MEASURES OF LEAN MANUFACTURING EFFECTIVENESS IN AUTOMOTIVE COMPONENTS MANUFACTURING

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I

INTRODUCTION TO THE RESEARCH

Research Purpose

The purpose of this research was to answer the question, "What are the appropriate measures of lean manufacturing effectiveness to manage the implementation of lean manufacturing principles in automotive components plants?" In more specific terms, What performance information should be provided to managers of automotive components manufacturing in order for them to:

- evaluate manufacturing systems performance against lean manufacturing theory and world class competition?
- assess how lean these manufacturing systems are?

In addition, this research sought an answer to the question, What factors either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing? Performance measurement may or may not be a critical factor either way. The specific research objectives were to:

1. To identify the appropriate measures of lean manufacturing effectiveness to use in managing successful implementation of lean manufacturing principles in automotive components manufacturing.
2. To identify factors that either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing.
3. To identify potential areas for future research on lean manufacturing in automotive components manufacturing and other industries.

Background

In the fall of 1984, the International Motor Vehicle Program (IMVP) was formed at the Massachusetts Institute of Technology to undertake a detailed study of Japanese production techniques as compared to Western mass production techniques [Womack, Jones, Roos, 1990]. The IMVP was to perform a comprehensive examination of all the activities necessary to manufacture an automobile: market assessment, product design, engineering, supply chain coordination, factory operations, sales, and service of the final product. The five year research project deployed 55 researchers to investigate productivity and management practices in the worldwide automotive industry. The IMVP coined the term *lean production* to describe the Japanese production techniques because their use required far fewer resources to produce an automobile than mass production techniques.

The IMVP spent five years studying the differences between mass production and lean production in the global automotive industry and looked at approximately 80 vehicle assembly plants while doing so. Afterwards, the main findings of the IMVP study were summarized in the 1990 book, *The Machine That Changed The World: The Story of Lean Production* [Womack, Jones, Roos, 1990]. The authors argued that the performance superiority of Japanese manufacturers was attributable to a set of lean principles governing the management practices in their factories, and also extending to design, development, retail, supply, and service. The main conclusion of the book is that the lean production model is systematically related to superior productivity and quality in vehicle assembly plants worldwide. The authors argued that the principles of lean production can be applied equally in any industry in any global locale, although the form may vary from country to country.

Lean manufacturing principles are found in their purest form in Japan at Toyota Motor Company in the Toyota production system. By all accounts in the literature on the subject, Toyota is the global master of lean production. The book, *The Toyota Production System: An Integrated Approach to Just-In-Time* production [Monden, 1993], describes in detail what is now referred to as the techniques of lean production. While *The Machine That Changed The World* focuses on validating the superiority of lean production, *The Toyota Production System* focuses on the actual factory practice and implementation of lean manufacturing principles.

The literature reveals that there has not been any comprehensive study into automotive components manufacturing comparable in depth to the IMVP study, however some research has been done on automotive component parts manufacture. Oliver, Delbridge, Jones, and Lowe (1994) studied and compared the performance and management practices of 18 automotive components plants. Of the plants studied, nine were located in the United Kingdom and nine were in Japan.

The study compared the performance of the plants and used quantitative measures to test the use of lean production techniques among the high performers. The purpose of the study was to advance the debate concerning the ability of lean production concepts to explain performance differentials. The data from the study were used to address four main questions:

1. Is it possible to identify a group of 'world class' firms, which are able to simultaneously perform at high levels of productivity and quality?
2. If so, what is the magnitude of the gap between these firms and non-world class firms?
3. To what extent can any gap be explained by lean production concepts?
4. To what extent does the evidence support criticisms of the lean production model?

The IMVP work had demonstrated that the vehicle assemblers that showed the highest productivity and quality according to their performance measures were located in Japan; it thus seemed reasonable that Japanese automotive components manufacturers could also be high performers. Four automotive component products were covered by the study: brake calipers, exhausts, seats, and wire harnesses. One of the major differences between this project and the IMVP was that this study looked at multiple products instead of just cars.

Based on the survey results, the plants were divided into world class plants and other plants. Across the plant performance measures the world class plants showed consistently better performance, with the greatest differentials for productivity and quality. The world class plants showed a 43% advantage on value of output per direct hour, a 38% advantage on floorspace utilization, and an 82% advantage on throughput time. When it came to plant characteristics, the world class plants had higher levels of automation, younger equipment, and significantly lower absenteeism. Next, the factory practice measures showed the world class plants using less rework and carrying significantly less inventory while turning inventory significantly more often. With regard to factory floor problem solving structures, both groups had similar structures, with about the same number of groups; however, in the world class plants the groups met more frequently, and on average more suggestions were received and implemented.

The findings of this study replicated the findings of the IMVP study in some areas and produced differences in others. The findings showed that there are companies who can simultaneously perform at high levels according to a range of performance measures. The results show that the 2:1 performance differential the IMVP found between Japanese and European automakers is mirrored in the relative performance of the Japanese and UK automotive components manufacturers. This study shows that many of the elements of the lean model are found in conjunction with high performance according to a range of measures. However, although most of the relationships are in the expected directions, relatively few achieved statistical significance. The statistically significant relationships were predominantly related to process discipline and control (productivity, quality, inventory, floorspace and absenteeism).

Over the past six years the term *lean production* has been used as an umbrella to describe Japanese production techniques, which according to all accounts are found in their purest form in the Toyota production system in Japanese plants. While the existing literature on automotive components manufacture identifies some "lean measures" for the industry, there is no clearly agreed upon set of measures that managers of automotive components manufacturing should use to evaluate manufacturing system performance against lean manufacturing theory, world class competition, and perfection. For example, managers at ABC Parts (a pseudonym for the actual company studied) track a set of measures to provide feedback to succeed in the implementation of lean manufacturing principles in their plants. Some of the measures tracked agree with those that are used in the literature; however, the set of measures used is only a subset of all the quantified measures used in the literature to measure leanness. In addition, no detailed treatment exists of the factors that facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing.

Definition of Terms

Automotive Components Manufacturing - Automotive components manufacturers produce the component parts and subsystems necessary to assemble an automobile. They manufacture the automotive component parts that are later assembled to create an automobile (e.g., fuel pumps, alternators, fuel injectors, exhaust oxygen sensors, etc.) and they are the interest of this research.

These automotive component manufacturers are suppliers to the automakers (e.g., GM, Ford, Chrysler, Toyota) or to another company that, in turn, supplies the automakers. A Tier One supplier makes a product and ships it directly to the automaker, while a Tier Two supplier makes a product that is shipped to a Tier One supplier. Some automotive components manufacturers are internal divisions of the automakers (e.g., Delco Electronics of General Motors), while many others operate as contracted suppliers to the automakers (e.g., Johnson Controls, American Axle, etc.) or to Tier One suppliers. Finally, some component manufacturers operate in joint ventures with the major automakers or other suppliers.

Automotive components manufacturing plants differ from automotive assembly plants in important ways. Automotive assembly plants have similar production processes (e.g., stamping, welding, painting, assembly) and are comparable regardless of the model being made because they all make automobiles. Automotive components manufacturing plants are home to a wide variety of production processes ranging from labor intensive assembly to highly automated precision machining and they make a many products (e.g., fuel pumps, solenoids, wire harnesses, generators, fuel injectors, instrument clusters, gas tanks, etc).

ABC Parts - ABC Parts is an automotive component manufacturer that supplies parts both as a Tier One and a Tier Two supplier to the automakers on a global basis. ABC Parts is a corporate division of an automaker and manufactures parts for this automaker and for various other domestic and international customers.

The Delphi Technique - The Delphi Technique is an iterative written survey method of scientific research for gathering expert opinions from a group of persons within a field of study without having to bring them together geographically for a meeting. Usually, an initial survey is distributed and the results are tallied. The results are sent back, anonymously, to the original respondents along with additional questions. Each subsequent questionnaire is built upon the responses of the preceding questionnaire. This process is repeated until the desired pool of information and viewpoints is attained. Since printed literature is frequently behind actual ongoing research, a Delphi Technique can provide a more updated exchange of technical information than a literature search by drawing upon the current knowledge of experts [Delbecq, Van de Ven, and Gustafson, 1986].

Facilitating and Inhibiting Factors - The factors that can positively or negatively (or both) impact the successful implementation of lean production principles in a company such as job security, labor-management relations, worker training, job rotation, and continuous improvement structure.

Factory Operations - The activities occurring at the plant or factory level within a company. The activities necessary to manage a factory that manufactures a product.

International Motor Vehicle Program (IMVP) - A program formed at Massachusetts Institute of Technology to undertake a detailed study of Japanese production techniques as compared to Western mass production techniques.

Kanban System - In a kanban system parts are only produced at the previous operation to supply the immediate demand of the next operation and the containers that carry the parts are the mechanism for sizing the parts buffer between two operations. Thus, empty containers are signals that regulate the 'pull system' in the Toyota production system by signaling to upstream production process what to produce. As each container is used up, it is sent back to the previous operation to signal to make more parts.

Lean Production - The IMVP coined the term *lean production* to describe the superior Japanese production techniques because they used less resources to manufacture an automobile than did mass production techniques. The lean producer combines the advantages of craft and mass production, while avoiding the high cost of the former and the rigidity of the latter. The lean producer employs teams of multi-skilled workers at all levels of the organization and use highly flexible, increasingly automated machines to produce volumes of products in wide variety. Lean production is "lean" because it uses less of everything compared with mass production. Lean production uses: half the human effort in the factory, half the engineering hours to develop a new product in half the time. Also, it requires keeping far less than half the inventory on site, results in fewer defects, and produces a greater variety of products [Womack, Jones, Roos, 1990]. Lean producers focus on perfection: declining costs, zero defects, zero inventories, and endless product variety.

Mass Production Techniques - Mass production uses narrowly skilled professionals to design products made by unskilled or semiskilled workers tending expensive, single-purpose machines. These churn out standardized products in very high volume. Because the machinery costs so much and is so intolerant of disruption, the mass-producer adds many buffers - extra supplies, extra workers, and extra space - to assure smooth production. Because changing over to a new product costs even more, the mass-producer keeps standard designs in production for as long as possible [Womack, Jones, Roos, 1990].

Process Monument - A process monument is a piece of equipment (usually large in size or capacity) that requires work-in-process to wait in a queue to be processed through the monument (e.g., heat treat ovens, plating tanks, paint booths, etc.).

Tier One Supplier - A tier one manufacturer supplies automotive components directly to an auto manufacturer (e.g. General Motors, Ford, Chrysler, etc.) For example, Delco Remy supplies car batteries directly to General Motors auto assembly plants in the role of a Tier One supplier.

Tier Two Supplier - A tier two manufacturer supplies parts directly to a Tier One supplier.

Toyota Production System - The Toyota production system is the manufacturing system that the term *lean production* was coined to describe. The Toyota production system is the worldwide benchmark for lean production. The main purpose of the Toyota production system is elimination of any waste within the company. The primary goal of the Toyota production system is cost reduction or productivity improvement, which is attained through elimination of various types of waste. Recognizing cost reduction as the system's primary goal, three subgoals must be met as a prerequisites: quality control, quality assurance, and respect for human resources. The Toyota production system's four main concepts follow:

1. Just-in-Time (JIT) involves producing the necessary units in the necessary quantities at the necessary time.
2. Autonomation is autonomous defects control that supports JIT production by never allowing defective parts from one process to flow on to a subsequent process.
3. Flexible Work Force involves varying the number of production workers in response to demand changes (no layoffs).
4. Creative Thinking and Inventive Ideas are sought and utilized in the form of worker suggestions.

In order to fully implement these four concepts, Toyota uses the following methods:

- A kanban system to maintain just-in-time production
- Quick changeover techniques
- Standardized work
- Design of flexible machines
- Design of flexible machine layouts
- Multi-function workers
- Team continuous improvement activities
- Suggestion system

- Visual control system
- Production smoothing
- Lead time reduction activities
- Small lot production (with a goal of one piece transfer)

[Monden, 1993].

General Approach

This research sought to identify the appropriate measures of lean manufacturing effectiveness to use in managing successful implementation of lean manufacturing principles in automotive components manufacturing. From a practical standpoint, managers need to be able to evaluate manufacturing systems performance against lean manufacturing theory and world class competition in order to assess how lean these manufacturing systems are. This exploratory research study was conducted using selected managers from ABC Parts to obtain expert opinions to address the research question: What are the appropriate measures of lean manufacturing effectiveness to manage the implementation of lean manufacturing principles in automotive components plants? Figure 1-1 depicts, in general, how the research purpose was accomplished.

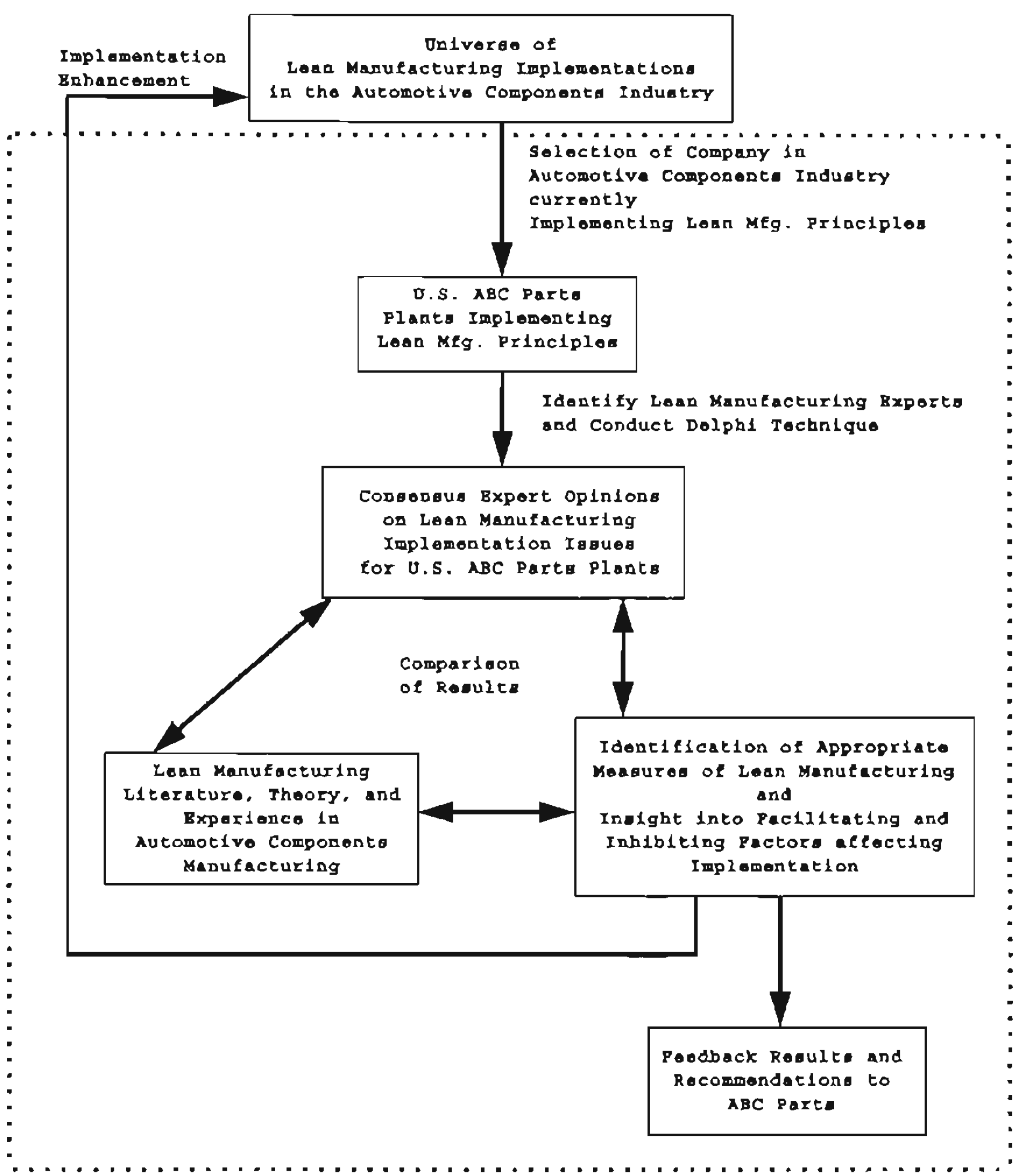

Figure 1-1. A Macro-level Process Flow Chart of the Research

The Delphi Technique was the method used to elicit consensus opinion among the expert respondents sampled within ABC Parts. The Delphi Technique is an iterative written survey method of research for gathering expert opinions from a group of persons within a field of study without having to bring them together geographically for a meeting. ABC Parts management agreement to participate in the Delphi Technique was obtained through the Divisional Industrial Engineering Superintendent. The Divisional Industrial Engineering Superintendent assisted in exact definition of the Delphi Technique, identification of potential expert respondents, and the details of the Delphi questionnaires where needed. The targeted number of respondents for the Delphi Technique was 25.

The prospective expert respondents to the research questions were identified by the Industrial Engineering Superintendent. The respondents qualified as experts on lean manufacturing based on the following criteria:

- Total years of work experience
- Years of experience in the automotive industry
- Years of experience with lean manufacturing principles

- Number of sites they have worked at in the automotive industry
- Number of lean manufacturing implementations in which they have been involved
- Level of education and training on lean principles

Detailed demographic information on the expert respondents can be found in Chapter Four.

The initial questionnaire asked experts to answer two broad questions (research objectives one and two) on lean manufacturing of automotive components. All questionnaires were returned to a 3rd party to insure the anonymity of the respondents. Once collected, the responses were used to develop the second questionnaire. Then the second questionnaire was sent to the respondents containing the results from the first questionnaire along with any comments from the respondents. Next, the results were compared to the existing literature, theory, experience, and practice. The results help broaden the body of knowledge on lean manufacturing implementation in automotive components manufacturing. Finally, the results were communicated to all respondents and the Industrial Engineering Superintendent to assist managerial decision making.

Delimitations

1. This research only considered lean manufacturing principles as they apply to factory operations and manufacturing. The research did not focus on product design, marketing, distribution, supply chain coordination, sales, etc. These are areas that are addressed when looking at lean production in the literature as it applies to all business functions.
2. This research did not use quantitative data to measure the level of lean implementation in the plants studied. This research was interested in the value of each lean measure as a tool for managers to use as a compass to direct a successful implementation of lean principles. Thus, the research was concerned with which lean measures are effective for managing implementation and does not focus on quantitative values of the measures themselves.
3. This research did not attempt to rate or order the automotive components plants studied according to leanness.
4. The automotive components plants studied were limited to plants that comprise ABC Parts.

Assumptions

1. Lean manufacturing is superior to mass production and should be adopted by automotive components manufacturers as a business philosophy.
2. Lean manufacturing in automotive component plants differs from lean manufacturing in automotive assembly plants.
3. Lean manufacturing experts can be identified and surveyed within the automotive components plants to be studied.
4. The surveyed experts experience with, and knowledge of, lean manufacturing represents the experience with, and knowledge of, lean manufacturing in automotive components plants.
5. The surveyed experts anonymous self-reporting is accurate.

Importance of Study

The results of this exploratory research contribute to the body of knowledge on lean manufacturing principles in the automotive components industry. To date, little literature exists regarding measurement and implementation of lean manufacturing principles in the automotive components plants. The results of this research yield valuable feedback on the appropriate measures to use to track and ensure effective implementations of lean principles in the automotive components industry. It also provides insight into facilitating and inhibiting factors in the industry that influence lean implementation.

The results of this research will be useful to managers in automotive components manufacturing because it provides expert consensus opinion on what measures should be used to better gauge the implementation of lean manufacturing principles. Specifically, it provides ABC Parts managers with feedback as to whether they need to modify the set of lean measures being used or continue using the current measures. It also provides information on catalysts for and barriers to implementation of lean manufacturing principles in automotive components manufacturing. This information would be paramount to accomplishing more timely and cost effective implementations of lean manufacturing within ABC Parts.

II

LITERATURE REVIEW

This literature review covers the topic of lean manufacturing in the automobile industry focusing specifically on lean principles in automotive components manufacturing. It is necessary to detail the searches that were performed for the literature review. The following areas were searched for literature:

- Oklahoma State University Library Catalog
- Periodical Abstracts (Magazine Article Index)
- Newspaper Abstracts (Newspaper Index)
- ABI Inform (Business Article Index)
- Current Contents Articles (Research Article Index)
- Current Contents Journals (Table of Contents)
- Library of Congress Information System
- University of Oklahoma Library Catalog
- Tulsa City/County Library Catalog
- University Center at Tulsa Library Catalog

- Texas A&M University Library Catalog
- Purdue University Library Catalog
- Iowa State University Library Catalog
- Indiana University Library Catalog
- Louisiana State University Library Catalog
- Michigan State University Library Catalog
- Auburn University Library Catalog
- Internet Webcrawler Search Engine
- Internet Yahoo Search Engine

The literature review begins with a discussion of the five year International Motor Vehicle Program (IMVP) that compared Japanese production techniques to Western mass production techniques and led to the book, *The Machine That Changed The World: The Story of Lean Production*. Next, drawing upon the above mentioned book, the measures used in the IMVP assembly plant survey, the universality of lean production, and the findings of the IMVP study are reviewed. Subsequently, some of the criticisms of *The Machine That Changed The World* are summarized. It is then necessary to provide a historical overview and general outline of the Toyota production system. Finally, an important review of lean manufacturing in the automotive components industry leads back to the purpose for this research.

Lean vs. Agile vs. Flexible

At this point, it is necessary to differentiate between lean manufacturing, agile manufacturing, and flexible manufacturing. It should be recognized that no standard definition exists for these terms, but what follows will compare and contrast lean, agile, and flexible.

Agility surpasses other management tactics like lean by delving much more extensively into various areas directly impacting an enterprise's operations and response to market-driven change [Goldman, 1997]. Lean is a response to competitive pressures with limited resources; agility is a response to complexity brought about by constant change. Lean is bottom-up driven, incrementally transforming the mass-production model. Agility is top-down driven, responding to large forces. Lean is a collection of operational techniques focused on productive use of resources. Agility is an overall strategy focused on thriving in an unpredictable environment.

There are considerable differences between agility and flexibility. Flexibility normally is used to refer to the capabilities of a factory floor to rapidly change from one task to another quickly and as a routine procedure [Goldman, 1997]. This includes the ability to change from one situation to another, with each situation defined ahead of time so that the procedures needed to manage it are in place. Agility refers to the strategic ability of the company to change quickly in an unplanned, unconventional response to changing market opportunities and pressures [Goldman, 1997].

Craft, Mass, and Lean

It is necessary to differentiate between craft production, mass production, and lean production. The automotive industry has its roots in craft production dating back to 1894. A small number of craft producers exist today focusing on tiny niches of the upper, luxury market in the automotive industry. Craft production has the following characteristics:

- A highly skilled workforce with knowledge in the areas of design, machining, and fitting. Typical workers would begin as an apprentice and progress to a full set of craft skills. Many craft workers would go on to become self-employed running their own machine shops.

- Craft production used general purpose machine tools to perform drilling, grinding, and other operations on metal and wood.
- Craft production had very low production volumes and produced a large number of customized designs.
- The organization of craft production was extremely decentralized. The system was usually coordinated by the owner/entrepreneur who was in direct contact with many small machine shops. Most of the parts and much of the design came from these small machine shops.
- Production costs were high for craft producers and the costs did not fall with increased volume.
- Craft production systems failed to provide quality and reliability in products due to a lack of systematic testing.

Henry Ford found a way to overcome the inherent problems of craft production. Ford's techniques reduced costs dramatically while increasing product quality. Ford called his innovative system mass production. Mass production has the following characteristics:

- Mass production introduced complete and consistent interchangeability of parts to the automotive industry. A key to mass production was simplicity of assembly and relative ease of attachment.
- Mass production uses narrowly skilled professionals to design products made by unskilled or semiskilled workers. Mass production has a high division of labor and requires less training than craft production.
- Mass production requires far less labor to build a given product than craft production.
- Mass production generally uses large, expensive, single-purpose equipment with short cycle times to make standardized products in very high volume. These machines are typically difficult to change over to another part number.
- Because the machinery costs so much and is so intolerant of disruption, the mass-producer adds many work-in-process buffers, extra supplies, extra workers, and extra floorspace to assure smooth

production and fully utilize the expensive equipment.

- Historically, mass production has not encouraged workers to suggest process improvements.
- Mass production often uses vertical integration and avoids the use of contracted suppliers where possible.
- Mass production uses standard product designs for as long as possible in order to overcome the high capital costs of dedicated equipment.

In the early 1950's Eiji Toyoda and Taiichi Ohno began to develop what would become the Toyota production system and would eventually be the model for lean manufacturing. Lean manufacturing has the following characteristics:

- Lean production strives for continually declining costs, zero defects, zero inventory, and endless product variety.
- Lean production employs teams of multi-skilled workers at all levels of the organization.
- Lean uses highly flexible and increasingly automated machines.

- Lean production seeks a large product variety with shorter product life cycles.
- Lean uses an organizational structure with fewer management levels and pushes responsibilities as far as possible down the organizational ladder.
- When compared with mass production, lean production requires about one half the amount of labor, floorspace, tooling, engineering effort, design/development effort, and inventory while producing better quality and greater product variety.

International Motor Vehicle Program

In the fall of 1984, the International Motor Vehicle Program (IMVP) was formed at Massachusetts Institute of Technology to undertake a detailed study of Japanese production techniques as compared to Western mass production techniques. The IMVP was to perform a comprehensive examination of all the activities necessary to manufacture an automobile: market assessment, product design, engineering, supply chain coordination, factory operations, sales, and service of the final product. The research project deployed 55 researchers to investigate productivity and management practices in the worldwide automotive industry. An IMVP researcher coined the term *lean production* to describe the superior Japanese production techniques because their use required far fewer resources per automobile than mass production techniques. The IMVP spent five years studying the differences between mass production and lean production in the global automotive industry and looked at approximately 80 vehicle assembly plants while doing so. Afterwards, the main findings of the IMVP study were summarized in the 1990 book, *The Machine That Changed The World: The Story of Lean Production.* This book is probably the most significant piece of literature on the subject of lean manufacturing and most paths searched lead back to the book and the IMVP study.

IMVP Lean Measures of Assembly Plants

In 1986, the IMVP researchers began to contrast lean production with mass production by surveying as many of the worlds vehicle assembly plants as possible [Womack, Jones, Roos, 1990]. Over time they systematically visited and acquired information from more than ninety vehicle assembly plants in seventeen countries. This equated to about half of the vehicle assembly capacity in the world at that time and was one of the most comprehensive industrial surveys ever done in any industry. The researchers for the IMVP developed the IMVP World Assembly Plant Survey which used a set of manufacturing measures to quantify the levels of leanness observed in the vehicle assembly plants. Out of necessity, the set of measures was based on common activities between assembly plants. A general description of the set of measures used in the surveys follows:

- Productivity (hours worked/vehicle)
- Quality (assembly defects/100 vehicles)
- Factory Floorspace (sq.ft./vehicle/year)
- Size of Repair Area (as % of assembly space)
- Inventory (measured in days)
- Percent of Workforce Using Teams
- Level of Job Rotation (0=none,4=frequent)
- Suggestion Program (suggestions/employee)
- Number of Job Classifications
- Training of New Production Workers (hours)
- Absenteeism (days/year)
- Welding - automation (% of direct steps)

- Painting - automation (% of direct steps)
- Assembly - automation (% of direct steps)

Universality of Lean Production

In the late 1980's, Japanese transplant facilities were being opened in North America and Europe and lean manufacturing principles were being applied in new cultural environments [Womack, Jones, Roos, 1990]. One main interest of the IMVP was whether lean manufacturing principles could be implemented successfully in facilities outside of Japan.

In 1984, General Motors (GM) entered a joint venture with Toyota to produce Toyota-designed cars for the U.S. market using a closed GM assembly plant. The New United Motor Manufacturing Inc. (NUMMI) in Fremont, California was to make no compromises on copying lean production using only senior managers from Toyota and implementing an exact copy of the Toyota production system. The plant was to be populated by the United Automobile Workers Union (UAW) under a special contract with only two job classifications and provisions for worker teams. By the fall of 1986, the assembly plant was at full production levels.

The IMVP survey results for NUMMI showed that it matched Toyota's quality and almost matched its productivity. Space utilization was somewhat inefficient due to the GM plant's poor layout. Inventory was higher because almost all component parts came 5,000 miles from Japan. It became clear to the IMVP researchers by the end of 1986 that lean production could be successfully implemented in environments like NUMMI.

IMVP World Assembly Plant Findings

The IMVP had expected that all the Japanese vehicle assembly plants in Japan would be comparably lean [Womack, Jones, Roos, 1990]. In addition, they expected that North American and European assembly plants would perform at about the same level with little variation and would significantly trail the plants in Japan. Finally, they expected assembly plants in developing countries to be marked by low productivity and quality. The IMVP results showed the reality to be different from their expectations.

In Japan, the best plants beat the worst by two to one on productivity and quality. The differences on the other lean measures (e.g. floorspace, inventory, rework) showed much less variation for Japanese plants. In North America, there was again wide variation observed between the best and worst plants. It is notable that Ford's survey results showed it to be practically as lean as the Japanese transplants in North America. In general the IMVP found the best U.S.-owned plants in North America to be almost as productive as the average Japanese plant and nearly equal in quality.

The findings in Europe were striking with the worst observed plant in North America being more productive than the average European plant. The IMVP found that the average Japanese transplant in North America had quality about equal to the average Japanese plant, but lagged about 25% in productivity. In general, the IMVP found that the best performing companies in Japan ran the best performing transplants in North America. Finally, the assembly plants in developing countries showed a very wide range of performance with one plant attaining the best quality in the world, while others had the worst in the world. The IMVP researchers concluded that lean production can be successfully implemented in Japanese-owned plants in North

America, in American-owned plants in North America, and in plants in developing countries.

The IMVP researchers concluded that a truly lean plant has two key organizational features as follows:

1. It transfers the maximum number of tasks and responsibilities to those workers actually adding value to the product.
2. It has in place a system for detecting defects that quickly traces every discovered problem to its root cause.

It should be noted that the discussion of the IMVP in this literature review focuses on the general state of leanness in vehicle assembly plants at the factory operations level and does not consider other areas of lean production such as market assessment, product design, engineering, supply chain coordination, sales, and service.

Criticisms of *The Machine That Changed The World*

Williams and Haslam (1992) produced a lengthy list of criticisms of *The Machine That Changed The World: The Story of Lean Production* as follows:

- Assembly plant productivity comparisons between the Japanese producers were exaggerated due to the exclusion of the variables of manufacturability and capacity utilization.
- Physical process comparisons of vehicle assembly (a relatively small part of the whole process of making cars) were overemphasized, giving an unrepresentative picture of the industry as a whole.
- Cause and effect relations were ambiguous, as was the weight assigned to individual variables.
- Companies were the units of analysis (and their management practices the explanatory factors) to the exclusion of wider context. Williams and Haslam (1992) argue that this means that the impact of cyclicality of markets and capacity utilization were ignored.
- The wider social implications of the model were not fully explored.
- Lean production is found in its purest form in the Toyota production system, and represents methods which are a historical response to Toyota's dominance of the Japanese car market which is

uniquely non-cyclical, rather than a universal recipe for success [Williams, Haslam, 1992].

There will be additional consideration of these criticisms in the discussion on lean production in the automotive components industry.

Development of The Toyota Production System

Lean manufacturing principles are found in their purest form in Japan at Toyota Motor Company in the Toyota production system. By all accounts in the literature on the subject, Toyota is the global master of lean production. The book, *The Toyota Production System: An Integrated Approach to Just-In-Time*, describes in detail what is now referred to as the techniques of lean production [Monden, 1993]. While *The Machine That Changed The World* focuses on validating the superiority of lean production, *The Toyota Production System* focuses on the actual factory practice and implementation of lean manufacturing principles.

This historical profile of the development of the Toyota production system is drawn from *The Toyota Production System: An Integrated Approach to Just-in-Time*. In 1950, Eiji Toyoda of the Toyota Motor Company toured Ford's Rouge plant in Detroit studying every detail of the most efficient manufacturing facility in the world. He observed some possibilities for improving the production systems and returned home to Nagoya to begin copying it. Soon after, it was determined that mass production would never work in Japan since it faced numerous post-war problems. This marked the beginning of the development of the Toyota production system which would be described as lean production many years later.

The techniques that Toyota referred to as the Toyota production system were born from necessity. Toyota was faced with the following problems:

1. A small domestic market demanding a wide range of vehicles.
2. A workforce that was unwilling to be considered a variable cost and new strong company unions.
3. A post-war economy that was starved for capital.
4. International automakers were anxious to setup operations in Japan, but were ready to defend against any Japanese exports.

Toyota's, Taiichi Ohno, realized mass production would not work under the constraints and began searching for a new manufacturing approach. The problem with mass production was the minimum production volume for economical performance was too large and the equipment too expensive. For example, Ohno's capital budget would not allow "dedicated" equipment to run specific parts. It necessitated using frequent changeovers on a few pieces of equipment to be able to run the required variety and volume of parts. Ohno's idea became to develop quick changeover techniques to allow frequent changeovers, every two to three hours, that would be performed by the production workers instead of skilled tradesmen.

Perfection of the quick changeover techniques led to the discovery that the cost per part was less while making small batches rather than running large lots. Small batches meant small work-in-process inventories and small inventory carrying costs. Also important, small batches meant that any quality defects would show up in the manufacturing system more quickly. Thus, small batches helped to reduce the waste of scrapped parts and reworked parts. However, to make this Toyota production system operate ideally with two hours or less of inventory, Ohno needed a very skilled and motivated workforce. Any problems in such a system with little work-in-process could quickly stop production, so it was essential for workers to anticipate problems and contribute to solutions.

A depression and heated labor disputes during the late 1940's left the Toyota employees with the balance of power. The compromise between the company and the union involved the two guarantees of lifetime employment, and pay steeply graded by seniority (not job function) and tied to company profitability through bonuses. In return, Toyota expected most employees to remain with the company for their entire working lives. Employees also agreed to flexible work assignments and active participation in improvements within the company. Taiichi Ohno realized that with these changes the workforce became a fixed cost and Toyota needed to get the most out of its human resources in the long term. The intention was to continuously improve workers' skills throughout their careers and to draw upon their knowledge and experience.

Ohno began to experiment by grouping workers into teams with a team leader instead of a foreman. Teams were given responsibility for a specific part of the production line and told to work together to determine the best method to perform the operations. A team leader would coordinate the team, do assembly tasks, and fill in for any absentees from the group. Teams were responsible for housekeeping, minor tooling repair, and quality inspection within their areas. After teams were running smoothly, Ohno set aside regular meetings focused on continuous process improvement working with industrial engineers.

When it came to rework, Ohno reasoned that unless a defective part were immediately detected, it would become embedded in a complex assembly and require considerable amounts of rework to later fix the assembly. In addition, the problem might not be discovered until much further down the line and a large number of defective pieces could be produced before the problem was found. Ohno's solution was to place a cord within the reach of every line worker and instruct them to stop the line immediately if there was a defect. The whole team was expected to work to solve the problem if there was a line stoppage. As a result, the production line was stopping all the time and workers were initially discouraged; however, the teams began to gain experience in identifying problems and tracking their root causes. This led to significant reductions in rework, improved quality, and smoothed production.

Finally, Ohno developed a different way to coordinate the flow of parts in the manufacturing system called kanban (just-in-time). Ohno dictated that parts would only be produced at the previous operation to supply the immediate demand of the next operation and the containers that carried the parts were the mechanism for sizing the parts buffer between two operations. As each container was used up, it was sent back to the previous operation to signal to make more parts. This simple idea was extremely difficult to implement because it eliminated excess inventories and quickly stopped the whole manufacturing system if one process failed. Ohno viewed this as the power of the kanban system. It removed the safety of inventory buffers and focused all eyes on anticipating production problems before they could stop the line.

The structures for the supply chain, product development and engineering, and sales and distribution under the Toyota production system are very different than those used in mass production. However, these business areas will not be discussed in detail in the literature review since this research focuses on lean production at the factory operations level.

It took Eiji Toyoda and Taiichi Ohno over twenty years of constant effort to fully implement the ideas of the Toyota production system, but when they succeeded the results were extraordinary productivity and quality improvements. Toyota had fully developed the principles of lean manufacturing by the early 1960's, but it took many years for the other Japanese automakers to adopt the Toyota production system and to this day some of them are much better in practicing the principles than others.

Overview of The Toyota Production System

The main purpose of the Toyota production system is elimination of any waste within the company [Monden, 1993]. This section examines the basic framework of the system, its ideas and goals, and the methods and tools employed in achieving these goals. The primary goal of the Toyota production system is cost reduction or productivity improvement, which is attained through elimination of various types of waste. Toyota notes four kinds of waste in manufacturing operations as follows: excessive production resources or capacity, overproduction, excess inventory, and unnecessary capital investment.

Recognizing cost reduction as the system's primary goal, three subgoals must be met as a prerequisites: quality control, quality assurance, and respect for human resources. Toyota notes that none of these three outputs can be achieved independently without influencing the others or the primary goal of cost reduction. Figure 2-1, depicts the Toyota production system emphasizing how costs, quantity, quality, and respect for human resources are system outputs.

Among the tools that Toyota applies to achieve the goals of the Toyota production systems four main concepts must be discussed.

1. Just-in-Time (JIT) involves producing the necessary units in the necessary quantities at the necessary time.

2. Autonomation is autonomous defects control that supports JIT production by never allowing defective parts from one process to flow on to a subsequent process.

3. Flexible work force involves varying the number of production workers in response to demand changes (no layoffs).

4. Creative thinking and inventive ideas are sought and utilized in the form of worker suggestions.

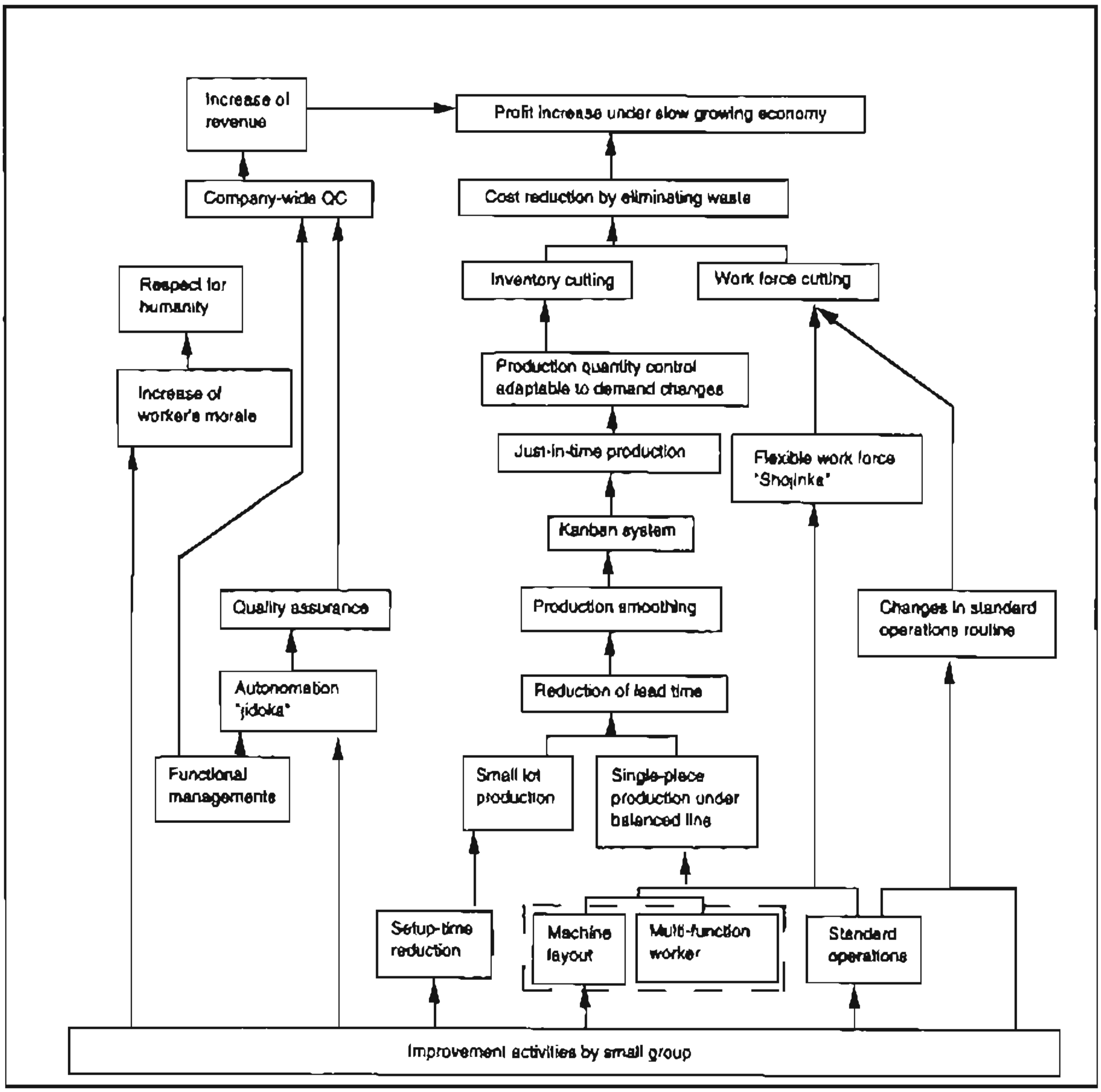

Figure 2-1. How costs, quantity, quality, and humanity are improved by the Toyota Production System [Monden, 1993].

In order to fully implement these four concepts, Toyota uses the following methods:

- A kanban system to maintain just-in-time production
- Quick changeover techniques
- Standardized work
- Design of flexible machines
- Design of flexible machine layouts
- Multi-function workers
- Team continuous improvement activities
- Suggestion system
- Visual control system
- Production smoothing
- Lead time reduction activities
- Small lot production (with a goal of one piece transfer)

The Toyota production system must adapt to market changes quickly and flexibly without being wasteful and this is accomplished with JIT production. The kanban system is the means of dispatching production during a month and managing JIT. Smoothing production levels is needed to implement the Kanban system which allows JIT. Production smoothing requires process lead time reductions, since a variety of parts may be required promptly each day. Process lead time reductions can be realized through use of small lot sizes in between processes. Small lot size production can be fulfilled through quicker setups and changeovers. Standardized work routines helps assure completion of one unit of a product with minimal cycle time variation. Autonomous defects control systems, or autonomation, provides 100% good product which allows the small inventories necessary under JIT. Finally, worker continuous improvement activities contribute to the Toyota production system through improved standardized work methods, and tracing problems to their root causes.

This has been a very brief outline of the Toyota production system's purpose, goals, inputs, outputs, and methods. It is now necessary to review lean manufacturing as it exists in another area of the automotive industry: the automotive components manufacturing industry that supplies the component parts necessary to assemble a car in a vehicle assembly plant.

Lean Manufacturing in the Automotive Components Industry

The literature reveals that there has not been any comprehensive study into automotive components manufacturing comparable in depth to the IMVP study, however some research has been done on automotive component parts manufacture. Oliver, Delbridge, Jones, and Lowe (1994) studied and compared the performance and management practices of 18 automotive components plants. Of the plants studied, nine were located in the United Kingdom and nine were in Japan. The study compared the performance of the plants and used quantitative measures to test the use of lean production techniques among the high performers.

The purpose of the study, into the performance of the Japanese and UK autocomponents industries, was to advance the debate about the determinants of manufacturing performance, particularly concerning the ability of lean production concepts to explain performance differentials [Oliver, et al., 1994]. The data from the study were used to address four main questions:

1. Is it possible to identify a group of 'world class' firms, which are able to simultaneously perform at high levels of productivity and quality?

2. If so, what is the magnitude of the gap between these firms and non-world class firms?
3. To what extent can any gap be explained by lean production concepts?
4. To what extent does the evidence support criticisms of the lean production model?

The IMVP work had demonstrated that the vehicle assemblers which showed the highest productivity and quality according to its performance measures were located in Japan; it thus seemed reasonable that Japanese automotive components manufacturers could also be high performers. Four automotive component products were covered by the study: brake calipers, exhausts, seats, and wire harnesses. The initial version of the benchmarking methodology drew on the IMVP assembly plant questionnaire, which was then refined through more than 20 drafts. One of the major differences between this project and the IMVP was that this study looked at multiple products instead of just cars. A generic methodology was developed, which was then customized for each of the four product areas.

Lean Measures of Automotive Components Plants

A general description of the set of measures used to survey each plant is as follows [Oliver, et al., 1994]:

Plant Performance

- Productivity (units/labor hour)
- Quality (% failures at final inspection and test)
- Value of output (output value/direct labor hour)
- Floorspace utilization (units produced/square meter)
- Throughput time (hours)

Plant Characteristics

- Automation (% operations automated)
- Absenteeism (%)
- Capacity utilization (%)
- Age of equipment (years)

Factory Practice

- First-time production (%)
- In-line rework and end-of-line rectification (%)
- Inventory (hours)
- Inventory turnover ratio (turns/year)

Factory floor problem-solving structures

- Problem-solving (number of problem-solving groups)

- Problem-solving (number meetings per month)
- Problem-solving (percentage of employees participating)
- Suggestion program (suggestions/employee)
- Suggestion program (percentage suggestions accepted)

In addition, many measures of customer relations and supplier relations were surveyed, but for the purposes of this literature review they will not be discussed since they are not directly part of factory operations.

Results of the Automotive Components Study

Based on the survey results the plants were divided into two categories: 1)world class plants 2)other plants. Across the plant performance measures, the world class plants showed consistently better performance, with the greatest differentials for productivity and quality [Oliver, et al., 1994]. The world class plants showed a 43% advantage on value of output per direct hour, a 38% advantage on floorspace utilization, and an 82% advantage on throughput time. When it comes to plant characteristics, the world class plants had higher levels of automation, younger equipment, and significantly lower absenteeism.

Next, the factory practice measures showed the world class plants using less rework and carrying significantly less inventory while turning inventory significantly more often. With regard to factory floor problem solving structures, both groups had similar structures, with about the same number of groups; however, in the world class plants the groups met more frequently, and on average more suggestions were received and implemented.

The findings of this study replicated the findings of the IMVP study in some areas and produced differences in others. The discussion is structured around the four research questions from the study as follows:

1. Is it possible to identify a group of 'world class' firms, which are able to simultaneously perform at high levels of productivity and quality? The findings show that there are companies who can perform at high levels according to a range of performance measures.
2. If so, what is the magnitude of the gap between these firms and non-world class firms? The results showed that the 2:1 performance differential the IMVP found between Japanese and European automakers

is mirrored in the relative performance of the Japanese and UK automotive components manufacturers. This finding does not support the criticism that the IMVP overestimated the performance differential between lean producers and mass producers [Williams, Haslam, 1992]. Also, Williams and Haslam argue that manufacturability and capacity utilization were important variables that were omitted from the IMVP analysis. The productivity figures in this study were corrected for product complexity, and therefore much of the 'manufacturability' effect should have been eliminated. Capacity utilization was measured, and showed that the world class plants actually had lower capacity utilization.

3. To what extent can any gap be explained by lean production concepts? This study shows that many of the elements of the lean model are found in conjunction with high performance according to a range of measures. Although most of the relationships are in the expected directions, relatively few achieved statistical significance.

The relationships that are statistically significant were predominantly related to process discipline and control (productivity, quality, inventory, floorspace and absenteeism).

4. To what extent does the evidence support criticisms of the lean production model? The higher performing companies actually showed lower levels of capacity utilization which would be expected with the slow Japanese economy at the time of the research. Manufacturability concerns were minimized for this study and that did not eliminate the performance gap between high and low performers as argued by Williams and Haslow.

Facilitating and Inhibiting Factors

Recall that this research sought an answer to the question, What factors either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing? Some of the factors thought to facilitate or inhibit successful implementation are listed from Day (1995) as follows:

- Job Security is a very important factor in the implementation of lean manufacturing principles. Possibly the single most important factor that must be overcome with factory employees is the fear of losing their jobs. Most companies implementing lean manufacturing make a commitment to job security that no layoff will occur as a result of productivity gains. Instead extra workers would be re-assigned to training, improvement teams, or other jobs within the company.
- Strong Leadership is a factor of consideration. To successfully implement lean manufacturing, the commitment has to start with senior management. Since most senior managers have been brought up in the theory and practice of mass production, they often must first be convinced that the principles of lean manufacturing can work. Next, senior managers must have a visible role in the implementation of lean manufacturing. This means senior managers must participate in training and problem-solving alongside the workers on the factory floor.

- Clear Communication is an important factor in lean implementation. Once senior management embraces lean manufacturing, the next challenge is to get the rest of the organization (line managers, engineers, clerks, etc.) to understand lean manufacturing and its benefits and then to successfully apply it. Thus, clear communication explaining how lean manufacturing will help the company improve cost, quality, and customer satisfaction is paramount to begin overcoming people's natural resistance to change.
- Training is a key factor in lean implementation. The companies that have been most successful implementing lean manufacturing have provided employees with intensive training. Some companies began with classroom training in lean principles, followed with participation in problem-solving teams, and finished with recognition of both individual and group achievements.
- Company Crisis can be factor in successful lean implementation. The literature discusses creative crisis or company crisis in a number of places. It

is thought that a creative crisis threatening the survival of a company breaks down the old thinking and entrenched culture which opens the door for the dramatic change from mass production to lean production.

The factors detailed above are but a few of those that can be found in the literature on lean manufacturing and are not an exhaustive listing; however, they are mentioned as examples of the types of factors that might be identified by the experts as significant as an outcome of this research.

Summary

Over the past six years the term *lean production* has been used as an umbrella to describe Japanese production techniques, which according to all accounts are found in their purest form in the Toyota production system in Japanese plants. While the literature identifies measures of lean, there is no clear set of measures that managers of automotive components manufacturing should use to evaluate manufacturing systems performance against lean manufacturing theory and world class competition and assess how lean these manufacturing systems are. For example, managers at ABC

Parts track a set of measures to provide feedback to manage the implementation of lean manufacturing principles in their plants. Most of the measures tracked agree with those that are used in the literature; however, the set of measures used is only a subset of all the quantified measures used in the literature to measure leanness. In addition, no detailed treatment exists of the factors that facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing.

III

RESEARCH METHODOLOGY

Type of Research Study

This chapter outlines the exploratory study used to identify the appropriate measures of lean manufacturing effectiveness for managing the implementation of lean manufacturing principles in automotive components plants. The study also sought to identify the factors that either facilitate or inhibit the implementation of lean manufacturing principles in automotive components manufacturing. In practice, managers need to be able to evaluate manufacturing systems performance against lean manufacturing theory and world class competition in order to assess how lean these manufacturing systems are. This research was qualitative since the data was obtained from 'lean experts' in the form of their judgments which were used iteratively to build expert consensus. Finally, the research was exploratory in that these research questions have not been answered for the automotive components industry. This research was an attempt at defining a set of lean measures appropriate for managing effective implementation of lean manufacturing principles in automotive components manufacturing and also an attempt at definition of factors significantly affecting these implementations.

Research Data Collection

This exploratory research study was conducted using selected managers from an automotive components manufacturer to obtain expert opinions that address the research question: What are the appropriate measures of lean manufacturing effectiveness to manage the implementation of lean manufacturing principles in automotive components manufacturing plants? The type of data obtained and used in this research are classified as descriptive survey data. The Delphi Technique was the method used to elicit consensus opinion among the expert respondents sampled within the automotive components company.

Overview of the Research

What follows is a description of how this research was accomplished. The research began with a review of the current body of knowledge in the area of lean manufacturing in the automobile industry with specific focus on automotive components manufacturing. The review of the related literature can be found in its entirety in Chapter Two.

Following the review of the related literature, a company within the automotive components industry to agreed to participate in the research. This exploratory research study was conducted using feedback from selected managers at ABC Parts (a pseudonym for the actual company) to obtain expert opinions that address the research questions using the Delphi Technique. ABC Parts management's agreement to participate in the Delphi Technique was obtained through the Divisional Industrial Engineering Manager. The Divisional Industrial Engineering Manager assisted in the identification of potential respondents, and the details of the questionnaires for the Delphi Technique as necessary.

The specific approach to defining and conducting the Delphi Technique was as follows:

1. **Develop the general structure of the Delphi Technique to be applied.**

The Delphi Technique is essentially a series of questionnaires and each subsequent questionnaire is built upon the feedback from the preceding one, where multiple iterations are possible. Originally, this research was to conduct three iterations. Due to the Industrial Engineering Managers' concerns about the total time requirements for respondents, it became necessary to limit the Delphi Technique to two iterations in order to gain agreement to conduct the questionnaires.

Some Delphi studies stop after the second questionnaire [Delbecq, Van de Ven, and Gustafson, 1986]. If another vote is not needed or additional clarification is not important, it may be sufficient to stop after two iterations and feed back the analysis of the second questionnaire to the respondents. The actual effect of having two questionnaires instead of three is discussed in the results in Chapter Four.

2. **Develop the Delphi question(s) for the technique.**

The Delphi questions for the technique were based upon the research questions in Chapter One. The Delphi questions were stated as follows:

- What are the appropriate measures of lean manufacturing effectiveness to manage the implementation of lean manufacturing principles in automotive components plants?
- What factors either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing?

These two Delphi questions formed the basis for the first questionnaire used in the Delphi Technique.

3. **Select and contact the respondents.**

The respondents had to at least meet the following criteria: have pertinent knowledge to share on lean manufacturing in the automotive industry, have adequate time and motivation to participate in the study, and have a level of personal commitment to the topic. In addition, each respondent had to have one of the following qualifications:

- Have completed a visit in GM's NUMMI joint venture with Toyota where they learned lean manufacturing in a vehicle assembly setting.
- Have past practical lean implementation experience working in a ABC Parts automotive components plant.
- Be currently functioning in a position responsible for implementing lean manufacturing principles within ABC Parts.

The target group of expert respondents was identified working with the Divisional I.E. Manager. Once a target group was identified, and agreed upon, they were contacted to obtain their agreement to participate in the study and were asked to nominate additional appropriate respondents since the technique was aimed at polling expert respondents. Since a nonrandom group of respondents was used, nominations were sought to help diversify the respondents in order to minimize any data distortion. Using nominations might also have encouraged respondent motivation, since there is an element of flattery tied to being an 'expert' respondent in a study. Following the nomination process the additional respondents were contacted to obtain agreement to participate.

The memo used to solicit the respondents' participation in the Delphi Technique is contained in Appendix A. The memo thanked the respondents for agreeing to participate, explained why their expert opinions were needed, briefly explained the research, and explained the expected benefits of the research for ABC Parts.

4. **Select the sample size for the Delphi Technique.**

The targeted number of respondents for this Delphi Technique was 25; however, the number of participants depended largely upon the initial size of the target group and the results of the nomination process. Thus, it was estimated that the study might involve between 15 and 25 expert respondents.

The actual sample size for the study and the fallout rate during the study are detailed in Chapter Four covering the results of the research.

5. **Develop Questionnaire One.**

The first questionnaire asked individuals to respond to the two Delphi questions (identified in step 2 above) regarding lean manufacturing in automotive components plants. Questionnaire One was accompanied by a cover letter thanking the respondent for participating, providing instructions, and providing a response date. The following activities were necessary for Questionnaire One:

A. Fax Questionnaire One, cover letter, and instructions to Respondents.

B. Receive responses from Questionnaire One. All questionnaires were returned by fax to a 3rd party to insure the anonymity of the respondents.

C. Follow up with a phone call if necessary.

A copy of Questionnaire One and its accompanying documents can be found in Appendix B.

6. **Analysis of Questionnaire One.**

At this point in the study, Questionnaire One had been sent to the respondents and returned to the independent 3rd party (Dr. Pratt). The analysis of

Questionnaire One resulted in a summary list of lean measures and facilitating and inhibiting factors along with all the comments made by respondents. Thus, the feedback from Questionnaire One became the content of Questionnaire Two.

7. **Develop Questionnaire Two.**

It was important that each item in Questionnaire Two accurately convey the meaning which respondents attempted to communicate through Questionnaire One. This implied a pretest of Questionnaire Two, which might have been accomplished with a small sample of respondents not participating in the formal Delphi Technique.

A formal pretest of Questionnaire Two was not conducted. This was because there were no extra respondents to participate in a pretest. Instead, an informal pretest was accomplished using the feedback of Dr. Paul Rossler and the Divisional Industrial Engineering Superintendent. Questionnaire Two was reviewed based on content, format, and readability and necessary changes were made to the document as a result of the informal pretest.

Questionnaire Two asked the respondents to review the lean measures and facilitating/inhibiting factors identified in Questionnaire One as summarized. Next, in keeping with common practice, respondents were asked to review all the responses and rank the ten most appropriate measures of lean manufacturing effectiveness to best manage the implementation of lean manufacturing principles in automotive components plants. Finally, respondents were asked to review all the responses and rank the ten most important factors that facilitate or inhibit the implementation of lean manufacturing principles in automotive components plants. Questionnaire two was accompanied by a cover letter that thanked the respondents again for participating, and provided instructions and a response date.

The format of Questionnaire Two allowed easy identification and understanding of the items taken from Questionnaire One, had clear voting instructions, and was short enough to complete in thirty to forty minutes. The following activities were necessary for Questionnaire Two:

A. Fax Questionnaire Two to Respondents.

B. Receive responses from Questionnaire Two. All questionnaires were returned to an independent 3rd party to insure the anonymity of the respondents.

C. Follow up with a phone call if necessary.

A copy of Questionnaire Two and its accompanying documents can be found in Appendix C.

8. **Analysis of Questionnaire Two.**

The analysis of Questionnaire Two compiled votes for lean measures and facilitating/inhibiting factors and summarized comments made about items. The analysis resulted in an overall ranking for the lean measures and facilitating/inhibiting factors. The overall rankings for the measures and factors were determined according to the following methodology:

- The number of votes received for each measure or factor were totaled. This was simply the number of actual ranking votes received for each measure or factor regardless of the numerical value of the vote. For example, a measure might have received the following votes: [3-10-6-2-1-5-6-7-2-4] and the number of votes received would equal 10.

- The score for the measures and factors was calculated. This was done by assigning point values to each of the actual ranking votes that a measure or factor received. The points were assigned using the following scale.

Table 3.1 Point Scale

Actual Ranking Vote	Point Value
1	10
2	9
3	8
4	7
5	6
6	5
7	4
8	3
9	2
10	1

- For the example mentioned above the score (total point value) would be 64 (8+1+5+9+10+6+5+4+9+7).
- Next, the measures or factors were sorted in descending order first by score and then by number of votes received.
- Finally, the overall rankings were assigned. The ranking of "1" went to the measure or factor with

the highest score...the "2" went to the next score in descending order and so on. When two or more measures or factors had the same score, then rank was assigned by highest number of votes received. When a tie occurred for two or more measures or factors in both the score and the number of votes received, then the measures or factors were assigned the same overall rank.

9. **Interpretation of Data**

This activity compared the final results of the Delphi Technique with the current lean measures being employed by ABC Parts and with the lean measures identified from the literature on automotive components manufacture.

10. **Prepare Final Report on Delphi Technique Results**

A final report that summarized the goals, the processes, and the results of this Delphi Technique was provided to the participants in the study. It was essential that participants were given a summary of the results from the questionnaires in order to fully achieve closure to the Delphi Technique. A copy of the final report to the respondents can be found in Appendix D.

11. **Develop the research Results, Summary, Conclusions, and Recommendations for future research.**

The results were to be compared to the existing literature, theory, experience, and practice. The results help broaden the body of knowledge on lean manufacturing implementation in automotive components manufacturing. The results were communicated to ABC Parts to assist managerial decision making. The results of the research can be found in Chapter Four.

IV

FINDINGS

Introduction

This chapter presents the findings from the exploratory research study (Delphi Technique) that was conducted to identify appropriate measures of lean manufacturing effectiveness and facilitating/inhibiting factors for managing the implementation of lean manufacturing principles in automotive components plants. First, the respondent sample sizes for the questionnaires are detailed. Second, the demographic information on the participants is presented to demonstrate the respondents' suitability as lean experts. Third, the lean measures identified are compared against the current lean measures used by ABC Parts and the lean measures found in the literature review. Fourth, the facilitating and inhibiting factors to successful lean implementation are presented and compared against those found in the literature review.

Respondent Sample Size for the Delphi Technique

With the help of the Industrial Engineering Manager, twenty-one potential respondents were identified and contacted. As a result of the initial contact memo asking for participation, five additional respondents were nominated. Thus, twenty-six people were asked to participate in the research questionnaires. Twenty-one people agreed to participate in the Delphi Technique.

Questionnaire One received seventeen responses (of twenty-one possible). Questionnaire Two was mailed to the original twenty-one people who agreed to participate and received fifteen responses. Thus, the final sample size for the Delphi Technique was fifteen which is suitable for a homogeneous group of experts [Delbecq, Van de Ven, and Gustafson, 1986].

Respondent Demographics

Demographic information was necessary to establish that the respondents in the Delphi Technique represented lean manufacturing experts for the automotive components industry. The respondents were asked seven questions, as part of Questionnaire One, to gather the demographic information. The questions asked of the respondents are as follows:

1. How many total years of work experience do you have (inside and outside of ABC Parts)?
2. How many years of work experience do you have with ABC Parts?
3. How many years of direct involvement with lean manufacturing do you have?
4. How many different sites have you worked at during your years with ABC Parts?
5. How many plant/site lean manufacturing implementations have you been involved with? (Do not count different departments within one plant as multiple implementations.)
6. How successful would you rate the lean implementations, that you have been involved with, relative to the expected benefits of lean manufacturing implementation. (circle one only)
   - Greatly exceeded expected benefits
   - Exceeded expected benefits
   - Met expected benefits

- Failed to meet expected benefits

- Miserably failed to meet expected benefits

7. What type of training and/or education do you have on lean manufacturing concepts?

(place a check mark next to all that apply)

______ 1 week visit to NUMMI.

______ 2 month visit to NUMMI.

______ 2 year assignment at NUMMI.

______ Have visited AMBRAKE.

______ Have made other ABC Parts site visits to review lean concepts.

______ Have read *The Machine that Changed the World*.

______ Have read *The Toyota Production System*.

______ Have read other texts on lean manufacturing.

______ Have received Quality Network training on lean concepts.

______ Have received divisional training on lean concepts.

______ Have received training outside ABC Parts on lean concepts.

______ Have taken college courses to further knowledge of lean mfg.

A summary of the responses for questions one through five is presented in Table 4.1. The average respondent had:

- 27.73 years of work experience
- 26.27 years with ABC Parts
- 8.20 years of involvement with lean manufacturing
- Had worked at 3.80 ABC Parts Sites
- Had been involved with 9.93 lean mfg. implementations

Note that the average respondent has spent about 30% of his/her career involved with lean manufacturing, but it is likely that the first 70% was spent working in a mass production setting. Notice that two respondents answered that they had been involved with 35 and 60 lean implementations. These answers are obvious misinterpretations of the question, since question four asked for the number of plant/site (not department) lean implementations and ABC Parts does not even have that many plants.

Table 4.2 displays a summary of the responses for question six which asked the respondents to rate the success of the lean implementations in which they had been involved.

As can be seen, 73.3% of the responses said the implementations had either met, exceeded, or greatly exceeded expectations, while 20.0% felt it had failed to meet expectations.

Table 4.1 Summary For Demographic Questions One-Five.

Respondent	Total Years of Work Experience	Total Years of ABC Parts Experience	Years of Involvement with Lean Mfg.	Number of ABC Parts Sites	Number of Lean Mfg. Implementations
1	32	28	10	3	12
2	15	15	6	5	35
3	35	33	8	4	2
4	20	20	15	3	4
5	27	27	3	5	2
6	31	31	3	5	1
7	33	31	4	2	2
8	34	31	6	3	12
9	28	28	10	2	2
10	30	29	8	4	10
11	27	27	8	4	1
12	32	30	16	6	2
13	25	23	5	2	60
14	20	18	10	5	3
15	27	23	11	4	1
Average	27.73	26.27	8.20	3.80	9.93
Maximum	35.00	33.00	16.00	6.00	60.00
Minimum	15.00	15.00	3.00	2.00	1.00
Std. Dev.	5.75	5.32	3.93	1.26	16.43
Coefficient of Variation	0.21	0.20	0.48	0.33	1.65

Table 4.2 Summary for Demographic Question Six.

Success of Lean Implementations (n=15)	Response
Greatly Exceeded Expected Benefits	20.0%
Exceeded Expected Benefits	23.3%
Met Expected Benefits	30.0%
Failed to Meet Expected Benefits	20.0%
Miserably Failed to Meet Expected Benefits	0.0%
No Answer	6.7%

Table 4.3 displays a summary for question seven on the respondents' level of training and education on lean principles. Note that 100% of the respondents had made site visits to review lean manufacturing and read texts on lean manufacturing concepts.

Table 4.3 Summary for Demographic Question Seven.

Training or Education on Lean Mfg. Principles	Response
One week visit to NUMMI	50%
One or two month visit to NUMMI	21%
Two year assignment at NUMMI	0%
Have visited AMBRAKE	36%
Have made other ABC Parts site visits to review lean concepts	100%
Have read *The Machine that Changed the World*	86%
Have read *The Toyota Production System*	64%
Have read other texts on lean manufacturing	100%
Have received Quality Network training on lean concepts	64%
Have received divisional training on lean concepts	57%
Have received training outside ABC Parts on lean concepts	50%
Have taken college courses to further knowledge of lean manufacturing	7%

Results of Using Two Iterations

Originally, this research was to conduct three iterations for the Delphi Technique. Later, it became necessary to limit the Delphi Technique to two iterations in order to gain agreement from ABC Parts to conduct the questionnaires. It is impossible to know the exact affect this had on the research results; however, it is likely that the effect was negligible. Some Delphi studies stop after the second questionnaire [Delbecq, Van de Ven, and Gustafson, 1986]. If another vote is not needed or additional clarification is not important, it may be sufficient to stop after two iterations and feed back the analysis of the second questionnaire to the respondents. The feedback from questionnaire one was straight-forward and did not require additional clarification and the voting results from questionnaire two yielded clear rankings, thus there was no strong need for a third iteration of the Delphi Technique.

Lean Measures

The *first* Delphi Question asked the respondents: What are the appropriate measures of lean manufacturing effectiveness to manage the implementation of lean manufacturing principles in automotive components plants? In Questionnaire One the respondents identified the appropriate lean measures and made comments supporting or clarifying the measures. Next, in Questionnaire Two the respondents ranked the lean measures by importance. Finally, the analysis of Questionnaire Two compiled the votes for the lean measures and resulted in an overall ranking of the lean measures. A detailed tabular summary of the ranked lean measures and all the respondent comments associated with each measure can be found in Appendix D.

Table 4.4 presents a comparison of the lean measures identified by the expert respondents, the current ABC Parts lean measures, and the lean measures identified in the literature review. A number of important observations can be made regarding the lean measures that were identified and ranked through the Delphi Technique as follows:

- The expert respondents ranked the ABC Parts Manufacturing Guide Assessment Forms as the number one most important lean measure. These forms are essentially gap assessments that are used to grade each plant according to their level of implementation of lean manufacturing principles. The forms apply a score (between one and four) to a number of criteria such as: Flow Mfg. Analysis, Continuous Improvement, Communication, Workplace Organization, Quality Control, Quick Setup, Planned Maintenance, and many more. These

Table 4.4 Comparison of Lean Measures Identified by Experts, Current ABC Parts Lean Measures, and Lean Measures from the Literature.

Overall Rank	Appropriate Lean Measures From Experts	ABC Parts Current Lean Measures	Lean Measures from Literature
1	ABC Parts Manufacturing System Guide Assessment Forms	ABC Parts Mfg. System Guide Assessment Forms (new in 1997)	
2	Quality	Quality	Quality
3	Leadtime		Throughput Time
4	Inventory Turns	Inventory Turns (new in 1997)	Inventory Turnover Ratio
5	Productivity	Productivity	Productivity
6	Inventory (amount on hand)		Inventory
7	First Time Quality	First Time Quality (new in 1997)	First Time Production
8	On Time Delivery	On Time Delivery (new in 1997)	
9	Value Added Activity		
10	Throughput		
11	Uptime	Uptime	
11	Unit Cost (cost/piece)		Value of Output
12	Scrap	Scrap	
13	Machine Utilization to TAKT Time		
14	Operator Utilization to TAKT Time		
15	Rework	Rework	In-line Rework
15	Average Batch Size for the Month		
16	Lean Education		
17	Return on Net Assets		
18	Lost Work Day Cases	Lost Work Day Cases	
18	Systems Approach to Measurement		
19	Queue Sizes		
20	Asset Utilization		
21	Maintenance	Maintenance	
22	Changeover Time of Constraint Operations		
23	Investment per Piece		
23	Number of Changeovers		
23	Response Time		
24	Distance Traveled		
25	Facilities		
25	Missed Shipments		
26	Customer Complaints		
26	Capacity Utilization	Capacity Utilization	Capacity Utilization
27	Levels of Management		
27	Floorspace		Floorspace Utilization
28	Delivery		
28	Multi-function Workers		
29	Raw Material Inventory of Top 3 Items		

forms are part of a newly created ABC Parts Manufacturing Systems Guide Book that gives information about lean principles and how to implement them. These forms were not expected to be ranked among the top ten and definitely were not expected to be number one. However, it is not surprising that the experts ranked the Assessment Forms number one since they were unveiled shortly before this research study (for use in 1997) and were probably fresh on the respondents' minds.

- Leadtime, Inventory (amount on hand), Value Added Activity, and Throughput were measures that ranked in the top ten, but are not currently being tracked by ABC Parts. All of the current lean measures being tracked by ABC Parts were identified and ranked by the respondents, but only six of the eleven measures that ABC Parts currently tracks were among the top ten measures identified by the respondents. The six measures are as follows: ABC Parts Guide Assessment Forms, Quality, Inventory Turns, Productivity, First Time Quality, and On Time Delivery. Note that Table 4.4 shows that four of the ABC Parts measures in the top ten had only begun to be tracked in 1997. Four of the current ABC Parts measures were ranked between ten and twenty, while the remaining two measures were ranked above twenty. Thus, using the expert rankings five of the eleven current ABC Parts measures would be replaced by measures that were ranked more important.

- It was surprising that uptime did not rank in the expert's top ten lean measures, because uptime is a current ABC Parts measure that has received a great deal of focus in the past few years; however, uptime was ranked number eleven in importance. This should certainly cause ABC Parts to question the continued level of expenditure of resources focused on uptime improvement if it is not considered one of the most important measures to help to get a successful implementation of lean manufacturing principles.
- In Chapter Two the literature review on lean manufacturing in the automotive components industry found eighteen measures. Six of the top ten lean measures, as ranked by the respondents, were found in the literature review. These six lean measures are as follows: Quality, Throughput Time (leadtime), Inventory Turnover Ratio, Productivity, Inventory, and First Time Quality.

Value of Output (unit cost), and In-line Rework were found in the literature review and ranked eleven and fifteen respectively according to the experts. Capacity utilization and floorspace utilization were ranked twenty-six and twenty-eight respectively. Ten of the eighteen lean measures found in the literature review were identified and ranked by the experts in the research.

Facilitating and Inhibiting Factors

The second Delphi Question asked the respondents: What factors either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing? In Questionnaire One the respondents identified facilitating and inhibiting factors and made comments supporting or clarifying the factors. Next, in Questionnaire Two the respondents ranked the facilitating/inhibiting factors by importance. Finally, the analysis of Questionnaire Two compiled the votes for the facilitating/inhibiting factors and resulted in an overall ranking of the factors. A detailed tabular summary of the facilitating/inhibiting factors and all the comments associated with the factors can be found in Appendix D.

Table 4.5 presents the facilitating/inhibiting factors identified and ranked by the expert respondents. A discussion will compare the factors identified by the experts with those that were identified in the literature review. A number of important observations can be made regarding the facilitating/inhibiting factors that were identified and ranked through the Delphi Technique as follows:

- Not surprisingly, Leadership/Management Commitment was ranked the number one factor according to the experts. Strong leadership was also found to be an important factor in the literature review. Chapter Five contains discussion and speculation about the role that strong leadership plays in lean implementation at ABC Parts.
- Training was ranked as the second most important factor to successful lean implementation. Training was also an important factor found in the literature review. Recall that the literature revealed that companies that have been most successful implementing lean manufacturing have provided employees with intensive training [Day, 1995].

- Appropriate Measurements were ranked the third most important factor. This was an important finding because it demonstrates that the experts consider appropriate lean measures to be very necessary in order to have a successful lean implementation.
- Several factors were identified and ranked that basically centered around knowledge of lean. Lack of understanding of lean principles was ranked fourth. Lean knowledge present was ranked sixth. Lack of knowledge of executives was tied for seventh. Lack of experts in ABC Parts to coach plants was ranked eleventh. Knowledge teacher was ranked nineteenth. Thus in multiple different descriptions the level of knowledge of lean manufacturing principles present in ABC Parts was considered to be a very important factor.
- The literature review identified job security as a very important factor in the implementation of lean manufacturing principles; however it was not identified as an important factor by the expert respondents. This could be due in part to the demographics of the respondents. All the respondents were in upper management at ABC Parts and the fact that job security

Table 4.5 Facilitating/Inhibiting Factors Identified by Experts.

Overall Rank	Facilitating or Inhibiting Factors from Experts
1	Leadership/management commitment
2	Training
3	Appropriate measurements
4	Lack of understanding of lean principles
5	Financial system does not encourage "lean"
6	Lean knowledge present
7	Lack of knowledge of executives
7	Absence of training, change agent, knowledge teacher, decisive action, and methodology
8	Conflicting priorities
9	Communications
10	Reward system
11	Engineers (design and process) need to get on board
11	Lack of experts in division to coach plants
12	On-site engineering support
13	Product engineering, sales, marketing, finance, etc.
14	Union
15	Purchasing
16	Decisive action
17	Capable processes
18	Education in "elimination of waste"
19	Knowledge teacher
19	Older equipment with long changeover times
20	Change agent
20	Systematic approach
21	Top leadership direction
21	Industrial engineering/process tool engineering functions
22	Process monuments
23	On-site statistical problem solvers
24	Trust and training
25	Lean hasn't been integrated into the business plan
25	Old manufacturing technology - monuments
26	Growth of business
27	Availability of capital to make improvements
27	Resistance to change
28	Fixed headcounts
28	Large degrees of massive automation with fixed conveyors
29	Error proofing
29	Levels of management
30	Inappropriate measurement systems
30	Process/methodology
31	Inconsistent direction
32	UNION "selective participation"
32	Un-level schedules on seasonal products
32	Visual control implementation
32	Failure to implement lean principles in proper sequence or natural order
33	Continuity of divisional core measurement requirements
33	Funding for equipment modification
33	Workers exposed to customers
34	Age and skill level of workforce
34	Improper focusing of available resources
35	Lack of system discipline

was not chosen as an important factor is a reflection on the sample group. Chapter Five contains additional discussion of possible reasons why job security was not identified by the experts.

- Communications was ranked as the ninth most important factor by the experts and was found as an important factor in the literature review. This was a factor that was expected to be ranked in the top ten.
- The seventh and sixteenth ranked factors involve the need for and absence of decisive action. Decisive action was not specifically found as a factor in the literature review.
- The union or United Auto Workers ranked fourteenth according to the experts. It was surprising that the union did not rank higher on the list of factors for successful lean implementation, given the importance of their role in the implementation and the adversarial relationships that have existed over the years.
- Several factors ranked by the experts referred to equipment in the ABC Parts plants. Older equipment with long changeover times ranked nineteenth. Process monuments ranked twenty-second. Old manufacturing

technology ranked twenty-fifth. Large degrees of massive automation with fixed conveyors ranked twenty-eighth. Although none of these factors was highly ranked for importance, it is interesting that they were identified. They essentially hit on the same theme as, age of equipment, one of the lean measures found in the literature review. Much of the older equipment tends to be larger, less flexible, and more cumbersome in a lean manufacturing environment. While the experts said it was a factor affecting successful lean implementation, they did not identify the need for a lean measure with regard to equipment age and did not rank any of their equipment factors highly amongst the factors.

Summary

This chapter presented the findings from the exploratory study conducted to identify appropriate measures of lean manufacturing effectiveness and facilitating/inhibiting factors for managing the implementation of lean manufacturing principles in automotive components plants. The respondent sample sizes for the questionnaires were detailed and the demographic information on the participants was presented. The lean measures identified were compared against the current lean measures used by ABC Parts and the lean measures found in the literature review. The facilitating and inhibiting factors to successful lean implementation were presented and compared against those found in the literature review. In summary the main findings were:

1. According to the experts, appropriate measurements are important to a successful lean implementation in the automotive components industry.
2. Only five of the eleven measures that ABC Parts currently tracks are among the top ten measures identified by the respondents. Using the expert rankings five of the eleven current ABC Parts measures would be replaced by measures that were ranked more important. Thus, according to the experts, ABC Parts is not using all the appropriate lean measures to guide implementation. Yet, they identified at least 73% of the implementation in ABC Parts as meeting or exceeding expectations.
3. The literature review found eighteen measures. Six of the experts' top ten lean measures were found in

the literature review. Ten of the eighteen lean measures found in the literature review were identified and ranked by the experts. Thus, the experts' lean measures only partially agreed with the measures found in the literature and four of the experts' top ten were newly identified relative to the literature.

4. The facilitating and inhibiting factors identified by the experts are somewhat generic. Leadership commitment, training, appropriate measurements, lean knowledge, conflicting priorities, and communications are examples of the general nature of the facilitating and inhibiting factors identified. These are factors that can be found listed in most management textbooks as being significant to any change effort (e.g., Total Quality Management, Reengineering, etc.);however, the general nature of these factors does not lower their importance to lean implementation. On the contrary, the fact that they are critical to any change effort underscores their importance.

V

CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter presents the conclusions and the recommendations for further research. The conclusions address how the research met the original research objectives. The objectives of this research were:

1. To identify the appropriate measures of lean manufacturing effectiveness to use in managing successful implementation of lean manufacturing principles in automotive components manufacturing.
2. To identify factors that either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing.
3. To identify potential areas for future research on lean manufacturing in automotive components manufacturing and other industries.

First, the conclusions regarding the lean measures are specified. Second, the conclusions regarding the facilitating and inhibiting factors are detailed. Third, recommendations are made for further research.

Conclusions for Lean Measures

The first research objective was to identify the appropriate measures of lean manufacturing effectiveness to use in managing successful implementation of lean manufacturing principles in automotive components manufacturing. The first Delphi question asked the respondents: What are the appropriate measures of lean manufacturing effectiveness to manage the implementation of lean manufacturing principles in automotive components plants? In Questionnaire One the respondents identified the appropriate lean measures and made comments supporting or clarifying the measures. Next, in Questionnaire Two the respondents ranked the lean measures by importance. Finally, the analysis of Questionnaire Two compiled the votes for the lean measures and resulted in an overall ranking of the lean measures.

Chapter Four presented a comparison of the lean measures identified by the experts, the current ABC Parts lean measures, and the lean measures identified in the literature. The findings on lean measures met the first research objective to identify the appropriate measures of lean manufacturing effectiveness to use in managing successful implementation of lean manufacturing principles in automotive components manufacturing. In addition, the findings on lean measures help broaden the body of knowledge on lean manufacturing implementation in automotive components manufacturing. Several important conclusions can be reached based on the findings for lean measures as follows:

- According to the findings on lean measures, ABC Parts is only using a subset of the appropriate lean measures to guide lean implementations. Only five of the eleven measures that ABC Parts currently tracks appeared among the top ten measures ranked by the experts. Therefore, using the expert rankings five of the eleven current ABC Parts measures would be replaced by measures that ranked as more appropriate. Based on these findings, ABC Parts should modify the set of lean measures being used to manage lean implementations.
- The findings showed (Table 4.2) that the experts identified 73.3% of the lean implementations in ABC Parts

as meeting or exceeding expectations and only 20% failing to meet expectations. This could mean that the current set of eleven lean measures being employed by ABC Parts provide a minimal level of satisfactory feedback for managing implementations. There is a strong possibility of reporting bias, since the respondents were rating the success of their own lean implementations.

- It should be noted that just because the experts felt that 73.3% of the lean implementations met or exceeded expectations does not mean that those successes were accomplished in the most efficient and effective manner. The demographics questions probably should have asked the respondents for more information on efficiency and effectiveness or the lean implementations. It is likely that those successes could have been accomplished in a more timely manner and consumed less resources if they had been guided with a more appropriate set of measures. Based on the expert feedback from this research, a more appropriate set of lean measures exists.
- The experts' lean measures only partially agreed with those found in the literature for automotive components manufacturing. Four of the experts' top ten measures

were newly identified relative to the literature, while six could be found in the literature. Overall, ten of the eighteen lean measures found in the literature review on automotive components manufacturing were identified and ranked by the experts. Even though the appropriate lean measures identified by this research do not exactly agree with the existing measures found in the literature, there is an arguement that the results of this research are generalizable for the entire automotive components industry.

- Uptime is an example of a current ABC Parts measure that has possibly received a disproportionate level of focus and amount of resources over the past several years. Uptime was ranked eleventh in importance by the experts. High machine uptime is an important part of a lean manufacturing system, but it is only one of many necessary ingredients. Spending a disproportionate amount of resources to improve one aspect of the lean system will only suboptimize the lean performance. ABC Parts should question the prioritization of its resources and consider focusing available resources more uniformly across the higher ranking lean measures. This may be symptomatic of the lack of lean knowledge mentioned in facilitating and inhibiting factors in the research. Managment at ABC Parts appears to lack a strong understanding of the interrelationships between the high ranking lean measures (i.e., uptime, inventory, leadtime, productivity, etc.). It many not be enough to adopt a more appropriate set of lean measures to guide the transformation from mass production to lean production. ABC Parts managers may need to take the fixed amount of resources available to them for the transformations and better prioritize their application to best accomplish the transformations to lean manufacturing.

- The lean measures identified by this research do not match closely with the twelve lean measures found in the literature review for the <u>auto assembly industry</u>. Only four of the lean measures identified by the experts can be found among the lean measures from the IMVP study on auto assembly. This helps confirm that the automotive components industry necessitates some differences from automotive assembly in the set of lean measures applied.

General Applicability of Lean Measures

At this point, the general applicability of the results of this research for lean measures must be addressed. The research results for lean measures will be addressed in terms of general applicability in the automotive components industry, the automotive industry, and other industries. Next, the research results on the facilitating and inhibiting factors will be covered in the same way.

The top ten lean measures identified in this research by the experts were as follows: ABC Parts Manufacturing System Guide Assessment Forms, quality, leadtime, inventory turns, productivity, inventory, first time quality, on time delivery, value added activity, and throughput. These measures do not exactly agree with the current ABC Parts measures and they do not exactly agree with the measures in the limited literature on the automotive components manufacture; however, these lean measures are definitely generalizable for automotive components manufacture, automotive assembly, aerospace/defense, government, service and other industries as well.

When compared with the lean manufacturing theory, each of the top ten measures identified are logical measures of lean. They measure outputs that are critical to successful lean implementation and they allow for a focus on the elimination of specific types of waste. Common sense confirms that these measures are useful for nearly any manufacturing endeavor. These measures themselves are nothing new, but what is new is the confirmation by this research that they are the appropriate measures for use in lean implementations. The lean measures identified from this research should be appropriate measures in a variety of industries. However, they would have to be tailored to fit the specifics of a given industry or company.

Conclusions for Facilitating and Inhibiting Factors

The second research objective was to identify factors that either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing. The second Delphi Question asked the respondents: What factors either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing? In Questionnaire One the respondents identified facilitating and inhibiting factors and made comments supporting or clarifying the factors. Next, in Questionnaire Two the respondents ranked the facilitating/inhibiting factors by importance. Finally, the analysis of Questionnaire Two compiled the votes for the facilitating/inhibiting factors and resulted in an overall ranking of the factors.

Chapter Four presented the facilitating/inhibiting factors ranked by the expert respondents and compared those factors with the factors identified in the literature review. A number of important observations were made regarding the facilitating/inhibiting factors that were identified and ranked through the Delphi Technique. The findings on facilitating and inhibiting factors met the second research objective to identify factors that either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing. In addition, the findings on facilitating and inhibiting factors helped broaden the body of knowledge on lean manufacturing implementation in automotive components manufacturing. Several important conclusions can be reached based on the findings for facilitating and inhibiting factors as follows:

- Leadership/Management Commitment was ranked the number one factor according to the experts and strong leadership was also found to be an important factor in the literature review. Since most of the respondents (upper managers from ABC Parts) have been brought up in the theory and practice of mass production, they often must first be convinced that the principles of lean manufacturing can work. The only way to convince some managers is through 'doing' and it takes strong leadership commitment to overcome the organizational inertia and force the steps down the road to lean. The general tone of the comments made in the lean questionnaires indicate that ABC Parts definitely has some leadership issues that need to be addressed with regard to lean implementation.
- Recall that, the average respondent has spent the first 70% of his/her 27.7 year career working in a mass production setting and only about 30% (8.2 years) working with lean production principles. Thus, it is likely ABC Parts will continue to struggle with the pasts of their managers throughout their lean implementations and the need for strong leadership will remain undiminished. It

is likely that other companies in the automotive components industry are facing similar challenges with regard to lean implementation and the mass production pasts of their managers. It is also reasonable to speculate that companies in other industries (electronics, aerospace, government, etc.) are facing similar circumstances with regard to adoption of lean manufacturing.

- The literature review identified job security as an important factor in the implementation of lean manufacturing principles; however it was not identified as an important factor by the expert respondents. This could mean that the ABC Parts upper managers do not recognize that hourly employees' fear of losing their jobs is a very important factor. If employees fear losing their jobs due to gains realized from lean implementation then they will likely 'hold back' from the company in many ways. The literature revealed that most companies implementing lean manufacturing make a commitment to job security that no layoff will occur as a result of productivity gains. However, it is possible that the ABC Parts managers did not note job security as a significant factor because it will be guaranteed at set levels to the union workers as a part of their negotiated bargaining agreement.

- Overall, the facilitating and inhibiting factors identified by the expert respondents were not surprising. In fact, the facilitating and inhibiting factors identified by the experts are fairly generic in nature. Leadership commitment, training, appropriate measurements, lean knowledge, conflicting priorities, and communications are examples of the general nature of the facilitating and inhibiting factors identified. These factors are found listed in most management textbooks as being significant to any change effort, but the general nature of these factors does not lower their importance to lean implementation. On the contrary, the fact that they are critical to any change effort underscores their importance. The fact that these research results on factors are very comparable to the significant factors for other change efforts is an important result.
- The results of the research on facilitating and inhibiting factors have essentially been seen many times before because they are very similar to the important

factors for other change efforts. There is value in knowing that the significant factors for lean implementations are similar to those for other change efforts. Although there will not be an exact overlap, managers can look to past experience and literature on other change efforts to identify areas of concern and benefit from past mistakes.

General General Applicability for Facilitating and Inhibiting Factors

The general applicability of the results of this research for facilitating and inhibiting factors must be addressed. The research results for the factors will be addressed in terms of general applicability in the automotive components industry, the automotive industry, and other industries.

Overall, the facilitating and inhibiting factors identified by the expert respondents were not surprising. In fact, the facilitating and inhibiting factors identified by the experts are fairly generic in nature. Leadership commitment, training, appropriate measurements, lean knowledge, conflicting priorities, and communications are examples of the general nature of the facilitating and inhibiting factors identified. These are factors that are noted in most management textbooks as being significant to any change effort regardless of whether the change is lean implementation. It is the general nature of these factors that make them applicable to automotive components manufacture, automotive assembly, aerospace/defense, government, service and other industries.

Recommendations

The third objective of this research was to identify potential areas for future research on lean manufacturing in automotive components manufacturing and other industries. Based on the findings for lean measures and facilitating/inhibiting factors, a number of recommendations can be made for future research as follows:

1. The IMVP study of automotive assembly plants (Chapter Two) was an in-depth study of that industry. A study of similar magnitude is need for the automotive components industry. Recall that a relatively small amount of literature exists on lean manufacturing in the automotive components industry. A comprehensive study would allow better definition of the unique aspects of

the industry, definition of appropriate lean measures, investigation of the homogeneity of the industry, and identification of any subgroups within the industry where approaches to lean need to differ. Such a study would allow better benchmarking to occur for the industry (just as the IMVP did for auto assembly). Overall, it could lead to a better understanding of how the transformation from mass production to lean can best be accomplished.

2. This research was conducted in the automotive components industry. Future research on lean manufacturing should be conducted in other industries (e.g., aerospace/defense, government, electronics, etc.) The findings of this effort should serve as an excellent starting point for such efforts.
3. Future research into lean manufacturing in automotive components manufacturing should seek feedback from a broader sample of respondents. This research relied on the feedback of ABC Parts' upper managers which may have resulted in a parochial view of lean implementation. It is advisable to seek responses from people at all levels of an organization who are involved in lean

implementation (e.g., hourly workers, first line supervisors, engineers, financial, middle management, etc.).

4. This research did not seek the feedback of academicians and/or consultants. It is recommended that future research consider the feedback of experts from these areas.
5. Based on the conclusions for lean measures and facilitating/inhibiting factors, a study into the effectiveness and efficiency of lean transformations from mass production to lean production is recommended.
6. Any future research should weigh the costs and benefits of using three or more iterations when using a Delphi Technique. An extra iteration of the Delphi Technique in this research would have allowed the respondents to review items from the first round, argue for or against them, and make necessary clarifications. Another iteration also would allow more exploration into individual reasoning versus group consensus. In a two iteration Delphi Technique the researcher is put in a position of having to do more speculation on the meaning

of the results and must make judgments on how to group the results into like or dissimilar categories.

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Appendices

Appendix A

Memo Soliciting Respondent Participation in Delphi Technique

MEMORANDUM

Date: November 13, 1996

Subject: Lean Manufacturing Questionnaire

From: Mitch Ballew

To: ABC Parts potential respondents

Please allow me to make a brief introduction. I am an Industrial Engineer supporting ABC Parts Operations. I am currently working to complete my research thesis for my M.S. in Industrial Engineering. The subject of my thesis is lean manufacturing in the automotive components industry.

With the support of XXXX XXXX and XXXXXX XXXXXX, I will be conducting a Lean Manufacturing Questionnaire (research survey technique) that will investigate lean manufacturing measures within ABC Parts. This research will help to complete my thesis requirements for my masters degree.
Your name was provided as a potential respondent for this Lean Manufacturing Questionnaire. The criteria used to select the candidates were as follows: a respondent must possess a high level of knowledge of lean manufacturing concepts or currently be involved in the implementation of lean concepts. I would like to ask for your participation in this Lean Manufacturing Questionnaire within ABC Parts.

The expected benefits to ABC Parts for conducting this Lean Manufacturing Questionnaire are as follows:

- The results of this research will be useful to ABC Parts because it will provide "subject matter expert" consensus opinion on what measures should be used to better implement lean manufacturing principles.
- Specifically, it will provide ABC Parts managers with feedback as to whether they need to modify the set of lean measures being used or it will affirm continuing use of the current measures.
- It will also provide information on catalysts and barriers to implementation of lean manufacturing principles in automotive components manufacturing.
- This information could help to accomplish more timely and cost effective implementations of lean manufacturing which remain within ABC Parts.

Your total time commitment to this effort is 1 1/2 to 2 hours spread out over two to three weeks. You will be asked to:

1. Confirm your participation. I will be calling to confirm your participation or you can send me a voice mail to confirm at XXX-XXX-XXXX. Your anonymity will be protected throughout; your responses will be mailed to a third party, who

will strip them of your identity and send them to me. Your original response will then be destroyed by the third party.

2. Fax a response to two questions in Lean Manufacturing Questionnaire #1:
   a. What are the appropriate measures of lean manufacturing implementation?
   b. What factors facilitate or inhibit the implementation of lean manufacturing?
   Your responses, along with other participant's responses, will be compiled into two lists, one for lean measures, the other for facilitating/inhibiting factors.
3. Given everyone's responses from Lean Manufacturing Questionnaire #1, rank the lean measures and facilitating/inhibiting factors in terms of their relative importance in Lean Manufacturing Questionnaire #2.
4. Final results will be shared with you in a Lean Manufacturing Feedback Report.

Please review the distribution list for this memo and determine if any appropriate respondents have been overlooked. If so, please nominate that person(s) using the attached nomination form and fax cover sheet. Next, fax the cover sheet and nomination form to the attention of Mitch Ballew at X-XXX-XXXX.

If you have any questions regarding this research, please contact Mitch Ballew at X-XXX-XXXX, (XXX) XXX-XXXX, VME XXXXXXXXXX and your call will be returned promptly. I will be calling in the next few days to confirm your participation in this Lean Manufacturing Questionnaire.

Respectfully,

Mitch Ballew

FAX TRANSMISSION

FROM:
TO: **MITCH BALLEW** **FAX to: X-XXX-XXXX or** **(XXX) XXX-XXXX**
DATE:
TIME:
COVER PAGE PLUS _______ PAGE(S) TO FOLLOW

NOTE: IF YOU MISTAKENLY RECEIVE THIS FAX TRANSMISSION, PLEASE FAX IT TO (405) 744-6187 AS SHOWN ABOVE. PLEASE DESTROY ANY COPIES YOU MAY HAVE RECEIVED.

Nomination Form

Please nominate any person within ABC Parts who possesses the criteria described below if they are not on the attached list of Currently Identified Respondents.

The criteria used to select the candidates were as follows: a respondent must possess a high level of knowledge of lean manufacturing concepts or currently be involved in the implementation of lean concepts.

Name of potential respondent:	Phone Number	Fax Number (if available)

Appendix B

Lean Manufacturing Questionnaire One

for the Delphi Technique

MEMORANDUM

Date: November 19, 1996

Subject: Lean Manufacturing Questionnaire #1

From: Mitch Ballew

To: Respondents

Thank you for agreeing to participate in two Lean Manufacturing Questionnaires. Your feedback will be invaluable.

Please find the following attachments:
1. Detailed instructions explaining Lean Manufacturing Questionnaire #1.
2. Lean Manufacturing Questionnaire #1 (the first of two questionnaires) is designed to gather your feedback on measures of lean manufacturing and the factors that facilitate/inhibit its effective implementation.
3. A Respondent Demographic Information Form.
4. A fax cover sheet for returning Lean Manufacturing Questionnaire #1 and the Respondent Demographic Information Form.

Please complete Lean Manufacturing Questionnaire #1 and the Respondent Demographic Information Form and return them using the attached fax cover sheet by **November 27, 1996**.

If you have any questions regarding Lean Manufacturing Questionnaire #1, the instructions, or the Respondent Demographic Information Form, please contact Mitch Ballew at X-XXX-XXXX, (XXX) XXX-XXXX, or VME XXXXXXXXXX. Again, thank you for your participation in this survey research.

Respectfully,

Mitch Ballew

INSTRUCTIONS FOR LEAN MANUFACTURING QUESTIONNAIRE #1

Please follow the following instructions:

1. List the appropriate measures of lean manufacturing effectiveness to best manage the implementation of lean manufacturing principles in automotive components plants.
2. If necessary, cite an example or give an explanation from your own personal experience to illustrate or clarify why the lean measure is appropriate.
3. List the factors that either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing.
4. If necessary, cite an example or give an explanation from your own personal experience to illustrate or clarify how the factor either facilitates or inhibits implementation of lean manufacturing principles.
5. Complete the Respondent Demographic Information Form.
6. Fax the completed Lean Manufacturing Questionnaire #1 and Respondent Demographic Information Form to the third party using the provided fax cover sheet.

NOTE:

- **PLEASE DO NOT FAX YOUR RESPONSES TO MITCH BALLEW.**
- **FAX ALL RESPONSES TO THE INDEPENDENT THIRD PARTY USING THE ATTACHED FAX COVER SHEET.**

FAX TRANSMISSION

FROM:
TO: **3RD PARTY - DR. PRATT** **I.E. & M. DEPARTMENT** **322 ENGINEERING NORTH** **FAX (405) 744-6187**
DATE:
TIME:
COVER PAGE PLUS ______ PAGE(S) TO FOLLOW

NOTE: IF YOU MISTAKENLY RECEIVE THIS FAX TRANSMISSION, PLEASE FAX IT TO (405) 744-6187 AS SHOWN ABOVE. PLEASE DESTROY ANY COPIES YOU MAY HAVE RECEIVED.

Respondent Demographic Information Form

NOTE: This demographic information will be carefully separated from Lean Manufacturing Questionnaire #1 by the independent third party. This will ensure respondent anonymity.

1. How many total years of work experience do you have (inside and outside of ABC PARTS)?

   ____

2. How many years of work experience do you have with ABC Parts ?

   ____

3. How many years of direct involvement with lean manufacturing do you have?

   ____

4. How many different sites have you worked at during your years with ABC Parts ?

   ____

5. How many plant/site lean manufacturing implementations have you been involved with? (Do not count different departments within one plant as multiple implementations.)

   ____

6. How successful would you rate the lean implementations, that you have been involved with, relative to the expected benefits of lean manufacturing implementation.

   (circle one only)
   - Greatly exceeded expected benefits
   - Exceeded expected benefits
   - Met expected benefits
   - Failed to meet expected benefits
   - Miserably failed to meet expected benefits

Respondent Demographic Information Form

7. What type of training and/or education do you have on lean manufacturing concepts?
   (place a check mark next to all that apply)

- ______ 1 week visit to NUMMI
- ______ 2 month visit to NUMMI
- ______ 2 year assignment at NUMMI
- ______ Have visited AMBRAKE
- ______ Have made other ABC Parts site visits to review lean concepts
- ______ Have read *The Machine that Changed the World*
- ______ Have read *The Toyota Production System*
- ______ Have read other texts on lean manufacturing
- ______ Have received Quality Network training on lean concepts
- ______ Have received divisional training on lean concepts
- ______ Have received training outside ABC Parts on lean concepts
- ______ Have taken college courses to further knowledge of lean manufacturing

LEAN MANUFACTURING QUESTIONNAIRE # 1

Please answer the following question clearly and concisely.

Question #1 - What are the appropriate measures of lean manufacturing effectiveness to best manage the implementation of lean manufacturing principles in automotive components plants?

If necessary, cite an example or give an explanation from your own personal experience to illustrate or clarify why the lean measure is appropriate.

Lean Measure	Unit(s) of Measure	Example or Explanation

Please continue on the table on the next page if you require additional space.

LEAN MANUFACTURING QUESTIONNAIRE # 1

Lean Measure	Unit(s) of Measure	Example or Explanation

If you still require more space, please attach additional page(s).

LEAN MANUFACTURING QUESTIONNAIRE # 1

Please answer the following question clearly and concisely.

Question #2 - What factors either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing?

If necessary, cite an example or give an explanation from your own personal experience to illustrate or clarify how the factor either facilitates or inhibits implementation of lean manufacturing principles.

Facilitating or Inhibiting Factor	Unit(s) of Measure	Example or Explanation

Please continue on the table on the next page if you require additional space.

LEAN MANUFACTURING QUESTIONNAIRE # 1

Facilitating or Inhibiting Factor	Unit(s) of Measure	Example or Explanation

If you still require more space, please attach additional page(s).

Appendix C

Lean Manufacturing Questionnaire Two

for the Delphi Technique

LEAN MANUFACTURING QUESTIONNAIRE # 2

Question #1 - What are the appropriate measures of lean manufacturing effectiveness to best manage the implementation of lean manufacturing principles in automotive components plants?

The table below contains all of the responses (appropriate lean measures) from Lean Manufacturing Questionnaire #1. Please review all the responses and rank the **ten** most appropriate measures of lean manufacturing effectiveness to best manage the implementation of lean manufacturing principles in automotive components plants.
Rank your ten most important lean measures from one to ten.
(1 = most important lean measure ... 10 = less important lean measure)
RANK ONLY TEN LEAN MEASURES!

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	Assessment Forms	• see explanation	• I believe the ABC Parts Mfg. System guide "Assessment" forms are the way we should rate and measure. These assessments force the correct changes in systems thinking, and will naturally drive the numbers in the right direction. Our culture is currently number focused and we'll try to make the numbers, but may not get lean in the process. A lean thinking plant would be one that has achieved at least level 3 and is moving toward level 4 (Continuous Improvement) and can demonstrate that all the "lean" activities are in place.
	Asset Utilization	• percentage of time producing	• Must fully utilize resources, especially if high capital costs.
	Average Batch Size for the Month	• number of pieces per run of a model	• Indicates progress towards single piece batch size.

Question #1

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	Capacity Utilization	• percentage	• Focuses on elimination of waste of excess equipment/facilities. • Use this measure at the "department level". • Use this measure at the "plant level". • Overseas is not the same penalty for 2nd and 3rd (e.g. 26% + 46%).
	Changeover Time of Constraint Operations	• minutes • seconds	• Amount of non-value added time spent in process model change.
	Customer Complaints	• number of documented complaints	• Department level measure for 1st line supervisor and hourly. • Plant level measures for mgr. and staff.
	Delivery	• pull response • number of pieces shipped per hour worked	• Use this measure at the "machine level". • Use this measure at the "department level".

Question #1

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	ABC Parts Manufacturing System Guide Assessment Forms	• see explanation	• Please refer to the ABC Parts Mfg. System guide Assessment Forms. These are the way I believe we should rate and measure. These assessments force the correct changes in systems and thinking, and will naturally drive the numbers in the right direction. Our culture is currently number focused and we'll try to make the numbers, but may not get lean in the process. • A lean thinking plant would be one that has achieved at least level 3 and is moving toward level 4 (continuous improvement) and can demonstrate that all the 'lean' activities are in place.
	Distance Traveled	• feet	• The distance traveled by parts to produce a product highlights waste of movement.
	Education	• percentage of workforce educated	• Establish general awareness and fit with objectives and put everyone through.
	Facilities	• feet squared per piece	• Size of manufacturing area.

Question #1

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	First Time Quality	• percentage acceptable • parts per million	• Indicates waste in the system. • Capable and stable processes must be employed to avoid the rework and scrap of poor quality. • Overall results of process controls and quality improvement activities. • Focuses on elimination of waste material, labor, and fixed assets. • Department level measure for 1st line supervisor and hourly. • Use this measure at the "machine level".
	Floorspace	• square feet	
	Inventory (amount on hand)	• dollars • days	• Focuses on elimination of waste of unnecessary inventory investment. • Raw material, WIP, finished goods, indirect. • Department level measure for 1st line supervisor and hourly. • Better than total turns since it focuses on need vs ship time, etc.
	Inventory Turns	• turns per year	• Lean operations must produce "just in time" and not batch build. • This is the broadest of measures. Simple visual means of calculating is often a barrier. • Focuses on elimination of waste of unnecessary inventory investment.

Question #1

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	Investment per Piece	• investment per piece	• Massive, complete automation is always costly - traditional rationale is labor savings.
	Leadtime	• minutes • hours • days	• Graphical representation of total time (dock to dock) for a part to get through the system (use to reduce waste). • Time it takes a product to get through the process/system. • Ability to reduce production time by eliminating waste defines lean. • Indicates trend in reducing time in flow, queue, etc. • Use this measure at the "product level in plant". • Breakdown of VA vs NVA steps. Focus on elimination of NVA activities.
	Lean Education	• number of hours per person • percentage of people trained	• There must be a common understanding of what is to be accomplished.
	Levels of Management	• number of layers - CEO to value added	• Say more about employee empowerment than any other method.
	Lost Work Day Cases	• cases per 100 employees	• Will find safety has a direct contribution to well organized workplace. • Plant level measures for mgr. and staff.

Question #1

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	Machine Utilization to TAKT Time	• seconds	• Shows the relationship of all the equipment in the manufacturing process in relation to its output - foundation of flow manufacturing.
	Maintenance	• MERV • number of tasks that are proactive • percentage of maint. hours that are proactive	• Percentage of maint. vs cost of equip. replacement is good only for newer plants. • Counting proactive tasks is wasted counting of tasks. • Wasted time counting.
	Man/Machine Chart	• seconds	• Graphically depicts relationship between operator and machine work - used to balance the system.
	Missed Shipments	• number of scheduled missed shipments	• None
	Multi-function Workers	• number of job classifications salaried or hourly	• Note that traditional salaried jobs are just as likely to be inflexible as traditional hourly.
	Number of Changeovers	• number of model changeovers per month/week/day	• Indicates implementation trend on quick change and mixed model flow.
	On Time Delivery	• percentage of shipments delivered on time	• Customers want the product when they want it. • Focuses on elimination of waste from past due orders. • Use this measure at the "product level in plant". • Use this measure at the "plant level". • Department level measure.

Question #1

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	Operator Utilization to TAKT Time	• seconds	• Same as the "machine utilization to TAKT time" but for operators - used to reduce waste.
	Process Audits	• percentage of process check complete	• Department level measure for 1st line supervisor and hourly.
	Productivity	• pcs/operator/hour • percentage of yearly improvement • D/L • parts per hour	• A healthy continuous improvement manufacturing system yields this level. • Focuses on elimination of waste through workplace and methods improvements. • Use this measure at the "department level". • Use this measure at the "plant level". • Not total - the indirect blurs production throughputs. • Indirect hours blur mfg. improvement mixing productivity of mfg. with structural cost improvement.
	Quality	• parts per million defective • percentage of significant operations capable and in control • percentage of supplier parts certified GP3 and GP8	• A natural fallout of lean is zero defects. • Use this measure at the "product level in plant". • Measures quality improvement process effectiveness. • Measuring supplier quality improves incoming quality.
	Queue Sizes	• pieces of production • hours of production	• Size of inhibitors to continuous flow.
	Quick Changeover	• minutes	• Ability to be quick and flexible to customer demand.

Question #1

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	Raw Material Inventory of Top 3 Items	• pieces • dollars	• Size of raw material stocks and state of pull systems with suppliers.
	Recordable Injuries	• recordables per 100	• Plant level measures for mgr. and staff.
	Response Time	• hours • days	• Time to respond to customer demand.
	Return on Net Assets	• percentage R.O.N.A.	• Focuses on elimination of waste from excess capitalization.
	Rework	• percentage rework • units or D/L • percentage vs prod. hours	• Bad parts divided by parts produced. • Rework is a cause for variation in the flow of product . • Focuses on elimination of waste from redundant processing. • Use this measure at the "department level". • Use this measure at the "plant level". • Inverse of scrap and supplier dependent.

Question #1

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	Scrap	• dollars • percentage • dollars per piece shipped • percentage vs COG	• Bad parts divided by parts produced. • Scrap is a cause for variation in the flow of product . • Focuses on elimination of wasted material, labor. • Use this measure at the "department level". • Use this measure at the "plant level". • Measure of the effectiveness of product and process variation reduction. • Department level measure for 1st line supervisor and hourly. • Better if percentage vs cost of material, not total cost.
	Suggestion savings	• dollars	• Plant level measures for mgr. and staff.
	Systems Approach to Measurement	• see explanation	• The key to utilizing appropriate measurement is in taking a systems approach rather than identifying discrete measurements. Each level in the organization is responsible for the accomplishment of different goals; therefore, the measures of performance need to be different. The various measurements and their linkage to each other are described by the Delco Remy Measurement triangle.
	Throughput	• parts/(employee hour worked) • leadtime • hour vs. prod	• Elimination of NVA, reduction of VA. • Total number of hour (direct, indirect, hourly, salary) versus productivity on line, dept., or plant.

Question #1

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	Training	• percentage of workforce trained	• Establish specific results training and put everyone through.
	Unit Cost (cost/piece)	• dollars/unit	• Determines if efforts are being seen in the bottom line. • Must capture total system cost. • Use this measure at the "product level in plant". • Department level measure for 1st line supervisor and hourly. • Plant level measures for mgr. and staff.
	Uptime	• percentage	• Focuses on elimination of wasted labor, burden, capital utilization. • Poor uptime is a cause for variation in the flow of product. • Use this measure at the "machine level". • Run time divided by scheduled run time. • Necessary for flow manufacturing techniques and to balance operator and machine. • Provides a method to focus on the critical few. • Plant level measures for mgr. and staff. • Uptime on three bottlenecks per product. • In our four product lines this drives improved prev. maint. and process capability. • Use uptime measure on 3 bottlenecks per product. • Uptime drives improved prev. maint. and Cpk.

Question #1

Rank	Lean Measure	Unit(s) of Measure	Example or Explanation
	Value Added Activity	• percentage VA of total process time	• Lean systems eliminate waste and focus on value added. • Indicates progress in eliminating NVA operations.

LEAN MANUFACTURING QUESTIONNAIRE # 2

Question #2 - What factors either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing?

The table below contains all of the responses (facilitating/inhibiting factors) from Lean Manufacturing Questionnaire #1. Please review all the responses and rank the **ten** most important factors that facilitate or inhibit the implementation of lean manufacturing principles in automotive components plants.
Rank your ten most important facilitating/inhibiting factors from one to ten.
(1 = most important factor ... 10 = less important factor)
RANK ONLY TEN FACTORS!

Rank	Facilitating or Inhibiting Factor	Example or Explanation
	Age and skill level of workforce	• Vast majority of existing workforce in the last years of their "work lives" and have not acquired the skills required to be proficient in today's lean, kaizen driven workplace.
	Absence of training, change agent, knowledge teacher, decisive action, and methodology	• Lack of desire, knowledge, ability, methodology, etc. • Must be pushed not pulled through organization.
	Appropriate change agent identified	• Change agent/champion must drive paradigm shift.

Question #2

Rank	Facilitating or Inhibiting Factor	Example or Explanation
	Appropriate measurements	• Facilitator. • Simple, clear, and understandable measurements. • Proper measurements at the various levels of the organization. • The key to utilizing appropriate measurements is in taking a "systems approach" rather than identifying discrete measurements (refer to Delco Remy measurement overview). • How people are measured and rewarded must support the concepts to be implemented.
	Availability of capital to make improvements	• Investment is available when cost savings justify expenditure.
	Capable processes	• Facilitator.
	Change Agent	• A dominant force to assure compliance to method and focus on objective. • An organization needs an identifiable motivation to change.
	Communications	• Good communications facilitates understanding and involvement.
	Conflicting Priorities	• An edict to do it "all at once" instead of in a logical transformation.
	Continuity of divisional core measurement requirements	• None.
	Decisive Action	• Clear direction written and communicated. • There needs to be an understanding of expectations.
	Defined roles and responsibilities	• None.
	Education in "elimination of waste"	• Specific education in principles of lean manufacturing, waste identification and elimination.

Question #2

Rank	Facilitating or Inhibiting Factor	Example or Explanation
	Engineers (design and process) need to get on board	• They are two years behind Manufacturing in "lean thinking".
	Error Proofing	• Specific initiative to identify and error proof equipment, people tasks and material movement.
	Expensive ventilation systems for environmental control	• Required due to lead in batteries. Make redesign of flow expensive.
	Facilitating Workshops	• PICOS or mfg. system design workshops to rearrange an area into a "lean process".
	Failure to implement lean principles in proper sequence or natural order	• None.
	Financial system does not encourage "lean"	• Plants are measured on performance to budget, not on their flexibility to respond to customers. More labor in a "lean process" hurts the plant's performance.
	Fixed Headcounts	• Secured employment levels delay cost savings until attrition reduces headcount.
	Funding for equipment modification	• None.
	Growth of business	• If you are not growing, improved productivity means job loss or loss of opportunities.
	Improper focusing of available resources	• None.
	Inconsistent direction	• Measurement changes - program of the day.
	Industrial Engineering/Process Tool Engineering Functions	• Lean concepts are understood and are gaining focus from the Manufacturing Engineering Groups.
	Inappropriate measurement systems	• Inhibitor.

Question #2

Rank	Facilitating or Inhibiting Factor	Example or Explanation
	Inventory In days	• Measure of effectiveness of material and manufacturing systems.
	Inventory turns	• Financial measure which can be severely impacted by non-manufacturing issues.
	Knowledge Teacher	• Someone who guides the change agent in focus on lean concepts, principles, and methodology.
	Lack of certification process (i.e. QS9000) to add sense of urgency	• Needing to get QS9000 certified rallied plants/organizations to "Get it done".
	Lack of experts in division to coach plants	• Everyone is learning as we go. Even people at headquarters agree that our "experts" are marginal at best.
	Lack of knowledge of executives	• We're all learning as we go and I'm not sure all our executives are creative enough and have a clear vision.
	Lack of system discipline	• Lost work day cases - an orderly, clean, bright work environment requires the discipline of follow up.
	Lack of understanding of lean principles	• Inhibitor. • Lack of understanding by mgmt of lean principles.
	Large degrees of massive automation with fixed conveyors	• Inflexibility in making quick, inexpensive changes in flow.
	Lean hasn't been integrated into the Business Plan	• New business plan should resolve this so long as plants and staff areas roll it into their planning process.
	Lean knowledge present	• The profound knowledge of the concepts to be implemented must exist at the top of the organization. If the manager does not have the knowledge, the he/she must bring someone in who has it.

Question #2

Rank	Facilitating or Inhibiting Factor	Example or Explanation
	Leadership/Management commitment	• Manager of organization must support and lead the implementation.
	Levels of Management	• Denial - current leaders work their way up through these levels; therefore, they must be needed.
	Long validation times for process/product changes	• Time to react.
	Maintenance metric	• Measuring proactive tasks is a wasted counting of tasks.
	Measurement quick and simple	• Managers want to kick in the “kitchen sink”.
	Older equipment with long changeover times	• Long changeover times drive long runs to spread time over more pieces.
	Old manufacturing technology - monuments	• Layouts not easy to change - cost or investment associated with moving equipment.
	On-site engineering support	• None.
	On-site statistical problem solvers	• None.
	PPM customer returns	• Quality and system variation reduction process implementation effect.
	Process/Methodology	• Written and communicated. • Beyond expectation is methodology of implementation.
	Process Monuments	• Historic “mass production” mentality has resulted in equipment/facilities which do not lend themselves to takt time and single piece flow.
	Product Engineering, Sales, Marketing, Finance, etc.	• Little understanding of how “lean” impacts non-manufacturing functions exists.

Question #2

Rank	Facilitating or Inhibiting Factor	Example or Explanation
	Purchasing	• Purchasing decisions made based on part cost only. Plants made to carry protection stock and overtime for poor quality and missed shipments (i.e. We have parts coming from China). Supplier quality has caused 75% of our quality problems. We can't get suppliers to repackage into small lots so we have to repackage. Bottom line is that our entire Purchasing philosophy needs to be re-thought. Purchasing is the most out of synch with our efforts to become lean.
	Reason to change	• An organization needs an identifiable motivation to change.
	Resistance to change	• Inhibitor.
	Reward system	• No reward system consistent with implementation. • How people are measured and rewarded must support the concepts to be implemented.
	Systematic approach	• An overall master plan for change is required to provide constancy of purpose. It should have long term vision and short term action.
	Top leadership direction	• Lean implementation is a top priority.

Question #2

Rank	Facilitating or Inhibiting Factor	Example or Explanation
	Training	• Awareness. • Especially for employees of affected area. • Capable workforce. • People involvement is a key. Involvement through training is a good way. • The tools to transition or maintain a lean system must be taught and used. • Appropriate training at the various levels of the organization. • The workforce, including management, must be educated and trained in the concepts.
	Tracking specific action plans	• Tracking the completion percentage.
	Trust and training	• Workers must trust the corp. direction involves value for them before they give their hearts.
	Union "selective participation"	• All trades issues are avoided by the union.
	Union	• Changes must be negotiated when PPL are impacted. Can be a "+" or a "-" ; usually a "-".
	Union, L.O.D.'s, and Classifications	• "Lines of Demarcation" resist multi-skill workforce development.
	Un-level schedules on seasonal products	• Seasonal products such as batteries exhibit large variation in month to month demand.
	Visual control implementation	• Management by sight.
	Workers exposed to customers	• When your customer is a real person you treat them right.

Appendix D

Final Feedback Report to Participants

in the Delphi Technique

FEEDBACK REPORT FOR
LEAN MANUFACTURING QUESTIONNAIRES

Question #1 - What are the appropriate measures of lean manufacturing effectiveness to best manage the implementation of lean manufacturing principles in automotive components plants?

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Lean Measure	Unit(s) of Measure	Example or Explanation
1	11	1-1-1-1-7-1-1-2-1-10-4-	ABC Parts Manufacturing System Guide Assessment Forms	• see explanation	• I believe the ABC Parts Mfg. System guide "Assessment" forms are the way we should rate and measure. These assessments force the correct changes in systems thinking, and will naturally drive the numbers in the right direction. Our culture is currently number focused and we'll try to make the numbers, but may not get lean in the process. A lean thinking plant would be one that has achieved at least level 3 and is moving toward level 4 (Continuous Improvement) and can demonstrate that all the "lean" activities are in place.

* The methodology used to determine the "Overall Rank" for each measure is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Lean Measure	Unit(s) of Measure	Example or Explanation
2	10	3-10-6-2-1-5-6-7-2-4	Quality	• parts per million defective • percentage of significant operations capable and in control • percentage of supplier parts certified GP3 and GP8	• A natural fallout of lean is zero defects. • Use this measure at the "product level in plant". • Measures quality improvement process effectiveness. • Measuring supplier quality improves incoming quality.
3	11	8-1-9-7-10-9-3-6-4-1-1	Leadtime	• minutes • hours • days	• Graphical representation of total time (dock to dock) for a part to get through the system (use to reduce waste). • Time it takes a product to get through the process/system. • Ability to reduce production time by eliminating waste defines lean. • Indicates trend in reducing time in flow, queue, etc. • Use this measure at the "product level in plant". • Breakdown of VA vs NVA steps. Focus on elimination of NVA activities.
4	7	7-3-2-1-4-2-5	Inventory Turns	• turns per year	• Lean operations must produce "just in time" and not batch build. • This is the broadest of measures. Simple visual means of calculating is often a barrier. • Focuses on elimination of waste of unnecessary inventory investment.

* The methodology used to determine the "Overall Rank" for each measure is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Lean Measure	Unit(s) of Measure	Example or Explanation
5	9	5-7-6-3-8-2-9-4-5	Productivity	• pcs/operator/hour • percentage of yearly improvement • D/L • parts per hour	• A healthy continuous improvement manufacturing system yields this level. • Focuses on elimination of waste through workplace and methods improvements. • Use this measure at the "department level". • Use this measure at the "plant level". • Not total - the indirect blurs production throughputs. • Indirect hours blur mfg. improvement mixing productivity of mfg. with structural cost improvement.
6	7	2-2-9-5-3-10-3-	Inventory (amount on hand)	• dollars • days	• Focuses on elimination of waste of unnecessary inventory investment. • Raw material, WIP, finished goods, indirect. • Department level measure for 1st line supervisor and hourly. • Better than total turns since it focuses on need vs ship time, etc.
7	8	2-8-8-5-5-9-3-6	First Time Quality	• percentage acceptable • parts per million	• Indicates waste in the system. • Capable and stable processes must be employed to avoid the rework and scrap of poor quality. • Overall results of process controls and quality improvement activities. • Focuses on elimination of waste material, labor, and fixed assets. • Department level measure for 1st line supervisor and hourly. • Use this measure at the "machine level".

* The methodology used to determine the "Overall Rank" for each measure is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Lean Measure	Unit(s) of Measure	Example or Explanation
8	9	4-10-3-10-4-9-3-8-7-	On Time Delivery	• percentage of shipments delivered on time	• Customers want the product when they want it. • Focuses on elimination of waste from past due orders. • Use this measure at the "product level in plant". • Use this measure at the "plant level". • Department level measure.
9	8	6-3-8-8-4-10-9-2	Value Added Activity	• percentage VA of total process time	• Lean systems eliminate waste and focus on value added. • Indicates progress in eliminating NVA operations.
10	7	9-10-4-2-7-3-6-	Throughput	• parts/(employee hour worked) • leadtime • hour vs. prod	• Elimination of NVA, reduction of VA. • Total number of hour (direct, indirect, hourly, salary) versus productivity on line, dept., or plant.
11	6	9-5-7-3-8-7	Uptime	• percentage	• Focuses on elimination of wasted labor, burden, capital utilization. • Poor uptime is a cause for variation in the flow of product. • Use this measure at the "machine level". • Run time divided by scheduled run time. • Necessary for flow manufacturing techniques and to balance operator and machine. • Provides a method to focus on the critical few. • Plant level measures for mgr. and staff. • Uptime on three bottlenecks per product. • In our four product lines this drives improved prev. maint. and process capability. • Use uptime measure on 3 bottlenecks per product. • Uptime drives improved prev. maint. and Cpk.

* The methodology used to determine the "Overall Rank" for each measure is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Lean Measure	Unit(s) of Measure	Example or Explanation
11	5	6-4-5-3-10	Unit Cost (cost/piece)	• dollars/unit	• Determines if efforts are being seen in the bottom line. • Must capture total system cost. • Use this measure at the "product level in plant". • Department level measure for 1st line supervisor and hourly. • Plant level measures for mgr. and staff.
12	6	5-6-5-10-9-6	Scrap	• dollars • percentage • dollars per piece shipped • percentage vs COG	• Bad parts divided by parts produced. • Scrap is a cause for variation in the flow of product . • Focuses on elimination of wasted material, labor. • Use this measure at the "department level". • Use this measure at the "plant level". • Measure of the effectiveness of product and process variation reduction. • Department level measure for 1st line supervisor and hourly. • Better if percentage vs cost of material, not total cost.
13	4	8-8-5-2	Machine Utilization to TAKT Time	• seconds	• Shows the relationship of all the equipment in the manufacturing process in relation to its output - foundation of flow manufacturing.
14	4	9-7-6-3	Operator Utilization to TAKT Time	• seconds	• Same as the "machine utilization to TAKT time" but for operators - used to reduce waste.

* The methodology used to determine the "Overall Rank" for each measure is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Lean Measure	Unit(s) of Measure	Example or Explanation
15	3	4-5-8	Rework	• percentage rework • units or D/L • percentage vs prod. hours	• Bad parts divided by parts produced. • Rework is a cause for variation in the flow of product . • Focuses on elimination of waste from redundant processing. • Use this measure at the "department level". • Use this measure at the "plant level". • Inverse of scrap and supplier dependent.
15	2	4-2-	Average Batch Size for the Month	• number of pieces per run of a model	• Indicates progress towards single piece batch size.
16	5	6-10-7-10-9	Lean Education	• number of hours per person • percentage of people trained	• There must be a common understanding of what is to be accomplished.
17	2	2-10-	Return on Net Assets	• percentage R.O.N.A.	• Focuses on elimination of waste from excess capitalization.
18	1	1-	Lost Work Day Cases	• cases per 100 employees	• Will find safety has a direct contribution to well organized workplace. • Plant level measures for mgr. and staff.
18	1	1-	Systems Approach to Measurement	• see explanation	• The key to utilizing appropriate measurement is in taking a systems approach rather than identifying discrete measurements. Each level in the organization is responsible for the accomplishment of different goals; therefore, the measures of performance need to be different. The various measurements and their linkage to each other are described by the Delco Remy Measurement triangle.

* The methodology used to determine the "Overall Rank" for each measure is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Lean Measure	Unit(s) of Measure	Example or Explanation
19	2	7-6-	Queue Sizes	• pieces of production • hours of production	• Size of inhibitors to continuous flow.
20	1	2-	Asset Utilization	• percentage of time producing	• Must fully utilize resources, especially if high capital costs.
21	2	8-6-	Maintenance	• MERV • number of tasks that are proactive • percentage of maint. hours that are proactive	• Percentage of maint. vs cost of equip. replacement is good only for newer plants. • Counting proactive tasks is wasted counting of tasks. • Wasted time counting.
22	1	3-	Changeover Time of Constraint Operations	• minutes • seconds	• Amount of non-value added time spent in process model change.
23	1	4-	Investment per Piece	• investment per piece	• Massive, complete automation is always costly - traditional rationale is labor savings.
23	1	4-	Number of Changeovers	• number of model changeovers per month/week/day	• Indicates implementation trend on quick change and mixed model flow.
23	1	4-	Response Time	• hours • days	• Time to respond to customer demand.

* The methodology used to determine the "Overall Rank" for each measure is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Lean Measure	Unit(s) of Measure	Example or Explanation
24	2	6-10-	Distance Traveled	• feet	• The distance traveled by parts to produce a product highlights waste of movement.
25	1	5-	Facilities	• feet squared per piece	• Size of manufacturing area.
25	1	5-	Missed Shipments	• number of scheduled missed shipments	• None
26	2	10-7-	Customer Complaints	• number of documented complaints	• Department level measure for 1st line supervisor and hourly. • Plant level measures for mgr. and staff.
26	2	9-8	Capacity Utilization	• percentage	• Focuses on elimination of waste of excess equipment/facilities. • Use this measure at the "department level". • Use this measure at the "plant level". • Overseas is not the same penalty for 2nd and 3rd (e.g. 26% + 46%).
27	1	7-	Levels of Management	• number of layers - CEO to value added	• Say more about employee empowerment than any other method.
27	1	7	Floorspace	• square feet	
28	1	8-	Delivery	• pull response • number of pieces shipped per hour worked	• Use this measure at the "machine level". • Use this measure at the "department level".
28	1	8-	Multi-function Workers	• number of job classifications salaried or hourly	• Note that traditional salaried jobs are just as likely to be inflexible as traditional hourly.

* The methodology used to determine the "Overall Rank" for each measure is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Lean Measure	Unit(s) of Measure	Example or Explanation
29	1	9-	Raw Material Inventory of Top 3 Items	• pieces • dollars	• Size of raw material stocks and state of pull systems with suppliers.
no votes	0	no votes	Education	• percentage of workforce educated	• Establish general awareness and fit with objectives and put everyone through.
no votes	0	no votes	Man/Machine Chart	• seconds	• Graphically depicts relationship between operator and machine work - used to balance the system.
no votes	0	no votes	Process Audits	• percentage of process check complete	• Department level measure for 1st line supervisor and hourly.
no votes	0	no votes	Quick Changeover	• minutes	• Ability to be quick and flexible to customer demand.
no votes	0	no votes	Recordable Injuries	• recordables per 100	• Plant level measures for mgr. and staff.
no votes	0	no votes	Suggestion savings	• dollars	• Plant level measures for mgr. and staff.
no votes	0	no votes	Training	• percentage of workforce trained	• Establish specific results training and put everyone through.

* The methodology used to determine the "Overall Rank" for each measure is explained in Appendix A.

LEAN MANUFACTURING QUESTIONNAIRE # 2

Question #2 - What factors either facilitate or inhibit implementation of lean manufacturing principles in automotive components manufacturing?

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Facilitating or Inhibiting Factor	Example or Explanation
1	8	1-3-1-1-6-5-6-1	Leadership/Management commitment	Manager of organization must support and lead the implementation.
2	8	1-7-6-3-2-3-7-6	Training	Awareness. Especially for employees of affected area. Capable workforce. People involvement is a key. Involvement through training is a good way. The tools to transition or maintain a lean system must be taught and used. Appropriate training at the various levels of the organization. The workforce, including management, must be educated and trained in the concepts.
3	8	2-6-10-4-1-5-7-9	Appropriate measurements	Facilitator. Simple, clear, and understandable measurements. Proper measurements at the various levels of the organization. The key to utilizing appropriate measurements is in taking a "systems approach" rather than identifying discrete measurements (refer to Delco Remy measurement overview). How people are measured and rewarded must support the concepts to be implemented.
4	6	5-1-7-3-7-6-	Lack of understanding of lean principles	Inhibitor. Lack of understanding by mgmt of lean principles.
5	8	6-2-9-8-9-9-8-1-	Financial system does not encourage "lean"	Plants are measured on performance to budget, not on their flexibility to respond to customers. More labor in a "lean process" hurts the plant's performance.

* The methodology used to determine the "Overall Rank" for each factor is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Facilitating or Inhibiting Factor	Example or Explanation
6	5	5-1-4-5-4	Lean knowledge present	The profound knowledge of the concepts to be implemented must exist at the top of the organization. If the manager does not have the knowledge, the he/she must bring someone in who has it.
7	5	2-2-8-6-2	Lack of knowledge of executives	We're all learning as we go and I'm not sure all our executives are creative enough and have a clear vision.
7	5	2-5-5-9-1	Absence of training, change agent, knowledge teacher, decisive action, and methodology	Lack of desire, knowledge, ability, methodology, etc. Must be pushed not pulled through organization.
8	5	6-4-8-3-4	Conflicting Priorities	An edict to do it "all at once" instead of in a logical transformation.
9	4	3-1-2-8-	Communications	Good communications facilitates understanding and involvement.
10	4	4-6-4-8	Reward system	No reward system consistent with implementation. How people are measured and rewarded must support the concepts to be implemented.
11	5	9-6-3-3-10-	Engineers (design and process) need to get on board	They are two years behind Manufacturing in "lean thinking".
11	5	4-10-1-9-7-	Lack of experts in division to coach plants	Everyone is learning as we go. Even people at headquarters agree that our "experts" are marginal at best.
12	4	7-2-7-4-	On-site engineering support	None.
13	5	8-3-8-3-10	Product Engineering, Sales, Marketing, Finance, etc.	Little understanding of how "lean" impacts non-manufacturing functions exists.
14	4	10-4-5-5-	Union	Changes must be negotiated when PPL are impacted. Can be a "+" or a "-" ; usually a "-".

* The methodology used to determine the "Overall Rank" for each factor is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Facilitating or Inhibiting Factor	Example or Explanation
15	6	7-10-10-4-9-7	Purchasing	Purchasing decisions made based on part cost only. Plants made to carry protection stock and overtime for poor quality and missed shipments (i.e. We have parts coming from China). Supplier quality has caused 75% of our quality problems. We can't get suppliers to repackage into small lots so we have to repackage. Bottom line is that our entire Purchasing philosophy needs to be re-thought. Purchasing is the most out of synch with our efforts to become lean.
16	2	1-2-	Decisive Action	Clear direction written and communicated. There needs to be an understanding of expectations.
17	4	8-4-4-10-	Capable processes	Facilitator.
18	3	4-6-6	Education in "elimination of waste"	Specific education in principles of lean manufacturing, waste identification and elimination.
19	2	3-2-	Knowledge Teacher	Someone who guides the change agent in focus on lean concepts, principles, and methodology.
19	2	3-2-	Older equipment with long changeover times	Long changeover times drive long runs to spread time over more pieces.
20	2	5-1-	Change Agent	A dominant force to assure compliance to method and focus on objective. An organization needs an identifiable motivation to change.
20	2	1-5	Systematic approach	An overall master plan for change is required to provide constancy of purpose. It should have long term vision and short term action.
21	2	5-2-	Top leadership direction	Lean implementation is a top priority.
21	2	5-2	Industrial Engineering/Process Tool Engineering Functions	Lean concepts are understood and are gaining focus from the Manufacturing Engineering Groups.
22	2	7-2-	Process Monuments	Historic "mass production" mentality has resulted in equipment/facilities which do not lend themselves to takt time and single piece flow.

* The methodology used to determine the "Overall Rank" for each factor is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Facilitating or Inhibiting Factor	Example or Explanation
23	2	8-3-	On-site statistical problem solvers	None.
24	3	7-9-9-	Trust and training	Workers must trust the corp. direction involves value for them before they give their hearts.
25	1	3	Lean hasn't been integrated into the Business Plan	New business plan should resolve this so long as plants and staff areas roll it into their planning process.
25	1	3	Old manufacturing technology - monuments	Layouts not easy to change - cost or investment associated with moving equipment.
26	1	4-	Growth of business	If you are not growing, improved productivity means job loss or loss of opportunities.
27	1	5-	Availability of capital to make improvements	Investment is available when cost savings justify expenditure.
27	1	5-	Resistance to change	Inhibitor.
28	2	10-7-	Fixed Headcounts	Secured employment levels delay cost savings until attrition reduces headcount.
28	2	9-8-	Large degrees of massive automation with fixed conveyors	Inflexibility in making quick, inexpensive changes in flow.
29	1	6-	Error Proofing	Specific initiative to identify and error proof equipment, people tasks and material movement.
29	1	6-	Levels of Management	Denial - current leaders work their way up through these levels; therefore, they must be needed.
30	1	7-	Inappropriate measurement systems	Inhibitor.
30	1	7-	Process/Methodology	Written and communicated. Beyond expectation is methodology of implementation.
31	2	9-10-	Inconsistent direction	Measurement changes - program of the day.
32	1	8-	Union "selective participation"	All trades issues are avoided by the union.
32	1	8-	Un-level schedules on seasonal products	Seasonal products such as batteries exhibit large variation in month to month demand.

* The methodology used to determine the "Overall Rank" for each factor is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Facilitating or Inhibiting Factor	Example or Explanation
32	1	8-	Visual control implementation	Management by sight.
32	1	8	Failure to implement lean principles in proper sequence or natural order	None.
33	1	9-	Continuity of divisional core measurement requirements	None.
33	1	9-	Funding for equipment modification	None.
33	1	9-	Workers exposed to customers	When your customer is a real person you treat them right.
34	2	10-10-	Age and skill level of workforce	Vast majority of existing workforce in the last years of their "work lives" and have not acquired the skills required to be proficient in today's lean, kaizen driven workplace.
34	2	10-10	Improper focusing of available resources	None.
35	1	10-	Lack of system discipline	Lost work day cases - an orderly, clean, bright work environment requires the discipline of follow up.
no votes	0	no votes	Appropriate change agent identified	Change agent/champion must drive paradigm shift.
no votes	0	no votes	Defined roles and responsibilities	None.
no votes	0	no votes	Expensive ventilation systems for environmental control	Required due to lead in batteries. Make redesign of flow expensive.
no votes	0	no votes	Facilitating Workshops	PICOS or mfg. system design workshops to rearrange an area into a "lean process".
no votes	0	no votes	Inventory in days	Measure of effectiveness of material and manufacturing systems.

* The methodology used to determine the "Overall Rank" for each factor is explained in Appendix A.

Overall Rank *	Number of Votes Received	Actual Ranking Votes	Facilitating or Inhibiting Factor	Example or Explanation
no votes	0	no votes	Inventory turns	Financial measure which can be severely impacted by non-manufacturing issues.
no votes	0	no votes	Lack of certification process (i.e. QS9000) to add sense of urgency	Needing to get QS9000 certified rallied plants/organizations to "Get it done".
no votes	0	no votes	Long validation times for process/product changes	Time to react.
no votes	0	no votes	Maintenance metric	Measuring proactive tasks is a wasted counting of tasks.
no votes	0	no votes	Measurement quick and simple	Managers want to kick in the "kitchen sink".
no votes	0	no votes	PPM customer returns	Quality and system variation reduction process implementation effect.
no votes	0	no votes	Reason to change	An organization needs an identifiable motivation to change.
no votes	0	no votes	Tracking specific action plans	Tracking the completion percentage.
no votes	0		Union, L.O.D.'s, and Classifications	"Lines of Demarcation" resist multi-skill workforce development.

* The methodology used to determine the "Overall Rank" for each factor is explained in Appendix A.

Appendix A.
Methodology for Determining Overall Rank of Lean Measures

The "Overall Rankings" for the lean measures were determined according to the following methodology:

1. Total the "Number of Votes Received" for each lean measure. This is simply the number of "Actual Ranking Votes" received for each lean measure. For example, Quality received the following votes: [3-10-6-2-1-5-6-7-2-4] and the Number of Votes Received for Quality would be 10.

2. Calculate the Score for the lean measure. This is done by assigning point values to each of the "Actual Ranking Votes" that a measure receives. The points are assigned using the following scale.

Actual Ranking Vote	Point Value
1	10
2	9
3	8
4	7
5	6
6	5
7	4
8	3
9	2
10	1

For the Quality example mentioned above the Score (total point value) would be 64 (8+1+5+9+10+6+5+4+9+7).

3. Next, sort the lean measure in descending order first by "Score" and then by "Number of Votes Received".

4. Finally assign the "Overall Rankings". The ranking of "1" goes to the lean measure with the highest score...the "2" goes to the next score in descending order and so on. When two or more measures have the same "Score", then rank is assigned by highest "Number of Votes Received". When a tie occurs for two or more measures in both the "Score" and the "Number of Votes Received" then the measures are assigned the same "Overall Rank".

NOTE: The methodology above is explained in terms of lean measures, but the methodology is exactly the same for facilitating/inhibiting factors.

Appendix E

Oklahoma State University Institutional Review Board

Human Subjects Review

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS REVIEW

Date: 12-16-96 **IRB#:** EG-97-001

Proposal Title: MEASURES OF LEAN MANUFACTURING EFFECTIVENESS IN AUTOMOTIVE COMPONENTS MANUFACTURING

Principal Investigator(s): David Pratt, Mitch Ballew

Reviewed and Processed as: Exempt

Approval Status Recommended by Reviewer(s): Approved

ALL APPROVALS MAY BE SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING, AS WELL AS ARE SUBJECT TO MONITORING AT ANY TIME DURING THE APPROVAL PERIOD.
APPROVAL STATUS PERIOD VALID FOR ONE CALENDAR YEAR AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL.
ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

Comments, Modifications/Conditions for Approval or Reasons for Deferral or Disapproval are as follows:

Signature: John H. Whyte [signature] Date: December 17, 1996

Chair of Institutional Review Board

cc: Mitch Ballew

VITA

Patrick Mitchell Ballew

Candidate for the Degree of

Master of Science

Thesis: MEASURES OF LEAN MANUFACTURING EFFECTIVENESS IN AUTOMOTIVE COMPONENTS MANUFACTURING

Major Field: Industrial Engineering and Management

Biographical:

Education: Graduated from Carl Albert High School, Midwest City, Oklahoma in May 1987; received a Bachelor of Science degree in Industrial Engineering and Management in May 1993. Completed the requirements for the Master of Science degree in Industrial Engineering and Management in July, 1997.

Professional Memberships: Institute of Industrial Engineers.