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A Taxonomy of the Adoption of Lean Production Tools and Techniques

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To the Graduate Council:

I am submitting herewith a dissertation written by Bradley Mullins Greene entitled "A Taxonomy of the Adoption of Lean Production Tools and Techniques." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Engineering Science.

Kenneth E. Kirby, Major Professor

We have read this dissertation and recommend its acceptance:

James M. Reeve, Mary C. Holcomb, Hampton Liggett, Adedeji Badiru

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Anne Mayhew

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A TAXONOMY OF THE ADOPTION OF LEAN PRODUCTION TOOLS AND TECHNIQUES

A Dissertation Presented
For the Doctor of Philosophy Degree
The University of Tennessee, Knoxville

Bradley M. Greene
December 2002

DEDICATION
To My Wife,
Julie Kerr Greene

ACKNOWLEDGMENTS

When completing a work such as this, you realize that you did not do it alone, and that we all stand on the shoulders of other men and women. There are people who either gave you a chance or an avenue to create, encouraged or exhorted you along the way, or supported you so that you might have the opportunity to pursue your dreams. I have been very blessed to be surrounded by these types of people on this piece of my life's journey, and I would like to take this space to acknowledge some of them.

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ABSTRACT

The purpose of this study is to discover if the pattern of lean tool adoption for mature lean enterprises varies by type of value stream. The study empirically tests the effect of types of production processes, production volume, and order fulfillment strategies on lean production tool adoption in mature lean enterprises. The results of the study show that each of these factors does affect the pattern of tool adoption among mature lean enterprises.

Eleven different value stream profiles are identified in the study (ex. Discrete, Low Volume, Build-to-Order, value stream such as a commercial satellite producer). A binary logistical regression model is developed for each tool and each profile. The results of these models are probabilities that a given value stream profile would adopt a given tool of lean production creating a taxonomy of the adoption of lean production tools.

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CHAPTER 1

INTRODUCTION

The purpose of this study is to discover if the pattern of lean tool adoption for mature lean enterprises varies by type of value stream. The study tests empirically the effect of types of production processes, order fulfillment strategies and production volume on lean production tool adoption in mature lean enterprises. This chapter provides an introduction to this research, including the motivation, an overview, and contributions of the study.

Motivation for the Study

In their 1991 book, The Machine That Changed The World, Womack, Jones and Roos (44) made the statement that not only is lean production a superior way for humans to make things, but that the principles of lean production can be applied in every industry across the globe. For the rest of the book, they unveil the manufacturing, supply chain, and product development techniques that Toyota has used to revolutionize the automotive industry. On the conceptual and strategic level, these authors have been proven correct as over the last ten years industry after industry has begun to apply the principles of lean production. On a tactical level, however, the face of lean production seems to change from company to company and industry to industry. The Toyota Production System, arguably the best system for manufacturing automobiles in the world, is not a one-size-fits-all production system. The following cases from my experience are examples of value streams that are trying to apply the tools of lean production and are vastly different from the automotive production systems.

Lean Production Case 1

A carpet-making mill is interested in applying the tools of lean production to its facility in order to improve inventory turns and reduce their lead times to their distributors. The carpet is woven through many yards of spools in a semi-continuous process. Machines do most of the work, and the only manual labor is setups between batches of carpet, and moving inventory from one part of the process to another. Orders to the distributors are filled from existing inventory, and the company sells millions of yards annually.

<u>Lean Production Case 2</u>

A producer of rocket engines is also interested in applying the tools of lean production to its focused factory in order to improve the lead times to their customer who launches commercial satellites. The engine is made of metal parts, fabricated on precision CNC milling machines. Some parts are made internal and some external. The demand for these rocket engines is about 2/year, and each engine is designed for a specific payload and the current lead-time is approximately 6 months.

The questions that are being asked by companies such as the ones in these cases are:

1) Do the tools of Lean Production apply outside of the automotive industry?
2) If so, which tools apply to my business?
3) How do they apply?

The body of research in the area of Lean Production/ JIT has alluded to the former questions, but never addressed them directly. Sakikabara et al. (36) claim that job shops will not apply all of the dimensions of JIT that repetitive-manufacturers will. Koufteros et al. (26) claim that further research needs to be conducted to determine whether current research instruments can be used across industries. The acknowledgement of the differences in application across industries and types of value streams, however, usually appears at the end of a study, as ideas for future research.

Much of the research in the area lean/JIT has focused on the impact the techniques on operation performance levels. In these studies, the control variables used most often are organizational size, and hierarchical layers of the organization (Claycomb et al., (6), White and Ruch, (42), Droge and Germain, (11)). In a 2001 article by Fullerton and McWatters (14) the authors reported the results of a distribution of respondents to their survey by Standard Industrial Classification code, but did not analyze (or did not have enough data to analyze) their results controlling for this variable.

As noted by Sakikabara et al. (36), while lean/JIT concepts were first applied in high volume repetitive manufacturing environments, the practices are spreading to other industries. Womack and Jones predicted this would happen in <u>The Machine That Changed the World</u> (44). Industry has reached a point in the diffusion of this technology in which a study comparing and contrasting the adoption of these tools across different types of value streams is not only viable but necessary.

Overview of Research Study

This research was developed after a thorough study of the literature of lean/JIT performance. The literature provides definitions for lean production, value streams, the individual tools of lean production, and the independent variables used in the study. The literature also provides the Capability Maturity Methodology that is used to filter the responses for mature lean enterprises.

The primary method of collecting data for this study is an online survey instrument sent by e-mail to lean practitioners through multiple venues. The venues used to solicit survey participants are three consortia of lean practitioners, and alumni of the University of Tennessee lean training. The survey is designed to test the hypotheses represented in the conceptual model in Figure 1. The tools of lean production that are used by a production system are dependent upon the types of production processes used, the production volume,

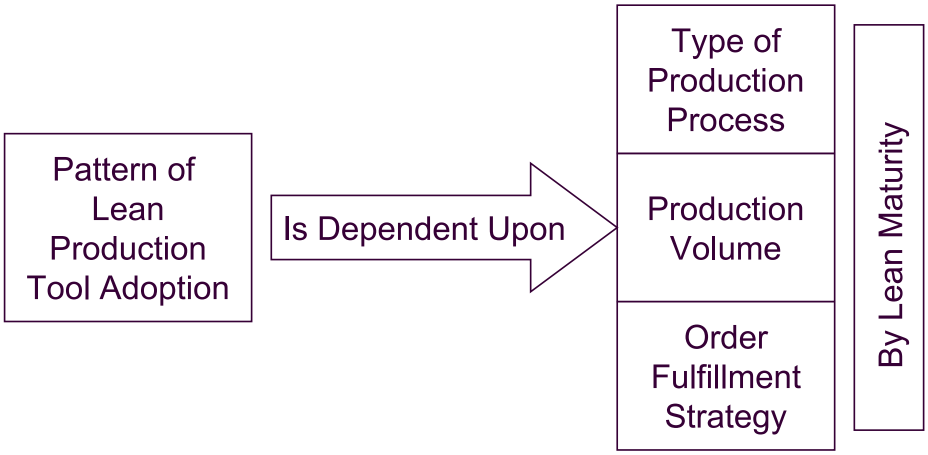

Figure 1: Conceptual Model of Hypothesized Relationships

and the dominant order fulfillment strategy. Companies are only considered in this study if they are determined to be at a high level of lean maturity.

The lean production toolset was determined by studying the proposed toolsets of similar studies and other lean production literature. Twenty-four sources were reviewed to develop the toolset used in this study. Fifteen of the twenty-four sources were books and nine were periodicals. All of the tools included this study, except two (predictive maintenance and reliability-centered maintenance), were defined in at least three sources (see Table 3 on page 25 and Table 4 on page 29). It is important to note here that most of the periodical literature in this area use the term JIT in place of lean production. However, the tools defined in the JIT toolkit are almost identical to the tools defined in the lean production toolset, so for the purposes of this study the term lean production will be used in place of JIT (unless JIT is used in a cited source).

The factors investigated in this study came from several sources. John Nicholas defines types of production systems by volume and size of process, which he classified into types of production processes, in his book, Competitive Manufacturing Management (30) (Figure 9.1, pg. 310). This table was used to derive the levels for the variables types of production process and volume for this study. Nicholas' book also provided the definitions for the order fulfillment strategies used in this study. Articles by Sakikibara et al. (36) and Billesbach (2) allude to the fact that production process type and volume have an effect on the application of lean/JIT tools and techniques.

The dataset in this study is stratified by the level of value stream's overall maturity with respect to lean production. Lean production maturity is tested using the Capability Maturity Model developed by the Software Engineering Institute at Carnegie Mellon University (34). In this methodology the maturity levels are ordinal variables defined by the survey developer, and the participant determines which level is most appropriate for their situation.

The results of this study show that there is a significant difference in the adoption of lean production tools dependent upon the characteristics of the value stream. The factors, Type of Production Processes, Production Volume, and Order Fulfillment Strategy are each tested for their individual impact on the adoption of each tool of the lean production toolkit. The study also provides a proposed taxonomy represented by eleven value stream profiles and the tools of lean production that a company from each profile is most likely to adopt.

Contributions of Research

There are three main areas of contributions by this research. First, the research uses the fundamental concept of the value stream and a thorough review of the literature to develop a broader definition of lean production and the tools that it constitutes. This definition leads to a larger, more comprehensive lean production tool set that incorporate tools traditionally categorized in other areas, such as tools of Quality and Maintenance. This is important because of the proliferation of terminology sets that include similar tools, such as Just-in-Time, Agile Manufacturing, etc. In addition, this study provides a more objective definition of the individual order fulfillment strategies (Build-to-Stock, Make-to-Order, and Build-to-Order). In industry and academics, these terms are often defined from the perspective of the manufacturer as opposed to the customer.

The second major contribution of this research is that the results provide evidence that Type of Production Processes, Production Volume, and Order Fulfillment Strategy do affect the adoption of some of the tools of lean production. These results imply that there is not a standard set of tools of lean production that all companies will adopt.

Finally, the research provides eleven distinct value stream profiles that exhibit distinct patterns of lean production tool adoption. These profiles provide a basis for comparing lean companies in future research. Each of these profiles should be studied at greater depth. There are limitations to the level of generalization that can be made from the results of this study, which will be detailed in the final section, but the research does propose a taxonomy to serve as a conceptual framework for future research.

Problem Statement

In summary, the purpose of this study is to investigate the characteristics of production systems that have an impact on the adoption of lean production tools and techniques. The results of the study provide a methodology for classifying production systems that can be used by researchers in future studies. The method for obtaining the data for this research is an online survey completed by 209 participants representing 154 different companies and 11 different value stream categories. The results of this study should also be of interest to companies undergoing lean transformation by providing a snapshot of the toolkit that is most applicable to their type of production system.

Organization of the Research

This dissertation is organized into four remaining chapters. In Chapter 2, the variables used in the study are thoroughly explained and compared to the relevant research in this area. Chapter 3 provides an explanation of the research methodology used in this study. Chapter 4 presents the results of the data analyses and draws some conclusions from the study. Finally, Chapter 5 summarizes the contributions of the research, discusses the limitations of the study, and suggests areas for extending this research.

CHAPTER 2

RELATED RESEARCH AND DEVELOPMENT OF HYPOTHESES

This chapter uses prior literature to develop hypotheses explaining lean production tool adoption. A brief discussion of the evolution of the tools of lean production is presented first. Next, the factors affecting lean production tool adoption are discussed in the context of related research. Then the research used to develop the control variable, maturity, is presented. Finally the resulting hypotheses are discussed.

Defining Lean Production

Most of the research on the tools and practices of lean production has been done in the last twenty years. However, in this time, researchers still have yet to propose a consistent set of dimensions to define lean production (35). Lean production in its purest form is nothing more than the integration of a myriad of tools and practices some of which were developed under the name of other management revolutions, such as Total Quality Management and Just-in-Time (JIT). Defining lean production as a set of practices borrowed from earlier initiatives with a few additional techniques, poses quite a problem for researchers searching for a consistent definition. This is reflected in the research; it has resulted in a lack of needed theory building in lean production. The purpose of this section is not to provide an exhaustive review of lean production research, but to provide enough background to support the working definition of lean production practices used in this study.

James Womack, Daniel Jones and Daniel Roos coined the term lean production in their book <u>The Machine That Changed the World</u> (44). The book, published in 1990, is the culmination of a five-year study of the automotive industry in the late eighties. The authors actually define a term broader than lean production called the lean enterprise. The lean enterprise is “the mechanism of coordination necessary to bring all these steps [beginning with product design and engineering then going far beyond the factory to the customer who relies on the product for daily living] into harmony…" The elements of the lean enterprise presented in this book are: 1) Lean production: the factory floor, 2) Product Design, 3) Supply Chain Coordination, 4) Customer Integration, and 5) Lean Management (finance, HR, etc.). For the purposes of this research we will concern ourselves with the lean production element. The term lean production was used to characterize the Japanese automakers that were producing the same volume of automobiles with less workers, less inventory, and less floor space, therefore it was a *leaner* way of producing automobiles.

Many of the practices termed lean production in The Machine That Changed the World (43), had been discussed in the literature for almost ten years prior. Richard Schonberger wrote Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity (37) in 1982. This book defines many of the techniques and practices that would become known as "lean production" eight years later. At the time, however, Schonberger referred to the practices as Just-in-Time (JIT) manufacturing. The following year a book by Yasuhiro Monden, called The Toyota Production System: An Integrated Approach to Just-in-Time (29) was published. This book is still seen as the quintessential how-to book on lean production/ JIT.

In 1995, Womack and Jones published a second book on lean, called Lean Thinking (43). This book provides the conceptual framework for categorizing all of the tools and practices of lean production into five basic areas:

1. Value - define value from the standpoint of the customer
2. The Value Stream – view your product delivery system as a continuous flow of processes that add value to the product
3. Flow – the product should constantly be moving through the value stream toward the customer at the pace of demand

4. Pull – products should be pulled through the value stream at the demand of the customer rather than being pushed on the customer
5. Perfection – the never-ending pursuit of eliminating waste in the system such that products can flow seamlessly through the value stream at the rate of demand

This book and specifically its concepts of value stream built upon the already expanded definition of lean production that had been presented in The Machine That Changed the World . Lean was no longer confined to the shop floor, but represented every process between the raw materials taken from the earth to the finished product in the hands of the customer. The difficulty of this paradigm shift to the researcher is that it has essentially cross-functionalized an entire area of study, and the academic community (being extremely functional) was not prepared to handle this. One of the negative results of this is the proliferation of sets of terminology defining essentially the same tools and practices. Each function within the academic community has defined a set of tools from the perspective of their own expertise. Table 1 provides a list of some of the terminology sets that contain some subset of the tools of lean production as proposed in this research. This table is not intended to be an exhaustive list of the terminology sets that exist in both practice and in research, but is intended to present the scope of the challenge facing researchers in this area.

One of the objectives of this research is to propose a more comprehensive definition of lean production tools and practices. In the next chapter, each tool is defined in Table 3, and each source that recognizes that tool is cited in Table 4. The selection criteria for including a tool are based on the conceptual framework of Womack and Jones. Taking the view that production systems are value streams, then the tools of lean production are any practices applied in or around the manufacturing area, that enable the product to flow smoothly through the value stream and eventually to the customer.

Table 1: Overlapping Terminology Sets

Terminology Sets	Alternative Names or Sets	Overarching Category	Academic Functions	Special Emphasis
Total Quality Management	Six Sigma, Total Quality Control	Quality	Management, Statistics, Industrial Engineering	Empowering workforce, statistical tools for instituting quality into product, service, etc.
Statistical Process Control	Six Sigma, Total Quality Control		Management, Statistics, Industrial Engineering	Sometimes subset of TQM, use of control charts to study and eliminate process variation
Design of Experiments	Six Sigma, Total Quality Control		Statistics, Industrial Engineering, Management	Use of statistical methods to design, execute, and analyze industrial experiments.
Lean Production	Lean manufacturing, Cellular manufacturing	Shop Floor Manufacturing Processes	Industrial Engineering	Flow of materials across shop floor
JIT – shop floor practices			Industrial Engineering, Logistics	
Agile Manufacturing			Industrial Engineering	Designing layouts to be changed rapidly
Time-Based Manufacturing			Industrial Engineering	Shrinking lead times
Toyota Production System			Industrial Engineering	Standardizing every process
Supply Chain Management		Managing Supply Base	Industrial Engineering, Logistics, Management	
JIT Supply			Industrial Engineering, Logistics, Management	Suppliers delivering to Point-of-use in small lot quantities
Supplier Integration			Industrial Engineering	
Reliability-Centered Maintenance		Maintenance and Reliability	Industrial, Mechanical, and Electrical Engineering	Developing specific maintenance plans for each critical piece of equipment
Total Productive Maintenance	Autonomous Maintenance		Industrial Engineering	Operator performs daily preventive maintenance

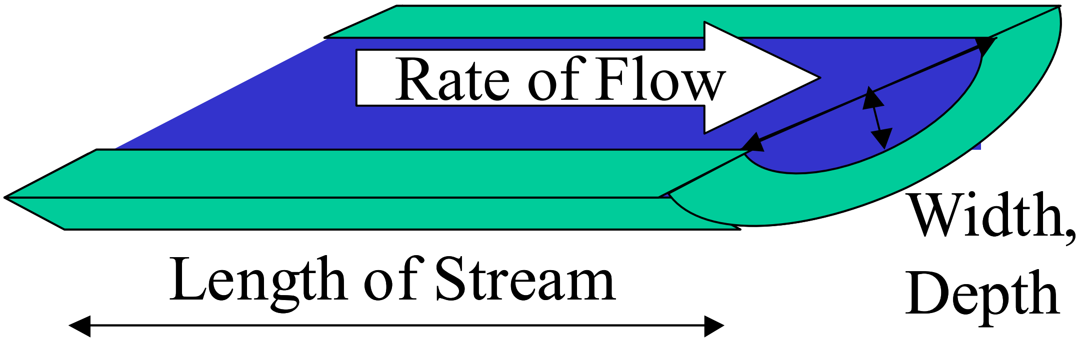

Figure 2: Value Stream Characteristics

Extending the analogy of the stream of value, there are three characteristics of a stream that define the flow through a given section of a stream: (See Figure 2)

1. The rate of flow
2. The dimensions (cross-sectional) of the stream
3. Length of the stream

Using this conceptual framework, the working definition of a tool of lean production is a tool or practice that:

a) Improves the rate of flow (such that it meets the expected rate of the customer); either of information, products, or materials.

And/Or

b) Creates flexibility, (increase the cross-sectional dimensions of the value stream) in capacity or order fulfillment.

And/Or

c) Reduce time in production process (thereby reducing the length of the stream).

The tools that will be identified in the next chapter will come from at least one of these three categories. Subcategories of these criteria are also defined in the next chapter.

Factors Affecting the Adoption of Lean Production Tools

Factors affecting lean tool adoption have been subject to limited research. Some researchers have made passing comments that some tools may not apply to every production system, but none have developed an empirical test to study these hypotheses. Moreover, the specific attributes of a production system that affect lean tool adoption have never been studied directly.

One of the reasons for the lack of research in this specific area may be that the initial adopters of lean practices were of one particular type of production system. The automotive industry is by far the most prolific user of these tools. Sakikibara et al. (35) indicates that as of 1992, JIT practices were common in the US transportation and electronics industries and was spreading to other industries. Both the automotive and electronic industries are high volume, build-to-stock, fabrication/assembly producers. This supports the hypothesis that there was not a need to study how lean is applied in different types of production systems, because there was only one type doing it. However, ten years later, industries that are very different from automotive are trying to apply the tools of lean production.

The following three sections will define and develop the three independent variables used in this study. These three variables are used to define or characterize a value stream profile. One of the fundamentals of lean production espoused by Womack and Jones in their book Lean Thinking (43) is that value and the value stream should be defined from the perspective of the customer. In this study the working definitions for the three factors (independent variables) are defined to reflect the customer's perspective.

Type of Production Process as a Factor

There is some evidence in the literature that researchers recognize that the type of production processes used in a specific production system might affect the application of lean production, but there has not been a definitive study to fully develop these factors. In a 1993 article, Sakikibara et al.(36) states that "although JIT was first adopted in repetitive manufacturing environments, the applicability of JIT to job-shop environments is undeniable." They go on to report that some of the tools of JIT do not apply in these environments, such as Kanban, pull-systems, and repetitive master scheduling. The focus of the paper, however, is on developing an assessment tool for JIT manufacturing. They do include a "where applicable" disclaimer on the tools of Kanban, pull-systems, and repetitive master scheduling, but the assessment maintains its bias toward the repetitive manufacturing environments.

In a 1994 article Thomas Billesbach (2), discusses applying lean production principles to a process facility. Billesbach makes the comment that each company is likely to have its own definition of what constitutes JIT. He goes on to define what JIT is in a process facility, effectively selecting tools from the macro lean production toolkit that fit the situation. The very purpose of the article is to describe the tweaking of JIT to fit the type of production processes found in a Dupont process facility.

Production Volume as a Factor

In the article by Sakakibara et al. (35), the authors observe that "the extent and type of JIT practice differs from job shops to repetitive-manufacturing environments." Two major attributes that differentiate job shops and repetitive-manufacturing are production volume and variety of products produced. The very nature of a job shop makes it a low volume/ high variety environment, so Sakakibara et al. (35) implicitly identify volume as a distinguishing factor affecting the adoption of JIT tools and techniques. The management science field is proliferated with articles on applying lean techniques in a low volume/high variety environment, with the assumption that this is a unique environment to apply these principles.

Order Fulfillment Strategy as a Factor

Order fulfillment strategy is the one factor that is not included in any of the prior studies. It is embedded in the categorization methodology of Umble and Srikanth (40) that will be discussed in the next section, but not stated explicitly. These authors do define order fulfillment strategies as they relate to the location of inventory in the production system. There is also a discussion of using customer-required lead-time to dictate order fulfillment strategies within the same product line. The results of this research provide evidence that companies are beginning to think in this manner, as the majority of companies report using multiple strategies within the same product family. For purposes of analysis, however, the dominant order fulfillment strategy is used to identify a specific value stream profile.

The order fulfillment strategies used in this study are derived from the work of John Nicholas in the book Competitive Manufacturing Management (30). Nicholas classifies all order fulfillment strategies into three categories: Make-to-Stock, Assemble-to-Order, and Make-to-Order. However, Nicholas uses the product structures and the levels at which master production scheduling is performed to guide his definitions of order fulfillment strategies. Using the criterion of defining the characteristics of the value stream from the customer's perspective, the definitions of order fulfillment strategies were altered from Nicholas's. For this study, the criterion used to define an order fulfillment strategy is the customer's required or expected lead-time. Another reason for deviating from Nicholas's definitions is to avoid confounding the effects of other factors in the study. For instance, the use of the terms Assemble-to-Order and Configure-to-Order are exclusive to the discrete-types of production processes.

The three order fulfillment strategies used in this study are: Build-to-Stock, Make-to-Order, and Build-to-Order. The first strategy, Build-to-Stock is used if the customer's expected lead-time is zero (which is the case for most products sold through retail channels, such as toothpaste, etc.) In this strategy the manufacturer must hold finished goods inventory. If the customer's expected lead time is greater than the manufacturers lead time, then the manufacturer can wait until it receives an order to fulfill that order, and therefore Make-to-Order or Build-to-Order.

The difference between Build-to-Order and Make-to-Order is the lead-time of the majority of raw materials and supplied parts. If the customer's expected lead-time is *less* than the lead-time of the manufacturer, then the manufacturer must hold inventory at some point in the production process. That point can be at the level of subassemblies that can be Assembled or Configured-to-Order, such as personal computers and some automobiles, or at the level of fabrication, where parts are machined and/or processed according to a specific order. For purposes of this study, all of these variations of the order fulfillment strategy are considered Make-to-Order.

If the customer's expected lead time is greater than the lead time of the manufacturer *and* the majority of the supplied parts then the manufacturer will use a Build-to-Order strategy. This means that the orders from the customer will then be placed on the supplier as well. A variation of the Build-to-Order strategy is the Engineer-to-Order strategy, in which the product is engineered and produced to a specific order.

One factor that is not included in this study, but is embedded in order fulfillment strategy is that of product complexity. As customer expected lead-time becomes smaller and smaller, companies must build ahead and therefore the risk of holding inventory on too many end-items increases. Just the opposite is true as well; as customer expected lead-time increases, the company can afford to customize the product to exact specifications, thereby exploding the number of end-items that can be created.

Categorization Methodology of Synchronous Management

Perhaps the best attempt to provide a method of categorizing production processes is found in a book by Michael Umble and Mokshagundam Srikanth called Synchronous Management (40). The book is published in two volumes, with the first book describing the concepts of synchronous management and the second detailing implementation issues and providing case studies. Synchronous management is a term defined by the authors for a group of tools and techniques referred to as the Theory of Constraints, popularized by Eli Goldratt in his book The Goal. Some of the tools in this toolset are also defined as tools of lean production (i.e. setup reduction, pull production using Drum-Buffer-Rope, etc.). In particular the tools of scheduling and producing material flow are similar. However, the synchronous management toolset does not address the tools and practices used at the cell level, such as standard work, and cross-trained workers, and the only method of pull production that is fully addressed is the Drum-Buffer-Rope method (production is pulled based on the production at the bottleneck).

In Volume 2 of Synchronous Management (40), Umble and Srikanth categorize all production systems into four categories:

1. V-plants – plants that convert basic raw materials or partially processed items into a variety of end items, sold either as consumer goods or as materials or component parts for other manufacturers, including assembly plants. (Ex. Pharmaceuticals, petroleum, chemicals)

2. A-plants – plants that build relatively few distinct products composed of mostly different components. (Ex. Automobiles, appliances)

3. T-plants – plants that assemble final products using a number of component parts, most of which are common to many different final products. (Ex. Configure-to-order computers)

4. Combination plants – plants that have some combination of the three aforementioned categories. (V-T,A-T,V-A,V-A-T, AV-T)

The VAT classification method encompasses all three of the factors studied in this research as can be seen in Table 2. However, for this study, it was decided to fully investigate the underlying factors as they affect the application of lean production tools before rolling them up into an aggregate category represented in the VAT classification.

Lean Maturity as a Stratification Variable

Many of the studies on the affects of implementing lean/JIT on performance metrics use lean/JIT maturity as a control variable (Fullerton and McWatters (14), Claycomb, Germain, and Droge (6)). The researchers are interested in understanding whether the more mature companies have outperformed the less mature companies in a certain performance metric. In this study, only value streams exhibiting high levels of maturity are included in the analysis of tool adoption patterns. The hypothesis is that there is a learning curve associated with applying certain of the lean tools, so more mature companies should be applying more of the tools, and will have determined whether or not some of the tools are applicable.

The method of measuring maturity is an adaptation of the Capability Maturity Model developed by the Software Engineering Institute (SEI) at Carnegie Mellon University from 1986-1993. The model was developed for the Department of Defense to assess the capabilities of their software providers. The resulting assessment methodology is a multilevel maturity ranking system for the software development process. SEI first published the Capability Maturity Model (CMM)

Table 2: Comparison of VAT Classification to Research Factors

VAT Classification	Type of Production Process	Production Volume	Order Fulfillment Strategy
V	Continuous, Semi-Continuous, Batch, Pure Fabrication	High, Medium, Low	BTS, MTO
A	Pure Assembly	High, Medium	BTS, MTO
T	Combination Fabrication/Assembly	High, Medium,	BTS, MTO, BTO
V-T	Continuous, Semi-Continuous, Batch, Combination Fabrication/Assembly	High, Medium, Low	BTS, MTO, BTO
A-T	Combination Fabrication/Assembly, Pure Assembly	High, Medium, Low	BTS, MTO, BTO
V-A	Continuous, Semi-Continuous, Combination Fabrication Assembly	High, Medium, Low	BTS, MTO, BTO
V-A-T	Continuous, Semi-Continuous, Combination Fabrication Assembly	High, Medium, Low	BTS, MTO, BTO
AV-T	Continuous, Semi-Continuous, Combination Fabrication Assembly	High, Medium, Low	BTS, MTO, BTO

for Software in 1990, and since then this methodology has been used to build assessments for a variety of processes including lean enterprise maturity (ex. Massachusetts Institute of Technology, Lean Aerospace Initiative used CMM to develop the Lean Enterprise Self-Assessment Tool (32)).

In a technical report published by the SEI, Mark Paulk, et al. (35) explain that their inspiration for the CMM came from Philip Crosby's quality management maturity grid published in his book Quality is Free (Crosby, 1979). The grid describes five evolutionary stages in adopting quality practices. The SEI researchers adapted this framework to the software development process. While the CMM framework is inspired by Crosby's work the content of the maturity levels is developed from the principles of product quality developed by W. Edwards Deming (Out of the Crisis, 1986) and Joseph Juran (1988, 1989).

The five maturity levels defined in the CMM (and generalized to measure maturity in any process) are:

1. Initial: The process is characterized as ad hoc, and occasionally even chaotic. Few processes are defined, and success depends on individual effort.

2. Repeatable: Basic processes are established to measure performance, and discipline is in place to repeat earlier successes.

3. Defined: A standard methodology for performing the process is defined and followed.

4. Managed: Detailed measures are collected and used to measure performance. The process is fully understood by all.

5. Optimized: Continuous process improvement is enabled by quantitative feedback from the process and from piloting innovative ideas and technologies.

This is the framework that is used in this study to develop the five levels of maturity with regard to the implementation of lean production. The specific CMM used in this study is explained in greater depth in Chapter 3.

Resulting Test Hypotheses

Based on the review of the pertinent literature and the preceding logic to develop the factors to study, it was determined to test the following three hypotheses:

H1: The type of production process affects lean production tool selection for a given product line.

H2: The volume of production affects lean production tool selection for a given product line.

H3: The dominant order fulfillment strategy (i.e. Build-to-Stock, Build-to-Order, etc.) affects lean production tool selection for a given product line.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter discusses the methodological approach for this study. The details regarding approach, the survey instrument, the pilot study, the survey respondents, and the data analysis methods are discussed.

Approach

The main method of data collection for this study is a survey instrument administered over the Internet. Surveys have well-documented weaknesses including low response rates, lack of variable manipulation, contextual information, and verbal exchanges (Birnberg et al. 1990; Runkel and McGrath 1972). The positive side of surveys is that with large cross-sectional samples a certain level of external validity can be reached (Birnberg et al. 1990; Runkel and McGrath 1972). Since the focus of this research is to describe how certain tools and technologies are being applied across industries, a survey is the only feasible method of research. Case studies and formal experiments can add depth to the generalizations of research such as this, but a survey instrument is the only way to provide the general framework.

Survey Instrument

Unit of Analysis

The unit of analysis for this study is a product line or product family. This is the lowest level of the organization that corresponds to the value stream. The difficulty of this unit of analysis, however, is that companies are not often organized around value streams, but around a site or business unit representing multiple value streams. Therefore, the survey participants were asked to complete the survey based on a product line or family.

Using the product line or product family as the unit of analysis also takes into account instances in which separate product lines in the same factory operate as different production systems. This is particularly the case in companies that operate as focused factories. Different products may require different order fulfillment strategies, be produced in different volume levels, and even use different production processes.

<u>Dependent Variables</u>

The dependent variables in this study are the level of lean production tool usage. For each tool the participant is asked to choose one of five levels of usage shown in Figure 3. A three or higher indicates that the production system for that product family has adopted the tool. Levels four and five represent higher levels of maturity for a given tool in a given production system.

Since the focus of this study is on the adoption of lean production tools, the five levels shown in Figure 3 are transformed into 3 levels to test the hypotheses H1-H3, and 2 levels to develop the binary logistical regression model. In the 3-level transformation, levels 3-5 are combined to be one level, since all 3 represent different levels of adoption. The purpose of testing the hypotheses at three levels is that the additional level adds variation and increases the difficulty that

(Level 1)	(Level 2)	(Level 3)	(Level 4)	(Level 5)
Tool is **not** a part of our Lean strategy.	Tool is applied **sporadically** across facility.	Everyone has had training in use of tool and it is in used **at least half of the time.**	Everyone has had training in use of tool and it is in use **almost all of the time.**	Use of tool is standard procedure **understood and used**

Figure 3: Levels of Lean Production Tool Usage

the null hypothesis is rejected. The binary logistical regression model, however, requires the data to be transformed into two levels. So for the regression model, levels 1 and 2 are combined as well. The rationale for this transformation is that a company at a level 2 in Figure 3 is experimenting with a given tool, but has not determined whether or not it fits their overall production system.

The Tools of Lean Production

For the purposes of this research, a lean production tool is defined as any tool or technique that contributes to the production system in one of the following categories and subcategories (Note: some tools could be classified in multiple categories):

1. Tools that improve the rate of *flow*.
    a. Tools of standardization that eliminate variation.
    b. Tools of maintenance
2. Tools that facilitate *flexibility*, in capacity or order fulfillment.
3. Tools that reduce *throughput* time.
    a. Tools of quality
4. Tools of *Continuous Improvement* and/or implementation

The toolkit shown in Table 3 was developed using the former working definition (on page 12) and the criterion that the tool must be identified in at least three sources. The resulting lean production toolkit presented in Table 3 is much larger and more comprehensive than any one toolkit represented in the literature (See Tables 5 and 6 for the toolkits from the literature). For instance, some of the statistical tools of the quality movement, such as Design of Experiments, Statistical Process Control, etc. are considered lean production tools in this study, because they fit into the category of tools of standardization through the elimination of variation. Stable, predictable processes are required to create and sustain flow.

Table 3: The Lean Production Toolkit and Working Definitions

Lean Production Tools			
Tool	**Category**	**Alternate Names or Similar Concepts**	**Definition**
5s	Flow: Standardize	Housekeeping	Five Japanese words for creating and maintaining a clean, organized work environment. Seiri (sifting), Seiton (Sorting), Seiso (Sweeping), Seiketsu (Standardize), Shitsuke (Sustain)
Set-up Reduction	Flexibility	Single Minute Exchange of Dies, SMED	An organized, scientific approach to reducing the amount of time it takes to change a machine from producing one product to another
Production to Takt time	Flow	Linearity	Takt time is the rate of customer demand for the part or product being made. Production to takt time refers to the balancing of work activities such that the average production rate is equivalent to takt time, no more no less.
Standard Work	Flow: Standardize	Standard Operating Routine	A series of tasks grouped together such that the sum of the individual task times is less than or equal to the takt time.
Method Sheets	Flow: Standardize	Graphical Work Instructions, Standard Work Instructions	Graphical depiction of the work instructions for a group of tasks at a particular workstation.
Flow Cells	Throughput	Cell Layout, Cellular Manufacturing, Continuous Flow Cells, U-shaped Cells	Manufacturing or assembling in a layout in which all (or most) of the parts and machines necessary to complete a part or assembly are in close proximity of one another.
Visual Controls	Flow: Standardize	Visual factory, management-by-sight, Visual Production Controls, Visual Material Controls, Visual Work Controls	Use of visual signs and signals to communicate the status of an operation or production line. Visual controls include any graphical marking or other visual signal that serves as a quick and complete communication to an operator or manager. Some examples are andon lights, in-process kanbans, schedule boards, standard work-in-process, color coded inventory boxes, defect bins, visually displayed tool locations, etc.
One-Piece Flow	Flow	Continuous flow	The ability to produce one part at a station at a time. This is contrasted with batch production, in which more than one part is processed at a station before moving to the next station.
Mixed-Model Production	Flexibility	Mixed-model, Mixed Model Scheduling	The ability to make several products on the same line in a random or sequenced order without a massive amount of changeover time.

Table 3: The Lean Production Toolkit and Working Definitions (continued)

Lean Production Tools (continued)			
Tool	**Category**	**Alternate Names or Similar Concepts**	**Definition**
Point-of-Use Material Storage	Throughput	Vendor Managed Inventory, Supermarkets	The preparation of work areas for direct presentation of supplied materials.
Smoothed Production Schedule	Flexibility	Level-loading, Production Smoothing	Development and use of a consistent and repetitive schedule across product offerings.
Pull Production Scheduling	Flow: Material	Kanban, Pull, Replenishment	As materials are consumed at a downstream operation, signals are sent back to previous steps in the production process to pull forward sufficient materials to replenish only those materials that have been consumed.
Cross-Trained Workforce	Flexibility	Flexible work force, Rotating Jobs, Multi-skilled workforce	Workers are trained and scheduled to do multiple jobs, thereby increasing the flexibility of the workforce to move to different cells and lines dependent upon the demand fluctuations.
Lean "Kaizen" Events	Continuous Improvement	Kaizen Blitz, Accelerated Improvement Workshop (AIW)	A focused improvement event during which a cross-functional team of operators, engineers, etc. spends several days analyzing and implementing improvements to a specific work area.
Total Productive Maintenance	Flow: Maintenance	Autonomous Maintenance	A maintenance strategy, which incorporates the operators in daily maintenance activities, such as, checking for vibrations, oil and lubrication, etc.
Reliability-Centered Maintenance	Flow: Maintenance		A maintenance strategy in which a detailed Failure Modes and Effects Analysis is done for each critical piece of machinery, and explicit maintenance strategies are created.
Preventive Maintenance	Flow: Maintenance		A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

Table 3: The Lean Production Toolkit and Working Definitions (continued)

Lean Production Tools (continued)			
Tool	**Category**	**Alternate Names or Similar Concepts**	**Definition**
Predictive Maintenance	Flow: Maintenance		A maintenance strategy in which machines are analyzed with special equipment that can predict machine failure based on vibration, lubrication, temperature, and other analyses, with an emphasis on planned maintenance.
Autonomation	Throughput: Quality	Jidoka, source inspection	Designing a machine to stop automatically when it detects an error in the production process.
Mistake-Proofing	Throughput: Quality	Pokayoke, error-proofing	The use of fixturing and tooling to eliminate or reduce the possibility of errors being made in the assembly of the product.
Self-Check Inspection	Throughput: Quality		Work is inspected before passing it on to the next station.
Successive Check Inspection	Throughput: Quality		Work is inspected at the succeeding workstation.
Line Stop	Throughput: Quality	Jidoka	Giving the operator the ability to stop an assembly line or cell flow when an error is detected in the process.
Design-of-Experiments	Continuous Improvement		Use of statistical tools to analyze a process to determine the variables that are affecting specific outcomes.
Root Cause Analysis	Continuous Improvement	5 Whys	Problem solving technique in which the team or individual attempts to drive down to the fundamental cause of the problem in order to keep it from recurring.
Statistical Process Control	Continuous Improvement		Use of control charts to study processes and determine when the process is out of control.
Team-Based Problem Solving	Continuous Improvement	Quality Circles, Self-directed Work Teams	Solutions to problems that arise in the production process are generated at daily or weekly meetings facilitated by the operators affected.

Every tool in this study's toolkit met the working definition. However two tools included in this study did not meet the criterion of being identified in at least three sources: Reliability-Centered Maintenance and Predictive Maintenance. Maintenance (and equipment uptime) is viewed as a critical component of lean production, which is reflected in the fact that 12 of the 22 sources in Table 4 indicated Total Productive Maintenance as a lean production tool. However, Total Productive Maintenance is only one component of a more comprehensive maintenance strategy being practiced in the continuous process industries, where capital expenditures on equipment are much higher, and downtime is more expensive. Therefore, it was decided to include the Reliability-Centered Maintenance and Predictive Maintenance as tools of lean production to provide a more comprehensive maintenance toolset. Also, as discrete part producers become more lean (i.e. less inventory), machine downtime will become more critical and it is predicted that these practices will be applied routinely in these industries as well.

Discussion of Discrepancies in Lean Production Toolkits

The literature provides many different toolsets for lean production. The discrepancies in these tool sets are due to the two following practices. The first is the practice of aggregating tools into a higher-level category. In one study, Claycomb et al. (6) chooses to test for JIT purchasing, JIT production, and JIT logistics. In this study, all of the tools of lean production would be aggregated to JIT production. Fullerton and McWatters (14) drive down deeper into the tools of Lean Production, but still aggregate all maintenance practices into total productive maintenance, and all quality tools into total quality control.

This leads to the second practice that affects the nature of the toolsets proposed in the literature, and that is the functionalization of tools. Some studies include quality and maintenance, but since these tools fall into different functional areas of research within academia, the toolsets are not incorporated into the tools of

Table 4: Lean Production Toolkit by Literature Source

Lean Production																							
Tool	Source (see Table 5 on pgs. 33-4)																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
5s	1	1	1	1	1	1	1			1	1			1		1	1					1	13
Set-up Reduction	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1	1	1	20
Standard Work	1	1	1	1	1	1	1	1		1	1			1		1	1	1				1	15
Method Sheets		1	1		1		1	1		1	1						1	1				1	10
Production to Takt time	1	1	1	1	1	1	1	1	1	1	1		1	1		1	1				1	1	17
Flow Cells		1	1	1	1	1	1		1	1	1		1	1		1	1			1	1	1	16
Visual Controls		1	1	1	1	1	1	1		1	1		1	1		1	1	1				1	15
One-Piece Flow		1	1	1	1	1	1		1	1	1		1	1		1	1				1	1	15
Mixed-Model Production		1	1		1	1	1		1	1	1			1								1	10
Point-of-Use Material Storage		1	1	1	1		1		1	1	1			1			1					1	11
Smoothed Production Scheduling		1	1	1		1	1	1			1					1					1		9
Pull Production Scheduling	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
Cross-Trained Workforce	1	1	1		1	1	1		1	1	1		1	1					1			1	13
Lean “Kaizen” Events		1	1	1	1	1			1							1							7
Total Productive Maintenance		1	1	1	1		1	1	1	1	1			1					1			1	12
Reliability-Centered Maintenance																							0
Preventive Maintenance							1		1											1			3
Predictive Maintenance																							0
Autonomation	1	1				1	1	1		1	1										1		8
Mistake-Proofing	1	1	1	1	1	1	1	1	1	1	1			1		1	1	1	1				16
Self-Check Inspection	1		1		1	1	1		1	1	1			1			1						10
Successive Check Inspection	1		1		1	1	1		1	1	1			1			1						10
Line Stop	1	1		1	1	1	1	1	1	1	1			1			1	1					13
Design-of-Experiments			1				1											1					3
Root Cause Analysis		1		1	1		1	1		1	1					1					1		9
Statistical Process Control		1	1	1	1		1		1		1							1			1		9
Team-Based Problem Solving		1		1	1		1	1	1	1	1						1	1	1	1			12

Table 5: Sources for Lean Production Toolkit in Table 4

Number	Bibliography Number	Book and Workshop Citations
1	7	Conner, Gary. Lean Manufacturing for the Small Shop. Dearborn, MI: Society of Manufacturing Engineers, 2001.
2	17	Giffi, C., Roth, A., Seal, G.M., 1990. Competing in World Class Manufacturing: America's 21st Century Challenge. Business One Irwin, Homewood, IL.
3	20	Greenwood, Tom, Ken Kirby, et. Al. Lean Enterprise Systems Design Institute. University of Tennessee Center for Executive Education.
4	21	Henderson, Bruce, Jorge L. Larco, and Stephen H. Martin. 1999. Lean Transformation. Richmond, VA: The Oaklea Press.
5	22	Hines, Peter, et. Al. 2000. Value Stream Management: Strategy and Excellence in the Supply Chain. London, Great Britain: Prentice Hall.
6	29	Monden, Yasuhiro. 1998. Toyota Production System: An Integrated Approach to Just-in-Time. 3rd Edition, Norcross, GA: Engineering & Management Press.
7	30	Nicholas, John. 1998. Competitive Manufacturing Management: Continuous Improvement, Lean Production, and Customer-Focused Quality. Boston: Irwin McGraw-Hill.
8	34	Ohno, Taichii. 1988. Toyota Production System : Beyond Large-Scale Production. Portland, OR : Productivity Press.
9	37	Schonberger, Richard J. 1982. Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity. Free Press, New York.
10	38	Shingo, Shigeo., 1988. Non-stock production: the Shingo System for continuous improvement. Productivity Press., Cambridge, MA.
11	39	Suzaki, K., 1985. The New Manufacturing Challenge. The Free Press. New York.
12	41	Vollman, Thomas E., William L. Berry, and D. Clay Whybark. Manufacturing Planning and Control Systems. 1997. New York: Irwin/McGraw Hill.
13	43	Womack, James P. and Daniel T. Jones. 1996. Lean Thinking. New York: Simon & Schuster
14	44	Womack, James P., Daniel T. Jones, and Daniel Roos, 1990. The Machine That Changed The World. New York: Harper Collins.

Table 5 (cont'd): Sources for Lean Production Toolkit in Table 4

Number	Bibliography Number	Periodical Citations
15	6	Claycomb, Cindy, Richard Germain, and Cornelia Droge. "Total system JIT outcomes: inventory, organization, and financial effects." International Journal of Physical Distribution & Logistics Management, Vol. 29 No. 10, 1999, pp. 612-630
16	9	Deluzio, Mark C. "The Tools of Just-In-Time." Cost Management. Summer 1993. pp. 13-19
17	10	Detty, Richard B. and Jon C. Yingling. "Quantifying benefits of conversion to lean manufacturing with discrete event simulation: a case study." International Journal of Production Research. 2000, vol. 38, no. 2, pp.429-445.
18	13	Flynn, Barbara B., Roger G. Schroeder, and E. James Flynn. "World class manufacturing: an investigation of Hayes and Wheelwright's foundation." Journal of Operations Management. 1999. Vol 17. pp. 249-269.
19	14	Fullerton, Rosemary R. and Cheryl S. McWatters. "The production performance benefits from JIT implementation." Journal of Operations Management. 2001. Vol 19. pp. 81-96.
20	26	Koufteros, Xenophon A, Mark A. Vonderembse, and William J. Doll. "Developing measures of Time-Based Manufacturing." Journal of Operations Management. 1998. Vol. 16. pp. 21-41.
21	28	McLachlin, Ron. "Management initiatives and just-in-time manufacturing." Journal of Operations Management. 1997. Vol. 15. pp. 271-292.
22	36	Sakakibara, S., Flynn, B.B., Schroeder, R.G., 1993, "A framework and measurement instrument for Just-in-Time manufacturing." Production and Operations Management 2 (3), pp. 177-194.

lean production. In this study, these two areas are defunctionalized and presented as part of the integrated production system. Total Quality Control is represented by nine tools discussed in the Lean literature: Autonomation, mistake-proofing, self-check inspection, successive-check inspection, line stop, Design of Experiments, Root Cause Analysis, Statistical Process Control, and Team-based problem solving. Four tools represent maintenance: Total Productive Maintenance, Reliability-Centered Maintenance, Preventive Maintenance, and Predictive Maintenance.

Independent Variables

In this study three variables are analyzed for their individual and interactive effects on the adoption of lean production tools: Type of Production Processes, Order Fulfillment Strategy, and Cycle Time between consecutive production units (which serves as an estimate for production volume). (See Table 6) For purposes of data collection there are more categories presented to the survey participant than could be analyzed. The “Levels Analyzed” column in Table 6 shows the aggregated levels that are used as the levels for the independent variables in the study.

Combining Variables

The survey is designed to elicit information from respondents using standard nomenclature. The treatment levels for the analysis are determined by combining survey components (2nd column in Table 6) which result in the Levels Analyzed (3rd column in Table 6). For the types of production processes, Pure Fabrication, Pure Assembly and Combination Fabrication/Assembly are combined into one variable called Discrete. The rationale for combining these three variables is that while there is some evidence of a significant difference in the adoption of lean production tools (ex. One-Piece Flow, Standard Work, and Method Sheets) between the Pure Fabrication, Pure Assembly, and Combination

Table 6: Survey Components and Levels

Independent Variable	Survey Components	Levels Analyzed	Examples
Type of Production Processes	Pure Fabrication	Discrete	Job Shop
	Pure Assembly		Computers
	Combination Fab/Assembly		Appliances
	Batch	Continuous	Food, Paint, Pharmaceuticals
	Semi-Continuous		Carpet, Wallpaper
	Continuous		Petroleum, Chemicals
Order Fulfillment Strategy	Build-to-Stock	Build-to-Stock	
	Configure-to-Order	Make-to-Order	
	Make-to-Order		
	Build-to-Order	Build-to-Order	
	Engineer-to-Order		
Cycle Time between consecutive production units (Production Volume)	Seconds	High Volume	
	Minutes		
	Hours	Medium Volume	
	Days		
	Weeks	Low Volume	
	Months		

Fabrication/Assembly it is not conclusive due to the lack of data for the Pure Fabrication level.

Table 7 summarizes the results of the Kruskal-Wallis tests (this test will be discussed further in the final section of this chapter) for significant differences for the adoption of specific lean tools between the companies with Pure Fabrication, Pure Assembly, and Combination Fabrication/Assembly processes and at least a Level 3 of Lean Maturity. (Table 31 in Appendix A provides the full details of the tests.) Even though the adoption of four tools (Standard Work, Method Sheets, One-Piece Flow, and Design-of-Experiments) is identified as being statistically significant, at least five more tools have averages that seem to be different. However, the category that is exhibiting the differences, Pure Fabrication, only has two data points representing at least Level 3 maturity.

The reason for combining Batch, Semi-Continuous, and Continuous into one level called Continuous is that the product in each of these cases is not a discrete entity until it is packaged. As seen in Table 7, there is evidence of differences in these three levels, but there is not enough data to provide conclusive evidence (See Tables 33 and 34 in Appendix A). The lack of data in these categories can be explained by the diffusion of lean philosophies through industry. Lean began in the early 80’s primarily in the automotive industries. As the OEMs began to teach their suppliers, and eventually their supplier’s suppliers, lean began to be diffused through other industries. It has just been a recent phenomenon, however, that lean is being adopted by the pure continuous process companies, and the pure fabrication (or job shop) companies. This explains the lack of representation in the dataset from these two groups in particular.

The Order Fulfillment Strategies were combined into three variables using the logic presented in Chapter 2. The differences in Configure-to-Order and Make-to-Order (as defined in the survey) are accounted for in the Type of Production

Table 7: Summary of Kruskal-Wallis Tests for Discrete and Continuous Groups

Independent Variable Level		Statistically Different Lean Production Tools	Mean Rank
Discrete	Pure Fabrication	Standard Work	21.5
	Pure Assembly		57.3
	Combination		45.5
	Pure Fabrication	Method Sheets	7
	Pure Assembly		46.6
	Combination		48.2
	Pure Fabrication	One-Piece Flow	13
	Pure Assembly		57.5
	Combination		45.7
	Pure Fabrication	Design of Experiments	17.5
	Pure Assembly		36.9
	Combination		49.9
Continuous	Batch	5s	11.6
	Semi-Continuous		15.4
	Pure Continuous		4.5
	Batch	Visual Controls	10.6
	Semi-Continuous		16.3
	Pure Continuous		3.8
	Batch	Total Productive Maintenance	8.7
	Semi-Continuous		16.7
	Pure Continuous		10.5
	Batch	Reliability-Centered Maintenance	8.2
	Semi-Continuous		16.1
	Pure Continuous		17
	Batch	Predictive Maintenance	8.4
	Semi-Continuous		16.7
	Pure Continuous		12
	Batch	Autonomation	9
	Semi-Continuous		16.2
	Pure Continuous		12.8
	Batch	Mistake-Proofing	8.8
	Semi-Continuous		16.5
	Pure Continuous		11

Process variable. The same is true for Build-to-Order and Engineer-to-Order. These more specific variables might affect the application of Lean Enterprise tools upstream and downstream of the factory floor, but are not expected to impact the adoption of Lean Production tools.

The variable for production volume is actually a transformation. The survey question asked the participants to indicate the best unit of measuring the time between consecutive production units. A cycle time of seconds (1-60s), at one shift a day (450 minutes/shift) for 250 days per year would be equivalent to 112,500 to 675,000 units of production annually. The question is asked in this manner to avoid the difficulty of asking for units of production when asking for annual production volumes (ex. linear feet, units, gallons, etc.).

Not all combinations of these factors are present in this study. Some combinations do not exist in reality. For instance, batch, semi-continuous process, and continuous process production is very capital intensive. Therefore, a high volume of demand must exist before the investment will be made to build these types of facilities. So the odds of there being a low volume, batch, semi-continuous, or continuous facility are very low. In addition, these types of facilities will primarily operate with a Build-to-Stock or Make-to-Order strategy as well, because the processing times per batch of material will most likely be longer than the customer lead time.

Sample Stratification Technique

The Capability Maturity Model for Software development (CMMS) developed by the Software Engineering Institute (SEI) at Carnegie Mellon (34) is used to define five levels of maturity (see Table 8). Level 1 is defined as the awareness stage. This corresponds to the Initial level in the CMMS, which is characterized as ad hoc or chaotic with few processes defined. For purposes of the Lean Production Maturity, this level indicates that some in the organization are aware of lean.

Table 8: Capability Maturity Model for Lean Production

Level 1: Awareness	Level 2: Sporadic Implementation	Level 3: Formal Implementation	Level 4: Completed Implementation	Level 5: Continuous Improvement
• A few (1-3) people in the organization are aware of Lean Production principles either through training overview, a book, or previous experience. • May have implemented one or two tools of lean (5S, Setup Reduction), but no formal, integrated implementation approach.	• Some tools of lean are implemented sporadically across the factory; islands of lean. • Some awareness training beginning to take place among managers. • Still no formal, integrated implementation approach.	• A formal, integrated approach to implementation has been developed and is being rolled out. • Awareness training is being performed at the operator level. • Focus improvement activities (ex. kaizen events or blitzes) are occurring on a regular basis. • Entire product flow is not yet fully integrated (ex. fabricated parts are not pulled into assembly processes).	• All of operations personnel have been exposed to the principles of lean. • Entire product flow is integrated (WIP is used strategically), product flows smoothly through facility. • Batch and one-piece flow operations have been connected by pull execution. • All relevant tools of lean production are fully deployed and accepted practices (i.e. kanban, flow cells, setup reduction). • Standard practices are operator-developed and adhered to.	• Lean Production is standard procedure; no longer a program. • Structured approach to continuously improving the production system is in place (ex. periodic kaizen events, employee suggestion systems and follow-up, etc.). • Continuous improvement activities are driven by the operators with management support.

production principles, but it has not been defined for the organization, and there definitely is not an orchestrated effort to implement.

Level 2 is defined as Sporadic Implementation. This is a stage that many companies find themselves, and is the one maturity level that does not correspond totally with the CMMS. The CMMS describes stage 2 as Repeatable, in which basic processes are established to measure performance, and there is some discipline in place to repeat earlier successes. In the Sporadic Implementation stage of Lean Production maturity, companies are beginning to experiment with some of the tools of lean, but a lean production strategy is not yet fully defined.

Level 3 is the maturity stage in which a Formal Implementation strategy has been established. This corresponds with the Defined stage in the CMMS, in which the organization develops a standard methodology for performing a process. In Level 3 of Lean Maturity, there is a certain level of buy-in from management that this is a strategic initiative, and a majority of the workforce has been targeted to do some level of awareness training. This is a transition stage, and the company is learning what lean means to them. Often implementation is performed one product line/family at a time. It is the contention of this research that at the beginning of Level 3 a company will define its lean toolset, and refine it by the end of this stage.

Level 4 is the maturity stage in which the formal implementation is complete. This corresponds to the CMMS Managed stage, in which the process is fully understood by all, and is simply managed for performance. Companies in this phase have a very good understanding of what lean tools apply to their situation. They have probably adopted all of the tools that apply, and are improving their maturity with using the individual tools

Level 5 is the fifth and final stage, in which a production system is in an endless state of continuous improvement. This stage corresponds directly with the

CMMS stage of Optimized, in which the focus is also on continuous improvement. In this stage lean production is standard procedure and a way of life. It is no longer a program pushed by management, but instead is owned by the operators of the system.

The first two levels of the Lean Production Maturity Model are considered pre-adoption phases, and it is not expected that a company would fully embrace all of the tools of lean that apply. However, beginning in Level 3, the company should begin to adopt a standard set of tools for their production system, and by Level 4 the set should be complete. Therefore, this study only considers the tool adoption patterns of values streams at this level or higher. The difference between Level 4 and 5 should only be reflected in the level of maturity among the individual tools, and not in the number of tools adopted.

The results of the study validate the use of this model to measure Lean Maturity. Table 9 portrays the average number of tools adopted by maturity level. In the table the columns represent the average number of tools adopted by the companies in that range of maturity levels. Tool adoption is defined as level of lean production tool usage of greater than or equal to three (See Figure 3). As seen in Table 9, as maturity increases the number of tools adopted increases as well. However, there is little to no difference between the average number of tools adopted by the production systems at maturity levels 4 and 5.

The average number of tools adopted at each range of maturity levels drops each time. Also noted are the results of the ANOVA in Table 10, testing the statistical differences between the average tools used per level of maturity and the tools used in the three column categories. The results of the F-tests and the corresponding p-values would indicate that there is a statistical significance by column and by row.

Table 9: Average Number of Tools Adopted by Maturity Level

Overall Lean Production Maturity Level As of 2001		Number of Tools Adopted at Levels 3, 4 and 5	Number of Tools Adopted at Levels 4 and 5	Number of Tools Adopted at Level 5
1	Mean	4.00	2.36	1.21
	N	14	14	14
	Std. Deviation	5.038	3.954	2.155
2	Mean	8.74	3.91	1.28
	N	69	69	69
	Std. Deviation	5.527	4.086	1.806
3	Mean	11.82	5.60	2.00
	N	87	87	87
	Std. Deviation	5.970	4.824	2.917
4	Mean	18.56	12.17	4.61
	N	18	18	18
	Std. Deviation	5.447	5.216	3.165
5	Mean	20.33	16.95	10.76
	N	21	21	21
	Std. Deviation	3.638	5.399	5.932
Total	Mean	11.71	6.53	2.81
	N	209	209	209
	Std. Deviation	6.964	6.213	4.119

Table 10: ANOVA Test for Significant Difference in Tool Usage by Maturity

		Sum of Squares	df	Mean Square	F	Sig.
Number of Tools Adopted at Levels 3, 4 and 5	Between Groups	3847.302	4	961.826	31.44	.000
	Within Groups	6241.473	204	30.595		
	Total	10088.78	208			
Number of Tools Adopted at Levels 4 and 5	Between Groups	3644.983	4	911.246	42.39	.000
	Within Groups	4385.064	204	21.495		
	Total	8030.048	208			
Number of Tools Adopted at Level 5	Between Groups	1641.510	4	410.377	44.34	.000
	Within Groups	1888.213	204	9.256		
	Total	3529.722	208			

Size as a Control Variable

Size of company was considered as a control variable for this study. The use of size as a control variable is supported very strongly in the literature (Gargaya and Thompson, 1994; Germain and Droge, (16); Inman and Mehra, (25), etc.). According to Claycomb et al., size should relate to wider spans of control and to a greater number of hierarchical layers, which should affect the rate of maturity of lean/JIT (Claycomb et al., (6)). However, it was decided not to include size as a control variable because the research was not analyzing the effects of implementation over time. Instead maturity was considered at a discrete point in time, which is the end of the year 2001.

Pilot Survey

Before the survey instrument was used to collect data for hypothesis testing, it was tested with 17 industry and academic participants for clarity of content and ease of facilitation. This resulted in some slight modifications to the survey, such as convenient definitions for the Order Fulfillment Strategies, and examples for each type of production process.

Survey Response

Participants in the survey were solicited through e-mails to several target groups shown in Table 11. The e-mail that was sent to each participant is included in Appendix C. The e-mail contains a short description of the research, a hyperlink to the survey location, and a standard username and password for all participants. The username and password is to protect the survey from being filled out by someone randomly surfing the Internet.

Table 11: Target Groups

Target Group	Number in Group
University of Tennessee: Lean Enterprise Systems Design Institute Alumni	285
UT Practical Strategies for Process Improvement Alumni	159
UT Executive MBA Alumni	80
UT Lean Enterprise Forum Members	272
Northwest Lean Manufacturing Network	2400
Lean Enterprise Institute, Canada	450
Total Possible	3646

University of Tennessee Target Groups

The target groups from the University of Tennessee (UT) all come from participants in the courses offered by the Center for Executive Education (CEE). The typical participant is a mid-upper level manager who attends to receive training in a specific area that pertains to his/her job. The main reason for using this group as a convenient sample for this research is that there is an established relationship between the individual and the university. That relationship makes it more likely that an individual would take the time to complete a survey from a member of that university. Overall four groups are targeted from the UT CEE alumni. There is some overlap between the groups, but it is not significant.

The UT Lean Enterprise Systems Design Institute (LESDI) is a one-week introductory course that has been taught 10-15 times per year since 1993. The participants of this course are typically mid-to-upper level management who are charged with implementing lean principles in their facilities. This group represents a good cross-section of the types of companies that are studied in this research. However, the continuous process and batch process companies are under-represented. The e-mail addresses for the alumni from all four UT groups from 1993-1998 were unavailable.

UT Practical Strategies for Process Improvement (PSPI) is a three-week course on the use of statistical tools to improve production processes. These participants may or may not belong to a company that is currently implementing lean. As a result, the response rate from this group is not as high as others. The other obstacle with this group is that the job descriptions of people in this group may or may not have anything to do with the implementation of lean. For this reason, the instructions in the e-mails are for the individual to forward the e-mail on to someone in their facility who would be able to answer the survey. The reason for including this group is that this course attracts companies in the continuous process and batch process industries, which are types of companies that were anticipated to have low response rates.

The alumni of the UT Executive MBA program represent mid-upper level management from a good cross-section of industries. Again, these participants may or may not belong to a company that is currently implementing lean, so the response rate is not as high as other groups. Also, the individuals in this group may not have a job description that has anything to do with lean or even production, so the e-mail would have to be forwarded to someone in the company who could complete the survey.

The final UT group targeted is the members of the Lean Enterprise Forum. These individuals are typically mid-level managers who are tasked with implementing lean in their facilities. They join groups such as these to network with other individuals implementing lean to share stories of success and failure. There is some overlap between this group and the LESDI group. The cross-section of industry for this group is similar to the LESDI.

External Target Groups

Groups external to the University of Tennessee constituency are included in this study to improve the ability to generalize the results. The two groups targeted are lean consortia that have large, diverse constituencies. The first group is the Northwest Lean Manufacturing Network. This is a virtual consortium, existing only online, whose purpose is to provide a forum for lean practitioners to share best practices, exchange ideas, and network with other industries. The group is made up of 2400 individuals from 475 companies and 40 different countries. The companies represented in this network are the most diverse of any of the groups.

The Northwest Lean Manufacturing Network did not provide an e-mail listing of their constituency. Instead, the e-mail soliciting participation was posted on the member's-only bulletin board. There is no way of knowing how many people viewed the bulletin board, and did or did not participate. After the original e-mail was posted it was followed by one update e-mail per week over three weeks (See Appendix C). Because there is no way of knowing exactly how many people viewed the electronic bulletin board containing the hyperlink to the survey, there is no way of estimating a response rate from this group.

The Lean Enterprise Institute, Canada (LEIC) is an independent partner of the Lean Enterprise Institute, Boston that was formed by James Womack in 1998. The LEIC is a 450-member consortium consisting of companies and universities from all over the world, in addition to a strong Canadian contingency. LEIC provides lean training, hosts conferences, and supports lean research. This was the more successful partnership of the two external target groups. The president of LEIC, Larry Cote, wrote a cover letter (Appendix C) that was sent out to their constituency with the e-mail soliciting participation in the survey. A follow-up e-mail was sent out two weeks after the initial e-mail. In exchange for their cooperation in collecting data for this research, the researcher provided summary analysis to be published on the websites of the two consortia.

Data Analysis

Two statistical techniques are used to analyze the data collected through the survey instrument. The first test is a nonparametric test proposed by Kruskal and Wallis that is analogous to a One-Way ANOVA. This test is used to test the six hypotheses proposed in Chapter 2. The second analytical technique is the development of a predictive model using binary logistical regression. The results of this model provide the probability of adoption of each tool by a specific value stream profile.

Kruskal-Wallis Nonparametric Test

The Analysis of Variance technique of testing for differences in the means of sample populations assumes that the dependent variable has an interval scale, that its distribution with each group follows a normal curve, and that the within-group variation is homogenous across groups. The dependent variable in this study is an ordinal variable, and the intervals between the levels of the variable cannot be assumed to be normal or equal. When any one of the former assumptions are violated, it is recommended to use a nonparametric test. The nonparametric test that is analogous to ANOVA is the Kruskal-Wallis test for ordinal dependent variables.

The Kruskal-Wallis test first rank orders the dependent measure throughout the entire sample. The test then calculates the mean rank for each sample group, and the probability (using the chi-square statistic) of obtaining group average ranks as weighted sums, as far apart as what is observed in the sample, if the population groups are identical. The assumption in the test is if the null hypothesis is true, there will be no difference between the averages of the ranks of the dependent variable between groups.

Each factor in the study is tested for significant differences between the means of tool adoption using the Kruskal-Wallis test for each tool of Lean Production.

Each two-way interaction of the factors is also tested for each tool of Lean Production. These tests address the three hypotheses proposed in Chapter 2.

Binomial Logistic Regression Model

The initial focus of this study was to test the hypotheses that different types of value streams adopt different tool sets within the lean production toolset. The Kruskal-Wallis tests examine that specific question. The results (to be developed in Chapter 4) show that there is a statistically significant difference in the adoption of specific lean production tools depending upon value stream characteristics. Therefore an additional goal of the study is to develop a model to predict the probability that a company with a given value stream profile would adopt specific tools within lean production. There are only two answers to the question of tool adoption: 1) The tool is adopted or 2) The tool is *not* adopted. Because of the dichotomous nature of the dependent variable, binary logistical regression is the preferred method of developing a predictive model. The binary logistical regression model uses the 2-level transformation of the dependent variable described earlier: Levels 1 and 2 = 0, Not Adopted, and Levels 3, 4, and 5 = 1, Adopted.

The equation for binary logistical regression model is defined on the following page. Table 12, on the next page, provides a summary of each of the hypotheses, the dependent, independent, and control variables, and statistical techniques used in this study. Chapter 4 will present the results of the Kruskal-Wallis tests for significant differences between each of the main effects and the interactions, as well as the resulting predictive regression model.

The binary logistical regression model developed for each tool in the lean production set is as follows:

$$P_{Adoption} = \frac{e^{\beta_0 + \beta_1(Discrete) + \beta_2(HighVolume) + \beta_3(MediumVolume) + \beta_4(BTO) + \beta_5(MTO)}}{1 + e^{\beta_0 + \beta_1(Discrete) + \beta_2(HighVolume) + \beta_3(MediumVolume) + \beta_4(BTO) + \beta_5(MTO)}}$$

Where β_i = Estimated coefficient for each factor
Discrete = Type of Production Process Variable (1,0)
High Volume = Production Volume Variable (1,0)
Med Volume = Production Volume Variable (1,0)
BTO = Order Fulfillment Strategy Variable (1,0)
MTO = Order Fulfillment Strategy Variable (1,0)

Figure 4: Equation for Binomial Logistic Regression Model

Table 12: Summary of Hypotheses, Variables, and Statistical Tests

Hypotheses	Dependent Variables	Independent Variables	Sample Stratification Technique	Analytical Techniques
H1: The type of production process affects lean production tool selection for a specific product line.	26 Tools of Lean Production (ex. 5s, Standard Work, Takt Time) 5-point scale reduced to 3-level variable for hypothesis testing: 1 = Not adopted, 2= Sporadic Adoption; 3,4,5 =1,Full Adoption 5-point scale reduced to dichotomous variable for regression model: 1,2=0 Not adopted; 3,4,5 =1, Adopted	Type of Production Processes (Discrete, Continuous, Service) Production Volume (Low, Medium, High) Dominant Order Fulfillment Strategy (BTS, BTO, MTO)	Lean Production Maturity at 5 levels: *Level 1*: Awareness *Level 2:* Sporadic Implementation *Level 3*: Formal Implementation *Level 4*: Completed Implementation *Level 5*: Continuous Improvement In all analyses, only cases that showed a maturity level of 3 and higher were examined.	Hypotheses were tested using the Kruskal-Wallis non-parametric test. Each main effect was tested, as well as two-level interactions. Binary logistical regression model was then developed for each tool.
H2: The volume of production affects lean production tool selection for a specific product line.				
H3: The dominant order fulfillment strategy (i.e. Build-to-Stock, Build-to-Order, etc.) affects lean production tool selection for a specific product line.				

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the results of the tests to determine the effects of type of production process, production volume, and type of order fulfillment process on the adoption of lean production tools and techniques. The initial section is a descriptive analysis of the survey respondents with regard to the variables studied. The next three sections describe the test for the effects of each factor on the response variable. The final section presents the predictive probabilities of tool adoption by value stream profile as determined by the binary logistical regression model. This model is used to develop a proposed taxonomy of lean application for eleven value stream profiles.

Descriptive Analysis

Table 13 reports the number of respondents at the five levels of lean production maturity. Of the 209 respondents, 126 (60.1%) of them are at least at Level 3 maturity as of December 2001. This is the group that is of most interest in this study. Level 3 is the stage in which the company has developed and is implementing a formal approach to lean production. The Level 3 maturity represents 87 (41.6%) of the total population. Levels 4 and 5 are the levels in which the companies should have adopted the full spectrum of tools that apply to their value stream profile. These levels represent 39 respondents and 18.6% of the total respondents.

The distribution of the respondents across maturity level is approximately normal (though skewed somewhat to the low end). It cannot be determined from this study, whether this distribution is indicative of the general manufacturing population or of companies who would be attracted to consortia on lean manufacturing. Most likely it is the latter, and the general manufacturing population is skewed even further to the low end.

Table 13: Frequency of Respondents by Maturity Level as of 2001

	Maturity Level As of 2001	
	Count	Percent
1	14	6.7%
2	69	33.0%
3	87	41.6%
4	18	8.6%
5	21	10.0%

Table 14 reports the number of respondents by the independent variable, type of production process. The Pure Fabrication and Continuous types of production processes are underrepresented in this population. This could be due to the nature of the diffusion of lean production through industry. Lean production began in the automotive industry, and was adopted next by high volume, repetitive production manufacturers and the automotive suppliers. Companies with Pure Fabrication and Continuous types of production processes are typically further away from the OEM in the extended value chain, and so the technology is just now diffusing to their level. It also could be hypothesized that these are the types of manufacturers that have the toughest time applying all of the traditional tools of lean production, and have therefore not adopted any of the practices.

Table 14: Frequency of Respondents by Type of Production Process

	Type of Production Process	
	Count	Percent
Pure Fab	7	3.3%
Pure Assy	24	11.5%
Combo	115	55.0%
Batch	25	12.0%
SemiCont	20	9.6%
Continuous	4	1.9%
Service	14	6.7%

For whatever reason, there is not enough data to fully examine the specific effects of types of production processes at this level, so Pure Fabrication, Pure Assembly, and Combination Fabrication/Assembly are combined into the Discrete level, and Batch, Semi-Continuous, and Continuous are combined into the Continuous level. The rationale is that the first three categories manufacture units of material that must be fabricated, assembled, or both into a discrete production unit. The continuous categories manufacture some product that would not be considered individual units until packaged. Services then are any operation that does not manufacture anything but information (and perhaps paperwork). This would include most administrative processes.

Table 15 reports the number of respondents by cycle time representation, which is used as an estimate of production volume. The participants are asked to indicate the metric that would be used to calculate the time between consecutive units of production. These six categories are then transformed into three levels of production volume, where Seconds and Minutes equal High volume, Hours and Days equal Medium volume, and Weeks and Months equal Low volume.

According to Table 15, the Seconds category represents over half of the respondents. This is consistent with the theory of lean production diffusing through the high volume, repetitive manufacturing environments at a faster rate

Table 15: Frequency of Respondents by Cycle Time Representation

	Cycle Time Representation	
	Count	%
Seconds	106	50.7%
Minutes	46	22.0%
Hours	24	11.5%
Days	21	10.0%
Weeks	8	3.8%
Months	4	1.9%

than other environments. Combined with the Minutes category, the resulting High volume category represents 152 (72.7%) of the population. The low level of respondents at the Low volume levels of Weeks and Months (12 at 5.7%) indicates a weakness in the diversity of the data that will need to be addressed in future studies.

Table 16 reports the number of respondents by the independent variable, Order Fulfillment Strategy. The word dominant is used in the title, because the respondents were categorized by the order fulfillment strategy that represents the largest percentage of demand for the given product line. The Make-to-Order strategy comprises 112 (53.6%) of the total. One of the explanations for this is that some of the companies in this group are first or second tier automotive or appliance suppliers, and therefore make to the specific orders that come from the OEM, even though the OEM is effectively building to stock. In these cases the MTO and BTS are probably not that dissimilar. It is also not surprising that the smallest representation of the respondents is Build-to-Order at 40 (19.1%) responses. BTO is by far the most complex of the three strategies, because of the level of customization of the given product lines. Therefore BTO companies must compare their complex world to the simpler, more repetitive world of automotive, when adapting lean production tools and technologies.

Table 16: Frequency of Respondents by Order Fulfillment Strategy

	Dominant Order Fulfilment Strategy	
	Count	%
BTS	57	27.3%
BTO	40	19.1%
MTO	112	53.6%

Table 17 reports the Pearson bivariate correlations among the three factors used in the hypothesis tests and the regression model. The table shows significant correlations between Category of Production Process and Volume and between Category of Production Process and Dominant Order Fulfillment Strategy. The combinations of these factors that exist naturally in industry explain both of these correlations. Continuous processes by nature require capital-intensive equipment and therefore tend to be high volume operations. All of the continuous process respondents classified themselves as high volume. Volume is not a very good method of classification for Service value streams as well, so two of the three categories of production processes only reported one level of volume.

The correlation between Category of Production Process and Dominant Order Fulfillment Strategy is explained using similar logic. Continuous process value streams either use Build-to-Stock or Make-to-Order strategies, but not Build-to-

Table 17: Pearson Bivariate Correlations Between Factors

Correlations

		Category of Production Process	Volume	Dominant Order Fulfilment Strategy
Category of Production Process	Pearson Correlation	1	.347**	.154*
	Sig. (2-tailed)	.	.000	.026
	N	209	209	209
Volume	Pearson Correlation	.347**	1	-.018
	Sig. (2-tailed)	.000	.	.799
	N	209	209	209
Dominant Order Fulfilment Strategy	Pearson Correlation	.154*	-.018	1
	Sig. (2-tailed)	.026	.799	.
	N	209	209	209

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Order. The reason for this is that many of the products produced in this fashion are commodities and the customer can get them from a variety of locations.

Therefore lead-time is a critical component of the buying decision and waiting for raw materials to be ordered is not an option. Like Volume, Order Fulfillment Strategy is not a very good method of classification for Service value streams, and was not considered for the Service respondents.

The correlations impact the methods used to analyze the data for the tests of hypotheses, and the regression model. In the Kruskal-Wallis test, the main effects of Category of Production Process are analyzed using all three factor levels, Discrete, Continuous, and Service. However, the tests of the main effects of Volume and Order Fulfillment Process are only performed on the Discrete and Continuous Process data. The Service cases are filtered, because of the ill-fit definitions for these two factors. Finally, the binary logistic regression model is performed on the data of the Discrete and Continuous groups, and not the Service cases. This will be examined further in the discussion of the regression model.

Effects of Type of Production Process on Tool Adoption

H1: The type of production process affects lean production tool selection for a given product line.

As described in the previous chapter, the Kruskal-Wallis test is used to examine each of the six hypotheses stated in this study. The first hypothesis is that the types of production processes, Discrete, Continuous, and Service affects the lean production tool selection for a given product line. The level of usage for each case is ranked for each of the twenty-seven lean production tools. The Kruskal-Wallis test examines significant differences in the average ranking for each type of production process by tool. Table 18 reports the average ranks for each tool by type of production process, as well as the number of cases

Table 18: Average Ranks of Tools by Type of Production Process[1]

	Category of Production Process	N	Mean Rank
5S	Discrete	93	63.74
	Continuous	25	59.90
	Service	8	71.94
	Total	126	
Set-up Reduction	Discrete	93	64.47
	Continuous	25	67.28
	Service	8	40.38
	Total	126	
Standard Work	Discrete	93	62.06
	Continuous	25	64.64
	Service	8	76.63
	Total	126	
Method Sheets	Discrete	93	65.78
	Continuous	25	49.26
	Service	8	81.50
	Total	126	
Takt Time	Discrete	93	66.11
	Continuous	25	53.30
	Service	8	65.00
	Total	126	
Flow Cells	Discrete	93	69.09
	Continuous	25	44.02
	Service	8	59.38
	Total	126	
Visual Controls	Discrete	93	65.27
	Continuous	25	56.54
	Service	8	64.63
	Total	126	

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[1] This is the only test of hypotheses that includes the Service group in the data set. It should be noted that the sample size for the Service group is small relative to the other two groups, and therefore should be taken into account when generalizing the results of this study.

Table 18 (cont'd): Average Ranks of Tools by Type of Production Process[1]

	Category of Production Process	N	Mean Rank
One-Piece Flow	Discrete	93	69.61
	Continuous	25	38.58
	Service	8	70.38
	Total	126	
Smoothed Production Scheduling	Discrete	93	63.41
	Continuous	25	60.46
	Service	8	74.00
	Total	126	
Mixed Model Production	Discrete	93	68.65
	Continuous	25	45.84
	Service	8	58.81
	Total	126	
Point-of-Use Material Storage	Discrete	93	67.28
	Continuous	25	50.38
	Service	8	60.50
	Total	126	
Pull Production Scheduling	Discrete	93	62.51
	Continuous	25	66.66
	Service	8	65.19
	Total	126	
Cross-Trained Workforce	Discrete	93	60.45
	Continuous	25	69.10
	Service	8	81.50
	Total	126	
Kaizen Events	Discrete	93	64.72
	Continuous	25	54.16
	Service	8	78.56
	Total	126	

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[1] This is the only test of hypotheses that includes the Service group in the data set. It should be noted that the sample size for the Service group is small relative to the other two groups, and therefore should be taken into account when generalizing the results of this study.

Table 18 (cont'd): Average Ranks of Tools by Type of Production Process[1]

	Category of Production Process	N	Mean Rank
Total Productive Maintenance	Discrete	93	65.09
	Continuous	25	63.02
	Service	8	46.56
	Total	126	
Reliability Centered Maintenance	Discrete	93	62.89
	Continuous	25	72.46
	Service	8	42.63
	Total	126	
Preventive Maintenance	Discrete	93	62.67
	Continuous	25	70.86
	Service	8	50.13
	Total	126	
Predictive Maintenance	Discrete	93	61.30
	Continuous	25	74.14
	Service	8	55.88
	Total	126	
Autonomation	Discrete	93	66.19
	Continuous	25	57.66
	Service	8	50.50
	Total	126	
Mistake Proofing	Discrete	93	65.20
	Continuous	25	51.82
	Service	8	80.25
	Total	126	
Self-Check Inspection	Discrete	93	64.46
	Continuous	25	56.70
	Service	8	73.56
	Total	126	

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[1] This is the only test of hypotheses that includes the Service group in the data set. It should be noted that the sample size for the Service group is small relative to the other two groups, and therefore should be taken into account when generalizing the results of this study.

Table 18 (cont'd): Average Ranks of Tools by Type of Production Process[1]

	Category of Production Process	N	Mean Rank
Successive-Check Inspection	Discrete	93	61.80
	Continuous	25	71.74
	Service	8	57.56
	Total	126	
Line Stop	Discrete	93	65.13
	Continuous	25	65.78
	Service	8	37.38
	Total	126	
Design of Experiments	Discrete	93	63.30
	Continuous	25	71.22
	Service	8	41.69
	Total	126	
Root Cause Analysis	Discrete	93	61.34
	Continuous	25	66.54
	Service	8	79.06
	Total	126	
Statistical Process Control	Discrete	93	59.85
	Continuous	25	71.02
	Service	8	82.38
	Total	126	
Team-Based Problem Solving	Discrete	93	61.23
	Continuous	25	66.36
	Service	8	81.00
	Total	126	

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[1] This is the only test of hypotheses that includes the Service group in the data set. It should be noted that the sample size for the Service group is small relative to the other two groups, and therefore should be taken into account when generalizing the results of this study.

Table 19: Kruskal-Wallis Test for Significant Differences in the Adoption of Lean Production Tools Between Types of Production Processes[1]

Test Statistics[a,b]

	Chi Square	df	Asymp. Sig.
5S	1.078	2	.583
Setup Reduction	4.378	2	.112
Standard Work	1.666	2	.435
Method Sheets	7.600	2	.022
Takt Time	2.840	2	.242
Flow Cells	12.986	2	.002
Visual Controls	1.943	2	.379
One-Piece Flow	17.641	2	.000
Smoothed Production Scheduling	1.014	2	.602
Mixed Model Production	9.383	2	.009
Point-of-Use Material Storage	5.721	2	.057
Pull Production Scheduling	.337	2	.845
Cross-Trained Workforce	5.166	2	.076
Kaizen Events	4.077	2	.130
Total Productive Maintenance	2.204	2	.332
Reliability-Centered Maintenance	4.864	2	.088
Preventive Maintenance	3.147	2	.207
Predictive Maintenance	3.178	2	.204
Autonomation	2.518	2	.284
Mistake Proofing	5.514	2	.063
Self-Check Inspection	2.326	2	.313
Successive-Check Inspection	1.950	2	.377
Line Stop	5.167	2	.075
Design-of-Experiments	4.553	2	.103
Root Cause Analysis	2.731	2	.255
Statistical Process Control	4.911	2	.086
Team-Based Problem Solving	3.865	2	.145

a. Kruskal Wallis Test

b. Grouping Variable: Category of Production Process

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[1] This is the only test of hypotheses that includes the Service group in the data set. It should be noted that the sample size for the Service group is small relative to the other two groups, and therefore should be taken into account when generalizing the results of this study.

examined. As stated earlier, these tests were performed on the 126 cases that indicated a lean production maturity level of at least three. Table 19 reports the p-values of the Kruskal-Wallis test for each tool. The tools shaded in gray are the tools that are adopted at significantly different levels across types of production processes.

As shown in Tables 18 and 19, there are four tools that are adopted at significantly different levels ($p<0.05$) across the three types of production processes: Method Sheets, Flow Cells, One-Piece Flow, and Mixed Model Production. Six other tools are adopted at a different levels where $p<.10$: Point-of-Use Material Storage, Cross-Trained Workforce, Reliability-Centered Maintenance, Mistake-Proofing, Line Stop, and Statistical Process Control.

<u>Test of H1: Tools Where p<0.05</u>

Method Sheets

According to the average rankings in Table 18, the continuous process value streams adopt Method Sheets the least. Method Sheets are graphical representations of the Standard Work at a given work center, and therefore it would be assumed that there would be a correlation between the adoption of Method Sheets and Standard Work. However, the results of the Kruskal-Wallis test report that the Continuous process companies in this study have adopted Standard Work at similar rates to the Discrete and Service companies, but not Method Sheets. It was anticipated that the Continuous Process companies in this study would adopt both tools at a lower rate than Discrete and Service companies.

One explanation is that the respondents viewed Standard Work as analogous to Standard Operating Procedures to operate equipment in their facilities, but do not require the graphical detail of a method sheet to communicate these procedures. This would indicate that while some of the tools do not translate exactly from one type of value stream to another, there are often tools that can be considered analogous. This still does not explain the lack of adopting Method Sheets.

Flow Cells

According to Tables 18 and 19, the adoption of Flow Cells as a tool of lean production was highest for the Discrete producers, and there probably is not a statistically significant difference between Discrete and Service groups. The Continuous group, however, adopted this tool at a much lower rate. The concept of Flow Cells arose out of the need to defunctionalize the factory and create flow for a given product family through dedicated equipment. This was never a problem for the Continuous process companies, because the volumes necessary to justify production also justify dedicated equipment.

One-Piece Flow and Mixed Model Production

The logic for explaining the differences in Types of Production Systems adopting One-Piece Flow and Mixed Model Production is similar to that of Flow Cells. The concept was developed to increase flow and quality for discrete part producers. Again the nature of continuous processes is that the product cannot be separated into parts that would constitute one-piece flow, and pure mixed model production is unattainable. However, the analogy in the Continuous process world is the reduction of batch size and the product mix cycle time (the time it takes to cycle through all product variations of a given product family). Both of these concepts were not directly included in the list of tools and techniques for lean production, but could be inferred from the tool of Setup Reduction. According to Table 18, Setup Reduction is adopted at a high rate for both Discrete and Continuous groups, and though the Service groups adopt at a lower rate it is not significantly different (although with more data on Service groups this could change). Therefore, it is concluded that while One-Piece Flow and Mixed Model Production by nature are biased toward the Discrete group, the concept of reducing batch size is adopted by both Continuous and Discrete groups.

Test of H1: Tools Where $p<0.10$

Most statisticians would not bother to speculate whether differences are significant below $p=0.05$, but for the purposes of discussion, some of these tools are investigated.

Point-of-Use Material Storage

As seen in Table 19, Point-of-Use Material Storage was adopted at a rate that is significantly different for $p<0.10$. The average rank of the adoption of this tool is lowest for the Continuous group. An explanation for this is that the average processing time for a batch of product in this group is much greater than the time it would take to gather raw materials out of a central storage point. As the Continuous group continues to reduce setup times and thus batch sizes and product mix cycle times, this adoption rate for this tool should increase.

Reliability-Centered Maintenance and Cross-Trained Workforce

There are four maintenance tools or practices included in the lean production toolset for purposes of this study. Interestingly enough, according to Table 18, the Continuous group had the highest average rank of tool adoption for 3 out of the 4 tools. The only one of the four that proved statistically significant at even a level $p<0.10$, is Reliability-Centered Maintenance. Total Productive Maintenance is the only practice that the Discrete group holds a higher average rank than Continuous. This is some evidence to support the hypothesis that the Continuous group places more emphasis on maintenance in general, and especially more sophisticated forms of maintenance such as Reliability-Centered Maintenance and Predictive Maintenance. This makes sense, because downtime for the Continuous group is often much more expensive than downtime in the Discrete group.

The level of adoption for maintenance practices in the Service group is much lower, possibly because equipment processes are not the focus in this group. It should be noted here that the adoption level for Cross-Trained Workforce is much higher on average in the Service group, which can be explained by the emphasis on people in the Service process versus equipment.

<u>Paired Comparison: Discrete vs. Continuous</u>

Because of the lack of data with regard to the Service group, it was decided to run a paired comparison of the two groups, Discrete and Continuous, with the most data. The results of the paired comparison can be found in Tables 35 and 36 in Appendix A. Table 20 summarizes the results of the tools adopted at different levels from both tests.

Table 20: Summary of Tests on Types of Production Processes

Levels Tested	Tools Adopted at Different Levels ($p<0.05$)	Tools Adopted at Different Levels ($p<0.10$)
• Discrete • Continuous • Service	• Method Sheets (-C)* • Flow Cells (-C) • One-Piece Flow (-C) • Mixed-Model Production (-C)	• Point-of-Use Material Storage (-C)* • Reliability-Centered Maintenance (-S) • Cross-Trained Workforce (+S) • Mistake Proofing (+S) • Line Stop (-S) • Statistical Process Control (-D)
• Discrete • Continuous	• Method Sheets (-C) • Flow Cells (-C) • One-Piece Flow (-C) • Mixed-Model Production (-C) • Point-of-Use Material Storage (-C)	• Takt Time (-C) • Predictive Maintenance (+C) • Mistake Proofing (-C)

*Significantly different adopter in parentheses; + or – is relative to other level(s).

The most significant differences are the greater statistical significance of Point-of-Use Storage, and the addition of Takt Time and Predictive Maintenance at $p<0.10$. In the case of Point-of-Use Storage the explanation given previously still holds true. Takt Time is adopted at a lower rate by the Continuous group than the Discrete, which is logical as well, because many continuous processes are not flexible enough to be run at different speeds without affecting quality. However, it also could be a function of traditional accounting metrics such as utilization of equipment are more likely to be used and enforced in the Continuous group versus the Discrete group. Finally, Predictive Maintenance is adopted at a higher rate in the Continuous group when compared directly to the Discrete group, which supports the previous discussion on maintenance practices.

Also significant in Table 20 are the tools that are not significantly different when the test is run without the Service group. Cross-Trained Workforce, Reliability-Centered Maintenance, Line Stop, and Statistical Process Control all are not adopted at significantly different levels between Discrete and Continuous groups.

Effects of Production Volume on Tool Adoption

> H2: The volume of production affects lean production tool selection for a given product line.

The second hypothesis is that the production volume, High, Medium, and Low, affects the lean production tool selection for a given product line. Table 21 reports the average ranks for each tool by level of production volume, as well as the number of cases examined. These tests are performed on the 118 cases that indicated a lean production maturity level of at least three. The eight Service cases are filtered out for this analysis, because production volume is not a good categorization variable for the Service group. Table 22 reports the p-values of the Kruskal-Wallis test for each tool. The tools shaded in gray are the tools that are adopted at significantly different levels across types of production processes.

Table 21: Average Ranks of Tools by Level of Production Volume[2]

	Category of Production Process	N	Mean Rank
5S	Low	6	49.50
	Medium	22	63.70
	High	90	59.14
	Total	118	
Set-up Reduction	Low	6	67.75
	Medium	22	58.70
	High	90	59.14
	Total	118	
Standard Work	Low	6	54.50
	Medium	22	48.82
	High	90	62.44
	Total	118	
Method Sheets	Low	6	70.83
	Medium	22	66.86
	High	90	56.94
	Total	118	
Takt Time	Low	6	55.83
	Medium	22	70.14
	High	90	57.14
	Total	118	
Flow Cells	Low	6	54.00
	Medium	22	63.82
	High	90	58.81
	Total	118	
Visual Controls	Low	6	53.25
	Medium	22	69.77
	High	90	57.41
	Total	118	

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[2] The sample size for the Low Volume group is small relative to the other two categories. This should be taken into account when generalizing the results of this study.

Table 21 (cont'd): Average Ranks of Tools by Level of Production Volume[2]

	Category of Production Process	N	Mean Rank
One-Piece Flow	Low	6	55.33
	Medium	22	64.70
	High	90	58.51
	Total	118	
Smoothed Production Scheduling	Low	6	67.25
	Medium	22	63.18
	High	90	58.08
	Total	118	
Mixed Model Production	Low	6	65.50
	Medium	22	71.09
	High	90	56.27
	Total	118	
Point-of-Use Material Storage	Low	6	46.33
	Medium	22	66.93
	High	90	58.56
	Total	118	
Pull Production Scheduling	Low	6	57.08
	Medium	22	61.55
	High	90	59.16
	Total	118	
Cross-Trained Workforce	Low	6	48.50
	Medium	22	59.05
	High	90	60.34
	Total	118	
Kaizen Events	Low	6	71.42
	Medium	22	59.80
	High	90	58.63
	Total	118	

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[2] The sample size for the Low Volume group is small relative to the other two categories. This should be taken into account when generalizing the results of this study.

Table 21 (cont'd): Average Ranks of Tools by Level of Production Volume [2]

	Category of Production Process	N	Mean Rank
Total Productive Maintenance	Low	6	55.17
	Medium	22	63.20
	High	90	58.88
	Total	118	
Reliability Centered Maintenance	Low	6	49.25
	Medium	22	62.64
	High	90	59.42
	Total	118	
Preventive Maintenance	Low	6	59.83
	Medium	22	61.45
	High	90	59.00
	Total	118	
Predictive Maintenance	Low	6	35.83
	Medium	22	59.45
	High	90	61.09
	Total	118	
Autonomation	Low	6	47.67
	Medium	22	43.59
	High	90	64.18
	Total	118	
Mistake Proofing	Low	6	58.00
	Medium	22	55.45
	High	90	60.59
	Total	118	
Self-Check Inspection	Low	6	61.00
	Medium	22	63.32
	High	90	58.47
	Total	118	

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[2] The sample size for the Low Volume group is small relative to the other two categories. This should be taken into account when generalizing the results of this study.

Table 21 (cont'd): Average Ranks of Tools by Level of Production Volume [2]

	Category of Production Process	N	Mean Rank
Successive-Check Inspection	Low	6	28.67
	Medium	22	70.59
	High	90	58.84
	Total	118	
Line Stop	Low	6	32.08
	Medium	22	58.34
	High	90	61.61
	Total	118	
Design of Experiments	Low	6	43.25
	Medium	22	54.02
	High	90	61.92
	Total	118	
Root Cause Analysis	Low	6	63.50
	Medium	22	59.77
	High	90	59.17
	Total	118	
Statistical Process Control	Low	6	48.83
	Medium	22	52.82
	High	90	61.84
	Total	118	
Team-Based Problem Solving	Low	6	55.08
	Medium	22	64.05
	High	90	58.68
	Total	118	

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[2] The sample size for the Low Volume group is small relative to the other two categories. This should be taken into account when generalizing the results of this study.

Table 22: Kruskal-Wallis Test for Significant Differences in the Adoption of Lean Production Tools Between Levels of Production Volume[2]

Test Statistics[a,b]

	Chi-Square	df	Asymp. Sig.
5s	1.337	2	.513
Setup Reduction	.468	2	.791
Standard Work	4.007	2	.135
Method Sheets	2.664	2	.264
Takt Time	3.056	2	.217
Flow Cells	.752	2	.687
Visual Controls	4.304	2	.116
One-Piece Flow	.815	2	.665
Smoothed Production Schedule	.865	2	.649
Mixed Model Production	4.216	2	.122
Point-of-Use Material Storage	2.675	2	.262
Pull Production Scheduling	.145	2	.930
Cross-Trained Workforce	1.060	2	.589
Kaizen Events	1.015	2	.602
Total Productive Maintenance	.452	2	.798
Reliability-Centered Maintenance	.842	2	.657
Preventive Maintenance	.138	2	.933
Predictive Maintenance	3.472	2	.176
Autonomation	8.315	2	.016
Mistake Proofing	.505	2	.777
Self-Check Inspection	.543	2	.762
Successive-Check Inspection	8.364	2	.015
Line Stop	5.033	2	.081
Design-of-Experiments	2.705	2	.259
Root-Cause Analysis	.126	2	.939
Statistical Process Control	2.173	2	.337
Team-Based Problem Solving	.852	2	.653

a. Kruskal Wallis Test

b. Grouping Variable: Volume

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[2] The sample size for the Low Volume group is small relative to the other two categories. This should be taken into account when generalizing the results of this study.

As shown in Tables 21 and 22, there are only two tools that are adopted at significantly different levels ($p<0.05$) across the three types of production processes: Autonomation and Successive Check Inspection. Only one additional tool is adopted at different levels where $p<0.10$: Line Stop. The Low Volume group reports adopting all three of these tools at much lower levels than the Medium or High Volume groups. In fact, with more data from the Low Volume group, six additional tools could prove to be adopted at lower rates as well: Point-of-Use Material Storage, Cross-Trained Workforce, Reliability-Centered Maintenance, Predictive Maintenance, Design-of-Experiments, and Statistical Process Control.

Test of H2: Tools Where $p<0.05$

Autonomation and Successive Check Inspection

The Low Volume group adopts all of the tools or practices showing significant differences between groups at a significantly lower rate. The reasons for this group not adopting Autonomation and Successive Check Inspection are functions of time. The Low Volume group defines the cycle time between production units in weeks or months. In these types of value streams the work is more project-oriented than production oriented, and products are often one-of-a-kind, making it more difficult to translate the lean production tools from the high volume, repetitive worlds. This is not to say that the tools do not apply, but just to say that it is more difficult to find the analogy.

Autonomation is the practice of designing machinery or equipment that detects quality defects and shuts itself down immediately. This is a sophisticated technique that often requires the repetition found in higher volume value streams to calibrate. This technique also requires consistent and well-defined specifications about the product characteristics. It is possible and conceivable that a Low volume producer would translate this technique to their world, but it would require a company to be very proactive, and very well integrated, especially between the design and manufacturing functions. The changes in the product specifications would have to be minimized, which is a difficult task in Low Volume environments.

The logic for why Low Volume producers report low adoption of Successive Check Inspection is similar to the logic presented for Autonomation. Specifications again have to be well-defined and consistent for operators to check the quality of the previous work center. Another issue is that often the Low Volume producer does not produce in a progressive manner. The products are often so big (ex. shipbuilding) that the product must be built in a station-build manner. This constraint inhibits the adoption of a tool like Successive Check Inspection.

Tools Where p<0.10

Line Stop

As stated previously, many Low Volume producers are constrained to a station-build approach because of the significant size of the products being manufactured. This inhibits the use of an assembly line and therefore the need for Line Stop.

Paired Comparison: Medium vs. High

Just as in the case of the Types of Production Process, a paired comparison is performed of the two levels, Medium and High, with the most data. The results of the paired comparison can be found in Tables 36 and 37 in Appendix A. Table 23 summarizes the results of the tools adopted at different levels from both tests.

The paired comparison analysis reports the High Volume group adopting three tools, Visual Controls, Mixed Model Production ($p<0.05$), and Takt Time ($p<0.10$), at a lower rate than the Medium Volume group. It also reports the Medium.

Table 23: Summary of Tests on Production Volume

Levels Tested	Tools Adopted at Different Levels ($p<0.05$)	Tools Adopted at Different Levels ($p<0.10$)
• Low • Medium • High	• Autonomation (-L)* • Successive-Check Inspection (-L)	• Line Stop (-L)
• Medium • High	• Visual Controls (-H) • Mixed Model Production (-H) • Autonomation (-M)	• Standard Work (-M) • Takt Time (-H)

*Significantly different adopter in parentheses; + or – is relative to other level(s).

Volume group adopting two tools, Autonomation and Standard Work, at a lower rate than the High Volume group.

The logic for the lower adoption of Visual Controls, Mixed Model Production and Takt Time by High Volume groups may stem from the fact that so much of the production system is readily defined in a high production volume environment. Product flow is easy to recognize in a high volume production system, and much of the work can be automated, so the need to communicate using visual signals is lessened. Higher volumes justify dedicated equipment; so focused factories eliminate the need for Mixed Model Production. High Volume, Discrete producers just as the High Volume, Continuous producers may also have long-standing utilization metrics in place that encourage producing to full capacity as opposed to a demand-driven takt time.

The logic behind the Medium Volume group's lower adoption rate of Autonomation is similar to the logic of the Low Volume group's lower adoption rate. As volume increases repetition increases and specifications are better defined and maintained, such that Autonomation can be incorporated into the equipment. The same logic applies to Standard Work. It is hard to establish a standard way to assemble or fabricate a product, when the product is rarely the same. Both Medium and Low volume producers will tend toward giving customer's flexibility in their product choices (BTO) as a trade-off for longer lead times. This added complexity makes repeatability decrease and makes it harder to develop Standard Work. Again this is not to say that the tools cannot or should not be applied, but there are more obstacles to overcome in order to transfer the technology into these environments.

Effects of Order Fulfillment Strategy on Tool Adoption

> H3: The dominant order fulfillment strategy (i.e. Build-to-Stock, Build-to-Order, etc.) affects lean production tool selection for a given product line.

The third hypothesis is that the Dominant Order Fulfillment Process, Build-to-Stock, Build-to-Order, and Make-to-Order, affects the lean production tool selection for a given product line. Table 24 reports the average ranks for each tool by level of production volume, as well as the number of cases examined. These tests are performed on the 118 cases that indicated a lean production maturity level of at least three. The eight Service cases are filtered out for this analysis, because order fulfillment process is not a good categorization variable for the Service group. Table 25 reports the p-values of the Kruskal-Wallis test for each tool. The tools shaded in gray are the tools that are the tools that are adopted at significantly different levels across types of production processes.

As shown in Tables 24 and 25, there is only one tool that is adopted at significantly different level ($p<0.05$) across the three types of order fulfillment strategies: Statistical Process Control. Two additional tools are adopted at different levels where $p<0.10$: 5s and Cross-Trained Workforce.

<u>Tools Where p<0.05</u>

Statistical Process Control

The Build-to-Stock group reports higher adoption rates of Statistical Process Control than do the other two groups. This is explained by the repetition needed to develop many of the Stewhart charts used in Statistical Process Control. Build-to-Stock product lines tend to have fewer numbers of end-items, and

Table 24: Average Ranks of Tools by Level of Order Fulfillment Process

	Category of Production Process	N	Mean Rank
5S	BTS	30	55.08
	BTO	21	49.98
	MTO	67	64.46
	Total	118	
Set-up Reduction	BTS	30	60.48
	BTO	21	55.29
	MTO	67	60.38
	Total	118	
Standard Work	BTS	30	60.43
	BTO	21	48.31
	MTO	67	62.59
	Total	118	
Method Sheets	BTS	30	53.10
	BTO	21	60.29
	MTO	67	62.12
	Total	118	
Takt Time	BTS	30	60.63
	BTO	21	57.31
	MTO	67	59.68
	Total	118	
Flow Cells	BTS	30	51.13
	BTO	21	60.43
	MTO	67	62.96
	Total	118	
Visual Controls	BTS	30	59.67
	BTO	21	60.57
	MTO	67	59.09
	Total	118	

Table 24 (cont'd): Average Ranks of Tools by Level of Order Fulfillment Process

	Category of Production Process	N	Mean Rank
One-Piece Flow	BTS	30	51.12
	BTO	21	62.55
	MTO	67	62.30
	Total	118	
Smoothed Production Scheduling	BTS	30	64.35
	BTO	21	56.07
	MTO	67	58.40
	Total	118	
Mixed Model Production	BTS	30	49.60
	BTO	21	62.50
	MTO	67	62.99
	Total	118	
Point-of-Use Material Storage	BTS	30	54.72
	BTO	21	59.81
	MTO	67	61.54
	Total	118	
Pull Production Scheduling	BTS	30	62.53
	BTO	21	51.62
	MTO	67	60.61
	Total	118	
Cross-Trained Workforce	BTS	30	49.83
	BTO	21	58.17
	MTO	67	64.25
	Total	118	
Kaizen Events	BTS	30	63.73
	BTO	21	63.50
	MTO	67	56.35
	Total	118	

Table 24 (cont'd): Average Ranks of Tools by Level of Order Fulfillment Process

	Category of Production Process	N	Mean Rank
Total Productive Maintenance	BTS	30	56.83
	BTO	21	65.12
	MTO	67	58.93
	Total	118	
Reliability Centered Maintenance	BTS	30	56.60
	BTO	21	62.79
	MTO	67	59.77
	Total	118	
Preventive Maintenance	BTS	30	61.03
	BTO	21	60.67
	MTO	67	58.45
	Total	118	
Predictive Maintenance	BTS	30	63.17
	BTO	21	53.07
	MTO	67	59.87
	Total	118	
Autonomation	BTS	30	61.93
	BTO	21	58.07
	MTO	67	58.86
	Total	118	
Mistake Proofing	BTS	30	64.53
	BTO	21	49.88
	MTO	67	60.26
	Total	118	
Self-Check Inspection	BTS	30	58.47
	BTO	21	57.60
	MTO	67	60.56
	Total	118	

Table 24 (cont'd): Average Ranks of Tools by Level of Order Fulfillment Process

	Category of Production Process	N	Mean Rank
Successive-Check Inspection	BTS	30	56.25
	BTO	21	53.62
	MTO	67	62.80
	Total	118	
Line Stop	BTS	30	59.48
	BTO	21	50.55
	MTO	67	62.31
	Total	118	
Design of Experiments	BTS	30	64.30
	BTO	21	53.76
	MTO	67	59.15
	Total	118	
Root Cause Analysis	BTS	30	57.20
	BTO	21	62.43
	MTO	67	59.61
	Total	118	
Statistical Process Control	BTS	30	74.02
	BTO	21	46.62
	MTO	67	57.04
	Total	118	
Team-Based Problem Solving	BTS	30	63.12
	BTO	21	59.05
	MTO	67	58.02
	Total	118	

Table 25: Kruskal-Wallis Test for Significant Differences in the Adoption of Lean Production Tools Between Levels of Order Fulfillment Process

Test Statistics[a,b]

	Chi Square	df	Asymp. Sig.
5s	5.530	2	.063
Setup Reduction	.490	2	.783
Standard Work	3.838	2	.147
Method Sheets	1.777	2	.411
Takt Time	.141	2	.932
Flow Cells	3.460	2	.177
Visual Controls	.053	2	.974
One-Piece Flow	2.923	2	.232
Smoothed Production Schedule	1.065	2	.587
Mixed Model Production	4.045	2	.132
Point-of-Use Material Storage	1.110	2	.574
Pull Production Scheduling	1.753	2	.416
Cross-Trained Workforce	5.804	2	.055
Kaizen Events	1.694	2	.429
Total Productive Maintenance	.904	2	.636
Reliability-Centered Maintenance	.481	2	.786
Preventive Maintenance	.223	2	.894
Predictive Maintenance	1.239	2	.538
Autonomation	.246	2	.884
Mistake Proofing	2.882	2	.237
Self-Check Inspection	.231	2	.891
Successive-Check Inspection	1.754	2	.416
Line Stop	2.255	2	.324
Design-of-Experiments	1.357	2	.507
Root-Cause Analysis	.398	2	.820
Statistical Process Control	10.274	2	.006
Team-Based Problem Solving	.732	2	.693

[a] Kruskal Wallis Test

[b] Grouping Variable: Dominant Order Fulfillment Process

therefore are more readily suited to use a tool such as Statistical Process Control.

Tools Where p<0.10

5s

The Make-to-Stock group reports the highest adoption rate of 5s, and Build-to-Order the lowest. One explanation for this is that Make-to-Order production systems are sensitive to both customer lead times and product variety (as opposed to customer lead times for Build-to-Stock and product variety for Build-to-Order). In this environment, organization of the workspace is at a premium, because the materials to pull together are more complex (more options to be offered) than in a Build-to-Stock product line, *and* production lead time is important and cannot be spent searching for tools and materials.

Cross-Trained Workforce

The Make-to-Stock group also reports the highest adoption rate of Cross-Train Workforce. Again because of the sensitivity to both customer lead times and product variety, capacity flexibility is vital to meeting customer expectations. One way to improve capacity flexibility particularly in a Discrete, assembly environment is to train workers to perform multiple jobs.

Paired comparisons were not performed on this factor, because the sample sizes were enough at each level that the Kruskal-Wallis test is adequate to show the differences across all three levels.

Summary of H1:H3

All three of the null hypotheses are rejected, because at least one tool per factor exhibited a significant difference in the level of adoption. Furthermore, when some of the levels that lacked sufficient data are removed, even more tools show up as being adopted at significantly different levels. Type of Production Process exhibits an effect on the largest subset of tools, followed by Volume. Interactions were not tested in this analysis, because of the lack of existence of a full factorial of variables, and because some of the treatments are sparsely populated.

Because each factor exhibited some influence on the selection of tools within the lean production toolset, it is determined that a model predicting the probability that a given value stream profile (made up of these three factors) would adopt a given tool will present a proposed taxonomy of lean production application. This model will be developed in the final section of this chapter.

A Model Predicting the Probability of Tool Adoption

As stated earlier, the model that is used to predict the probability of tool adoption by Value Stream profile is a binary logistic regression model. Logistic regression is designed to take a mix of continuous and/or categorical predictor variables to predict a categorical outcome. In this case we have both categorical predictor and response variables, so logistical regression is the best tool. There are not as many assumptions for the logistic regression model as those of regular linear regression. However, one assumption that is the same as that of linear regression is the assumption that there is an absence of perfect multicollinearity between independent variables. Table 26 reports the tests for collinearity between factors.

Table 26: Test for Collinearity Between Factors

Collinearity Diagnostics

				Variance Proportions			
Model	Dim.	Eigenvalue	Condition Index	Constant	Category of Production Process	Volume	Dominant Order Fulfilment Strategy
1	1	3.791	1.000	.00	.01	.00	.01
	2	.131	5.384	.00	.19	.02	.68
	3	5.729E-02	8.134	.08	.80	.22	.15
	4	2.112E-02	13.397	.91	.00	.76	.16

Evidence for collinearity among independent variables exists if the condition index is larger than 15. In this case there is no evidence for collinearity.

Table 27 reports the resulting predictive model for each tool, using the logistical regression equation defined earlier. The Hosemer and Lemeshow p-value is a test of fit of the model, in which a small p-value would indicate a poor fit. As can be seen in the table, all of the models have a high Hosemer and Lemeshow p-value indicated a significant fit for the models.

Predictability of Models

Once the model is generated and tested for goodness of fit using the SPSS binary logistical regression commands, it is then tested for its ability to predict. The sensitivity and specificity of the model can then be determined. The sensitivity of the model is the probability that the model would predict the tool to be adopted by a given value stream profile *and* the tool was actually adopted. The specificity of the model is the probability that the model would predict the tool would not be adopted *and* the tool was not adopted.

The actual predictability of the model is reflected in the total percent of the data that was predicted correctly. This number is then compared to the case in which we knew nothing about the independent variables, and just used the distribution of the dependent variable to predict tool adoption. The predictive improvement is the difference in the regression model and the distribution of the dependent variable. The regression model improved the predictability of six of the twenty-seven tools, some much more than others. The tools that were improved the most were Set-up Reduction, Total Productive, Reliability-Centered, and Predictive Maintenance, Autonomation, and Design-of-Experiments. These tools had the most amount of variation in tool adoption by value stream profile.

Table 27: Logistic Models by Tool

Model*	β_0	β_1: Disc	β_2: Med	β_3: High	β_4: BTO	β_5: MTO	Hosemer and Lemeshow	Sensitivity P(1 & 1)	Specificity P(0 & 0)	Overall Percent	Accuracy Given Dependent Variable	Predictive Improvement
5s	0.351	0.23	-0.003	0.758	-0.806	0.705	0.982	0.94	0.20	0.72	0.70	0.02
Setup Reduction	-0.413	-0.205	0.821	0.028	-0.299	0.284	0.982	0.02	1.00	0.61	0.40	0.21
Standard Work	0.483	0.166	-0.151	-0.661	-0.624	0.155	0.501	0.89	0.17	0.61	0.61	0.00
Method Sheets	-0.9	0.862	1.189	0.624	-0.611	0.525	0.969	0.60	0.59	0.59	0.46	0.13
Takt Time	-0.679	0.543	-0.013	0.643	-0.633	-0.125	0.842	0.16	0.93	0.60	0.42	0.18
Flow Cells	-1.253	1.59	-0.886	-0.237	0.279	0.65	0.884	0.84	0.42	0.69	0.63	0.05
Visual Controls	0.677	0.426	0.826	1.431	-0.348	-0.168	0.837	1.00	0.00	0.75	0.75	0.00
One-Piece Flow	-2.511	2.128	-1.031	-0.273	0.155	0.359	0.961	0.64	0.66	0.65	0.47	0.18
Smoothed Production Schedule	0.123	0.157	1.29	0.66	-0.972	-0.339	0.992	0.46	0.67	0.56	0.52	0.04
Mixed-Model Production	-1.206	0.996	0.134	0.701	-0.087	0.491	0.994	0.64	0.58	0.61	0.52	0.09
Point-of-Use Material Storage	-0.879	1.281	-1.505	0.176	0.394	0.492	0.966	0.85	0.43	0.68	0.60	0.08
Pull Production Scheduling	0.186	-0.122	1.368	0.437	-0.876	0.092	0.77	0.91	0.18	0.57	0.53	0.03
Cross-Trained Workforce	0.737	-0.867	-1.085	-0.225	1.203	1.279	0.922	0.85	0.36	0.70	0.69	0.01
Kaizen Events	0.334	0.555	1.201	0.007	-0.434	-0.691	0.951	0.90	0.16	0.59	0.58	0.01
Total Productive Maintenance	-1.202	0.502	-1.751	0.119	0.914	0.414	0.982	0.20	0.90	0.63	0.39	0.24
Reliability-Centered Maintenance	-0.823	-0.601	-1.177	0.199	1.085	0.403	0.823	0.00	1.00	0.70	0.30	0.41
Preventive Maintenance	1.437	-0.871	-0.026	0.378	0.203	-0.083	0.992	1.00	0.00	0.69	0.69	0.00
Predictive Maintenance	-0.437	-0.891	-7.558	-0.38	0.747	0.324	0.677	0.00	1.00	0.72	0.28	0.44
Autonomation	-0.99	0.114	-0.733	-8.216	0.05	-0.279	0.992	0.00	1.00	0.80	0.20	0.59
Mistake Proofing	-0.41	1.071	0.505	-0.375	-1.332	-0.28	0.946	0.73	0.51	0.62	0.50	0.12
Self-Check Inspection	0.363	0.475	0.348	0.373	-0.591	0.071	0.875	1.00	0.00	0.68	0.68	0.00
Successive-Check Inspection	0.099	-0.658	-1.138	0.978	0.057	0.238	0.621	0.51	0.70	0.61	0.47	0.14
Line Stop	0.225	-0.347	-0.357	0.103	-0.327	0.305	0.999	0.72	0.44	0.59	0.52	0.07
Design-of-Experiments	-1.092	-0.442	-0.672	-0.217	0.607	0.543	0.957	0.00	1.00	0.75	0.25	0.49
Root Cause Analysis	0.581	-0.474	0.105	0.096	0.52	0.293	0.996	1.00	0.00	0.62	0.62	0.00
Statistical Process Control	1.061	-0.325	0.194	0.119	-1.75	-1.041	0.511	0.49	0.72	0.61	0.48	0.13
Team Based Problem Solving	1.46	-0.444	0.052	0.601	-0.352	-0.488	0.733	1.00	0.00	0.70	0.70	0.00

*The Service level is not included in the logistical regression model.

Predicted Probabilities of Adoption by Profile

Table 28 reports the probability that a given tool will be adopted by a given value stream profile. Eleven profiles were represented in the data. The Discrete group almost had the full factorial of profiles, but there were no Low Volume, Build-to-Stock cases. It is very likely that this treatment does not exist in industry. Other treatments that are likely not to exist are Continuous at Low or Medium volume and/or Build-to-Order. The Service cases are not included in the logistical regression model, because volume and order fulfillment process do not characterize the individual value streams very well, and the number of respondents is low. Therefore, the probabilities for these cases are the actual percentage of the population that reports adopting the respective tool.

Proposed Taxonomy of Lean Production Tool Adoption

Table 29 reports three levels of tool adoption for each value stream profile. Type A tool adoption is the set of tools with a probability of adoption greater than or equal to 60% for a given value stream profile. These are the tools that you would expect to see being applied at a facility with a level of lean production maturity of 3 or greater (as defined by this research). Type B tool adoption is the set of tools with a probability of adoption greater than 30%, but less than 60% for a given value stream profile. These are the tools that you may or may not see being applied, but it should at least be investigated as to why a specific tool does not apply to their situation. Finally, Type C tool adoption is the set of tools with a probability of adoption less than 30% for a given value stream profile. These are the tools that you would not expect to see being applied at a given location, because they either do not make sense to use in their situation, or an analogous tool has not been developed.

It is important to point out that in this proposed taxonomy, there are tools that have a low probability of being adopted that are not necessarily a bad fit for a given value stream profile. A good example of this is the Maintenance tools.

Table 28: Probability of Tool Adoption by Value Stream Profile

Tool	Discrete								Continuous		Service*
	High Volume			Medium Volume			Low Volume				
	BTS	BTO	MTO	BTS	BTO	MTO	BTO	MTO	BTS	MTO	
5s	0.64	0.44	0.78	0.79	0.63	0.89	0.44	0.78	0.59	0.74	0.88
Setup Reduction	0.55	0.48	0.62	0.36	0.29	0.42	0.29	0.42	0.60	0.67	0.25
Standard Work	0.62	0.47	0.66	0.50	0.35	0.54	0.51	0.69	0.58	0.62	0.88
Method Sheets	0.76	0.63	0.84	0.64	0.49	0.75	0.34	0.62	0.57	0.69	0.88
Takt Time	0.46	0.31	0.43	0.62	0.47	0.59	0.32	0.44	0.33	0.31	0.5
Flow Cells	0.58	0.65	0.73	0.73	0.78	0.84	0.82	0.87	0.22	0.35	0.63
Visual Controls	0.87	0.83	0.85	0.93	0.90	0.91	0.68	0.72	0.82	0.79	0.75
One-Piece Flow	0.24	0.27	0.31	0.40	0.44	0.49	0.50	0.55	0.04	0.05	0.5
Smoothed Production Schedule	0.83	0.65	0.77	0.72	0.49	0.65	0.33	0.49	0.80	0.75	0.63
Mixed-Model Production	0.49	0.47	0.61	0.63	0.61	0.73	0.43	0.58	0.26	0.37	0.5
Point-of-Use Material Storage	0.25	0.33	0.35	0.64	0.73	0.74	0.69	0.71	0.08	0.13	0.63
Pull Production Scheduling	0.88	0.89	0.88	0.66	0.68	0.66	0.84	0.83	0.65	0.65	0.63
Cross-Trained Workforce	0.23	0.50	0.52	0.41	0.70	0.72	0.75	0.76	0.41	0.72	1
Kaizen Events	0.89	0.84	0.80	0.71	0.61	0.55	0.61	0.55	0.82	0.70	0.88
Total Productive Maintenance	0.08	0.18	0.12	0.36	0.58	0.46	0.55	0.43	0.05	0.07	0.38
Reliability-Centered Maintenance	0.07	0.18	0.10	0.23	0.47	0.31	0.42	0.26	0.12	0.17	0.00
Preventive Maintenance	0.37	0.35	0.35	0.33	0.31	0.31	0.27	0.27	0.38	0.36	0.5
Predictive Maintenance	0.00	0.00	0.00	0.15	0.28	0.20	0.36	0.27	0.00	0.00	0.38
Autonomation	0.17	0.17	0.13	0.00	0.00	0.00	0.30	0.24	0.15	0.12	0.25
Mistake Proofing	0.76	0.46	0.71	0.57	0.26	0.50	0.34	0.59	0.52	0.45	0.75
Self-Check Inspection	0.77	0.64	0.78	0.77	0.65	0.78	0.56	0.71	0.67	0.69	0.88
Successive-Check Inspection	0.15	0.16	0.19	0.60	0.62	0.66	0.38	0.42	0.26	0.31	0.38
Line Stop	0.38	0.31	0.46	0.50	0.41	0.57	0.39	0.55	0.47	0.54	0.25
Design-of-Experiments	0.10	0.17	0.16	0.15	0.24	0.23	0.28	0.27	0.15	0.23	0.00
Root Cause Analysis	0.55	0.68	0.62	0.55	0.67	0.62	0.65	0.60	0.67	0.73	0.88
Statistical Process Control	0.72	0.31	0.47	0.70	0.29	0.45	0.27	0.42	0.78	0.55	0.75
Team Based Problem Solving	0.74	0.67	0.64	0.83	0.78	0.76	0.66	0.63	0.82	0.74	1

*The Service level is not included in the logistical regression model. The results reported here are the actual probabilities from the sample.

Reliability-Centered Maintenance and Predictive Maintenance are very powerful maintenance strategies that have a rate of infusion across industry that may not correlate with the implementation of lean production. Both quality and maintenance practices (exceptfor Total Productive Maintenance) are often implemented separately from a formal lean implementation. For this reason, a Type C tool should be analyzed for goodness of fit in each value stream prior to discarding it as a practice of lean production.

While there is not conclusive evidence from this study that a Type C tool does not apply to a given Value Stream profile, there is strong evidence that a Type A tool does apply to a given Value Stream profile. It should be noted that the differences in the Type A tool sets across profiles are further evidence to support our hypotheses that lean production tools are adopted differently dependent upon characteristics of the value stream.

Table 30 summarizes some of the significant findings of the previous two tables. The gray boxes identify the tools that are adopted at an average of at least 60% *and* at least nine of the eleven of the profiles adopt the tool with at least 60% probability. There is evidence that these tools in particular are almost universally applied, particularly Visual Controls, Pull Production Scheduling, and Team-Based Problem Solving, which are adopted with at least 60% probability by every profile. Self-Check Inspection is adopted at the same rate by every profile except for the Discrete, Low Volume, Build-to-Order profile, which adopts the tool at a probability of 56%. Kaizen Events is another tool that is adopted with at least 60% probability by every profile but two. Companies with a Discrete, Medium or Low Volume, Make-to-Order profile are predicted to adopt Kaizen Events with a 55% probability. Also notable are the eight tools that are not predicted to be adopted at greater than 60% by any profile: One-Piece Flow, all four of the maintenance practices, Autonomation, Line Stop, and Design-of-Experiments.

Table 29: Taxonomy of Lean Production Tool Adoption

Value Stream Profile	Type A: P(Adoption)>0.60	Type B: 0.60>P(Adoption)>0.3	Type C: P(Adoption)<0.3
Discrete - High Volume – BTS Mature Sample Size: 19 Total Sample Size: 31 Percent Mature: 61.3%	5s Standard Work Method Sheets Visual Controls Smoothed Production Schedule Pull Production Scheduling Kaizen Events Mistake Proofing Self-Check Inspection Statistical Process Control Team-Based Problem Solving	Setup Reduction Production to Takt Time Flow Cells Mixed Model Production Preventive Maintenance Line Stop Root Cause Analysis	One-Piece Flow Point-of-Use Material Storage Cross-Trained Workforce Total Productive Maintenance Reliability-Centered Maintenance Predictive Maintenance Autonomation Successive-Check Inspection Design-of-Experiments
Discrete - High Volume - BTO Mature Sample Size: 6 Total Sample Size: 13 Percent Mature: 46.2%	Method Sheets Flow Cells Visual Controls Smoothed Production Schedule Pull Production Scheduling Kaizen Events Self-Check Inspection Root Cause Analysis Team-Based Problem Solving	5s Setup Reduction Standard Work Production to Takt Time Mixed Model Production Point-of-Use Material Storage Cross-Trained Workforce Preventive Maintenance Mistake Proofing Line Stop Statistical Process Control	One-Piece Flow Total Productive Maintenance Reliability-Centered Maintenance Predictive Maintenance Autonomation Successive-Check Inspection Design of Experiments
Discrete - High Volume – MTO Mature Sample Size: 26 Total Sample Size: 44 Percent Mature: 59.1%	5s Setup Reduction Standard Work Method Sheets Flow Cells Visual Controls Smoothed Production Schedule Mixed Model Production Pull Production Scheduling Kaizen Events Mistake Proofing Self-Check Inspection Root Cause Analysis Team-Based Problem Solving	Production to Takt Time One-Piece Flow Point-of-Use Material Storage Cross Trained Workforce Preventive Maintenance Line Stop Statistical Process Control	Total Productive Maintenance Reliability-Centered Maintenance Predictive Maintenance Autonomation Successive-Check Inspection Design of Experiments

Table 29 (cont'd): Taxonomy of Lean Production Tool Adoption

Value Stream Profile	Type A: P(Adoption)>0.60	Type B: 0.60>P(Adoption)>0.3	Type C: P(Adoption)<0.3
Discrete - Med Volume – BTS Mature Sample Size: 6 Total Sample Size: 6 Percent Mature: 100%	5s Method Sheets Takt Time Flow Cells Visual Controls Smoothed Production Schedule Mixed Model Production Point-of-Use Material Storage Pull Production Scheduling Kaizen Events Self-Check Inspection Successive-Check Inspection Statistical Process Control Team-Based Problem Solving	Setup Reduction Standard Work One-Piece Flow Cross-Trained Workforce Total Productive Maintenance Preventive Maintenance Mistake Proofing Line Stop Root Cause Analysis	Reliability-Centered Maintenance Predictive Maintenance Autonomation Design-of-Experiments
Discrete - Med. Volume – BTO Mature Sample Size: 9 Total Sample Size: 22 Percent Mature: 40.9%	5s Flow Cells Visual Controls Mixed Model Production Point-of-Use Material Storage Pull Production Scheduling Cross-Trained Workforce Kaizen Events Self-Check Inspection Successive-Check Inspection Root Cause Analysis Team-Based Problem Solving	Standard Work Method Sheets Production to Takt Time One-Piece Flow Smoothed Production Schedule Total Productive Maintenance Reliability-Centered Maintenance Preventive Maintenance Line Stop	Setup Reduction Predictive Maintenance Autonomation Mistake Proofing Design-of-Experiments Statistical Process Control
Discrete - Med. Volume – MTO Mature Sample Size: 8 Total Sample Size: 17 Percent Mature: 47.1%	5s Method Sheets Flow Cells Visual Controls Smoothed Production Schedule Mixed Model Production Point-of-Use Material Storage Pull Production Scheduling Self-Check Inspection Successive-Check Inspection Root Cause Analysis Team-Based Problem Solving	Setup Reduction Standard Work Production to Takt Time One-Piece Flow Kaizen Events Total Productive Maintenance Reliability-Centered Maintenance Preventive Maintenance Mistake Proofing Line Stop Statistical Process Control	Predictive Maintenance Autonomation Design-of-Experiments

Table 29 (cont'd): Taxonomy of Lean Production Tool Adoption

Value Stream Profile	Type A: P(Adoption)>0.60	Type B: 0.60>P(Adoption)>0.3	Type C: P(Adoption)<0.3
Discrete - Low Volume – BTO Mature Sample Size: 6 Total Sample Size: 10 Percent Mature: 60%	Flow Cells Visual Controls Point-of-Use Material Storage Pull Production Scheduling Cross-Trained Workforce Kaizen Events Root Cause Analysis Team Based Problem Solving	5s Standard Work Method Sheets Production to Takt Time One-Piece Flow Smoothed Production Schedule Mixed-Model Production Total Productive Maintenance Reliability-Centered Maintenance Predictive Maintenance Autonomation Mistake Proofing Self-Check Inspection Successive-Check Inspection Line Stop	Setup Reduction Preventive Maintenance Design of Experiments Statistical Process Control
Discrete - Low Volume – MTO Mature Sample Size: 2 Total Sample Size: 4 Percent Mature: 50%	5s Standard Work Method Sheets Flow Cells Visual Controls Point-of-Use Material Storage Pull Production Scheduling Cross-Trained Workforce Self-Check Inspection Root Cause Analysis Team Based Problem Solving	Setup Reduction Production to Takt Time One-Piece Flow Smoothed Production Schedule Mixed-Model Production Kaizen Events Total Productive Maintenance Mistake Proofing Successive-Check Inspection Line Stop Statistical Process Control	Reliability-Centered Maintenance Preventive Maintenance Predictive Maintenance Autonomation Design of Experiments

Table 29 (cont'd): Taxonomy of Lean Production Tool Adoption

Value Stream Profile	Type A: P(Adoption)>0.60	Type B: 0.60>P(Adoption)>0.3	Type C: P(Adoption)<0.3
Continuous – BTS Mature Sample Size: 13 Total Sample Size: 19 Percent Mature: 68.4%	Set-up Reduction Visual Controls Smoothed Production Schedule Pull Production Scheduling Kaizen Events Self-Check Inspection Root Cause Analysis Statistical Process Control Team-Based Problem Solving	5s Standard Work Method Sheets Production to Takt Time Cross-Trained Workforce Preventive Maintenance Mistake Proofing Line Stop	Flow Cells One-Piece Flow Mixed Model Production Point-of-Use Material Storage Total Productive Maintenance Reliability-Centered Maintenance Predictive Maintenance Autonomation Successive-Check Inspection Design of Experiments
Continuous – MTO Mature Sample Size: 20 Total Sample Size: 27 Percent Mature: 74%	5s Setup Reduction Standard Work Method Sheets Visual Controls Smoothed Production Schedule Pull Production Schedule Cross-Trained Workforce Kaizen Events Self-Check Inspection Root Cause Analysis Team-Based Problem Solving	Production to Takt Time Flow Cells Mixed Model Production Preventive Maintenance Mistake Proofing Successive Check Inspection Line Stop Statistical Process Control	One-Piece Flow Point-of-Use Material Storage Total Productive Maintenance Reliability-Centered Maintenance Predictive Maintenance Autonomation Design of Experiments
Service Mature Sample Size: 11 Total Sample Size: 16 Percent Mature: 68.8%	5s Standard Work Method Sheets Flow Cells Visual Controls Smoothed Production Schedule Point-of-Use Material Storage Pull Production Scheduling Cross-Trained Workforce Mistake Proofing Self-Check Inspection Root Cause Analysis Statistical Process Control Team-Based Problem Solving	Production to Takt Time One-Piece Flow Mixed-Model Production Total Productive Maintenance Preventive Maintenance Predictive Maintenance Successive Check Inspection	Setup Reduction Autonomation Line Stop Design-of-Experiments

Table 30: Summary Table of Probability of Tool Adoption > 0.60

Tool	Average Tool P(Adoption)	Number Adopted >.60
5s	0.69	8.00
Setup Reduction	0.45	3.00
Standard Work	0.58	5.00
Method Sheets	0.66	8.00
Takt Time	0.44	1.00
Flow Cells	0.65	8.00
Visual Controls	0.82	11.00
One-Piece Flow	0.34	0.00
Smoothed Production Schedule	0.65	8.00
Mixed-Model Production	0.52	4.00
Point-of-Use Material Storage	0.48	6.00
Pull Production Scheduling	0.75	11.00
Cross-Trained Workforce	0.61	6.00
Kaizen Events	0.72	9.00
Total Productive Maintenance	0.30	0.00
Reliability-Centered Maintenance	0.21	0.00
Preventive Maintenance	0.35	0.00
Predictive Maintenance	0.15	0.00
Autonomation	0.14	0.00
Mistake Proofing	0.54	3.00
Self-Check Inspection	0.72	10.00
Successive-Check Inspection	0.38	3.00
Line Stop	0.44	0.00
Design-of-Experiments	0.18	0.00
Root Cause Analysis	0.66	8.00
Statistical Process Control	0.52	4.00
Team Based Problem Solving	0.75	11.00

CHAPTER 5

CONTRIBUTIONS, CONCLUSIONS, AND RECOMMENDATIONS

Contributions of the Research

Applied research such as this often provides both theoretical and managerial contributions. This research has three main areas of contribution, and each area contributes to theory and management. First, the research uses the fundamental concept of the value stream and a thorough review of the literature to develop a broader definition of lean production and the tools that it constitutes. This definition leads to a larger, more comprehensive lean production tool set that incorporate tools traditionally categorized in other areas, such as tools of Quality and Maintenance. In addition, this study provides broader, objective, and customer-focused definitions of the major order fulfillment strategies. A broader, more comprehensive lean production tool set provides future researchers a standard by which to compare companies applying lean technologies, and it is based on the well-conceived concept of the value stream. For managers, this toolset provides a holistic approach to developing an integrated production strategy for the company.

The second major contribution of this research is that it provides evidence of the existence of a taxonomy of lean production tool adoption. The implicit assumption in many of the studies on the performance of companies adopting lean production is that each company adopts the same lean production tools. This study provides evidence that the factors of Type of Production Processes, Production Volume, and Order Fulfillment Strategy do affect the adoption of some of the tools of lean production, and therefore can be used as additional predictors in future studies of this nature. For managers, the taxonomy can be used to develop a lean production strategy in terms of tool selection, or it can be used to amend the current lean production strategy. Also, for companies with many diverse kinds of production systems, this taxonomy provides a framework for a consistent lean production strategy across the company while allowing for customization based on type of value stream.

The factors also provide eleven distinct value stream profiles that can be studied at greater length. The tools of lean production are categorized into three types for a given profile. While there are limitations to the level of generalization that can be made from the results of this characterization, the value stream profiles presented in this research should serve as a method for more objective comparisons in future research. For managers, these types, A, B, and C, can be used as guidelines for the tools that are most likely to be applicable in their given situation. However, it is recognized in this study, that each and every tool should be examined by managers of a given value stream for its direct applicability and/or analogous application.

Conclusions of the Research

The purpose of this research was to show empirically that there is a difference in the pattern of adoption between mature lean companies with different value stream characteristics. The major conclusion of this research is that this difference does exist. The purpose of the predictive model and resulting taxonomy presented in this research is to begin to explore how the differences in the value streams affect the adoption of specific tools. The taxonomy presented in this paper is a “proposed” taxonomy because this study was not designed to provide conclusive evidence of the actual taxonomy itself, but rather to provide evidence that a taxonomy exists.

In addition to the main conclusion drawn in this study, there were several surprises that resulted from the study, with regard to the adoption pattern for specific tools. According to the data, Setup Reduction is adopted at lower-than-expected rates for all types of value streams, but particularly the Discrete, Low and Medium Volume groups. Takt time is another tool of lean production that is adopted a very low level across all types of value streams, and particularly

Discrete, High and Low Volume, and Continuous profiles. The adoption of a Cross-Trained Workforce seems to directly correspond with the need for flexibility and quick response driven by a Make-to-Order or Service environment. Companies reported all forms of maintenance (except for preventive maintenance) being adopted at low levels for all types of value streams, but in particular the Discrete, High Volume and Continuous profiles. The most surprising of the maintenance tools is that Total Productive Maintenance, which is mentioned in 12 of the 22 sources as a tool of lean production is being adopted at very low rates in the aforementioned profiles. Finally, companies reported the Design of Experiments as a tool of lean production is being adopted at low levels across all types of value streams, but in particular the Discrete, High Volume and Continuous profiles.

Recommendations for Future Research

As is the case with most research, this study provides more questions than answers. Though all of the factors in this study are shown to affect the adoption of lean production tools, additional research is needed to better explain the variation in the factor levels. In particular, further investigation of the factor levels within the Discrete, Continuous, and Volume groups is needed. For the purposes of this study, Volume was investigated at three levels, but there could be four or five levels that have an influence on the response variable.

The pattern of infusion of lean production across industries and value stream categories should be studied at greater length. Lean production is spreading across all industries, but at different rates. The levels of analysis for this study were affected by the distribution of types of value streams represented in the dataset. As can be seen in Tables 18, 19, 20 and 21, the majority of respondents are clumped in one or two categories. The Service, Pure Fabrication, Pure Continuous, and Low Volume groups are largely under represented. Deeper investigation into the differences in the patterns of tool adoption among the Discrete groups (Pure Fabrication, Pure Assembly, and Combination Fab/Assembly), the Continuous groups (Batch, Semi-Continuous, and Pure Continuous), and the Service group is needed.

The tools of lean production that are most relevant to the Service and Discrete, Low Volume groups need deeper investigation as well. The factors of Production Volume and Order Fulfillment process are not the best levels of categorization for the Service group. Also future research should make the allowance for administrative processes within a manufacturing organization to be included in the Service group. In this study, the term Service Industry is used, and is more exclusive than inclusive. Using the term Service Industry also is a source for potential misclassification, because some companies in the Service Industry have processes that are more like manufacturing processes than administrative processes.

Some research is also needed to eliminate or confound the bias in terminology toward the Discrete, High Volume, repetitive manufacturers. A problem with this research is that the terminology is taken from the prior literature, where most studies are performed on companies of one or two particular value stream profiles. The survey reflected this bias, and potentially drove away potential respondents or influenced their specific responses. It is the position of this research that many of the tools are applicable across industries, but the analogous terminology is not currently present.

Finally, further research is needed to investigate the reasons for companies adopting lean production practices, not adopting the maintenance and quality practices presented in this research. Using the broadened definition of lean production, these practices should be adopted at higher rates by companies espousing lean production. Yet practices such as Reliability-Centered Maintenance, Predictive Maintenance, and Design-of-Experiments are not adopted at high rates, according to this study.

Bibliography

Bibliography

1 Balakrishnan, R., Linsmeier, T.J., Venkatachalam, M., "Financial benefits from JIT adoption: effects of customer concentration and cost structure. The Accounting Review. 1996. Vol. 71, No.2, pp.183-205.

2 Billesbach, Thomas J. "Applying lean production principles to a process facility." Production and Inventory Management Journal. Alexandria. Third Quarter, 1994. pp. 40-46.

3 Billesbach, Thomas J. "A study of the implementation of just-in-time in the United States."." Production and Inventory Management Journal. Alexandria. Third Quarter, 1991. pp. 1-4

4 Billesbach, Thomas J. and Hayen, R. Long-term impact of just-in-time on inventory performance measures." Production and Inventory Management Journal. Alexandria. First Quarter, 1994. pp. 62-67

5 Celley, A.P., Clegg, W.H., Smith, A.W., and Vonderembse, M.A., "Implementation of JIT in the United States." Journal of Purchasing and Materials Management. 1986.22 (4). pp.9-15

6 Claycomb, Cindy, Richard Germain, and Cornelia Droge. "Total system JIT outcomes: inventory, organization, and financial effects." International Journal of Physical Distribution & Logistics Management, Vol. 29 No.10, 1999, pp. 612-630

7 Conner, Gary. Lean Manufacturing for the Small Shop. Dearborn, MI: Society of Manufacturing Engineers, 2001.

8 Crawford, K.M., Cox, J.F., " Designing performance measurement systems for just-in-time operation." International Journal of Production Research. Vol.128. No.11, pp. 2025-2036.

9 Deluzio, Mark C. "The Tools of Just-In-Time." Cost Management. Summer 1993. Pp. 13-19

10 Detty, Richard B. and Jon C. Yingling. "Quantifying benefits of conversion to lean manufacturing with discrete event simulation: a case study." International Journal of Production Research. 2000, vol. 38, no. 2, pp.429-445.

11 Droge, C. and Germain, R. " The just-in-time inventory effect: does it hold under different contextual, environmental, and organization conditions?" Journal of Business Logistics. 1998. Vol. 19 No.2, pp. 53- 71.

12 Feld, William. 2001. Lean Manufacturing: Tools, Techniques, and How to Use Them. Boca Raton, FL: St. Lucie Press

13 Flynn, Barbara B., Roger G. Schroeder, and E. James Flynn. "World class manufacturing: an investigation of Hayes and Wheelwright's foundation." Journal of Operations Management. 1999. Vol 17. Pp. 249-269.

14 Fullerton, Rosemary R. and Cheryl S. McWatters. "The production performance benefits from JIT implementation." Journal of Operations Management. 2001. Vol 19. Pp. 81-96.

15 Gargeya, V .B. and Thompson, J.P. "Just-In- Time production in small jobs shops." Industrial Management. 1994. Vol. 36, No.4, pp. 23-26.

16 Germain, R. and Droge, C. "Just-in-time and context: predictors of electronic data interchange technology adoption." International Journal of Physical Distribution and Logistics Management. 1995. Vol. 25, No.1, pp. 18-33.

17 Giffi, C., Roth, A., Seal, G.M., 1990. Competing in World Class Manufacturing: America's 21st Century Challenge. Business One Irwin, Homewood, IL.

18 Gilbert, J.P. " The state of JIT implementation and development in the USA." International Journal of Production Research. 1990.28 (6) pp. 1099-1109

19 Golhar, D.Y., Stamm, C.L., and Smith, W.P. "JIT implementation in small manufacturing firms." Production and Inventory Management Journal. 1990. Vol. 10, 2nd Quarter. Pp. 44-8.

20 Greenwood, Tom, Ken Kirby, et. al. Lean Enterprise Systems Design Institute. University of Tennessee Center for Executive Education.

21 Henderson, Bruce, Jorge L. Larco, and Stephen H. Martin. 1999. Lean Transformation. Richmond, VA: The Oaklea Press.

22 Hines, Peter, et. al. 2000. Value Stream Management: Strategy and Excellence in the Supply Chain. London, Great Britain: Prentice Hall.

23 Huson, M., Nanda, D. " The impact of Just-in-time manufacturing on firm performance in the US." Journal of Operations Management. 1995. Vol. 12, No.3-4. pp.297-310.

24 Im, J.H. and Lee, S.M. "Implementation of JIT systems in US manufacturing firms." International Journal of Operations and Production Management. 1989.9 (1), pp. 5-14.

25 Inman, R. A. and Mehra, S. " The transferability of just-in-time concepts to American small businesses." Interfaces. 1990. Vol. 20, No.2, pp. 30-37.

26 Koufteros, Xenophon A, Mark A. Vonderembse, and William J. Doll. "Developing measures of Time-Based Manufacturing." Journal of Operations Management. 1998. Vol. 16. Pp. 21-41.

27 Liker, Jeffery. 1998. Becoming Lean. Portland, OR: Productivity Press.

28 McLachlin, Ron. "Management initiatives and just-in-time manufacturing." Journal of Operations Management. 1997. Vol. 15. Pp. 271-292.

29 Monden, Yasuhiro. 1998. Toyota Production System: An Integrated Approach to Just-in-Time. 3rd Edition, Norcross, GA: Engineering & Management Press.

30 Nicholas, John. 1998. Competitive Manufacturing Management: Continuous Improvement, Lean Production, and Customer-Focused Quality. Boston: Irwin McGraw-Hill.

31 Norris, D.M., Swanson, R.D., and Chu, Y., "Just-in-time production systems: a survey of managers." Production and inventory Management Journal. 1994. 2. pp.63-66.

32 Ockree, K.A., " A just-in-time production philosophy: empirical analyses and field study." Unpublished Doctoral Dissertation, 1993, School of Business, University of Kansas

33 Nightengale, Deborah, et al. Lean Enterprise Self-Assessment Tool. Massachusetts Institute of Technology and University of Warwick, 2001.

34 Ohno, Taichii. 1988. Toyota Production System: Beyond Large-Scale Production. Portland, OR : Productivity Press.

35 Paulk, Mark, et al. "Capability Maturity Model for Software (Version 1.1)." Technical Paper of Carnegie-Mellon Software Engineering Institute, 1993

36 Sakikabara, S., Flynn, B.B., Schroeder, R.G. 'A framework and measurement instrument for Just-in- Time manufacturing.' Production and Inventory Management. 1993. vol2. no.3. pp. 177-194.

37 Schonberger, Richard J. 1982. Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity. Free Press, New York.

38 Shingo, Shigeo., 1988. Non-stock production: the Shingo System for continuous improvement. Productivity Press., Cambridge, MA.

39 Suzaki, K., 1985. The New Manufacturing Challenge. The Free Press. New York.

40 Umble, Michael and Mokshagundam Srikanth. Synchronous Management: Profit-based Manufacturing for the 21st Century. Volume 2. Guilford CT: The Spectrum Publishing Company, 1997.

41 Vollman, Thomas E., William L. Berry, and D. Clay Whybark. Manufacturing Planning and Control Systems. 1997. New York: Irwin/McGraw Hill.

42 White, R.E., and Ruch, W.A. "The composition and scope of JIT." Operations Management Review. 1990. Vol. 7 No. 3/4. pp. 9-18.

43 Womack, James P. and Daniel T. Jones. 1996. Lean Thinking. New York: Simon & Schuster

44 Womack, James P., Daniel T. Jones, and Daniel Roos, 1990. The Machine That Changed The World. New York: Harper Collins.

APPENDICES

Appendix A: Tables

Table 31: Kruskal-Wallis Test for Significant Differences Between Pure Fabrication, Pure Assembly, and Combination Fabrication/Assembly

Test Statistics[a,b]

	Chi-Square	df	Asymp. Sig.
P5S	1.717	2	.424
SUR	.378	2	.828
SW	5.840	2	.054
MS	5.816	2	.055
TT	2.390	2	.303
FC	1.485	2	.476
VC	.960	2	.619
OPF	7.587	2	.023
SPS	3.131	2	.209
MMP	3.760	2	.153
POU	1.642	2	.440
PPS	1.854	2	.396
CTW	1.790	2	.409
KE	2.894	2	.235
TPM	3.699	2	.157
RCM	2.065	2	.356
PVM	.495	2	.781
PDM	2.818	2	.244
ATM	2.807	2	.246
MP	2.111	2	.348
SLI	3.218	2	.200
SUI	1.597	2	.450
LS	.529	2	.768
DOE	6.310	2	.043
RCA	1.176	2	.555
SPC	3.271	2	.195
TBP	1.215	2	.545

a. Kruskal Wallis Test

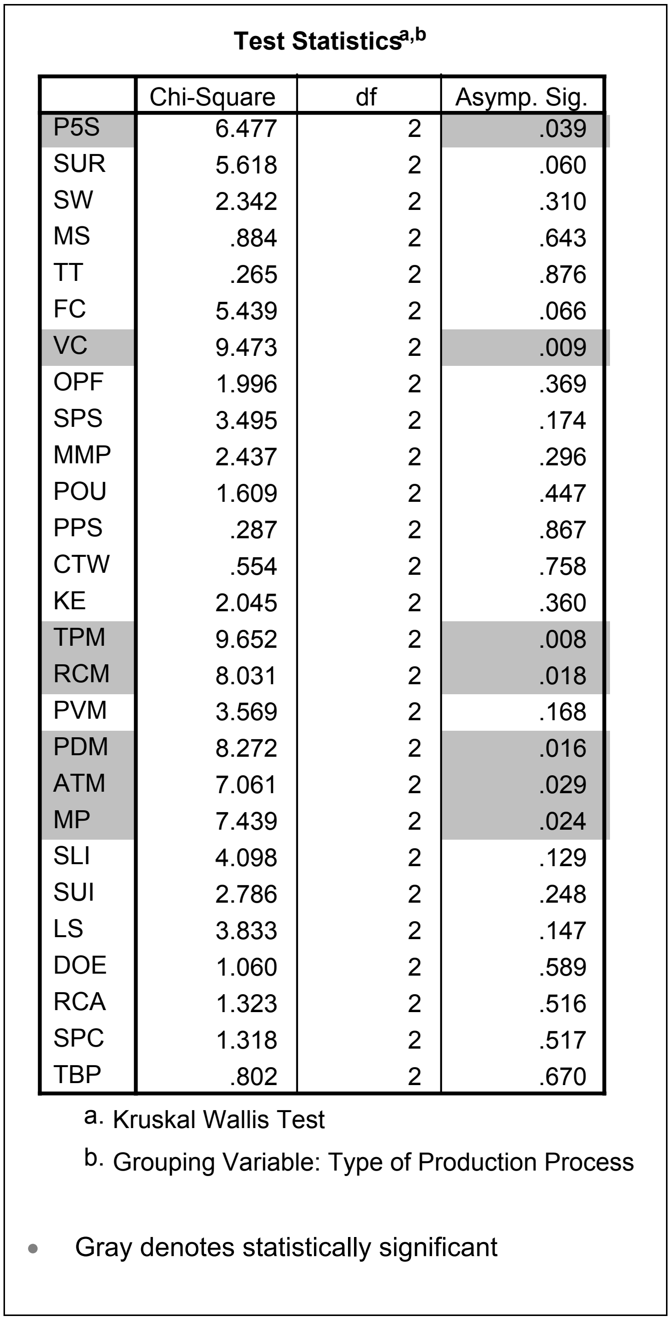
b. Grouping Variable: Type of Production Process

- Gray denotes statistically significant

Table 32: Average Rankings from the Kruskal-Wallis Test for Discrete Processes

Ranks			
	Production Process	N	Mean Rank
SW	Pure Fab	2	21.5
	Pure Assy	16	57.3
	Combo	75	45.5
	Total	93	
MS	Pure Fab	2	7.0
	Pure Assy	16	46.6
	Combo	75	48.2
	Total	93	
OPF	Pure Fab	2	13.0
	Pure Assy	16	57.5
	Combo	75	45.7
	Total	93	
SPS	Pure Fab	2	20.0
	Pure Assy	16	43.1
	Combo	75	48.5
	Total	93	
TPM	Pure Fab	2	23.3
	Pure Assy	16	55.3
	Combo	75	45.9
	Total	93	
RCM	Pure Fab	2	23.5
	Pure Assy	16	50.3
	Combo	75	46.9
	Total	93	
PDM	Pure Fab	2	18.0
	Pure Assy	16	49.6
	Combo	75	47.2
	Total	93	
ATM	Pure Fab	2	19.0
	Pure Assy	16	44.8
	Combo	75	48.2
	Total	93	
DOE	Pure Fab	2	17.5
	Pure Assy	16	36.9
	Combo	75	49.9
	Total	93	

Table 33: Kruskal-Wallis Test for Significant Differences Between Batch, Semi-Continuous, and Continuous Processes



Test Statistics[a,b]

	Chi-Square	df	Asymp. Sig.
P5S	6.477	2	.039
SUR	5.618	2	.060
SW	2.342	2	.310
MS	.884	2	.643
TT	.265	2	.876
FC	5.439	2	.066
VC	9.473	2	.009
OPF	1.996	2	.369
SPS	3.495	2	.174
MMP	2.437	2	.296
POU	1.609	2	.447
PPS	.287	2	.867
CTW	.554	2	.758
KE	2.045	2	.360
TPM	9.652	2	.008
RCM	8.031	2	.018
PVM	3.569	2	.168
PDM	8.272	2	.016
ATM	7.061	2	.029
MP	7.439	2	.024
SLI	4.098	2	.129
SUI	2.786	2	.248
LS	3.833	2	.147
DOE	1.060	2	.589
RCA	1.323	2	.516
SPC	1.318	2	.517
TBP	.802	2	.670

a. Kruskal Wallis Test

b. Grouping Variable: Type of Production Process

- Gray denotes statistically significant

Table 34: Average Rankings from the Kruskal-Wallis Test for Continuous Processes

Ranks			
	Type of Production Process	N	Mean Rank
P5S	Batch	10	11.6
	SemiCont	13	15.3846
	Continuous	2	4.5
	Total	25	
VC	Batch	10	10.6
	SemiCont	13	16.2692
	Continuous	2	3.75
	Total	25	
TPM	Batch	10	8.7
	SemiCont	13	16.6923
	Continuous	2	10.5
	Total	25	
RCM	Batch	10	8.2
	SemiCont	13	16.0769
	Continuous	2	17
	Total	25	
PDM	Batch	10	8.4
	SemiCont	13	16.6923
	Continuous	2	12
	Total	25	
ATM	Batch	10	8.95
	SemiCont	13	16.1538
	Continuous	2	12.75
	Total	25	
MP	Batch	10	8.8
	SemiCont	13	16.5385
	Continuous	2	11
	Total	25	

Table 35: Average Ranks of Tools for Paired Comparison: Discrete vs. Continuous

	Category of Production Process	N	Mean Rank
5S	Discrete	93	60.28
	Continuous	25	56.60
	Total	118	
Set-up Reduction	Discrete	93	58.92
	Continuous	25	61.64
	Total	118	
Standard Work	Discrete	93	58.98
	Continuous	25	61.42
	Total	118	
Method Sheets	Discrete	93	62.82
	Continuous	25	47.16
	Total	118	
Takt Time	Discrete	93	62.06
	Continuous	25	49.98
	Total	118	
Flow Cells	Discrete	93	64.51
	Continuous	25	40.86
	Total	118	
Visual Controls	Discrete	93	61.23
	Continuous	25	53.06
	Total	118	
One-Piece Flow	Discrete	93	65.69
	Continuous	25	36.46
	Total	118	
Smoothed Production Scheduling	Discrete	93	60.08
	Continuous	25	57.34
	Total	118	
Mixed Model Production	Discrete	93	64.05
	Continuous	25	42.58
	Total	118	

Table 35 (cont'd): Average Ranks of Tools for Paired Comparison: Discrete vs. Continuous

	Category of Production Process	N	Mean Rank
Point-of-Use Material Storage	Discrete	93	62.90
	Continuous	25	46.86
	Total	118	
Pull Production Scheduling	Discrete	93	58.67
	Continuous	25	62.60
	Total	118	
Cross-Trained Workforce	Discrete	93	57.78
	Continuous	25	65.90
	Total	118	
Kaizen Events	Discrete	93	61.62
	Continuous	25	51.60
	Total	118	
Total Productive Maintenance	Discrete	93	59.96
	Continuous	25	57.80
	Total	118	
Reliability Centered Maintenance	Discrete	93	57.61
	Continuous	25	66.54
	Total	118	
Preventive Maintenance	Discrete	93	57.85
	Continuous	25	65.62
	Total	118	
Predictive Maintenance	Discrete	93	56.90
	Continuous	25	69.18
	Total	118	
Autonomation	Discrete	93	61.19
	Continuous	25	53.22
	Total	118	
Mistake Proofing	Discrete	93	62.17
	Continuous	25	49.58
	Total	118	

Table 35 (cont'd): Average Ranks of Tools for Paired Comparison: Discrete vs. Continuous

	Category of Production Process	N	Mean Rank
Self-Check Inspection	Discrete	93	61.06
	Continuous	25	53.70
	Total	118	
Successive-Check Inspection	Discrete	93	57.53
	Continuous	25	66.84
	Total	118	
Line Stop	Discrete	93	59.30
	Continuous	25	60.26
	Total	118	
Design of Experiments	Discrete	93	57.92
	Continuous	25	65.36
	Total	118	
Root Cause Analysis	Discrete	93	58.47
	Continuous	25	63.34
	Total	118	
Statistical Process Control	Discrete	93	57.28
	Continuous	25	67.74
	Total	118	
Team-Based Problem Solving	Discrete	93	58.47
	Continuous	25	63.32
	Total	118	

Table 36: Kruskal-Wallis for Paired Comparison: Discrete vs. Continuous

Test Statistics[a,b]

	Chi-Square	df	Asymp. Sig.
5s	.356	1	.551
Setup Reduction	.157	1	.692
Standard Work	.136	1	.712
Method Sheets	5.044	1	.025
Takt Time	2.863	1	.091
Flow Cells	13.067	1	.000
Visual Controls	1.919	1	.166
One-Piece Flow	17.401	1	.000
Smoothed Production Schedule	.152	1	.696
Mixed Model Production	9.308	1	.002
Point-of-Use Material Storage	5.807	1	.016
Pull Production Scheduling	.321	1	.571
Cross-Trained Workforce	1.733	1	.188
Kaizen Events	2.181	1	.140
Total Productive Maintenance	.092	1	.761
Reliability-Centered Maintenance	1.561	1	.211
Preventive Maintenance	1.532	1	.216
Predictive Maintenance	2.876	1	.090
Autonomation	1.242	1	.265
Mistake Proofing	3.281	1	.070
Self-Check Inspection	1.346	1	.246
Successive-Check Inspection	1.692	1	.193
Line Stop	.019	1	.891
Design-of-Experiments	1.063	1	.303
Root-Cause Analysis	.548	1	.459
Statistical Process Control	2.167	1	.141
Team-Based Problem Solving	.624	1	.430

[a] Kruskal Wallis Test

[b] Grouping Variable: Category of Production Process

Table 37: Average Ranks of Tools for Paired Comparison: Medium vs. High Volume

	Category of Production Process	N	Mean Rank
5S	Medium	22	59.95
	High	90	55.66
	Total	112	
Set-up Reduction	Medium	22	56.18
	High	90	56.58
	Total	112	
Standard Work	Medium	22	46.16
	High	90	59.03
	Total	112	
Method Sheets	Medium	22	64.05
	High	90	54.66
	Total	112	
Takt Time	Medium	22	66.36
	High	90	54.09
	Total	112	
Flow Cells	Medium	22	60.27
	High	90	55.58
	Total	112	
Visual Controls	Medium	22	66.00
	High	90	54.18
	Total	112	
One-Piece Flow	Medium	22	61.16
	High	90	55.36
	Total	112	
Smoothed Production Scheduling	Medium	22	60.39
	High	90	55.55
	Total	112	
Mixed Model Production	Medium	22	67.68
	High	90	53.77
	Total	112	

Table 37 (cont'd): Average Ranks of Tools for Paired Comparison: Medium vs. High Volume

	Category of Production Process	N	Mean Rank
Point-of-Use Material Storage	Medium	22	62.84
	High	90	54.95
	Total	112	
Pull Production Scheduling	Medium	22	58.32
	High	90	56.06
	Total	112	
Cross-Trained Workforce	Medium	22	55.50
	High	90	56.74
	Total	112	
Kaizen Events	Medium	22	57.39
	High	90	56.28
	Total	112	
Total Productive Maintenance	Medium	22	59.77
	High	90	55.70
	Total	112	
Reliability Centered Maintenance	Medium	22	58.95
	High	90	55.90
	Total	112	
Preventive Maintenance	Medium	22	58.36
	High	90	56.04
	Total	112	
Predictive Maintenance	Medium	22	55.18
	High	90	56.82
	Total	112	
Autonomation	Medium	22	40.68
	High	90	60.37
	Total	112	
Mistake Proofing	Medium	22	52.57
	High	90	57.46
	Total	112	

Table 37 (cont'd): Average Ranks of Tools for Paired Comparison: Medium vs. High Volume

	Category of Production Process	N	Mean Rank
Self-Check Inspection	Medium	22	60.18
	High	90	55.60
	Total	112	
Successive-Check Inspection	Medium	22	65.50
	High	90	54.30
	Total	112	
Line Stop	Medium	22	54.02
	High	90	57.11
	Total	112	
Design of Experiments	Medium	22	50.55
	High	90	57.96
	Total	112	
Root Cause Analysis	Medium	22	56.95
	High	90	56.39
	Total	112	
Statistical Process Control	Medium	22	49.64
	High	90	58.18
	Total	112	
Team-Based Problem Solving	Medium	22	60.61
	High	90	55.49
	Total	112	

Table 38: Kruskal-Wallis for Paired Comparison: Medium vs. High Volume

Test Statistics[a,b]

	Chi-Square	df	Asymp. Sig.
5s	.495	1	.482
Setup Reduction	.003	1	.954
Standard Work	3.802	1	.051
Method Sheets	1.794	1	.180
Takt Time	2.943	1	.086
Flow Cells	.517	1	.472
Visual Controls	4.046	1	.044
One-Piece Flow	.682	1	.409
Smoothed Production Schedule	.470	1	.493
Mixed Model Production	3.896	1	.048
Point-of-Use Material Storage	1.419	1	.234
Pull Production Scheduling	.106	1	.745
Cross-Trained Workforce	.041	1	.839
Kaizen Events	.026	1	.872
Total Productive Maintenance	.325	1	.569
Reliability-Centered Maintenance	.182	1	.670
Preventive Maintenance	.136	1	.712
Predictive Maintenance	.051	1	.821
Autonomation	7.521	1	.006
Mistake Proofing	.495	1	.482
Self-Check Inspection	.519	1	.471
Successive-Check Inspection	2.466	1	.116
Line Stop	.193	1	.661
Design-of-Experiments	1.047	1	.306
Root-Cause Analysis	.007	1	.932
Statistical Process Control	1.447	1	.229
Team-Based Problem Solving	.697	1	.404

[a] Kruskal Wallis Test

[b] Grouping Variable: Volume

Appendix B: Research Questionnaire

Lean Enterprise Classification Survey

Please provide the following information, with respect to a *specific* product line or family within your business. Enter "NA" for those questions that are not applicable. Enter "DK" for those questions you do not know the answer.

Your Title/Role:
Company Name:
Division/Business Unit:
Product Family:
City:
State:
Country:

Value Stream Classification

Type of Production Process:	Pure Fabrication
Number of Employees for Product Family:	0-50
Number of Organizational Layers for Product Family:	1
Number of Organizational Layers at Site:	1
Time between production units is best measured in:	Seconds
Product Mix Cycle Time (Average time required to cycle through major styles/part numbers for this product family.):	Hours

Order Fulfillment Strategy

Indicate the percent of volume that is sold through the following strategies (The selections should total to 100%). Select "0%" for those strategies your site does not use.

Build-to-Stock	0%	Build-to-Stock: Strategy in which the end consumer purchases goods from an existing inventory.
Build-to-Order	0%	Build-to-Order: Strategy in which product is made or assembled to a specific customer order, but not all parts or materials are held in the manufacturer's inventory.
Configure-to-Order	0%	Configure-to-Order: Strategy in which the consumer chooses from available options whose parts are all kept in inventory and assembled based on the customer's desired configuration.
Make-to-Order	0%	Make-to-Order: Strategy in which the product is fabricated from inventoried raw material at the customer's request.
Engineer-to-Order	0%	Engineer-to-Order: Strategy in which a new set of engineering instructions must be created for each individual order. Parts to build the product can be pulled out of existing inventories or not.
Selections Must Equal	**100%**	

Relative Value Stream Location

Indicate the percentage of production that is received by the next customer in your value stream. The next customer is defined as an entity that either uses your product as a final consumer or another manufacturer, or an entity that stores inventory such as a distributor or retailer.(The selections should total to 100%). Select "0%" for those strategies your site does not use.

Final Consumer	0%	Final Consumer: Customer who consumes product and does not assemble your product into another product.
Retailer	0%	Retailer: Customer who sells your product to a final consumer or end user of the product.
Distrbutor	0%	Distributor: Customer who sells your product to a customer other than the final consumer.
OEM	0%	OEM (Original Equipment Manufacturer): A manufacturer who uses assemblies or subassemblies from a supplier to build an end product.
General Manufactuers (not OEM)	0%	General Manufacturer (Other than OEM)
After-Market	0%	After-Market: Manufacturing of replacement parts sold for a product that the company also sells.
Selections Must Equal	**100%**	

Lean Production Tools

With each Lean Production tool listed indicate the relative importance of that specific tool with regard to your company's overall Lean Strategy.

Position the mouse over the Lean tool to display its definition.	Tool is **not** a part of our Lean JIT strategy.	Tool is applied **sporadically** across facility.	Everyone has had training in use of tool and it is in used **at least half of the time.**	Everyone has had training in use of tool and it is in use **almost all of the time.**	Use of tool is standard procedure **understood and used by all.**
5S	☐	☐	☐	☐	☐
Set-Up Reduction	☐	☐	☐	☐	☐
Standard Work	☐	☐	☐	☐	☐
Method Sheets	☐	☐	☐	☐	☐
Production to Takt Time	☐	☐	☐	☐	☐
Formation of Flow Cells	☐	☐	☐	☐	☐
Visual Controls	☐	☐	☐	☐	☐
One-Piece Flow	☐	☐	☐	☐	☐
Smoothed Production Scheduling	☐	☐	☐	☐	☐
Mixed Model Production	☐	☐	☐	☐	☐
Point-of-Use Storage	☐	☐	☐	☐	☐
Pull Production Scheduling	☐	☐	☐	☐	☐

	Tool is **not** a part of our Lean JIT strategy.	Tool is applied **sporadically** across facility.	Everyone has had training in use of tool and it is in used **at least half of the time.**	Everyone has had training in use of tool and it is in use **almost all of the time.**	Use of tool is standard procedure **understood and used by all.**
Cross-Trained Workforce	☐	☐	☐	☐	☐
Lean "Kaizen" Events	☐	☐	☐	☐	☐
Total Productive Maintenance	☐	☐	☐	☐	☐
Reliability Centered Maintenance	☐	☐	☐	☐	☐
Preventive Maintenance	☐	☐	☐	☐	☐
Predictive Maintenance	☐	☐	☐	☐	☐
Autonomation	☐	☐	☐	☐	☐
Mistake-Proofing	☐	☐	☐	☐	☐
Self-Check Inspection	☐	☐	☐	☐	☐
Successive Check Inspection	☐	☐	☐	☐	☐
Line Stop	☐	☐	☐	☐	☐
Design-of-Experiments	☐	☐	☐	☐	☐
Root-Cause Analysis	☐	☐	☐	☐	☐
Statistical Process Control	☐	☐	☐	☐	☐
Team-Based Problem Solving	☐	☐	☐	☐	☐

Lean Production Maturity

For each year in the table below indicate the most appropriate level of maturity for Lean Production for the stated product line/family.

	Level 1: Awareness	Level 2: Sporadic Implementation	Level 3: Formal Implementation	Level 4: Completed Implementation	Level 5: Continuous Improvement
❑	❑ A few (1-3) people in the organization are aware of Lean Production principles either through training overview, a book, or previous experience. ❑ May have implemented one or two tools of lean (5S, Setup Reduction), but no formal, integrated implementation approach.	❑ Some tools of lean are implemented sporadically across the factory; islands of lean. ❑ Some awareness training beginning to take place among managers. ❑ Still no formal, integrated implementation approach.	❑ A formal, integrated approach to implementation has been developed and is being rolled out. ❑ Awareness training is being performed at the operator level. ❑ Focus improvement activities (ex. kaizen events or blitzes) are occurring on a regular basis. ❑ Entire product flow is not yet fully integrated (ex. fabricated parts are not pulled into assembly processes).	❑ All of operations personnel have been exposed to the principles of lean. ❑ Entire product flow is integrated (WIP is used strategically), product flows smoothly through facility. ❑ Batch and one-piece flow operations have been connected by pull execution. ❑ All relevant tools of lean production are fully deployed and accepted practices (i.e. kanban, flow cells, setup reduction). ❑ Standard practices are operator-developed and adhered to.	❑ Lean Production is standard procedure; no longer a program. ❑ Structured approach to continuously improving the production system is in place (ex. periodic kaizen events, employee suggestion systems and follow-up, etc.). ❑ Continuous improvement activities are driven by the operators with management support.
	Level 1:Awareness	Level 2:Sporadic Implementation	Level 3:Formal Implementation	Level 4: Completed Implementation	Level 5: Continuous Improvement
Dec1997	☐	☐	☐	☐	☐
Dec 1998	☐	☐	☐	☐	☐
Dec 1999	☐	☐	☐	☐	☐
Dec 2000	☐	☐	☐	☐	☐
Dec 2001	☐	☐	☐	☐	☐

Appendix C: Solicitation and Follow-up E-mails

Initial Solicitation E-mail

Dear Lean Practitioners:

My name is Brad Greene and I am a doctoral student in Industrial Engineering at the University of Tennessee. The purpose of this e-mail is to ask for your help in my dissertation research. The focus of the research is to develop profiles of the application of Lean Production based on types of value streams. Example profiles:

1. Discrete part, combination fabrication/assembly, Build-To-Stock, High Volume (ex. Appliances)
2. Discrete part, combination fabrication/assembly, Build-to-Order, Low Volume (ex. Airplanes)
3. Semi-continuous, Build-to-Order, High volume (ex. Carpet)
4. Batch, Build-to-Stock, High Volume (ex. Paint, pharmaceuticals)

Research question: What are the tools of lean production that apply to each of these profiles?

With enough data, the results of this research will provide some standard profiles of the application of lean production. All that is required of you is to complete the 5-10 minute survey at the following web address:

http://160.36.180.73/dsearcy/lesa/leansurvey.cfm

Username: lean
Password: 2002

The perspective that the survey should be taken from is that of an individual product group or family. Therefore, feel free to forward this e-mail on to others in your organization, or other organizations (ex. suppliers to your organization) that are implementing lean. If you decide to forward this e-mail, please CC: me on the forward, so that I can send a follow-on e-mail directing participants to the results.

Thank you for your support of this research effort.

Sincerely,

Brad Greene

Follow-up E-mail

Dear Lean Practitioners:

There has been a good response to the survey so far, and I should be able to post some preliminary results in the next few weeks. If you have not completed the survey, please do so, so that you and your company may have access to the results of this research.

There have been some server problems, so if you have tried to access the survey and not been able to, please try again. The hyperlink is below.

Also, some have questioned whether or not their business fits the profiles in which I am interested. I am interested in all types of value streams: Discrete (Fabrication and Assembly Processes), Continuous, and Batch; Build-to-Stock, Build-to-Order, Configure-to-Order, and Engineer-to-Order, etc. I am even interested in how service industries are applying lean techniques. So if you fit into any of these categories then the survey is applicable to your company.

Thanks for your interest and participation.

http://160.36.180.73/dsearcy/lesa/leansurvey.cfm

Username: lean
Password: 2002

Sincerely,

Brad Greene

Cover Letter from Larry Cote, President of Lean Enterprise Institute Canada

Dear LEIC Members,

Please find attached a Lean practices survey from the University of Tennessee. Brad Greene is a Doctoral student in their fine Industrial Engineering program. His thesis is on the comparative use of Lean tools for various types of value streams.

Value Stream focus is the critical first step in successful Lean transformation. Time and again we hear from companies that identifying those value streams and their Lean needs is challenging work. Research like Brad's will be an important aid to organizations at various stages of their Lean journey.

I encourage you to take a few minutes out of your day to fill out this easy online survey. Those minutes may save others days or weeks of time for future Lean implementation in parts of your own organization as well as for others.

As Brad notes in his letter, you will be among the first to receive the report when it's complete. LEIC will make sure you get it "hot off the press". Be sure to send Brad or me any comments or feedback you may have on the survey itself.

Thanks for your participation,

Larry Cote
LEIC

VITA

Bradley Mullins Greene is completing his doctorate of philosophy with a concentration in Industrial Engineering at the University of Tennessee. Bradley completed his Bachelor's and Master's in Industrial Engineering at the University of Tennessee as well. During his graduate studies he served as a research assistant with the Center for Executive Education, where he helped to develop and deliver curriculum in the areas of Discrete Event Simulation, Lean Enterprise Systems Design, and Supply Chain Network Design, for executive-level training, as well as the MBA programs (full-time, weekend, and executive). He also served as a facilitator for an airplane manufacturer, a wire harness assembler, and an oral surgery clinic participating in the 9-month Lean Enterprise Implementation System in 2000 and 2001. From 1998 –2002, Bradley directed the development of the Lean Enterprise Site Assessment, including its application to the assessment of supply chain networks.