, 2010a, p. 6). By integrating lean manufacturing with Snee's version of LSS, the holisticity is interjected.

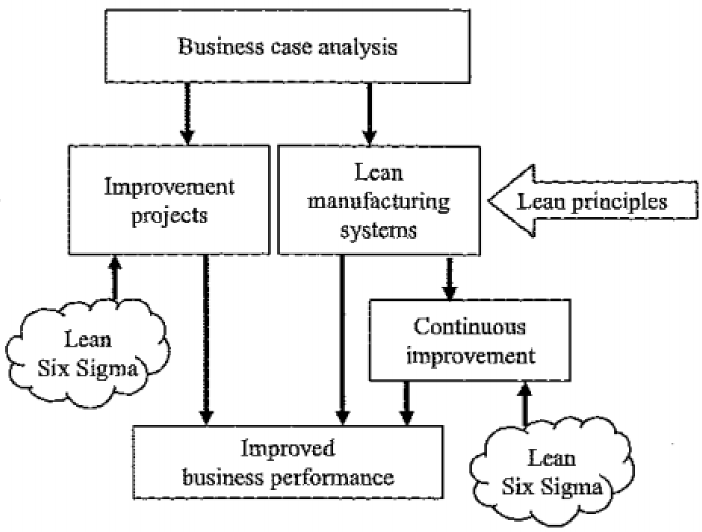

Figure 3. Integration of lean manufacturing systems and Lean Six Sigma (Snee, 2010, p. 18)

Theory

LSS needs Theory

A theory that describes the meaning, role, and execution of lean six sigma, as an integration of lean and six sigma, is needed (Ngo, 2010, pp. 18, 29; Pepper & Spedding, 2010, p. 148; Snee, 2010, p. 24). Theories, which can explain the manifestation of LSS and six sigma, should be explored via academic research (Ngo, 2010, p. 13). The theoretical structure of a lean six sigma model should achieve a "balance between complexity and sustainability" (Pepper & Spedding, 2010, p. 149).

Models

A model is a portrayal of an actual system (Khalil, 2000, p. 259). They take various forms including descriptive models which pictorially depict how a system works (Beach & Alvager, 1992, p. 171; Khalil, 2000, p. 259). Process improvement approaches are complicated systems, the effective description thereof is facilitated by the use of a model.

Various researchers have proposed models for describing improvement approaches. Bendell (2006) suggested a holistic model for business process improvement which incorporates both lean and six sigma (p. 260). Duarte, Montgomery, Fowler, and Konopka (2012) depict a proposed model for identifying lean six sigma projects (p. 193). Salah *et al* (2010) present several lean six sigma models, with varying degrees of lean versus six sigma dominance (p. 252). The varying models add support to the claim that there is a not a single lean six sigma model accepted universally, despite the need for a unifying theory.

Theories

There are some existing theories that may directly or tangentially explain lean six sigma. For example, pareto analysis reflects a theory for project prioritization within the six sigma DMAIC framework (Hoerl & Snee, 2010b, pp. 125-126). Thomas Kuhn (1996) offers a theory in the form that a paradigm becomes obsolete at the point that a new paradigm addresses unresolved issues that the old model could not (p. 153). Systems theory implies that the methods therein must be orchestrated rather than random, so as to ensure a synergistic outcome (Assarlind *et al*, 2012, p. 23). If the lean objective of reducing inventory is executed without concern for the stability of the operations, then outcomes may worsen rather than improve, for neglect of the systems consideration (Pepper & Spedding, 2010, p. 151). Systems theory might dictate that six sigma methodology be deployed to areas of instability, in order to make ready for lean deployment requiring a stable environment (Liker, 2004, p. 142; Rother, 2010, p. 126). There is a supposition that methodologies such as LSS impact market competitiveness (Mayeleff *et al*, 2012, p. 543). Hoerl and Snee (2010b) argues that it was based upon improved theory that lean six sigma superseded six sigma, and that the LSS theory should continue to be updated as more knowledge is acquired (Hoerl & Snee, 2010b, p. 126).

Theory that supports lean six sigma may be described as follows. If business metrics, as depicted as Y's, are important, and if all work is performed in processes, and if all processes can be depicted by the cause-and-effect equation $Y=f(X)$, then it logically follows that it is important to pursue the knowledge that is expected by solving the $Y=f(X)$ process equations, the essence of six sigma. Six sigma is a framework for resolving $Y=f(X)$ and thereby increasing knowledge that is of supreme importance to the organization.

Project based CI vs Culture of CI

A theory offered by Juran is that "improvement happens project-by-project and in no other way" (Hoerl & Snee, 2010b, p. 126). A holistic system will not be fully realized until the project-by-project improvement mentality is supplanted by the embracing of improvement as a daily activity of the entire workforce (Snee, 2010, p. 26). This is a nod to the Toyota Kata philosophy (Rother, 2010). The employee as strategic improvement asset is a cultural distinction between lean with its Japanese roots and six sigma founded in America (Chiarini, 2011, p. 349). Lean six sigma that reflects the American initiated DMAIC will not capture the highly acclaimed Japanese way of relying upon a highly coached workforce (Chiarini, 2011, p. 349).

Justification for Lean Six Sigma

Evolution of Lean and Six Sigma

The hallmark of a sustaining body of knowledge is acquiescence that an active changing environment requires continual updates (Mayeleff *et al*, 2012, p. 551). "Each approach builds on previous approaches adopting the effective aspects of previous approaches and adding new concepts, methods and tools to remove limitations that have been identified" (Snee, 2010, pp. 9-10). Changing times and actors have contributed to a diverging evolution of six sigma (Goh, 2012, p. 21). Save for the evolution, six sigma is destined to the dustbin of continuous improvement methodologies, like others before it (Goh, 2012, pp. 23-24; Pepper & Spedding, 2010, p. 142). One shortcoming of an earlier version of six sigma is a lack of continuous improvement cycle, as in plan-do-check-act (PDCA) (Gibbons *et al,* 2012, pp. 316-317). Since its inception six sigma has been "augmented, extended, and transformed" creating various derivations (Goh, 2010, p. 302). The DMAIC framework is conducive to the addition of tools and techniques as modules (Chiarini, 2011, p. 343; Hoerl & Snee, 2010b, p. 126). The original framework was MAIC, only to have the define phase added to the front end by General Electric (Hoerl & Snee, 2010b, p. 126). It is expected that this evolution will continue into the future (Hoerl & Snee, 2010a, p. 5). This evolution can be further informed by academic study (Hoerl & Snee, 2010a, p. 5).

Given their shared origins, it is quite reasonable that lean and six sigma methodologies would be merged (Assarlind *et al*, 2012, pp. 22-23). Some firms have "adopted LSS after a lengthy journey with other improvement programs and were looking for an approach that would give greater benefits and build on the earlier work" (Corbett, 2011, p. 125). One model of lean six sigma is six sigma with lean tools added, as an evolutionary replacement for six sigma, but not as a replacement for lean as defined and practiced as the Toyota Production System. The six sigma methodology's scope has been elevated (for instance, enhancing the emphasis on process flow), toolbox increased, and effectiveness heightened by incorporating lean into its own body of knowledge (Goh, 2012, pp. 23-24; Hoerl & Gardner, 2010, p. 31; Hoerl & Snee, 2010b, p. 126). Conversely, there is less evidence that lean practitioners seek out to absorb six sigma into the lean body of knowledge, except as it already present in the practice executed by trained engineers (Watson as reported by Antony, 2010, p. 188).

System Synergies

It is widely posited that lean and six sigma relate complementarily (Assarlind *et al,* 2012, p. 28; Salah *et al*, 2010, p. 250). Six sigma's focus on defects and lean's emphasis on waste are parallel approaches indicating similar objectives (Montgomery, 2010, p. 63). "Waste elimination should go hand in hand with variation reduction" (Goh, 2010, p. 302). The evolutions of lean and six sigma respectively have been informed by the other (Assarlind, *et al*, 2012, p.21). While it is obvious to numerous researchers that lean and six sigma should be combined, due to the shortcomings inherent in each (Antony, 2011, p. 186; Corbett, 2011, p. 119; Oguz *et al*, 2012, p. 8), an optimally effective merger should not be haphazardly derived (Assarlind, *et al*, 2012, p.22). The lean six sigma hybrid yields synergisms as compared to the parallel deployment of the singular approaches (Oguz *et al*, 2012, p. 8; Salah *et al*, 2010, p. 251). Parallel deployment of lean and six sigma can result in clashing for common resources (Liker, 2004, p. 296; Salah *et al*, 2010, p. 251). A common description of the respective benefits includes the emphasis on speed by lean methodology and on capability by six sigma (Duarte *et* al, 2012, p. 189). Succinctly, lean and six sigma together address both efficiency and effectiveness (Antony, 2011, p. 190; Duarte *et* al, 2012, p. 189; Dumitrescu & Dumitrache, 2011, p. 539). The DMAIC framework belonging to six sigma affords an improvement deployment structure that is often lacking in lean approaches (Ngo, 2010, p. 21). Moreover, control and improvement of processes often requires a higher level of statistical analysis that is inherent in six sigma but is often missing from many lean deployments (Assarlind *et al*, 2012, p. 23; Pepper & Spedding, 2010, p. 146). On the other hand, six sigma is regarded as not effectively addressing process flow (Antony, 2010, p. 190), a key principle of lean (Womack & Jones, 1996, p. 21). A fundamental tenet of lean is the requirement for stability (Liker, 2004, p. 142; Rother, 2010, p. 126). Complex stability is best rooted out via six sigma (Antony, 2011, p. 190; Salah *et al*, 2010, p. 251). "Six sigma complements lean philosophy in as much as providing the tools and know-how to tackle specific problems identified along the lean journey" (Pepper & Spedding, 2010, p. 145).

A novel example of lean and six sigma synergy is in reaction to the claim that six sigma projects often suffer the effects of entropy during the control phase (Assarlind *et al*, 2012, p. 25). The lean practice of continuous improvement during the six sigma control phase can counteract such retreat in performance post six sigma project closure (Assarlind *et al*, 2012, p. 25). Such integration "facilitates the transfer of six sigma project results to daily operations for sustained improvements" (Assarlind *et al*, 2012, p. 27).

Speeds of project versus problem complexity are additional criteria wherein the uniqueness of lean versus six sigma reveals a synergistic opportunity. "Six sigma is not the best method for routine problem solving – other methods [such as lean] will typically arrive at the same solution faster" (Hoerl & Gardner, 2010, p. 31; Snee, 2010, p. 10).

Need for holistic CI

"Improvement is the issue and both [lean and six sigma] are needed to effectively solve the problems encountered by an organization" (Snee, 2010, p. 12). Lean and six sigma merged together "provides a more integrated, coherent and holistic approach to continuous improvement" (Pepper & Spedding, 2010, p. 151). As a corollary to the Juran Trilogy (Bisgaard, 2008) - Hoerl and Snee (2010a) argue that a holistic continuous improvement should consist of process design (quality planning), process control (quality control) and process improvement (quality improvement) (p. 6). Process design may be optimized with the six sigma variant design for six sigma (DFSS). Processes that deviate from status quo are brought back into control via every day problem solving, as is characteristic of the lean philosophy, and process improvement is generally addressed by both six sigma and lean (Hoerl & Snee, 2010a, p. 6).

Some problems originate within processes - the domain of six sigma - while other problems are confined to the space between processes, the primary focus of lean (Antony, 2011, p. 186; Arumugam as reported in Antony, 2011, p. 189; Liker, 2004, p. 296; Snee, 2010, p. 16). Because within-process problems can negatively impact flow of material, and vice-versa, a holistic approach would deploy both lean and six sigma concepts concurrently in order to address the underlying interactions at play (Snee, 2010, p. 15). Therein demonstrates the need for a holistic system of process improvement (Snee, 2010, p. 12).

The Joiner Triangle (Joiner, 1994) is a model which depicts quality management as being equally balanced between three major concepts; quality, scientific approach, and "all one team" (Pepper & Spedding, 2010, pp. 143). The six sigma methodology has skewed quality management in the direction of the scientific approach corner of the triangle model discounting the "all one team" people aspect (Pepper & Spedding, 2010, p. 144). Diminishing the emphasis on cultural issues, including leadership and coaching (Antony, 2011, p. 186; Rother, 2010), hinders the holisticity of the improvement methodology (Pepper & Spedding, 2010, p. 144). "A state of equilibrium needs to be achieved" between the integrated elements (Pepper & Spedding, 2010, p. 147; Salah *et al*, 2010, p. 252). A holistic answer "is to embed a coherent systems philosophy that integrates culture with a scientific approach through a unified hard/soft systems thinking philosophy" (Pepper & Spedding, 2010, p. 144); the hard systems being the technical aspects of the six sigma methodology and the soft systems comprising the cultural emphasis of lean. Liker (2004) refers to six sigma and lean as tool kits that are important and necessary but both still lacking the cultural aspect that distinguishes the Toyota Production System (TPS) as a holistic management philosophy (Liker, 2004, p. 297).

It is often argued that organizations that deploy lean suffer for the lack of the technical analysis afforded by six sigma (Antony, 2011, p. 190; Pepper & Spedding, 2010, p. 151). However mature lean organizations in Japan integrate "production engineers" into their continuous improvement activities, bringing to bear the same quantitative skills that are part of six sigma (Watson as cited in Antony, 2011, p. 188).

Another view point on a holistic continuous improvement system entails the recognition that six sigma facilitates the resolution of complex problems, often requiring statistical analysis conducted by the few specialists, while concurrently deploying the remainder of the organizational human resources to engaging in daily continuous improvement on a smaller yet more frequent scale (Corbett, 2011, p. 126; Watson as reported in Antony, 2011, p. 188).

Montgomery (2010) "advocate[s] a deployment of six sigma combined with DFSS and lean as an ideal systems framework in which to bring about Deming's philosophy of continuous improvement" (p. 64).

Research Needs

LSS cannot be Evaluated until Defined

A number of researchers recommend that a holistic model of lean six sigma needs to be defined (Ngo, 2010, pp. 1-2). A contribution to this priority is to identify and study organizations that are successful practitioners of LSS (Akbulut-Bailey *et al*, 2012, p. 20; Salah *et al*, 2010, p. 271). Because there are already so many versions of LSS, it may be too late to rally a unified model (Marsh, Perera, Lanarolle, & Ratnayake, 2011, p. 42). The Japanese influence on successful integrators of lean six sigma remains undefined (Chiarini, 2011, p. 349).

Summary

This chapter delineated a review of the current literature pertaining to lean, six sigma, and the topic at hand, lean six sigma. Lean, as derived from the Toyota Production System, and as interpreted by researchers was described. Six sigma, as invented by Motorola, and as has evolved since the beginning, was summarized. The distinctness (as compared to lean and six sigma individually) and diversity (as one model is compared to another) of lean six sigma was explored. The role of lean six sigma theory was summarized. The evolution of lean six sigma, leading to the consensus that such a hybrid is desired, was described. Finally research needs identified in the literature were stated. The next chapter describes the methodology that was deployed to assess existing lean six sigma models, and develops an optimal lean six sigma model based upon the data collected and analyzed.

CHAPTER 3

METHODOLOGY

This chapter describes the methodology that was used in answering the research questions. The research focused on quantitizing the qualitative data via a data mining scheme. The analysis investigated for the presence of lean and six sigma dominant variants of lean six sigma. This analysis, along with associated theory, informed the proposal of an optimal lean six sigma model.

Introduction

The methodology consisted of a literature study whereby various lean six sigma models were investigated and categorized as having a lean dominance, six sigma dominance, or undetermined. The source of the literature study was the *International Journal of Lean Six Sigma.* Word counts were utilized for determining content and attributes for each category. The literature search informed the holisticity and theory for each model.

Restatement of Research Questions

1. Is lean six sigma different from lean?
2. Is lean six sigma different from six sigma?
3. What are the characteristics of a lean dominant lean six sigma model?

4. What are the characteristics of a six sigma dominant lean six sigma model?
5. What is the best derived model for lean six sigma?

The associated hypothesis statements are as follows:

1. There is no significant inverse relationship between lean dominance and six sigma dominance as described in the lean six sigma literature.
2. The distribution of lean six sigma models, as described in the lean six sigma literature, are not clustered into two distinct lean dominant and six sigma dominant versions.
3. There is no significant difference between the ratios of lean key words to six sigma key words among identified clusters of articles/models.

Data Collection

The data collection was according to the following steps:

1. The *International Journal of Lean Six Sigma* was selected for the research. The time period utilized for this study extended from the inaugural issue in 2010 through Volume 4 Issue 2 in 2013. Journals that are affiliated specifically with either lean or six sigma (e.g *Six Sigma Forum Magazine*) were precluded, to avoid any bias that might be inherent. From the *International Journal of Lean Six Sigma* articles, or segments of articles, that pertain to the descriptions, definitions or examples of lean six sigma were identified for data mining. This researcher reviewed each article in this journal for context and subjectively assigned whole articles, or sections thereof, as valid text mining samples. For example, all but two sections of the article "Lean Six Sigma – Getting Better all the Time" was

considered to be a valid text mining sample. The section on page 10 entitled "Six Sigma Began at Motorola" was excluded because it described six sigma only, and should not be considered as describing lean six sigma. Likewise, the section on page 17 entitled "Integration of Lean Manufacturing and Lean Six Sigma" was excluded because is primarily described lean only, and should not be considered as describing lean six sigma. The articles used in this study are identified in Appendix A.

2. Key words that are exclusively associated with lean and six sigma respectively were identified, based upon lean versus six sigma contrast tables found in the literature (see Appendix B). These four articles contained tables of dimensions (Anderssen *et* al, 2006, p. 256), factors (Chiarini, 2011, p. 343), tools, techniques and principles (Antony *et al*, 2003, p. 42) which compare and contrast lean and six sigma. From these tables, common terms which distinctly describe lean and six sigma respectively become apparent. The dominant terms typically and exclusively associated with lean are "waste", "value" and "kaizen." The terms "waste" and "value" are found in all four tables as pertaining to lean, but in none of the tables as pertaining to six sigma. The term "kaizen" was found in three out of four of the tables as pertaining to lean, but in none of the tables as pertaining to six sigma. The dominant terms typically and exclusively associated with six sigma are "DMAIC", "variation", "statistical", "statistics", "project" and "define." The term "statistical" was found in all four of the tables as pertaining to six sigma, but in none of the tables as pertaining to lean. The term "project" was found in all four of the tables as pertaining to six sigma, but in only one of the

tables as pertaining to lean. The term “project” was incrementally added to the six sigma dominant terms list as a result of an exploratory derived improvement of the interpretability of the cluster analysis solution (Sharma, 1996, pp. 211, 217). It was not in the original data mining list. The term “DMAIC” was found in three out of four of the tables as pertaining to six sigma, but in none of the tables as pertaining to lean. The term “variation” was found in two out of four of the tables as pertaining to six sigma, but in none of the tables as pertaining to lean. The term “statistics” was found in only one out of four of the tables as pertaining to six sigma, and in none of the tables as pertaining to lean, yet this term has the same root as “statistical” and was incrementally added to the six sigma dominant terms list as a result of an exploratory derived improvement of the interpretability of the cluster analysis solution (Sharma, 1996, pp. 211, 217), in order to capture both forms of the root word “statistic” that might be reflected in the literature. The term “define” was found in only one out of four of the tables as pertaining to six sigma, and in none of the tables as pertaining to lean, yet this term is the first word making up the acronym key term “DMAIC” and was incrementally added to the six sigma dominant terms list as a result of an exploratory derived improvement of the interpretability of the cluster analysis solution (Sharma, 1996, pp. 211, 217), in order to capture both forms DMAIC framework key term in the literature, either as an acronym and spelled out in whole. The identification of key terms remains somewhat subjective but are validated in the subsequent data mining and cluster analysis.

3. From the journal selected, the articles, or segments of articles, that pertain to the descriptions, definitions or examples of lean six sigma were data mined for the key words associated with lean and six sigma respectively. The counts of the respective terms were aggregated into a single count for the lean and six sigma terms respectively. Care was taken to ensure that key words associated with unintended definitions were not included in the counts. Instances of the term "value" as a synonym for "amount" were excluded. Likewise, instances of the term "project" used as a synonym for the verb "predict" were excluded. A frequency was calculated by dividing the single count associated with lean and six sigma respectively by the total number of words found in the article/segment. Because the total count of words is generally larger than the count of key words by a magnitude of 1000, the ratio was multiplied by 1000 in order to generate numbers that have one or two values to left of the decimal point, for ease of reading. Each article/segment was a sample and was mined for these frequencies of terms, which are referred to as the lean and six sigma index respectively. From the sample sections of the article "Lean Six Sigma – getting better all the time", the key lean term "waste" was counted seven times, the key lean term "value" was counted twenty times, and the key lean term "kaizen" was counted six times for a total single count of 33 for key lean terms. The total number of words in this article sample sections was 7854. The lean index for the article "Lean Six Sigma – Getting Better all the Time" was calculated as being 33 divided by 7854 times 1000 equals 4.2.

Analysis

The analysis of the data was as follows:

1. Descriptive statistics were calculated for the lean and six sigma indices. For lean and six sigma respectively there were twenty one indices calculated, one for each article in the sample group. The descriptive statistics for the respective distribution of these twenty one indices was determined using Minitab 16 software. The results were assessed in the classical manner, but were discounted given their lack of impact on cluster analysis (Sharma, 1996, p. 197).
2. Each article results in a pair of indices, one each for lean and for six sigma. A regression analysis was conducted on the pairs of indices, to determine if an inverse relationship exists, which is what was expected if the literature samples were primarily stratified into lean dominant and six sigma dominant variants respectively. The regression analysis was performed using Minitab 16 and was assessed via visual consideration of the scatter plot and statistical consideration of the p-value.
3. A cluster analysis (Sharma, 1996) was performed on the pairs of indices, to see if the samples fall into two distinct clusters, lean and six sigma dominant models respectively. The cluster observations analysis was performed with Minitab 16, using the complete lineage method. The squared euclidean distance between samples was used to assess the similarity or differences, thereby forming clusters of lean six sigma articles/segments based upon key terms counted in the literature. A dendrogram was used to visually depict the clusters created via the hierarchical method. The knee in the similarity level of the clusters analysis, along with the

dendogram, was utilized for determining the final partition of clusters. The selection of the final number of clusters was dependent upon subjective interpretability of the solution (Sharma, 1996, p. 217).

4. As the data fell into lean and six sigma dominant clusters respectively, a one-way ANOVA was performed on both indices corresponding to the respective clusters. This one-way ANOVA analysis was performed using Minitab 16. The statistical significance of the distinctiveness of the mean index value assigned to each cluster was determined by consideration of the p-value. A p-value below 0.05 is an indication that the mean index values are not equal and at least one cluster is distinctly different from the others. The identification of the distinct cluster was determined by visual observation of the sample means and corresponding intervals, as well as visual assessment of the individual value plots also provided by Minitab 16. The key words used in the text mining were used to identify potential clusters. At least one of these clusters was determined to be distinctly different from the others, as characterized by the key words, providing validation that the lean six sigma model represented by the cluster if represented in the literature.
5. Based upon the research performed, the identified clusters reflect divergent lean six sigma models. The particular models of interest are those that reflect a lean dominance and those that reflect a six sigma dominance. Some of these improvement models are explicitly described (Bendell, 2006, p. 260; Salah *et al*, 2010, p. 252). Other models are implied by the narrative contained within the articles. This research methodology characterized these implied models by cluster

analysis of key words – inherent model data - that are associated with said respective models. These model characteristics, along with theory associated with the well-established lean and six sigma models, were utilized for identifying and optimal lean six sigma model.

6. The identified and recommended optimal lean six sigma model was described diagrammatically, as informed by the cluster analysis defined lean six sigma models that exist in the literature. Further, the optimal lean six sigma model was formulated as a model that is supported by, and advances, the tenets of both lean and six sigma. As such, the formulated model is offered as an optimal lean six sigma model.

Summary

This chapter described the methodology used in answering the research questions. The research focused on quantitizing the qualitative date via a data mining scheme. The analysis investigated for the presence of lean and six sigma dominant variants of lean six sigma. The next chapter displays the results and findings of the research.

CHAPTER 4

RESULTS

In this chapter, the results of the data collection and analysis are described. The statistical significance of hypothesized relationships was examined. The cluster analysis was iteratively deployed so as to identify hypothesized lean six sigma models. The identified clusters were statistically tested for heterogeneity between LSS models. The intent was to answer the research questions pertaining to the hypothesized LSS models.

Data Collection and Index Development

Twenty one articles from the *International Journal of Lean Six Sigma* were determined to have sufficient description of LSS so as to warrant being included in the research. Each article was assumed to represent LSS as a distinct model consisting of particular characteristics, and therefore this research uses the term "model" when referring to the assessment of any given article. Data mining methodology was used to collect the data from each article. Key words associated with the hypothesized LSS models, lean dominant and six sigma dominant respectively, were counted, and an index value for said LSS models were calculated for each article. These indices reflect the proportion of lean key words and six sigma key words respectively, as compared to the total count of words in the article that pertains to LSS. Those sections of the articles which are completely void of LSS discussion were omitted from the data mining. Furthermore, because the total count of words is larger than the count of key words by a magnitude of 1000, the ratio was multiplied by 1000 in order to generate numbers that have one or two values to left of the decimal point, for ease of reading. The lean associated key words used in the initial analysis were "waste", "value", and "kaizen." The six sigma associated key words were "DMAIC", "variation", "statistical", "statistics", "project", and "define."

Descriptive Statistics

The descriptive statistics for the two indices, according to methodology analysis step one, were calculated and displayed in Figures 4 and 5. The distribution of the lean index is skewed as is expected since the mean value, 4.26, is relatively close to zero, which is a hard limit beyond which an index value is impossible (the data are counts of words and so negative data is not possible). The distribution for the six sigma indices is normally distributed because although it is

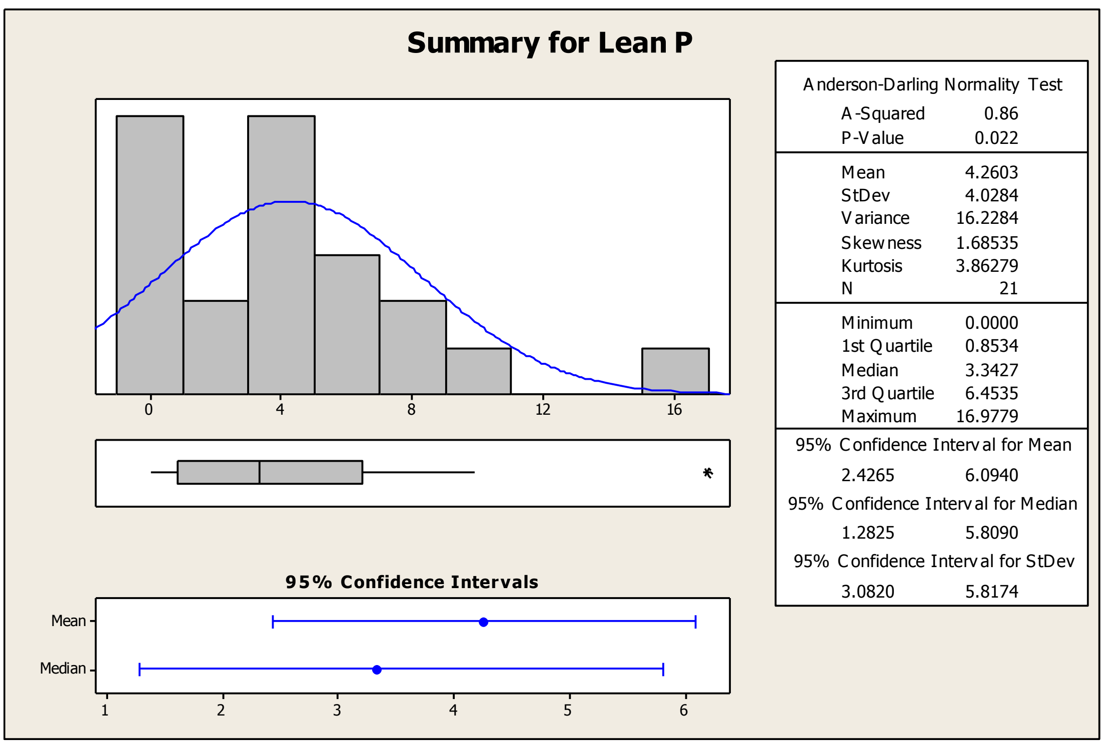

Figure 4. Descriptive Statistics for the Lean Index

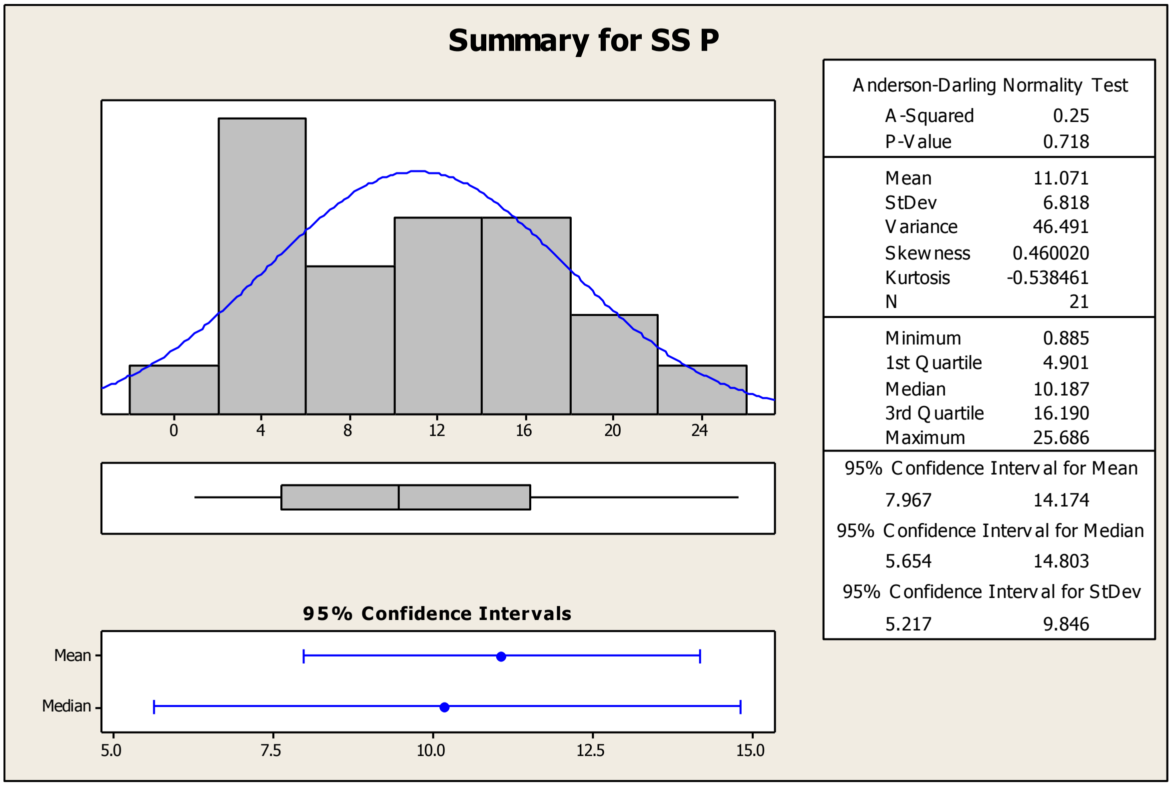

Figure 5. Descriptive Statistics for the Six Sigma Index

also bounded by zero, the mean, 11.071, is far enough away from be zero as to not cause truncation. It is not important that the mean six sigma index is more than double that of the lean index because it is simply a reflection of the respective key words selected for the data mining study. Nonetheless, descriptive statistics is not an important part of cluster analysis since "cluster analysis does not make any distributional assumptions" (Sharma, 1996, p. 197).

Hypothesis Statement One: Inverse Relationship of Indices

According to step two of the methodology analysis, the lean index was regressed against the six sigma index, to check for an inverse relationship. The scatter plot, shown in Figure 6 indicates that there is virtually no correlation between the lean index and the six sigma index. The regression analysis in Figure 7 indicates a p-value of 0.904 which concludes that the null hypothesis of independence between variables should be whole heartedly accepted. The relationship between the lean index and the six sigma index is not significant.

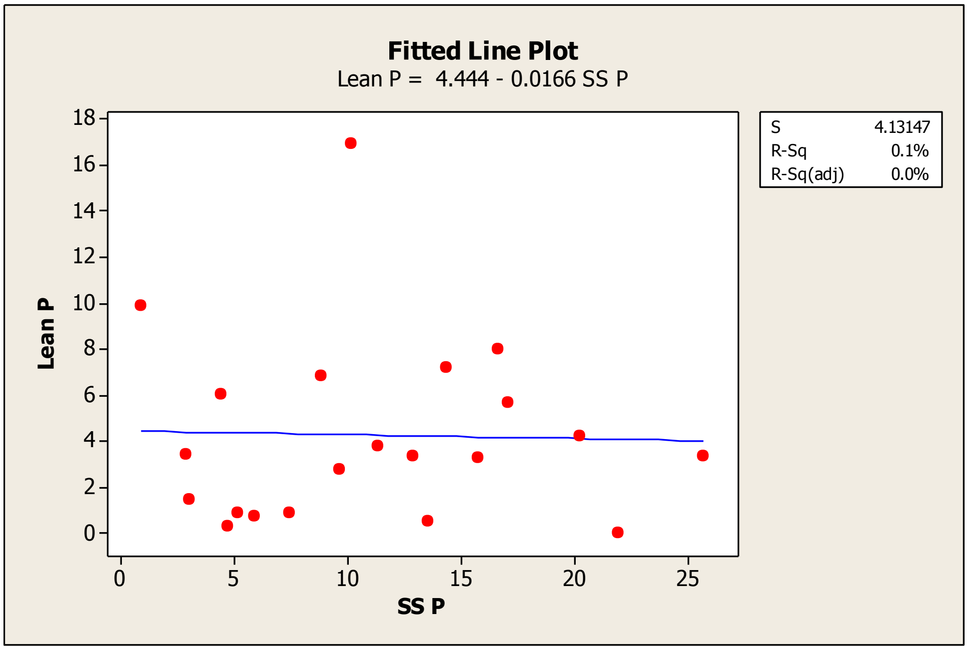

Figure 6. Scatterplot with Fitted Line of Lean Index versus Six Sigma Index

Regression Analysis: Lean P versus SS P

```
The regression equation is
Lean P = 4.444 - 0.0166 SS P


S = 4.13147   R-Sq = 0.1%   R-Sq(adj) = 0.0%


Analysis of Variance

Source      DF       SS       MS     F      P
Regression   1    0.255   0.2550  0.01  0.904
Error       19  324.312  17.0691
Total       20  324.567
```

Figure 7. Regression Analysis of Lean Index versus Six Sigma Index

Hypothesis Statement Two: Cluster Analysis of LSS Articles/Models

Further insight was expected from the cluster analysis (Figure 8) which is step three of the stated methodology. Cluster analyses is a methodology for identifying a group - in this case a

Cluster Analysis of Observations: Lean P, SS P

Standardized Variables, Squared Euclidean Distance, Complete Linkage
Amalgamation Steps

Step	Number of clusters	Similarity level	Distance level	Clusters joined		New cluster	Number of obs. in new cluster
1	20	99.9290	0.0147	13	21	13	2
2	19	99.7901	0.0436	2	13	2	3
3	18	99.6803	0.0663	11	14	11	2
4	17	99.2653	0.1525	9	15	9	2
5	16	99.1425	0.1780	2	12	2	4
6	15	98.9218	0.2237	6	19	6	2
7	14	98.8179	0.2453	11	17	11	3
8	13	98.4270	0.3264	5	9	5	3
9	12	97.8168	0.4531	16	18	16	2
10	11	97.6508	0.4875	1	10	1	2
11	10	96.3703	0.7533	8	11	8	4
12	9	95.9712	0.8361	2	6	2	6
13	8	95.2570	0.9843	3	4	3	2
14	7	93.4625	1.3567	1	5	1	5
15	6	90.6753	1.9351	7	16	7	3
16	5	85.7872	2.9495	2	8	2	10
17	4	78.1908	4.5260	1	3	1	7
18	3	61.2595	8.0397	7	20	7	4
19	2	45.5473	11.3004	1	2	1	17
20	1	0.0000	20.7526	1	7	1	21

Final Partition
Number of clusters: 3

	Number of observations	Within cluster sum of squares	Average distance from centroid	Maximum distance from centroid
Cluster1	7	4.76854	0.75152	1.21578
Cluster2	10	4.09897	0.60040	0.92139
Cluster3	4	5.73403	1.11796	1.84708

Cluster Centroids

Variable	Cluster1	Cluster2	Cluster3	Grand centroid
Lean P	0.06611	-0.610412	1.41033	-0.0000000
SS P	1.13546	-0.502649	-0.73044	0.0000000

Distances Between Cluster Centroids

	Cluster1	Cluster2	Cluster3
Cluster1	0.00000	1.77231	2.29968
Cluster2	1.77231	0.00000	2.03354
Cluster3	2.29968	2.03354	0.00000

Figure 8. Cluster Analysis Amalgamation Table

group of articles as measured by their lean and six sigma index respectively - that are homogenous in nature and are distinctly different from other homogenous groups (Sharma, 1996). The hierarchical method of cluster analysis was performed iteratively. The incremental drop in similarity level is visually apparent in the dendrogram (Figure 9). With each additional step in the amalgamation table, the similarity level drops by values not exceeding 7 until the 18th step which reduces from four clusters to three clusters, dropping the similarity level from 78 to 61. The three cluster solution is the solution after which the similarity level begins to level off, creating a knee effect. The three cluster solution exhibits homogeneity within the clusters and heterogeneity between clusters.

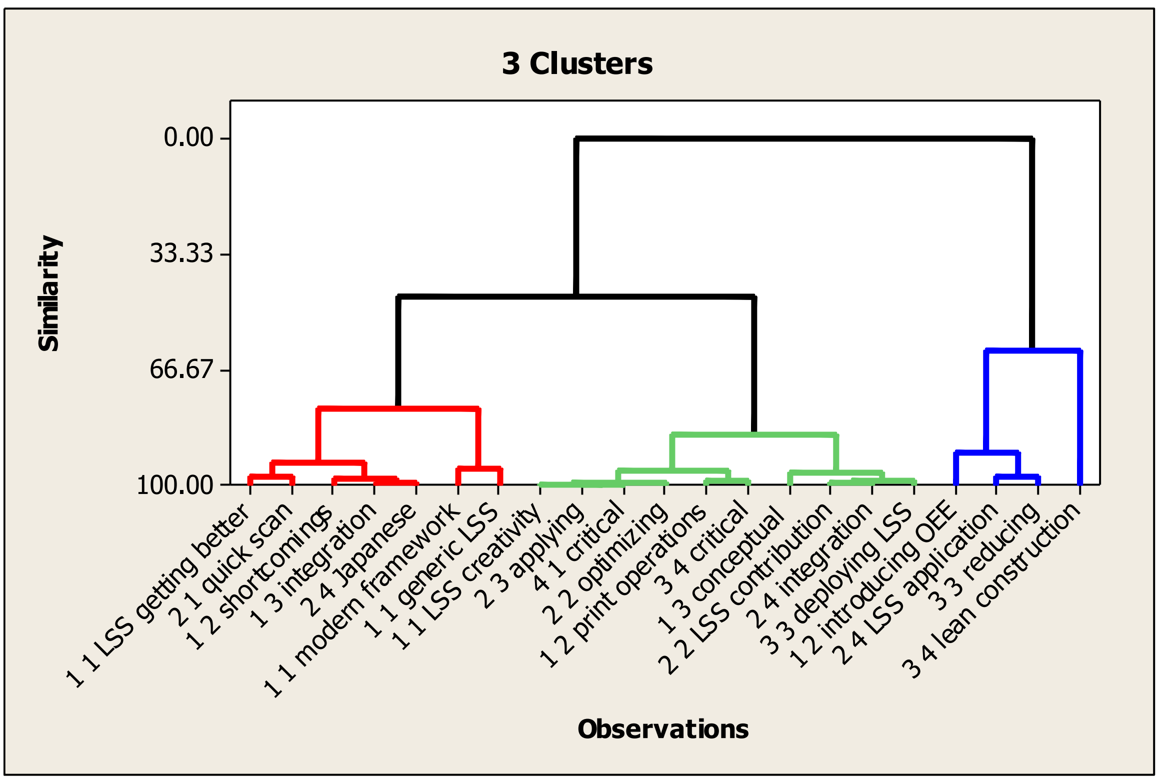

Figure 9. Dendrogram Demonstrating Three Clusters

Hierarchical cluster analysis is an exploratory method wherein the contexts of the derived cluster solutions help to inform the optimal cluster solution (Sharma, 1996). The cluster analysis solution should be evaluated for its interpretability (Sharma, 1996, p. 217). Investigations into the content of the articles may reveal some characteristics that might suggest that additional clusters are warranted. This would indicate that the totality of LSS models are not concentrated only in the lean or six sigma dominant models, as hypothesized. The articles in the three cluster solution were targeted for context evaluation as pertains to their level of lean and six sigma indices respectively.

Hypothesis Statement Three: Statistical Confirmation of Cluster Analysis Results

The three clusters are graphically depicted in a scatter plot (Figure 10) wherein the two variables are the lean and six sigma indices respectively. The three clusters are coded as black (circle symbol), red (square symbol), and green (diamond symbol).

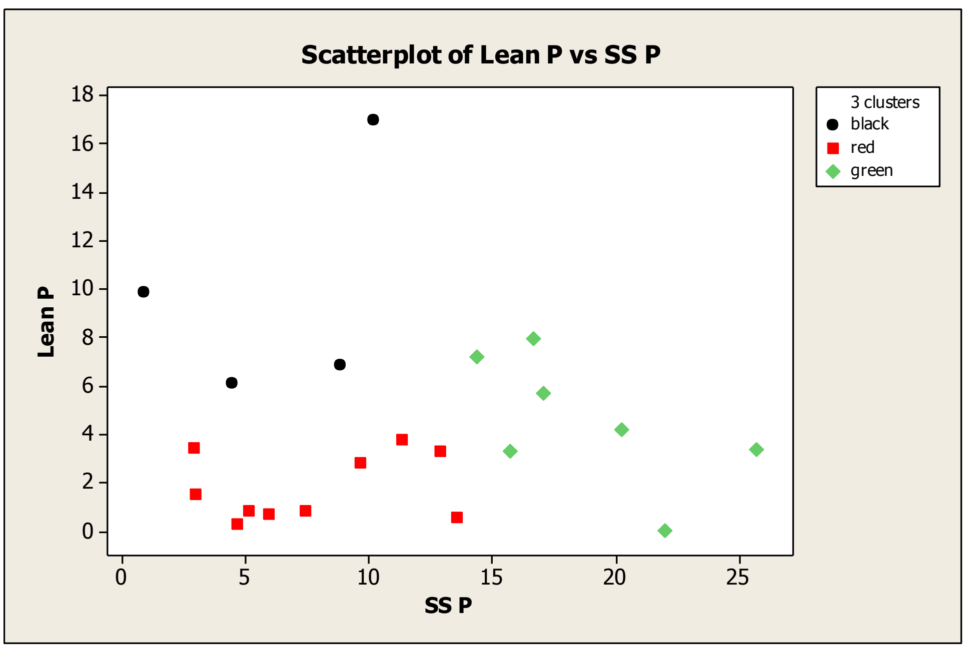

Figure 10. Scatterplot of Lean Index versus Six Sigma Index

The green cluster appears to have the largest percentage of six sigma key words. The black cluster appears to have the largest percentage of lean key words. The red cluster has a small percentage of both Lean and Six Sigma key words. This is confirmed statistically with one-way ANOVA (Figure 11), as per methodology step four. At least one cluster lean index mean is statistically different as verified by the 0.00 p-value. Visual observation of the Figure 11 sample means and respective confidence intervals, as well as of the corresponding individual value plot (Figure 12) makes clear that the black cluster has a statistically higher lean index mean than do

One-way ANOVA: Lean P versus 3 clusters

```
Source       DF      SS     MS      F      P
3 clusters    2  190.08  95.04  12.72  0.000
Error        18  134.49   7.47
Total        20  324.57

S = 2.733   R-Sq = 58.56%   R-Sq(adj) = 53.96%


                          Individual 95% CIs For Mean Based on Pooled StDev
Level   N   Mean  StDev   +---------+---------+---------+---------
black   4  9.942  4.971                     (-------*--------)
red    10  1.801  1.360   (----*----)
green   7  4.527  2.699          (-----*-----)
                          +---------+---------+---------+---------
                        0.0       3.5       7.0      10.5

Pooled StDev = 2.733
```

Figure 11. One Way ANOVA of Three Clusters by Lean Index

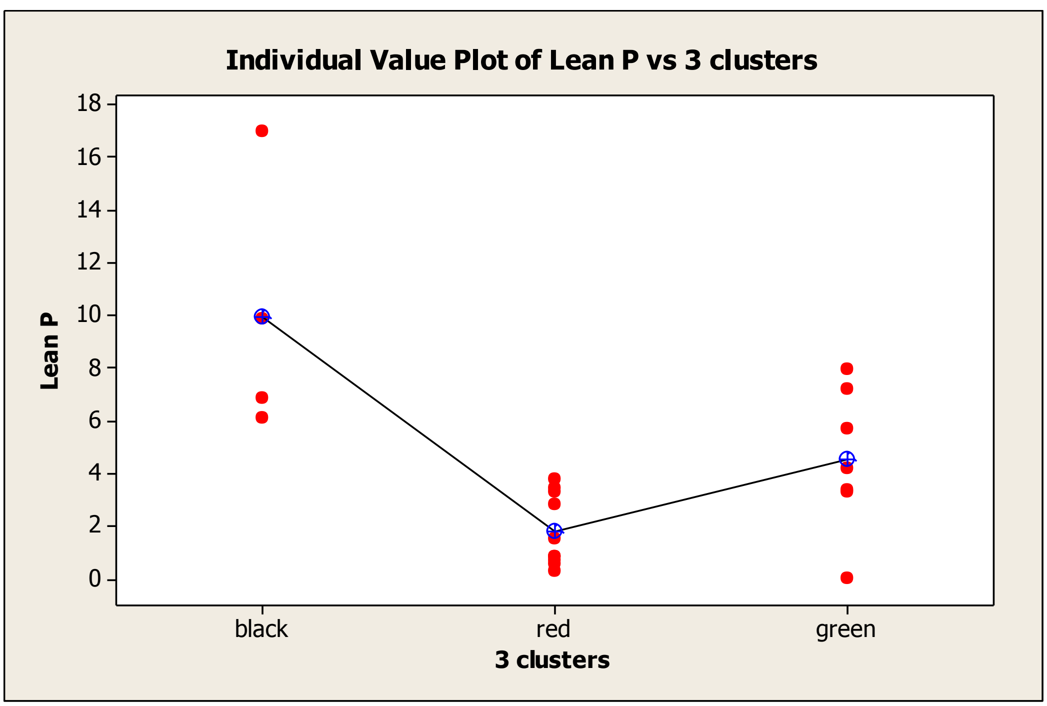

Figure 12. Individual Value Plot of Three Clusters by Lean Index

the other two clusters, statistically validating the cluster analysis. Similarly, utilizing the six sigma index, the green cluster has far and away the largest mean proportion of six sigma key words (Figures 13 and 14).

One-way ANOVA: SS P versus 3 clusters

```
Source       DF     SS     MS      F      P
3 clusters    2  636.3  318.1  19.51  0.000
Error        18  293.6   16.3
Total        20  929.8

S = 4.038   R-Sq = 68.43%   R-Sq(adj) = 64.92%


                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level    N    Mean  StDev  -------+---------+---------+---------+--
black    4   6.090  4.250  (------*------)
red     10   7.643  3.984       (----*---)
green    7  18.813  4.010                         (----*-----)
                           -------+---------+---------+---------+--
                                6.0      12.0      18.0      24.0

Pooled StDev = 4.038
```

Figure 13. One Way ANOVA of Three Clusters by Six Sigma Index

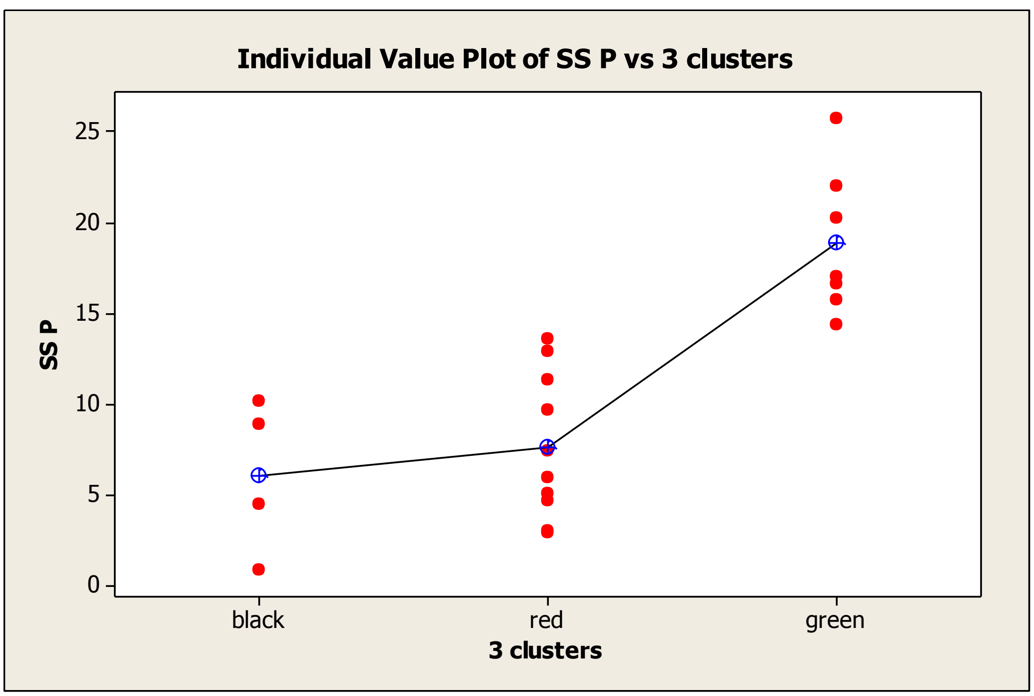

Figure 14. Individual Value Plot of Three Clusters by Six Sigma Index

There is not an inverse relationship between the proportion of lean key words and the proportion of six sigma key words, converse to what might be expected if the data mined LSS articles pertain to either lean dominant or six sigma dominant models only. The red cluster contains articles consisting of a comparably small indices, both lean and six sigma. The presence of this red cluster likely obscures a statistically validated inverse relationship.

Cluster Analysis Interpretation

Based upon the above research findings, according to step five of the methodology, the identified clusters were assessed for distinct inherent characteristics, for the purpose of identifying specific lean six sigma models. Investigation into the content of the articles identified four categories into which to sort the articles. These categories are defined as follows:

1. LSS=SS – These are articles for which the LSS method is basically the six sigma method yet rebranded as LSS
2. lSS – These are articles for which the LSS models are six sigma dominant (upper case SS) and lean subordinate (lower case l)
3. integrated – These articles integrated the lean and six sigma approaches together into a single tool box, for which the problem being addressed will determine the relative lean/six sigma emphasis and which corresponding tools will be utilized
4. Lss – These are articles for which the LSS models are lean dominant (upper case L) and six sigma subordinate (lower case ss)

One article was deemed to have insufficient information pertaining to LSS and has been categorized as NA. A scatter plot of the three clusters is shown in Figure 15, with the abovementioned categories identified.

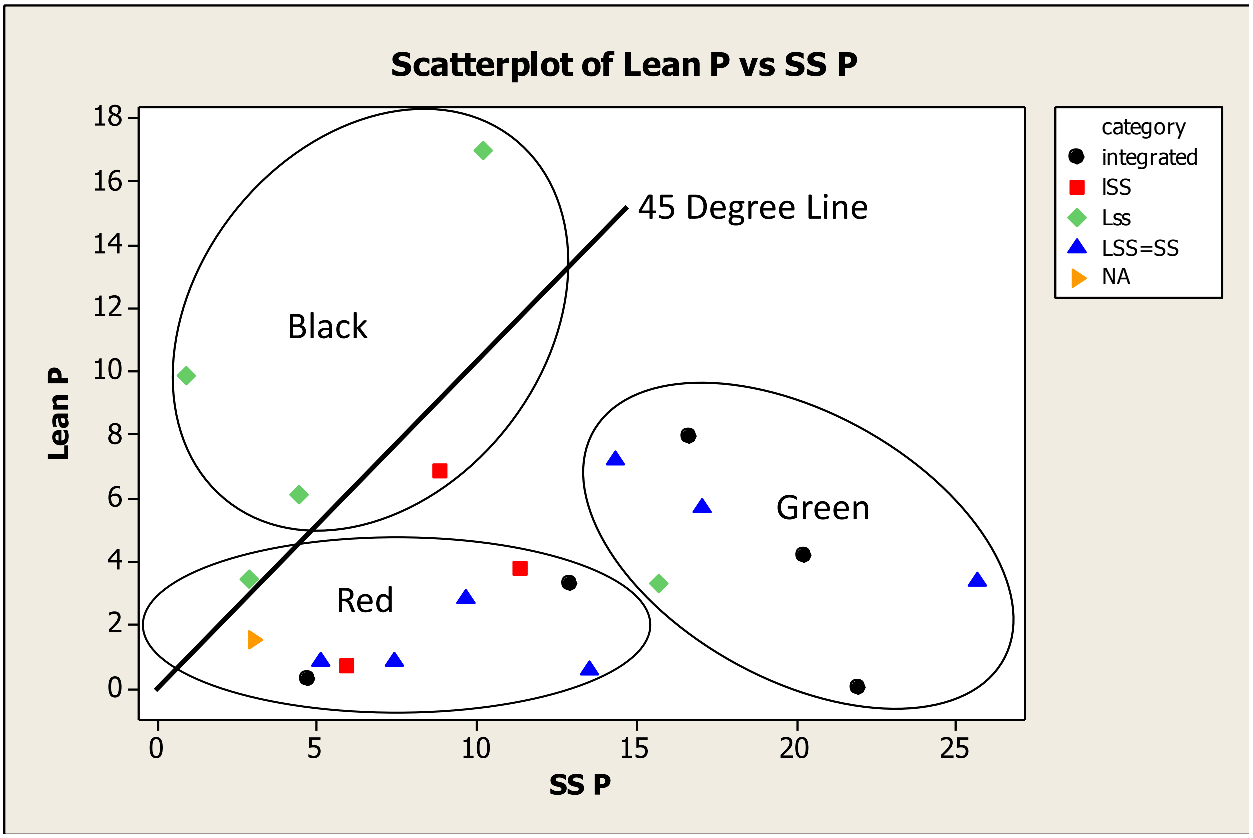

Figure 15. Scatterplot of Three Clusters by LSS Model Categorization

The Lss models fit effectively into the upper left black cluster, which was derived based upon a high proportion of lean key words and a low proportion of six sigma key words. All but one Lss model falls above the forty five degree diagonal which identifies an equal proportion of lean and six sigma key words. The LSS=SS and lSS models fall into both of the remaining two clusters which consist of a low proportion of lean key words. In fact, none of the LSS=SS and lSS models falls above the forty five degree diagonal. The integrated articles also fall into the two lower clusters. Theoretically, these integrated articles would tend to fall along the forty five degree diagonal. The article designated NA has been determined to provide insufficient description so as to prohibit assignment to a category, and was therefore eliminated from forth going analysis.

Subsequent Cluster Analysis

Further investigation into those articles which were the furthest displaced from their respective clusters was conducted. New key words dominant in those articles were identified. A subsequent cluster analysis was conducted with the addition of those newly discovered key words. This practice is consistent with the exploratory approach of iteratively optimizing the clusters until the most interpretive solution is discovered (Sharma, 1996).

Upon review of six sigma dominant articles, it was determine that two additional six sigma key words needed to be added to the analysis. Those words were "quality" and "optimiz." The truncated root word “optimize” captures the words “optimize”, “optimizing”, and “optimization”, which along with the word “quality”, are more distinctly related to six sigma than to lean.

The cluster analysis was performed with the linkages set to single, which has the "advantage for identifying nonhomogeneous clusters" (Sharma, 1996, p. 217) as suspected for the Lss category. The optimal dendrogram (Figure 16) results in 6 clusters. In the dendrogram,

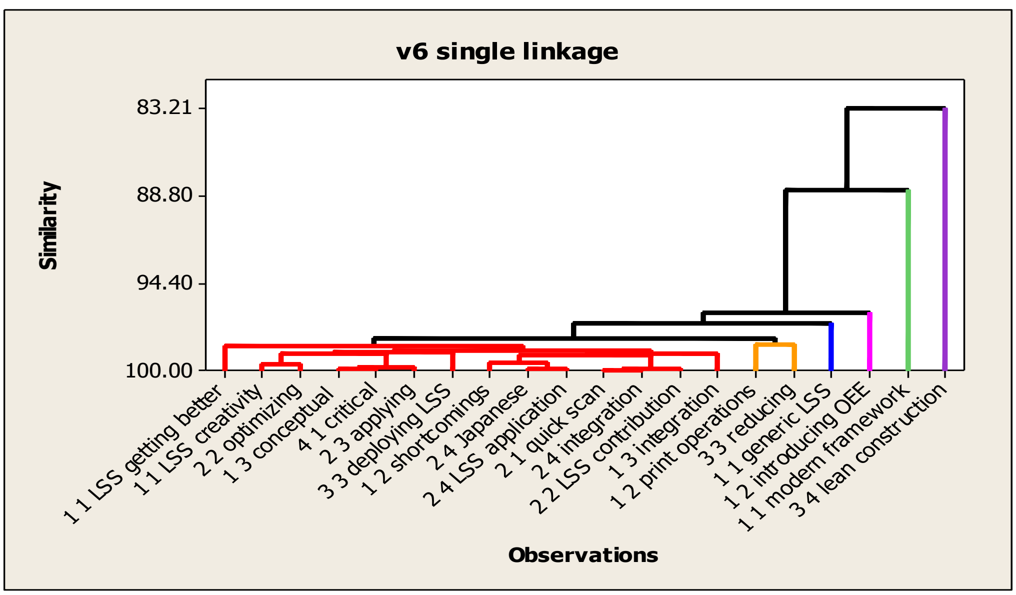

Figure 16. Dendrogram for Subsequent Cluster Analysis

the four articles to the far right are single article clusters. The fifth and sixth article from the right – "1 2 print operations" and "33 reducing" – make up the fifth cluster. All other articles to the left of "1 2 print operations" make up the final catch-all cluster.

Three of the clusters contain only Lss articles. One single article cluster contains an integrated model, and one single article cluster contains a LSS=SS model**.** The remaining catch-all cluster contains a mix of all remaining articles.

Statistical Confirmation of Subsequent Cluster Analysis

A new scatter plot (Figure 17) was created based upon the addition of the new key words. The Lss articles, being lean dominant, was expected to have larger ratio of lean index to six

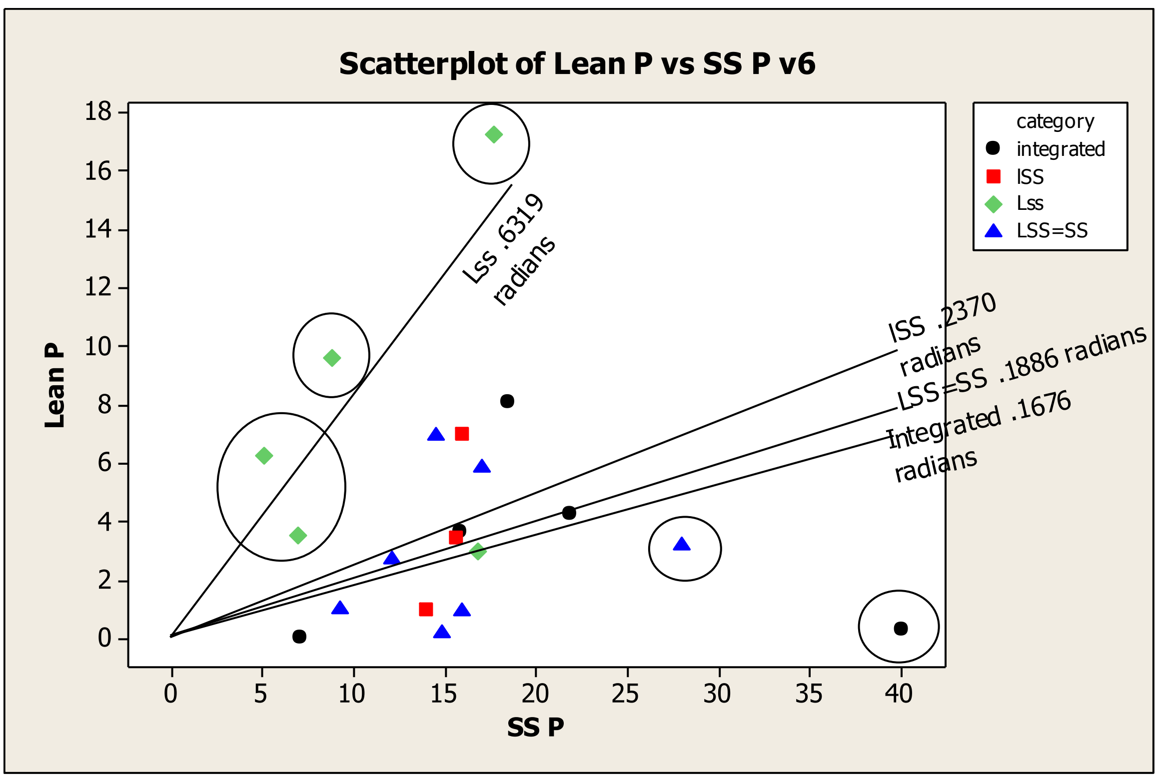

Figure 17. Scatterplot of Subsequent Cluster Analysis

sigma index, as compared to other models. A convenient way to display this condition with a single measure is based upon the polar coordinate system. Taking the horizontal line at lean index equals zero and measuring counterclockwise, the angle for each data point was identified. Visually it can be seen that four of the five largest polar angles are attributable to Lss data points as is expected. A one-way ANOVA (Figure 18) was conducted to determine if the observed

One-way ANOVA: angle (radians) versus category

```
Source    DF      SS      MS     F      P
category   3  0.7372  0.2457  6.14  0.006
Error     16  0.6399  0.0400
Total     19  1.3771

S = 0.2000   R-Sq = 53.53%   R-Sq(adj) = 44.82%


                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level       N    Mean   StDev   -+---------+---------+---------+--------
integrated  5  0.1676  0.1585   (-------*------)
lSS         3  0.2370  0.1833    (---------*---------)
Lss         5  0.6319  0.2836                      (------*-------)
LSS=SS      7  0.1886  0.1584     (------*-----)
                                -+---------+---------+---------+--------
                               0.00      0.25      0.50      0.75

Pooled StDev = 0.2000
```

Figure 18. One Way ANOVA of Mean Polar Angle by LSS Model

differences in mean polar angles, by category, are statistically significant. The p-value of 0.006 indicates that the polar angle means (radians) of the four categories are not equal and it is clear from the Figure 18 grouping table with 95% confidence intervals that the mean of the Lss group, 0.6319 radians, is the mean that differs from all others. The remaining groups have significant overlap in their confidence intervals. This is evidence that the Lss articles, which present LSS models which are lean dominant, have a higher ratio of lean key words as compared to six sigma key words, than do the three remaining models, which are either six sigma dominant or of an equal integration. The key words are not sufficient for parsing the remaining three LSS model categories.

Interpretation

The methodology step five was conducted by assessing the articles contained within the identified clusters, in order to determine what makes the clusters unique. The reason for the three Lss clusters is clearly attributable to their Lss nature, however the reasons that the single integrated cluster and single LSS=SS cluster are unique were not understood and were therefore investigated. The findings are as follows:

1. The far right cluster in Figure 17 consists of an article that describes a very unique and distinct model that integrates six sigma DMAIC, DFSS, lean and Deming principles into a single framework that is very conceptual in nature and not very prescriptive in detail.
2. The second most far right cluster in Figure 17 consists of an article that describes a LSS model that is essentially equal to six sigma (LSS=SS). The reason that it is far to the right of the main catch-all cluster is because the focus of the article is on improving project definitions. The word “project” is a key word for six sigma and the many occurrences of the phrase “project definition” or “defining projects” has inflated the six sigma index. Removing the 23% of the occurrences of the key word “project” that are associated with “project definition” or “defining projects” would move this article back into the realm of the catch-all cluster.
3. The cluster at the top of Figure 17 consists of a lean dominant LSS model (Lss) that contains very little integration of six sigma.
4. The next highest cluster in Figure 17 consists of a Lss model that describes a bit more six sigma integration in that an actual DMAIC project is referenced.
5. The two-article cluster in the far left side of Figure 17 consists of two Lss models wherein greater six sigma integration is achieved however lean remains dominant.

6. The articles in the remaining catch-all cluster were not further examined.

Summary

In this chapter, the results of the data collection and analysis were described. The statistical significance of hypothesized relationships was examined. The cluster analysis was iteratively deployed so as to identify hypothesized lean six sigma models. The identified clusters were statistically tested for heterogeneity between LSS models. The intent was to answer the research questions pertaining to the hypothesized LSS models. The research assumes that the key words selected are good proxies for lean and six sigma dominant models respectively.

CHAPTER 5

DISCUSSION AND RECOMMENDATIONS

The objective of this chapter was to determine the answers to the research questions as informed by data mining of lean six sigma articles and the LSS models contained therein. Cluster analysis was used to determine if hypothesized models existed. The cluster analysis was statistically validated with one-way ANOVA. The fifth and final research question was addressed by the recommendation of an optimal LSS model as informed by the data mining analysis as well as an extrapolation of articles cited and analyzed.

Research Questions One and Two

The research has demonstrated that there are varying interpretations of LSS and as such there is no one LSS model that can be compared to either lean or six sigma. All of the articles assessed contained LSS models which consisted of six sigma to some degree, which is not typical of the classical lean model. That is not to say that all organizations that embrace lean do not use statistical methodologies typified in six sigma. Toyota uses every tool that is part of the six sigma tool box (Liker, 2004, p. 252) however they do not have a six sigma program per se.

Conversely, one of the LSS models identified in the research was categorized as LSS=SS in that these LSS models are no different from other improvement models that are simply coined as six sigma (Chiarini, 2011, pp. 348-349; Duarte *et al*, 2012, pp. 189-190). For these models, LSS is not different from six sigma

Research Question Three

The data mining criteria used the following key words associated with lean; “waste”, “value” and “kaizen.” Given that the lean dominant lean six sigma (Lss) model was identified and validated via cluster analysis and one-way ANOVA, it can be postulated that these key words represent distinct characteristics of the Lss model. The five articles associated with this model ascertain lean as the dominant philosophy, and that six sigma was one tool among others that can be utilized in support of the lean objectives (Gibbons & Burgess, 2010, p. 136). Some Lss case studies demonstrate the use of six sigma DMAIC in order to achieve lean objectives such as the reduction of waste and non-value added activities (Roth & Franchetti, 2010), and the removal of bottlenecks that have stagnated lean progress (Thomas & Barton, 2011, p. 53).

Research Question Four

The data mining criteria used the following key words associated with six sigma: “DMAIC”, “variation”, “statistical”, “statistics”, “project” and “define.” The data mining research did not result in a homogenous six sigma dominant (lSS) LSS model. lSS models occupied the same clusters as the LSS=SS models as well as the LSS models that merge lean and six sigma to a more or less equal degree (integrated).

Research Question Five: Best Derived Model for LSS

These differing LSS models were evaluated for meeting the intent of the root methodologies, lean and six sigma, as well as for continuous improvement theory in general. A LSS model which best satisfies these intents was derived and recommended.

The major finding of the data mining analysis and resulting scatterplot is that the lean dominant LSS model is a distinct, albeit minority, version of LSS. All other versions – except for two special cases – are indistinguishable from the catch-all cluster. A model that is not currently textually articulated has been derived and is being recommended. Key words from a heretofore nonexistent description are not available for calculating lean and six sigma indices respectively. It is therefore not yet possible to overlay the recommended model onto the analysis scatterplot. It is hypothesized that such a model would fall along the Lss angle of 0.6319 radians, reflecting a dominance of lean over six sigma.

The selection of a lean dominant (Lss) model should not only be consistent with Lss models identified on the scatterplot, but should also be supported by logic and theory as supported with citations from the articles that served as the source of the data mining study, as well as by references identified in the literature.

The derived and recommended model differs from any other model identified thus far in that it introduces statistical process control (SPC) as another tactic, wherein the model is hereby named Lean-six sigma-spc (Lssspc). These three methods, one dominant and two subordinate, have been synthesized into a derived and recommended model, as supported by the literature. This model, which is informed by the data mining research as well as an extrapolation of the literature, is shown in Figure 19.

This model is a lean dominant model that holds up lean as the strategic element (Hines, Holwe & Rich, 2004, p. 1006; Pepper & Spedding, 2010, p. 150). The lean model consists of establishing a target condition, comparing that target to the current condition, and then following the established lean principles and practices – in particular the plan-do-check-act (PDCA) method of continual kaizen experimentation by the workforce at large – in pursuit of the target condition (Rother, 2010). Not only will the process be improved, but organizational learning will

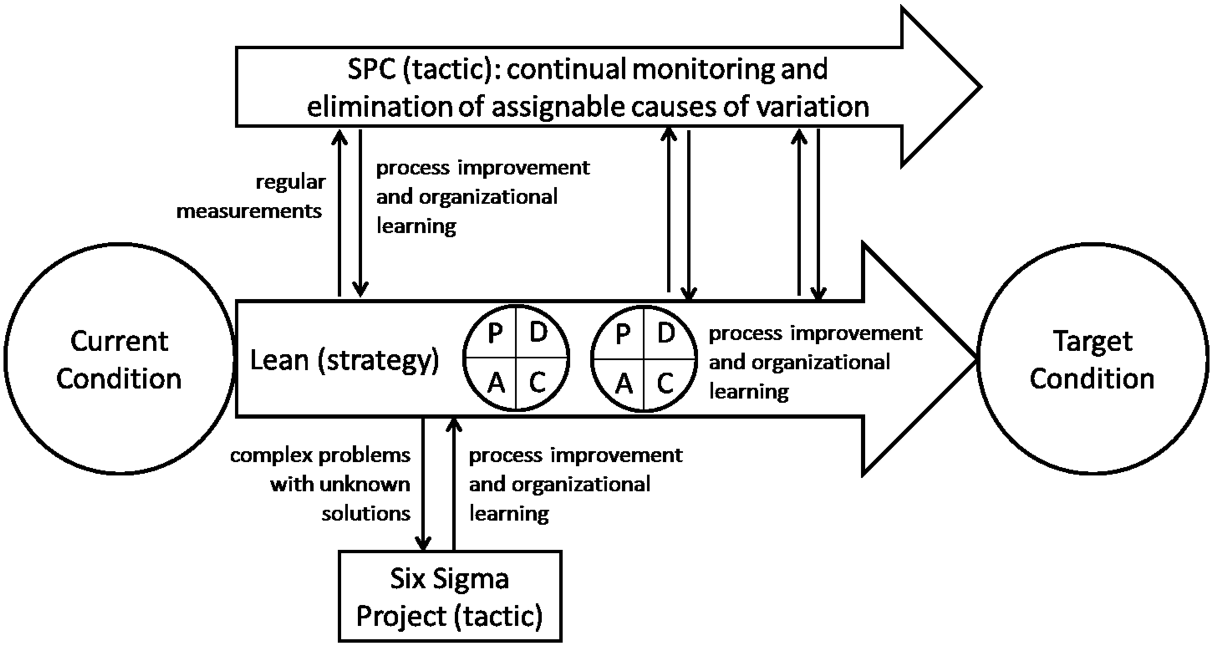

Figure 19. Derived and Recommended Lean-six sigma-spc (Lssspc) Model

occur, which may largely contribute to a sustaining competitive advantage (Behling, 2014; deMast, 2006). In support of this lean dominant strategy, there are two supporting tactics that operate in parallel. Six sigma can be used as a tactical project tool to address complex problems with unknown solutions (Hoerl & Gardner, 2010, p. 31; Snee, 2010, p. 14), as depicted in the LSS model proposed by Pepper and Spedding (2010, p. 150). For each six sigma project deployed as such, processes will be improved and organizational learning will occur. Finally, statistical process control (SPC) will be deployed at regular intervals for monitoring key metrics, and elimination of assignable cause variation detected therein (Wheeler, 2007). This practice also leads to process improvement and organizational learning.

Discussion

The data mining research corroborates the presumption that lean six sigma is not standardized. At one extreme is the article “A Lean Construction Framework With Six Sigma Rating” which projects a lean dominant LSS model. Focusing on the construction industry, “lean thinking and lean principles" are embraced and emphasized reflecting a lean dominant approach wherein Six Sigma "play(s) a complementary role to lean" (p. 301). At the other extreme is the article "Lean Six Sigma – Getting Better all the Time" which is a LSS=SS article. The authors claim that LSS is a "unified framework" (p. 39) within which LSS projects are "managed strictly according to….DMAIC" (p. 40). This LSS=SS extreme is anecdotally very prevalent in the consulting and publishing realms. This writer conducts Six Sigma seminars using a resource provided by Open Source Six Sigma which is entitled *Lean Six Sigma Black Belt* (2007). This training manual is essentially the same as the Six Sigma manuals that this writer has used for many years. Another supplementary LSS resource that is used by this writer "focuses on Six Sigma combined with a selection of key lean tools" (p. 4). To this extent, LSS=SS has an apparent large following as a standardized approach that differs little from classical six sigma.

Some variants of LSS use the six sigma DMAIC framework as the foundation yet deviate from the LSS=SS model by varying degrees of lean integration. These forms of integration typically are an integration of tools, which reflect lean as a tool box, not lean as strategy (Hines *et al*, 2004, p. 1006). An integrated model that does not clearly reflect lean nor six sigma dominance is "Integration of Lean Six-Sigma with ISO 9001:2008 Standard." This model follows the six sigma DMAIC framework but more fully integrates lean tools through each phase.

There is a broad agreement that lean and six sigma can and should be profitably merged (Assarlind *et al*, 2012, pp. 22-33). A unified approach to lean six sigma is desired (Marsh *et al*, 2011, p. 42; Ngo, 2010, pp. 1-2). Marsh *et al* (2011) posit that it would require a single organization to exert an influence of such magnitude that the mass of practitioners would adopt a single approach. They question how this objective could possibly be achieved given that "LSS is so recognized and already well into its lifecycle within industry, it could be possible that this step in its evolution will be missed altogether" (Marsh *et al*, 2011, p. 42).

An important distinction concerning improvement methodologies pertains to why they benefit the organization that adopts and implements them De Mast (2006) that the sustaining benefit of six sigma is not in the results that are realized project-by-project. These results, he argues, can be replicated by competitors which enable an organization to not suffer competitive disadvantage, they are not a source of sustainable competitive advantage. His research argues that sustainable competitive advantage is generated by the competencies that are developed as a result of practicing six sigma. These competencies, developed as in organizational learning are not easily replicated. Hines *et al* (2004) also use the vehicle of organizational learning to describe how lean has evolved from a tool based tactical tool to a strategy that "seeks to maximize the learning opportunities for employees" (p. 1005). Each potential revision is addressed according to the scientific method wherein subsequent analysis build on the knowledge gained previously. These improvement loops provide project results in the immediate and organizational learning as a long term investment. Approaches to immediate results and organizational learning are afforded in the proposed LSS model in three ways. The PDCA method as used by Toyota (and others) is the cornerstone of the lean strategic approach (Rother, 2010). The lower level problem solving methods typically used in lean, such as PDCA, are often insufficient for resolving complex matters (Pepper & Spedding, 2010, p. 151). Therefore the six sigma approach of addressing complex problems in a tactical way (Pepper & Spedding, 2010) is merged into this model. Thirdly, statistical process control is continually applied to process metrics as a tactical means of identifying and correcting special causes of variation, and as is often the case, defects). Classical six sigma models consider SPC as a subset of six sigma, predominantly in the control phase as a monitoring tool (Stauffer, 2008, p.56). There are some that argue for a more integrated approach of SPC in the measure and/or analyze phases, given that some problems are of an assignable cause nature and can be resolved more efficiently with SPC than with the six sigma project method (Stauffer, 2008, p. 58; Wheeler, 2007, p. 10). It is this theory and logic upon which SPC was integrated into the model.

An important criteria for consideration for all manner of LSS models is the degree to which its emphasis is on tactical versus strategic. While six sigma has been proposed as a strategic approach, lean has clearly been delineated as a long term strategy (Hines *et* al, 2004) that is exemplified by such world class organizations as Toyota. For this purpose, in agreement with Pepper and Spedding (2010), this recommended LSS model presents lean as the superordinate strategic framework, supported tactically by six sigma and statistical process control.

Lean, six sigma, and lean six sigma are all variants of continuous improvement systems which have evolved from focused methodologies, primarily originating in manufacturing, to "comprehensive, systematic methodologies that focus on the entire organization" (Bhuiyan & Baghel, 2005, pp. 768-769). Organizations will continue to evolve their improvement methodologies and as such, there is only a limited shelf life for any given model. As in the marketplace of goods as well as with the marketplace of ideas, those that bring value will sustain and those that are inferior will be neglected.

Implications and Future Work

The results of this study indicate that lean six sigma models can be organized into unique and distinct categories based upon key terms utilized in describing them in research articles, by way of cluster analysis. Most models are considered in this body of research were of a six sigma dominant nature or of a balanced integration, however the spectrum of these variants could not be distinguished based upon key terms utilized. Future text mining research should be deployed using different key terms that might better be able to provide some discrimination. The determination of such terms will further inform the underlying LSS models.

The identification of a distinct lean dominant LSS model implies that such that the variation amongst such models is greater than the variation between these lean dominant models and all other models, as in one-way ANOVA type of thinking.

There are implications for practitioners in that many organizations are utilizing all three approaches; lean, six sigma, and statistical process control. Wherein explicit models of integration ma have heretofore been nonexistent, such integration may be haphazard, which is not recommended (Assarlind *et al*, 2012, p. 22). The model developed in this research provides such a framework for consideration. It is recommended that case study organizations that utilize such a model be identified and studied for objective assessment of the model.

Opportunities for future research abound given that the nature of cluster analysis is bounded only by the algorithms selected. Continued search for an algorithm that distinguishes six sigma dominant lean six sigma models from integrated models is an area recommended for future research.

Future work related to lean six sigma models in general, and this optimal model in particular, is recommended. One such work can be along theoretical lines in further developing a model which incorporates lean as the dominant component and six sigma and statistical process control as subordinate components. Other recommended opportunities for future work includes practical studies consisting of case study data that reflect the execution of the optimal lean six sigma model described in the work, as a means of assessing the effectiveness of the model herein.

Summary

The objective of this chapter was to answer the research questions as informed by the research. The research consisted of data mining of lean six sigma articles and the LSS models contained therein. Cluster analysis was used to determine if hypothesized models existed. The cluster analysis was statistically validated with one-way ANOVA. The fifth and final research question was addressed by the recommendation of an optimal LSS model as informed by the data mining analysis as well as an extrapolation of articles cited and analyzed. The derived and recommended model is a hybrid that consists of lean as the superordinate strategic element. Six sigma is used as supporting tactical elements, for the purpose of addressing complex problems with unknown solutions that are incurred. Statistical process control is also used as a continual tactical tool for monitoring and addressing assignable cause variation in real time. The model is a holistic model that contributes to process improvement and organizational learning, a chief contributor to organizational competitive advantage.

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APPENDIX A: *INTERNATIONAL JOURNAL OF LEAN SIX SIGMA* ARTICLES USED AS THE SOURCE FOR THIS STUDY

Title	Volume, Issue	pp
Lean Six Sigma – getting better all the time	1,1	9-29
Lean Six Sigma, creativity, and innovation	1,1	30-38
Generic Lean Six Sigma project definitions in publishing	1,1	39-55
A modern framework for achieving enterprise excellence	1,1	56-65
Process improvements projects shortcomings and resolutions	1,2	92-98
Process improvement for printing operations through the DMAIC Lean Six Sigma approach	1,2	119-133
Introducing OEE as a measure of lean Six Sigma capability	1,2	134-156
A conceptual framework for critical success factors of lean Six Sigma	1,3	191-215
The integration of Six Sigma and lean management	1,3	249-274
Using the Quick Scan Audit Methodology (QSAM) as a precursor towards successful Lean Six Sigma implementation	2,1	41-54
Lean Six Sigma: the contribution to business excellence	2,2	118-131
Optimizing employee time in a purchasing department: a Six	2,2	180-190

Sigma case study		
APPENDIX A (continued)		
Applying the DOE toolkit on a Lean-and-Green Six Sigma Maritime-Operation Improvement Project	2,3	270-284
Integration of Lean Six-Sigma with ISO 9001:2008 standard	2,4	309-331
Japanese total quality control, TQM, Deming's system of profound knowledge, BPR, Lean and Six Sigma	2,4	332-355
Lean Six-Sigma application in business process outsourced organization	2,4	371-380
Deploying LSS in a global enterprise – project identification	3,3	187-205
Reducing electronic component losses in lean electronics assembly with Six Sigma approach	3,3	206-230
Critical success factors for the effective implementation of Lean Sigma	3,4	274-283
A lean construction framework with Six Sigma rating	3,4	299-314
Critical success factors of Lean Six Sigma for the Malaysian automotive industry	4,1	60-82

APPENDIX B: LEAN VERSUS SIX SIGMA CONTRAST TABLES

Anderssen *et al*, 2006	Table 1	The table shows the author's view concerning the similarities and differences between TQM, six sigma and lean
Antony *et al*, 2003	Table 3	Tools, Techniques and Principles of the Integrated Approach
Chiarini, 2011	Table 1	Results, critical implementation factors and approaches to implementation of the six systems
Salah *et al*, 2010	Table 1	Similarities and the relationship between Six Sigma and lean