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Perceptions on the Status of Lean-Manufacturing in Thermoplastics-Manufacturing Industry

Ning Jin
ning.jin943@topper.wku.edu

PERCEPTIONS ON THE STATUS OF LEAN-MANUFACTURING IN THERMOPLASTICS-MANUFACTURING INDUSTRY

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PERCEPTIONS ON THE STATUS OF LEAN-MANUFACTURING IN THERMOPLASTICS-MANUFACTURING INDUSTRY

Date Recommended 3/27/17

Dr. Mark Doggett, Director of Thesis

Dr. Daniel Jackson

Dr. John Khouryieh

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Dean, Graduate Studies and Research Date

I dedicate this thesis to my parents Jianli Jin and Guimei Shao. Your endless supports and motivations carried me through all the difficulties and hardships. I also dedicate this work to my beautiful girlfriend Yuting Peng. Your love and understanding make me fearless.

I love you all.

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Directed by: Dr. Mark Doggett, Dr. Daniel Jackson, and Dr. John Khouryieh

Department of Architectural and Manufacturing Sciences Western Kentucky University

The current study gathers thermoplastics professionals' perceptions on the implementation of lean-manufacturing in the Thermoplastics-manufacturing industry through Qualtrics, which is a survey website. From the professionals' perceptions, the current study infers the current status of lean-manufacturing implementation in the thermoplastic-manufacturing industry and identifies the best lean theories and tools for the industry. However, the results of the current study are not generalizable to the entire thermoplastic-manufacturing industry.

The current study reviews thermoplastic-manufacturing processes from the house of lean's perspective. The foundations of the house are stability and standardization, the pillars are Just-In-Time (JIT) and Jidoka, the roof is customer focus, and the heart is employee involvement. Thermoplastic-manufacturing processes include extrusion, fiber spinning, film casting, film blowing, and injection molding.

The questionnaire of this survey includes six rating-scale, two multiple-choice (multiple-answer), and three closed-ended questions. The questionnaire was distributed to the respondents through email, LinkedIn, and Society of Plastic Engineers (SPE). The expected responses' quantity was 35. Since some of the respondents did not complete the whole survey, the actual responses' quantity for each question was between 39 and 45.

Based on the respondents' perceptions, the implementation of lean manufacturing in the thermoplastic-manufacturing industry is incomplete. The industry professionals should put more attention and effort on the implementation of JIT and Jidoka. To fully implement JIT and Jidoka, thermoplastic-manufacturing companies should use lean tools that are related to JIT and Jidoka, such as kanban, takt time, heijunka, Value Stream Mapping (VSM), and poka-yoke, more often. Additionally, the thermoplastic-manufacturing industry practitioners perceived that the best lean theories for the industry were standardization, involvement, and stability, and the best lean tools were 5S, Total Production Maintenance (TPM), and poka-yoke.

Introduction

Background

Lean is a philosophy that eliminates waste and enhances communication in cultural settings. Organizations are able to address and eliminate waste or non-value activities within their processes through lean implementation, which enables organizations to continuously improve themselves. Lean has resulted in great success in the automotive industry, particularly Toyota (Jackson, 2007). However, a question may arise on the current status of the application of lean manufacturing in other industries, for example, the thermoplastics-manufacturing industry.

Deficiency

A deficiency of the literature is the lack of articles and books that directly link lean-manufacturing theories and tools to the thermoplastic-manufacturing industry. The current applications of lean manufacturing in the industry were unknown.

Significance

The plastic-manufacturing industry plays a very important role in the field of material science. The application of the industry's products covers many different areas including packaging, building, electrical transportation, and furniture. In 1993, the US market sold 31 million tons of plastics and about 90% of them were thermoplastics (McCrum, Buckley, & Bucknall, 1997). In such a large production quantities, defective products could result in serious losses. Hence, these manufacturing systems should be managed very carefully. Moreover, thermoplastic manufacturing has systems that can influence the entire materials supply chain. Through lean tools and theories, organizations can rapidly respond to issues and problems. Many lean theories and tools are available to help management teams identify issues faster, such as the Value Stream Mapping (VSM) and 5S (Maskell & Katko, 2007). In addition, lean implementation can make employees feel that they are a part of something greater, which consequently improves their loyalty and involvement (Kennedy & Brewer, 2007).

Purpose of the Research

The purpose of the current study is to understand the current status of lean-manufacturing implementation in the thermoplastic-manufacturing industry based on industry practitioners' perceptions. In addition, the purpose is to identify the practitioners' perceptions of the appropriate lean theories and lean tools for their industry. The current study gathered descriptive statistics on the perceptions of practitioners in the thermoplastic-manufacturing industry to support the findings. The practitioners were thermoplastic professionals who understood relevant manufacturing processes.

Research Questions

1. Do thermoplastic-manufacturing industry practitioners perceive they have knowledge of lean-manufacturing?
2. Do thermoplastic-manufacturing industry practitioners perceive that their organizations have knowledge of lean-manufacturing?
3. What lean theories do practitioners perceive to have used in their manufacturing processes?
4. What lean tools do practitioners perceive to have used in their manufacturing processes?
5. What outcomes do practitioners perceive to have accomplished by the lean-manufacturing implementation?

6. Which lean theories do practitioners perceive to have the best results after implementation?
7. Which lean tools do practitioners perceive to have the best results after implementation?

Assumptions

The study assumed that managers who are in charge in the thermoplastic-manufacturing industry were interested in the implementation of lean tools and theories. In addition, the current study also assumed that quantitative methods could measure perceptions on the implementation of lean tools and theories in the thermoplastic-manufacturing industry.

Limitations

One of the limitations of the current study was that the result was only valid for the period of the study, and the implementation of lean manufacturing was limited to existing lean theories and lean tools. Moreover, the performance of lean manufacturing was analyzed based on existing measurement methods. Additionally, the exact geographic location of respondents was unknown. Therefore, the survey results were not generalizable to the entire thermoplastic-manufacturing industry.

Delimitations

The current study was based on the opinions of a small group of people. Some people, who were not included in the research, might have different opinions from the current study's findings. The research focused on the application of lean manufacturing in the thermoplastic-manufacturing industry. The findings do not reflect perceptions in other manufacturing industries. In addition, the data-collection period was 3 months.

Definitions of Terms

- 5S: "Five Japanese words that begin with the letter "S" and translate to English as *Seri* = Sort, *Seiton* = Set in order, *Seiso* = Shine, *Seiketsu* = Standardize, *Shitsuke* = Sustain. Collectively, they mean maintaining an orderly, well-inspected, clean, and efficient working environment" (Manos & Vincent, 2012, p. 387).
- Conveyance: "This waste happens when material is moved around the shop; loaded on the truck or trailer; hauled to the jobsite and unloaded, and when the material is moved from the lay-down or staging area to the installation point or moved to got out of another trade's area" (Soward, 2011, p. 48).
- Defect: "doing the wrong installation, defects in fabrication, punch lists and many kinds of change orders. Not meeting the required code is waste" (Soward, 2011, p. 48).
- Heijunka: "A method of leveling production for mix and volume" (Manos & Vincent, 2012, p. 389).
- Jidoka: "Combining human intelligence with automation so that equipment is able to detect defects, alert personnel of the abnormality, and immediately stop production" (Manos & Vincent, 2012, p. 388).
- Just-in-time: "A philosophy that has the elimination of waste as its ultimate objective. To achieve this goal, each operation must be synchronized with subsequent operations. The concept refers to the manufacturing and conveyance of only what is needed, when it is needed, and in the amount needed. Originally developed by the Toyota Motor Company as a production system, it is also known

as the “Toyota Production System,” “lean manufacturing,” and “lean production system” (Manos & Vincent, 2012, p. 390).

- Kanban: “Meaning “sign board.” A communication tool (e.g., open space, two-bin, and kanban cards) that ensures that every operation produces only the amount that will be used in the next step of the process. Kanban serves as instruction from both production and replenishment” (Manos & Vincent, 2012, p. 390).
- Lead time: “(1) The time required for one piece to move all the way through a system of processes, from start to finish. (2) The time from when the order is taken until the item is shipped” (Manos & Vincent, 2012, p. 390).
- Motion: “These 'treasure hunts' happen when material is stored away from the job or when workers must go looking for tools, material or information. This waste also happens in the office or jobsite trailer, when looking for files, reports, reference books, drawings, contractor vendor catalogs” (Soward, 2011, p. 48).
- Overall equipment effective (OEE): “The product of a machine’s operational availability, performance efficiency, and first pass yield” (Manos & Vincent, 2012, p. 391).
- Poka-yoke: “Also known, as “mistake-proofing.” In Japanese, poke means “inadvertent error,” and yoke means “prevention.” The implementation of simple, low-cost devices or innovations that can either detect abnormal situations before they occur in a process, or if they do occur. Stop the operation or equipment and prevent the production of defective units” (Manos & Vincent, 2012, p. 391).

- Polymer: “A *substance* composed of molecules which have long sequences of one or more species of atoms or groups of atoms linked to each other by primary, usually covalent, bonds” (Young & Lovell, 2011, p. 4).
- Polymerization: The process of “linking together monomer molecules through chemical reactions” (Young & Lovell, 2011, p. 4).
- Standard work: “A precise description of each work activity specifying cycle time, takt time, the work sequence of specific tasks, and the minimum inventory of parts on hand needed to conduct the activity. All jobs are organized around human motion to create an efficient sequence without wastes” (Manos & Vincent, 2012, p. 392).
- Standardization: “A system using policies and common procedures to manage process” (Manos & Vincent, 2012, p. 392).
- Takt time: “The available production time divided by the rate of customer demand. The heartbeat of any lean system, takt time sets the pace of production to match the rate of customer demand” (Manos & Vincent, 2012, p. 393).
- Total production Maintenance (TPM): “A system to ensure that every machine in a production process is able to perform its required tasks so that production is never interrupted. Uptime is maximized, along with machine performance and first pass yield” (Manos & Vincent, 2012, p. 393).
- Value stream mapping: “The process of creating a drawing of the value stream using icons that show that information flow and material flow of a process family (similar processing steps) in an organization” (Manos & Vincent, 2012, p. 387).

- Waiting: “Includes when a crew waits for instructions or materials at the jobsite; when a fabrication machine waits for material to be loaded; and when payroll waits for the always late timesheets” (Soward, 2011, p. 48).
- Work-in-process (WIP): “Incomplete products or services that are awaiting further processing prior to being forwarded to the customer as finished product or completed services” (Manos & Vincent, 2012, p. 393).

Literature Review

Main Concepts of Lean

Muda and Kaizen are the most critical lean concepts that need to be explained since both of them play very important roles in lean implementation. Before executing any lean activities, lean practitioners must first understand the five key lean principles that can transform practitioners' perspective and change the way they evaluate their manufacturing processes. During lean implementation, one of the most critical activities is to identify the Muda, which means waste, within manufacturing processes. Afterward, companies apply lean activities, using Kaizen, to eliminate waste.

Five key lean principles. The five most important lean principles are the following: 1) view the customer value as the primary goal, 2) understand the value stream of each product, 3) eliminate interruptions for the value flow, 4) pull the value through the organization to the customer, and 5) seek for perfection (Li, Sawhney, Arendt & Ramasamy, 2012).

The value of the customer is the chief consideration of lean thinking. All organizations that implement lean principles should produce valuable products for customers. Meanwhile, those organizations need to review their processes from the customers' perspective to identify waste or non-value phases for elimination. After organizations have evaluated their processes, they might receive two outcomes: one is the reduction of product price and the other is the improvement of product value. Both of these outcomes improve customer satisfaction and loyalty. Furthermore, organizations' products should be able to satisfy customers' requirements by using pull system. In addition, lean thinking believes that no matter how perfectly the organizations' goals are accomplished, there are always deficiencies. By pursuing perfection, organizations are able to continuously improve themselves (Seddigh & Alimohamadi, 2009).

Muda

Muda refers to the non-value adding activities for which customers are not supposed to pay. Therefore, Muda is considered to be the opposite of value. According to Sowards (2011), there are seven kinds of Muda: Defects (correction), Over-production of goods, Transportation (conveyance), Waiting, Over-processing, Motion, and Inventory (as illustrated in Figure 1). Dennis (2007) stated that Knowledge disconnection was the

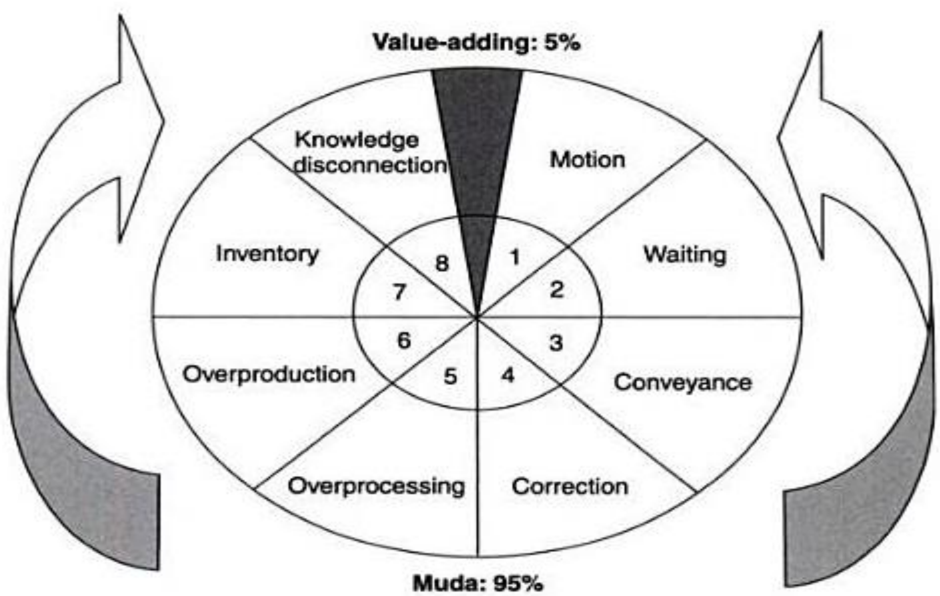

Figure 1. Muda. Reprinted from *Lean Production Simplified*, 2nd edition (p. 22), by P. Dennis, 2007, Florida, FL: Taylor & Francis Group.

eighth Muda. For instance, if the Knowledge disconnection happens between companies and their customers, companies might not be able to produce a product that satisfies the customers. However, having Muda is not necessarily a bad indication; it means companies have room for improvement. Either they can eliminate waste to reduce cost or they can add more value to their product to improve customer satisfaction.

Kaizen

Kaizen is a lean approach that can become a chief mechanism in fully inserting lean into manufacturing. Its ability is not limited to making small improvements in an organization. There are four types of Kaizen: (1) high-impact Kaizen, which can bring significant change in the entire production area; (2) training and implementation Kaizen, which aims to provide knowledge to the entire workforce; (3) problem-resolution Kaizen, which is able to provide a specific solution to improve production; and (4) sustaining Kaizen, which is a short-duration event to improve an area that has been improved by the other three Kaizen (Davis, 2011).

Lean Tools and Theories

Even if the management teams understand lean concepts clearly, the method to start implementing lean in practice is still unclear. Many different theories have been established, such as standardization, stability, and employee involvement; however, these theories are difficult to grasp as a system. Instead of individually selecting those theories, lean implementation requires companies to consider lean tools and theories as a system and pick the tools or theories that fit their situation (Dennis, 2007).

Hence, addressing the relationship between tools and theories is as important as addressing the tools and theories themselves. Therefore, the researcher decided to introduce lean tools and theories based on the integrated system illustrated in Figure 2, which is referred to as the house of lean. The foundations of the lean system are stability and standardization. Just-In-Time (JIT) and Jidoka are the pillars of the system, whereas the roof is customer focus. More importantly, involvement is a critical part as it represents the heart of the house of lean. Without flexible, motivated team members, a lean system could not be successfully implemented (Dennis, 2007).

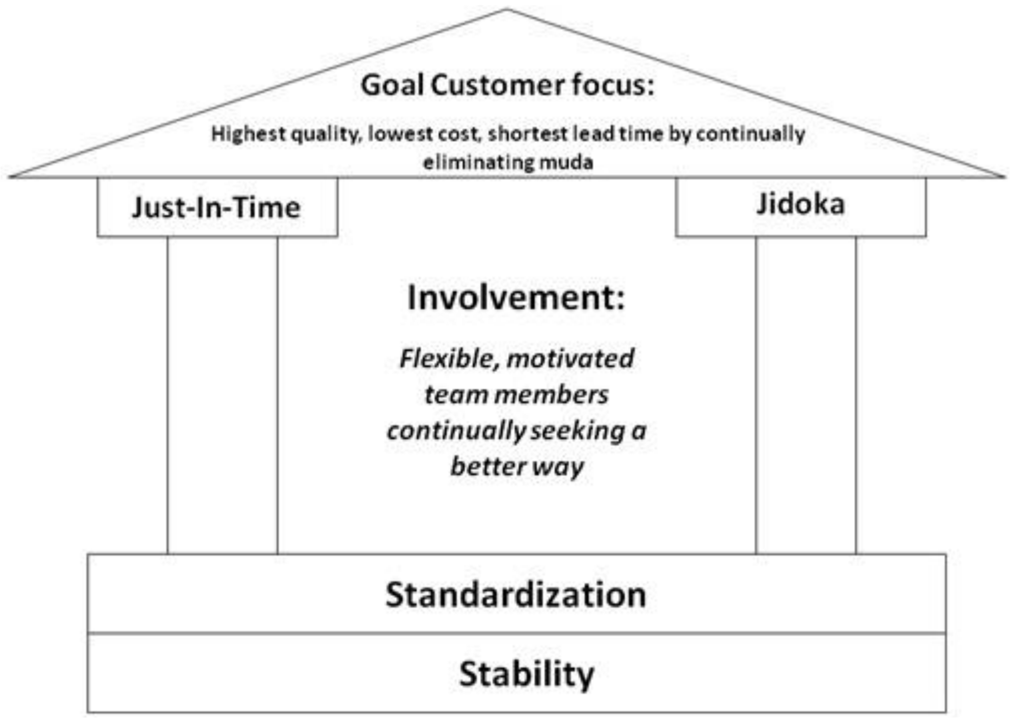

Figure 2. The house of lean. Reprinted from *Lean Production Simplified* (p. 19), by P. Dennis, 2007, Florida, FL: Taylor & Francis Group.

The Foundation of Lean: Stability and Standardization

Stability and Standardization are the foundations of lean manufacturing. Stability ensures a stabilized labor force, machine capability, materials, and methods, whereas standardization offers the safest, easiest, and most effective way to complete tasks. Stability begins with Visual management and 5S (Dennis, 2007). Standardization begins with the development of standard work through discussion with workers and the production management team. Additionally, even the best processes can contain waste. Therefore, the modification of standard work is required regularly (Dennis, 2007).

5S. 5S is a simple system that stands for Sort, Set in order, Shine, Standardize, and Sustain, which create a clean and well-ordered workplace. Companies must sort (S1) what is not needed. Commonly, workplaces are filled with items that complicate the flow of work such as parts, storage, shelves, bins, documents, packaging materials, and tools (Dennis, 2007). Those unnecessary items reduce production effectiveness and quality. Therefore, production teams must leave only essential items that are needed for current operations and remove the rest (Grover, 2012). An effective method of sorting idling items is to mark those items with red tags that include item classification, item ID, quantity, reason for red tagging, work section, and date (Dennis, 2007), in case production teams need to relocate those items at another time.

After organizing idling items, the next step - Set in order (S2) - is to arrange the rational locations for the needed items. Organization of the workplace is paramount to efficiency. Production teams can attach a label containing useful information about the items, such as their location and the quantity so that anyone can find them or put them back in the right place (Grover, 2012). One way of accomplishing that goal is to develop a color standard for the label to improve transparency. Meanwhile, production teams can also use visual systems consisting of visual indicators, visual signals, and visual controls (Dennis, 2007). The purpose of S2 is to eliminate time lost searching for items, difficulty in using items, and difficulty in returning items; hence, the purpose of S2 is to create an organized and efficient workplace (Grover, 2012).

A work environment that incorporates Shine (S3) seeks to create an enjoyable workplace and has a positive influence on production. During the S3 phase, 5S teams need to establish cleaning standards including cleaning targets, cleaning methods, cleaning responsibilities, and schedules (Dennis, 2007). As a result, production teams can keep things in a condition that is ready to be used whenever they are needed (Grover, 2012).

Once companies complete Sort, Set in order, and Shine, the company should have a clean and well-organized workplace. However, to ensure the maintenance of the good condition, a clear, simple, and visual standard (S4) that integrates Sort, Set in order, and Shine together is necessary (Grover, 2012). Finally, companies must Sustain (S5) 5S, ensuring that it is a part of a company's system. Sustain can be achieved by 5S promotion, communication, and training. These activities help 5S to become deeply rooted in an organization (Dennis, 2007) by installing the rules that are necessary to avoid backsliding (Grover, 2012).

Total Productive Maintenance. 5S is the basic requirement for ensuring the stability of a production system, and it supports Total Productive Maintenance (TPM), which is a system that keeps machines in a stable condition (Dennis, 2007). TPM is a tool that reduces breakdown maintenance through preventive maintenance and productive maintenance. It optimizes the overall equipment effectiveness (OEE), which is the critical metric for TPM performance (Carlino, 2012). To maximize OEE, production teams need to concentrate on eliminating all equipment losses (Rizzo, 2008) and reducing equipment breakdowns, equipment inventory, overall lead time and cost (Carlino, 2012).

In total, there are three categories of equipment losses: availability, performance, and quality. The losses that relate to equipment availability are breakdowns and changeover. These losses could make equipment unavailable during scheduled production time. Types of equipment performance losses that happen in production include idling, minor stops, and reduced speed. Additionally, equipment quality losses occur on start-up (reduced yield) and finished product (defective product) (Rizzo, 2008). These losses are the greatest challenges of improving OEE.

While understanding the obstacles to improving TPM, addressing the responsible party to achieve TPM is also important. According to Carlino (2012), everyone from workers to top management shares the responsibility for the implementation of TPM. Operators need to take care of the equipment during operation. Top management needs to work with employees to evaluate the measure and make the right adjustments. Moreover, TPM requires the coordination of all the departments, which creates an environment for improvement.

The next foundation of the house of lean is standardization, which provides methods (the combination of man, machine, and material) to stabilize production (Dennis, 2007). According to Whitmore (2008), if workers are allowed to perform their own method while working, the result of their work could be different, thus leading to unpredictable products. Hence, to eliminate variation, the implementation of standardized work is crucial. Standardized work is also a basic requirement for continuous improvement, which is the key principle of lean. Additionally, according to Dennis (2007), all processes can contain waste; hence, the standardized work should be evaluated and improved regularly.

Takt time, work sequence, and standard work-in-process (WIP) are the three essential elements of standardization. Takt time is the required time to produce one product based on customer demand; it is considered to be the pace of production. The work sequence indicates detailed operational procedures that should be done to finish the work correctly. Using visual pictures is one of the best methods of communicating the work sequence. Standard WIP refers to the minimum number of in-process items that operators need to perform a work sequence (Whitmore, 2008).

Companies use many specific tools to create and evaluate standardized work. For instance, the standard work layout and spaghetti diagrams are two typical tools for identifying issues and make improvements in the workplace. Another example could be the standard work combination sheet, which is used to monitor the performance of manufacturing and to train new operators (Labach, 2010).

The Pillars: Just-in-time and Jidoka

The pillars of the house of lean, JIT and Jidoka, support the roof of the house, which is customer focus. Just-in-time helps production teams produce only the required quantity of a required product at the required time period based on customers' demand (Agrawal, 2010). Jidoka, which means automation with a human mind in Japanese, is the ability of a machine or device to automatically detect defects. It helps companies prevent the production of defective products, which satisfies their customers and reduces costs (Osterling, 2012).

The JIT system is closely associated with one of the five key lean principles: the pull system. The components of JIT include Kanban and production leveling (heijunka). The pull system matches the first rule of JIT: do not produce until an order is received from customers (Dennis, 2007). The key elements of pull systems that support JIT production include the elimination of any non-value adding activities, the improvement of profits and ROI by reducing inventory levels, the implementation of quality programs and lead time reduction by changing the layout of workstations (Agrawal, 2010).

Kanban. Kanban is a visual tool that can improve process management and be physically or digitally presented. Kanban contains information regarding part types and quantities, instructions, and time of production required by the downstream process (Agrawal, 2010). According to Dennis (2007), to effectively implement Kanban, production teams must understand these six critical rules: 1) Never ship defective products; 2) customers order only what is needed; 3) produce only the ordered quantities; 4) ensure production leveling; 5) make slight adjustments of production based on Kanban; and 6) stabilize and strengthen processes (Dennis, 2007).

Production leveling. Production leveling, also referred to as heijunka, is a tool for distributing the production volume evenly over time; it helps production management decide how many operators and how much equipment and material are needed. The benefits of production leveling consist of shorter lead time, reduced WIP inventory, and elimination of production unevenness or overburden. The key target of heijunka is to adjust production to meet customer demand, which can be accomplished by the development of different standardized work scenarios (Dennis, 2007).

Value Stream Mapping. Additionally, JIT is also supported by continuous flow, another key principle of lean (Dennis, 2007). Hence, the introduction of VSM is necessary. Value Stream Mapping is a visual tool that makes a continuous flow possible. It includes specific processes required to bring the product to customers, such as manufacturing, inventory, and transportation (Howell, 2013). These processes combine materials and information flow. When production teams observe the map, they can easily identify non-value adding steps and find out a more efficient method to organize the processes.

According to Howell (2013), creating a VSM requires 10 steps: 1) gather information, 2) create a product quantity routing analysis, 3) group customers and sort materials, 4) sort product families by process sequence, 5) choose one value stream, 6) create an operations flowchart, 7) review the shop floor, 8) collect data, 9) construct the value stream map, and 10) summarize the data to get the big picture. Furthermore, companies can learn and apply VSM in a short period of time. (Howell, 2013).

Jidoka is the combination of automation and mistake-proofing that aims to reduce cost and control overproduction. (Osterling, 2012). Machines that incorporate Jidoka are capable of manufacturing defect-free products, which is accomplished by improving process capability and increasing the speed of defect identification and countermeasures (Dennis, 2007). To fully implement Jidoka, companies must understand six key concepts, which consist of quality at the source, no defects passed forward, man/machine separation, multi-process handling, self-detection of errors, and stop and fix (Maio, 2012).

Poka-yoke. Poka-yoke, which means mistake-proofing, is the most critical tool in Jidoka (Dennis, 2007). The goal of Poka-yoke is to produce products without any defects. Even if is not possible to prevent defects from happening, Poka-yoke methods aim to detect them as soon as possible (Dudek-Burlikowska & Szwieczek, 2009). An effective Poka-yoke device must be simple, long life, low maintenance, highly reliable, low cost, and designed for workplace conditions (Dennis, 2007).

Additionally, Poka-yoke devices identify errors by detecting the deviations of workpieces and work methods and deviations from a fixed standard value. Once a Poka-yoke device detects an error, one of two methods can be implemented. One is the control method that stops production for corrections, and the other is the warning method that uses sounds, lamps or other signals to prompt operators (Dudek-Burlikowska & Szwieczek, 2009).

The Heart of the House of Lean: Involvement

The heart of the house of lean, involvement, is connected with every other part of lean. Without the involvement of dedicated employees, companies cannot achieve lean production and continuous improvement. As Dennis (2007) mentioned, today's workers are more educated and are able to access all kinds of knowledge including higher education, TV, and the Internet. Hence, they are able to offer creative and effective suggestions for solving problems.

Suggestion program. Suggestion program is an effective tool that helps companies to involve their employees. Good suggestion program is able to involve all employees and make them feel that they contribute to the success of their company (McMahon, 2012). A successful suggestion program has many characteristics. One is that the suggestion program should be simple and accessible to all employees (McMahon, 2012). For instance, employees can submit their suggestion through a single-paged form that includes source information, the problem, possible changes, results, and supporting data (Dennis, 2007). Another characteristic is that the decision regarding the approval of the submitted suggestion should be made at the lowest level possible. Typically, the individual who makes the decision should be the supervisor of the employee who submits the suggestion. If the suggestion is approved, the supervisor and the employee work together to take it into action and report the result to management (McMahon, 2012). Additionally, rewarding excellent suggestions is also an important characteristic. The rewards could be extrinsic, such as cash or gifts, or intrinsic, such as peers' recognition and personal growth (Dennis, 2007).

The Benefit of Lean Implementation

Hobbs (2004) stated that the implementation of lean tools can bring benefits to manufacturing. Just-in-time can improve organizations' response time to customers. Because of the improvement of response time, companies do not have to carry large amounts of unnecessary inventory. Moreover, the short lead time of production results in the reduction of working capital requirement. Standardized work can enable production teams to identify defects and abnormalities easily. In addition, Jidoka can ensure the quality of products while reducing costs by shutting down production immediately through Poka-yoke devices.

The traditional equation of profit can be described as the difference between actual cost and a set profit margin. In a highly competitive environment, the product would have a fixed price to compete with other firms. Conversely, in lean, the profit equation should be the difference between market price and cost. Hence, companies can only improve profitability if they can reduce cost without reducing quality. Lean is a continuous improvement system that is capable of helping companies reduce cost without retrenching team members, cutting maintenance budgets, and weakening companies in the long term (Dennis, 2007).

Polymers - Brief History

The development of polymers has a very short period of history, which is approximately 150 years. Polymers have three main forms: plastics, rubbers, and fibers. In the current study, polymers are also referred to as plastics. In London, in 1862, Alexander Parkes exhibited the first human-made plastic Parksine, a form of cellulose nitrate, at the Great International Exhibition. In 1863, based on the research of Parkes, John Hyatt invented the first truly commercial process for the production of cellulose nitrate (Celluloid). His discovery of celluloid is still being used today to make billiard balls and table tennis balls (McCrum, Buckley, & Bucknall, 1997).

Parkes, Hancock, Goodyear, and Hyatt were remarkable individuals who pushed the development of plastic and rubber industries during the mid-19th century. However, their understanding of rubbers and plastics was very limited; until Staudinger presented his revolutionary idea that all plastics and rubbers are macromolecules, which is a term coined by Staudinger himself in 1920 (Young & Lovell, 2011). Staudinger’s hypothesis offered reasons for experiments and provided industrial chemists with a proper method to guide their labors. For his extraordinary discovery, Staudinger was awarded the Nobel Prize in 1953 (McCrum, Buckley, & Bucknall, 1997).

During the 1930s, the development of polymers grew rapidly in the United States and Germany, which led to the discovery of many significant polymers. Two of the polymers were nylon and polyethylene. Wallace Carothers, who was hired by Du Pont de Nemours & Co as the leader of a research program, successfully created nylon. Meanwhile, ICI’s research program led to the synthesis of polyethylene (McCrum, Buckley, & Bucknall, 1997). After the 1950s, the discovery of many advanced polymers continuously pushed the progress of the polymer industry. Since the 21st century, more attention focused on the specialized and functional polymers for biomedicine, optics, and electronics (Young & Lovell, 2011).

Polymers - Production Waste

Although plastics played crucial roles in many industries, traditional views still consider plastics as cheap and low-quality materials. According to McCrum, Buckley, and Bucknall (1997), an interview in Italy indicated that only 35% of participants thought plastics were essential. However, 25% of those surveyed respondents held a view against plastics.

In consumers' minds, plastics were usually considered as the substitutes of real products (i.e. imitation marble laminates), thus the public perceived plastics as cheap materials. From a historical perspective, plastics were developed for replacing materials such as metals and cotton. However, plastics were still able to play essential roles, even as replacements for bio-materials. For instance, false teeth are made from plastics, which can be very valuable for patients. Additionally, the artificial hip joint, also referred to as the polyethylene hip joint, has improved many people's lives immeasurably (McCrum, Buckley, & Bucknall, 1997).

Meanwhile, in common view, the word "plastic" was connected to waste and environmental damage. This view might be the other reason that the public had biases toward plastic products; however, such a view was incorrect. From energy consumption's perspective, compared with metal alloys, plastics required less energy to manufacture (McCrum, Buckley, & Bucknall, 1997).

McCrum, Buckley, and Bucknall (1997) presented an example of the application of plastics in the automotive industry. On a volume basis, as shown in Figure 3, all the plastics from Polyoxymethylene (POM) to Low-density polyethylene (LDPE) required less energy to produce. Hence, if applicable, plastics were more favorable than metal alloys during the material selection process. Furthermore, since plastics are lightweight, they are able to lower energy consumption. Hence, plastics saved energy in two aspects: one was at the assembly line, which required less energy during manufacturing, and the other was throughout cars' life cycles, as cars consumed less fuel than those

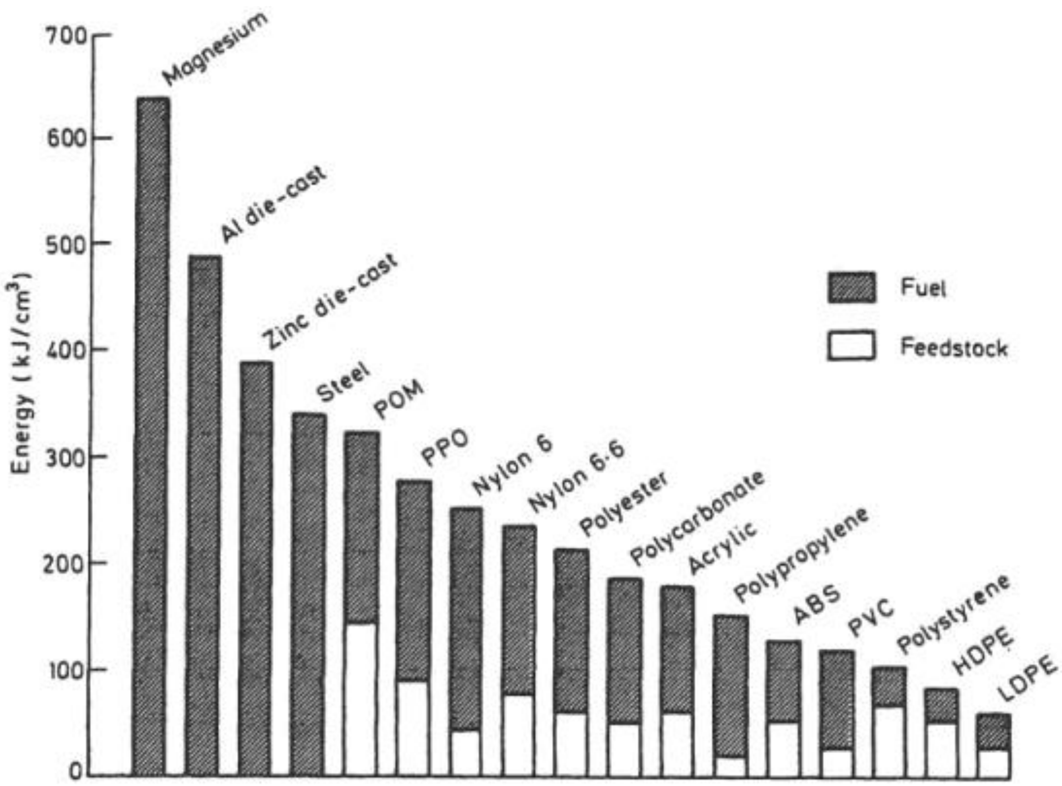

Figure 3. Energy consumptions of metal alloys and plastics. Reprinted from *Principles of Polymer Engineering*, 2nd edition (p. 12), by N. G. McCrum, C. P. Buckley, and C. B. Bucknall, 1997, New York, NY: Oxford University Press.

manufactured using metal alloys. Data indicated that replacing steel bonnets with plastic bonnets could save 23,000 tons of crude oil for every 1 million vehicles (McCrum, Buckley, & Bucknall, 1997).

Another reason that the public held the negative view towards plastics was that plastic waste might damage the environment. At the initial stage of the polymer industry, landfills were the main approach to deal with plastic scraps (McCrum, Buckley, & Bucknall, 1997). Indeed, landfills could damage the land considering some polymers were hard to degrade naturally, and some polymers might release toxic monomers to the land. However, as the polymer industry developed, scientists invented many effective approaches to eliminate plastic waste without damaging the environment, including energy recycling, chemical recycling, and mechanical recycling (McCrum, Buckley, & Bucknall, 1997).

Mechanical recycling is the approach that divided different kinds of plastic waste into categories and reformed them into new plastic products, which required much effort compared to the other two approaches. To make the system work, companies had to disassemble plastic parts from different machines; then, different plastics needed to be identified and separated. Afterward, each of the categorized plastics had to be transported to particular locations for mechanical recycling. This approach required much human effort and money to operate (McCrum, Buckley, & Bucknall, 1997).

Energy recycling was a very simple method to dispose plastic wastes. When the plastics were burned, the steam could be used to generate electricity, or the plastic scraps could be directly used in heating systems. Since the calorific value of many plastics was close to the heating oil, many countries such as Japan, Denmark, and Switzerland favored energy recycling. Some opponents of the incineration approach argued that gases from burning plastic scrap might contain toxic components; for instance, dioxins, which are toxins that could damage humans' health or the environment. However, the proved fact was that as long as the incineration processes can be well engineered and managed, with the most advanced emission controls, the energy recycling approach could be safe and reliable (McCrum, Buckley, & Bucknall, 1997).

Chemical recycling used chemical technologies to transform plastic waste back into short molecules that can be used to synthesize new polymers. It was an approach that was favored by governments. Figure 4 illustrates a designed system of chemical recycling. When the life cycle of plastic products ended, they were turned into plastic scraps that were later processed by washing, drying, and sorting. Sequentially, the DE polymerization unit transformed the processed plastic scraps into syncrude, which went into refinery with crude oil; the refinery then produced fuel and monomer feedstock. Thereafter, monomer feedstock was processed into new plastic products through polymerization processes (McCrum, Buckley, & Bucknall, 1997).

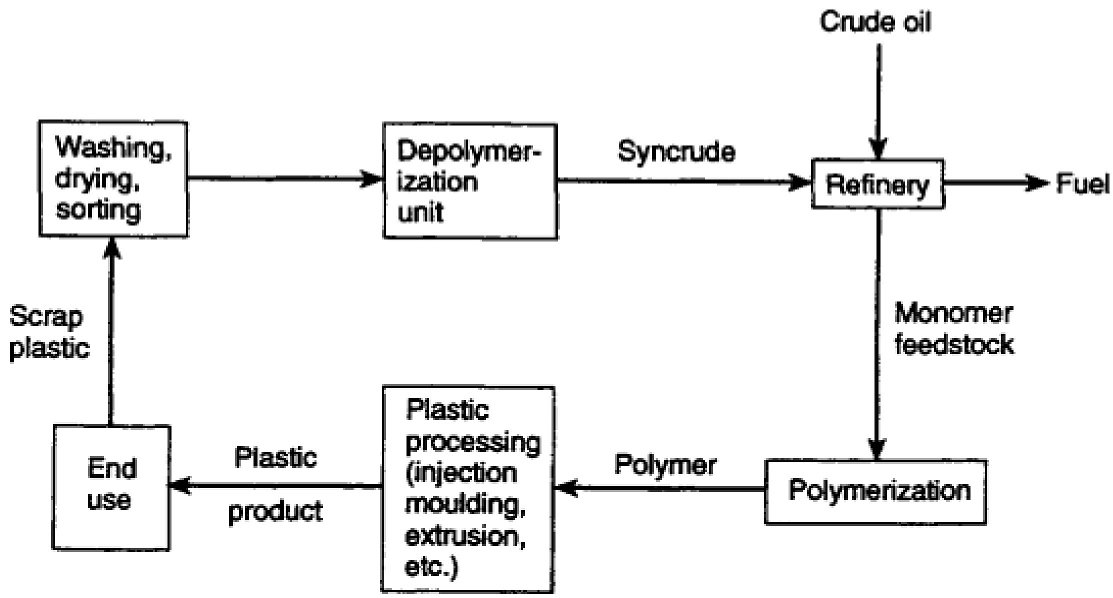

Figure 4. Chemical recycling. Reprinted from *Principles of Polymer Engineering*, 2nd edition (p. 15), by McCrum, Buckley, and Bucknall, 1997, New York, NY: Oxford University Press.

Polymers - Common Thermoplastics

The category methods of polymers are quite various. In the current study, polymers are categorized into three groups: thermoplastics, thermoset plastics, and elastomers (Young & Lovell, 2011). Bryce (1996) defined thermoplastics as plastic materials that are able to change physically when heat is applied to them and that can be reheated and reformed over and over again. By contrast, a thermoset plastic was defined as a plastic material that is able to change chemically when heat is applied to it. The structure of a thermoset plastic is maintained during heating; thus it cannot be reformed, and applying heat on it can only degrade it. Typically, thermoplastics are linear and branched polymers, whereas thermoset plastics are cross-linked polymers. Elastomers are cross-linked rubbery polymers that are able to return to their original shape while the applied force is being released. The current study focuses on thermoplastics, as they made the largest portion of the production of commercial polymers (Young & Lovell, 2011).

The thermoplastics had two forms: crystalline and amorphous. Crystalline polymers are polymers that have well-ordered molecular structures. Amorphous polymers are those with random molecular structures. The molecular structure has a great influence on polymers' physical properties. Hence, amorphous and crystalline thermoplastics have different properties. For instance, amorphous thermoplastics are usually clear polymers that have low shrinkage, high impact strength, poor chemical resistance, and poor lubricity; they can only become soft. On the contrary, crystalline thermoplastics are typically opaque polymers that have high shrinkage, low impact strength, good chemical resistance, and good lubricity; besides, they melt instead of becoming soft (Bryce, 1996).

The common crystalline thermoplastics are polyethylene (PE), polypropylene (PP), nylon, poly(ethylene terephthalate) (PET), poly(butylene terephthalate) (PBT), and polyetheretherketone (PEEK). By contrast, the common amorphous thermoplastics include polycarbonate (PC), polystyrene (PS), polyurethane (PU), and polyvinyl chloride (PVC) (Bryce, 1996).

Polyethylene has two major forms, which are LDPE and high-density polyethylene (HDPE), both of which are low-cost plastics manufactured in large quantities by many corporations. LDPE, also known as branched polyethylene, has excellent electrical properties. Therefore, its major application is manufacturing electrical cables. HDPE is linear polyethylene, which has wider applications, such as bottles, crates, kitchenware, and pipes. Polypropylene is a low-cost plastic that is manufactured in large quantities using all four processing approaches: molding, extrusion, blown film, and fiber spinning.

It can be used for pipes and automobile parts (McCrum, Buckley, & Bucknall, 1997). Polystyrene can interact with rubbers to improve roughness for other materials, such as high-impact polystyrene and acrylonitrile-butadiene-styrene (ABS). Applications of PS are mainly packaging and kitchenware. In addition, blending PS with blowing agents could produce PS foam (Young & Lovell, 2011).

Nylon is considered to be the most commonly used engineering thermoplastic, and it can also be processed into excellent fibers. Nylon is a strong, tough, and abrasion-resistant material. The nylon family includes nylon 6.6, nylon 6.10, nylon 6.12, nylon 6, nylon 11, and nylon 12. Additionally, glass, carbon fiber, and minerals can reinforce nylon for better physical properties. Polyvinyl chloride has two states: plasticized and unplasticized (McCrum, Buckley, & Bucknall, 1997). When it is in the unplasticized state, PVC can be used to produce water pipes, gutters, bottles, and gramophone records. However, when PVC is mixed with low-molecular-weight liquids, it turns into a soft plasticized state, in which the applications of PVC are PVC leather cloth, raincoats, flexible pipes, and electrical cable sheaths (Young & Lovell, 2011).

Poly(ethylene terephthalate) and PBT are both under the polyester category. They are both common engineering thermoplastics, and their applications include housing materials, bearings, film, and bottles (McCrum, Buckley, & Bucknall, 1997). Besides, PET also serves as good-quality textile fiber. Polycarbonate and PEEK are also high-performance thermoplastics. Polycarbonate is transparent and tough. Therefore, it can be processed into safety glasses, screens, and glazing. However, PEEK has high continuous use temperature (260 °C) that can be used for moldings, composites, and coatings (Young & Lovell, 2011).

Polymers - Manufacturing Processes

While introducing the aforementioned common thermoplastics, it is equally important to identify major thermoplastic-processing methods since they have a great influence on the forms and applications of those polymers. Extrusion, molding, and calendaring are the three major approaches to process thermoplastics, and each of these approaches can produce several types of thermoplastic products.

Extrusion. According to Baird and Collias (1998, p. 213), “Extruders are the heart of polymer processing industry. They are used at some stage in nearly all polymer processing operations.” Screw, disk, and ram extruders are the three main extruder categories. The current study focuses on screw extruders since they are the most commonly used extruders (Baird & Collias, 1998).

The function of an extruder is to melt and pump thermoplastics into a shaping device, known as a die. The components of extruders typically are the drive, feed hopper, screw, barrel, barrel heater, and head camp, as illustrated in Figure 5 (Baird & Collias, 1998). During the processing procedure, the solid thermoplastic feedstock enters the barrel through the feed hopper and moves forward as the screw rotates. While the solid feedstock moves forward, it is softened and mixed to become a homogeneous mixture. Afterward, the homogeneous mixture is pumped through the die and goes into different shape units (Wilkinson & Ryan, 1999).

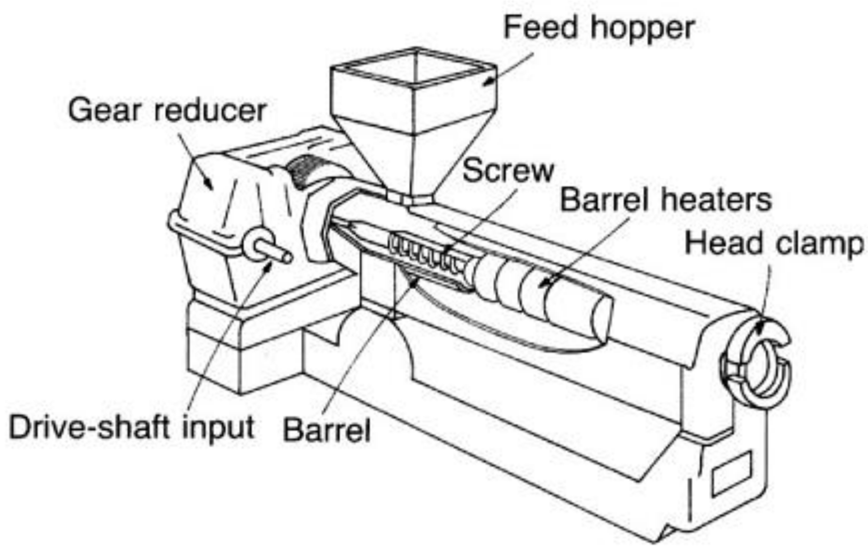

Figure 5. A single-screw extruder. Reprinted from *Polymer Processing* (p. 1), by Baird and Collias, 1998, New York, NY: John Wiley & Sons.

A common extruder's screw consists of three zones: feed, compression, and metering. The function of the feed zone is to ensure the steady feed rate of solid feedstock. The steady feed rate can be accomplished by using deep flights, which can create a high channel volume. The function of the compression zone is to complete the solid-melt transition. Heat and pressure are the two key factors of completing the transition. The heat comes from barrel heaters, whereas the pressure comes from two sources. One pressure source is the decrease of channel's depth, and another is the shearing action that results from the rotation of the extruder screw. The last metering zone has shallow flights, which are aimed at homogenizing and pumping the melt into the die. The ratio of volume transported by one turn of the screw in the feed zone to the volume transported by one turn of the screw in the metering zone is the compression rate (CR). It is the indicator of the pressure-generation ability of a screw (Wilkinson & Ryan, 1999).

After the extrusion processes have completed, many post-die treatments are available for further processing. The major treatments consist of fiber spinning, film casting and stretching, and film blowing.

Fiber spinning. Fiber spinning had two types, which are solution spinning and dry spinning. In dry spinning, a solution is extruded into a dry-gas stream, whereas a solution is extruded into a non-solvent or reaction bath in solution spinning. A spinning machine performs all spinning processes in polymers' steady state, and fibers generally have uneven microstructures (Wilkinson & Ryan, 1999). As illustrates in Figure 6, there are six critical unit operations during the manufacturing of polymer fibers, which consist of the following: preparation, gear pump, filter, filament extrusion, solidification, and finishing. Preparation ensures that the polymer enters the metering unit at the right temperature and pressure. The gear pump controls the flow rate of the polymer melt or solution. The filter eliminates all the unnecessary material from the polymer flow. After filtration, the polymer flow enters the spinneret, which is the most critical part of fiber spinning. The polymer flow is shaped into a fiber by filament extrusion and then solidified by a solidification device. The solidified fiber polymer is able to transform into usable material through post-process stretching, heating treatment, surface finishing, etc.

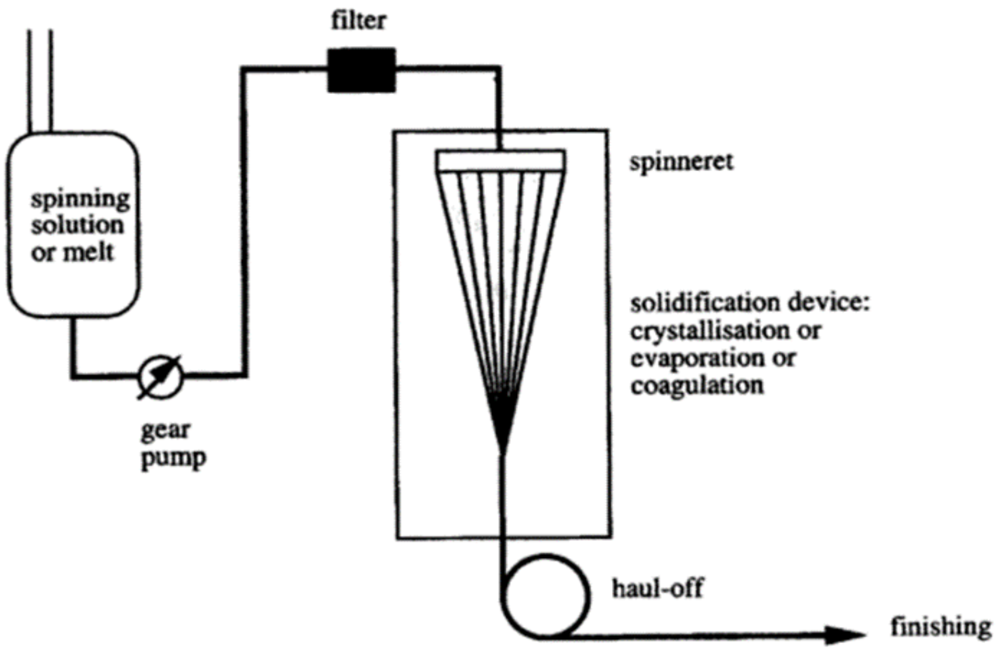

Figure 6. Operations during fiber spinning. Reprinted from *Polymer Processing and Structure Development* (p. 397), by Wilkinson and Ryan (1999), Massachusetts, MA: Kluwer Academic Publishers.

Film casting. The film and sheet production made a large part of the thermoplastic-manufacturing industry. A film represents a material whose thickness is less than 250 µm, and a sheet is referred to thicker materials. However, the length or width to thickness ratios of films and sheets are approximately 10^3 (Baird & Collias, 1998).

Figure 7 illustrates a common PET-casting process. The polymer is plasticized by a single-screw extruder, and the plastic melt is pulled forward by a metering pump to the end feed die. The die is directly connected to adjust lips to control the flow rate of the plastic melt. The extruded film was stretched for a short distance, and long stretching follows through chill rolls that rotate at constant speed, which is called forward stretch. Transverse stretch follows forward stretch to enlarge the width of the film. When the stretches complete, the film goes through the stabilization phase and is finally collected by the wind-up process (Wilkinson & Ryan, 1999).

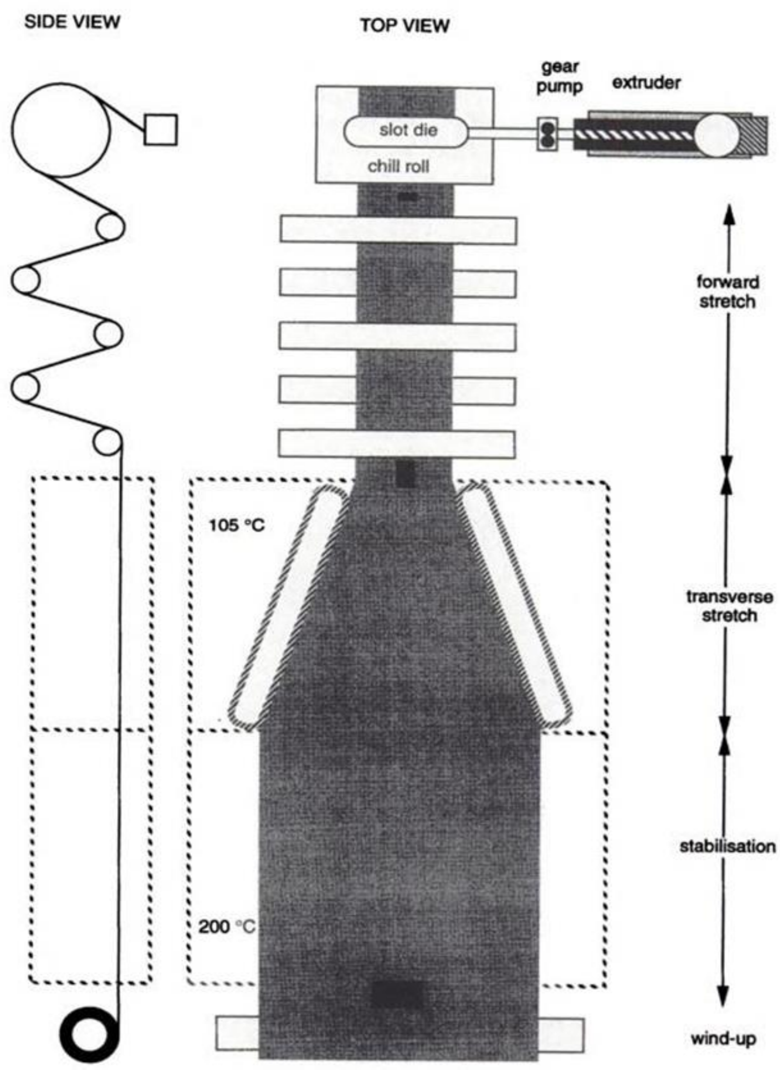

Figure 7. Film-casting process. Reprinted from *Polymer Processing and Structure Development* (p. 438), by Wilkinson and Ryan, 1999, Massachusetts, MA: Kluwer Academic Publishers.

Film blowing. Film blowing is the process of manufacturing a tubular film. Film blowing uses various types of PEs, including LDPE, LLDPE, and HDPE. Furthermore, over 70% of LDPEs and LLDPEs are produced using this approach (Wilkinson & Ryan, 1999).

Figure 8 indicates the processes of film blowing. The extruder plasticizes the polymer melt that passes an annular die, and the film is then stretched in two directions: the machine direction and the transverse direction. The air flow inside the annular film creates a “bubble” that enables the stretching and inflating activity. Simultaneously, cooling air flows on the outside surface to enable crystallization and solidification of the polymer melt. There is a freeze line in which the bubble no longer stretches transversely.

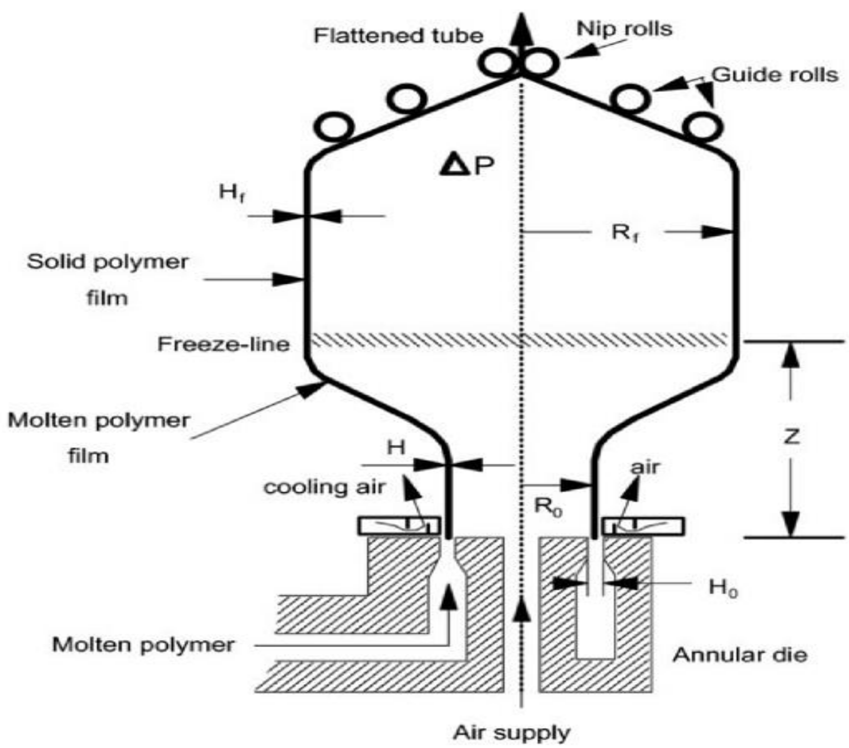

Figure 8. Film-blowing process. Reprinted from *Polymer Processing* (p. 266), by Baird and Collias, 1998, New York, NY: John Wiley & Sons.

The film is then flattened by a guide roll and taken up by nip rolls that seal the annular film. Finally, the film is wound up onto the cylinder, and the film-blowing process is completed (Baird & Collias, 1998).

Injection molding. Injection molding is the most popular and widely used thermoplastic-manufacturing method. During the injection-molding process, a screw extruder melts and pumps a polymer and then exerts it under the force of a hydraulic system, and the melt is pushed into the mold, in which the polymer cools down and solidifies. Finally, the polymer is ejected from the mold (Baird & Collias, 1998).

Figure 9 is the basic injection-molding machine, which consists of two parts: the clamp unit and the injection unit. The injection unit, which is responsible for injecting the polymer melt into the mold, includes a hopper, a heating cylinder with an injection screw inside it, and a stationary platen. The clamp unit, which is used for maintaining a proper force that ensures that the mold stays closed during the injection and cooling phase, has a machine that can create a clamping force and a moving platen (Bryce, 1996).

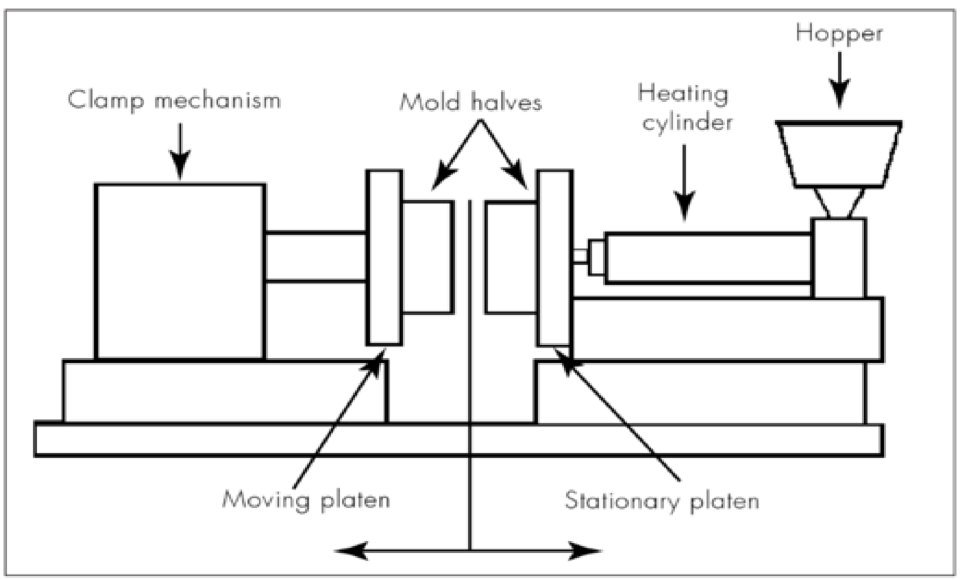

Figure 9. A basic injection molding machine. Reprinted from *Plastic Injection Molding* (p. 12), by Bryce, 1996, Michigan, MI: Society of Manufacturing Engineers.

Methodology

The Survey Design

The purpose of the current study is to answer seven research questions:

1. Do thermoplastics-manufacturing industry practitioners perceive they have knowledge of lean-manufacturing?
2. Do thermoplastics-manufacturing industry practitioners perceive their organizations to have knowledge of lean-manufacturing?
3. What lean theories do practitioners perceive to have used in their manufacturing processes?
4. What lean tools do practitioners perceive to have used in their manufacturing processes?
5. What outcomes do practitioners perceive to have accomplished by the lean-manufacturing implementation?
6. Which lean theories do practitioners perceive to have the best result after implementation?
7. Which lean tools do practitioners perceive to have the best result after implementation?

To answer these questions, the current study requires analysis of the perceptions of thermoplastics manufacturing industry practitioners who understand the manufacturing processes.

The Population and Sample

The population of the current study had two main characteristics: one is that they worked in the thermoplastic-manufacturing industry, and the other is that they worked closely with the manufacturing processes. The respondents might be working at any level at their organization, such as high-level presidents, vice presidents and directors; mid-level production managers, plant managers and quality managers; and lower-level process engineers and quality engineers. The expected participant quantity was 35 individuals from various companies. Additionally, the geographic locations of the participants were unknown, as the questionnaire was distributed through LinkedIn, the SPE, and email.

Procedure

The first step was to create the questionnaire for the survey. The next step was to randomly pick participants who would take the survey. Initially, the researcher obtained a list of thermoplastic-manufacturing companies from thomasnet.com and selected 30 companies from that list using the randomization tool provided by random.org. The researcher identified 71 email addresses of potential respondents. For the following 60 days, the researcher communicated with the potential participants, to answer any questions that they might have regarding the survey questions and to ensure that they completed the survey in a timely fashion.

However, there were only two responses at the end of the time period, and finding more emails was not an option since researcher had already attempted to collect as many email addresses as possible. Therefore, a decision was made to distribute the questionnaire using LinkedIn.com and the Society of Plastic Engineers (SPE). The researcher also joined two groups (Machinery for Plastics Processing and Support Plastics USA) on LinkedIn.com and signed up for SPE membership. The questionnaire was then sent to these groups using the anonymous link provided by Qualtrics. After receiving the expected numbers of responses, the researcher continued to collect data through Qualtrics for the following three weeks.

Instrumentation

The survey was created using Qualtrics, the Western Kentucky University (WKU)'s survey-design website. The completed survey consisted of eight closed-ended questions (six rating-scale questions and two multiple-choice (multiple-answer) questions) and three open-ended questions (see Appendix A for the entire questionnaire). The survey also provided explanations regarding the definitions of lean tools and theories in case some participants were not familiar with lean concepts. The definitions provided were based on published books and peer-reviewed articles.

Method of Data Analysis

The participants answered the survey on Qualtrics' website. The researcher then used the website to convert the collected data into Microsoft Excel files and consequently transform those data into clustered column charts and tables. Those charts and tables contained descriptive statistics, including mean, standard deviation, and percentages. Mean and percentage values were used to analyze the orders and trends of the collected data, whereas standard deviation values were used to analyze the variation of the data.

Threats to Validity

Threats to validity included the following

- Potential participants did not finish the survey. In this case, the solution was to send the survey to more people beyond the expected response numbers of participants. In addition, if the potential respondents did not reply after three weeks, the researcher would send an e-mail to each participant each week reminding them to complete the survey.

- The participants may not answer the questions truthfully.
- Some participants might not have had a true understanding of lean manufacturing.
- Some participants might not have understood the actual thermoplastic-manufacturing processes.

Results

Data collection was completed through Qualtrics, using the questionnaire shown in Appendix A. Since some of the respondents did not complete the whole survey, the counted responses for each question varied from 39 to 45, which still exceeded the expected responses' quantity (35).

Respondent Demographics: Questions 1 and 2

The first question of the questionnaire was: What is your job title? As shown in Table B-1 in Appendix B, the respondents' job titles ranged from process engineers to presidents. The top three job titles were manager, engineer, and president and vice-president. Out of the 44 respondents, 12 were managers, 10 were engineers, and 9 were presidents and vice-presidents.

Question 2 of the questionnaire was: How many years have you worked in the thermoplastic-manufacturing industry? Figure B-1 in Appendix B illustrates the precise years of experience the 44 respondents had in the thermoplastic-manufacturing industry. The range was between 5 and 50 years. The average experience (mean) was 23.9, and the standard deviation was 10.3.

Results of Question 3

The question 3 of the questionnaire was as follows: What is your perception of how well you understand lean manufacturing? Forty-four responses were counted. From Figure 10, the completed questionnaire indicates that 36.4% of the respondents perceived their knowledge of lean manufacturing as above average, 34.1% of the respondents chose average, 22.7% of the respondents perceived they understood lean manufacturing very well, 4.6% of the respondents chose “below average,” and 2.3 % of the respondents chose “very poor.” The mean for this question was 3.7, and the standard deviation was 0.9.

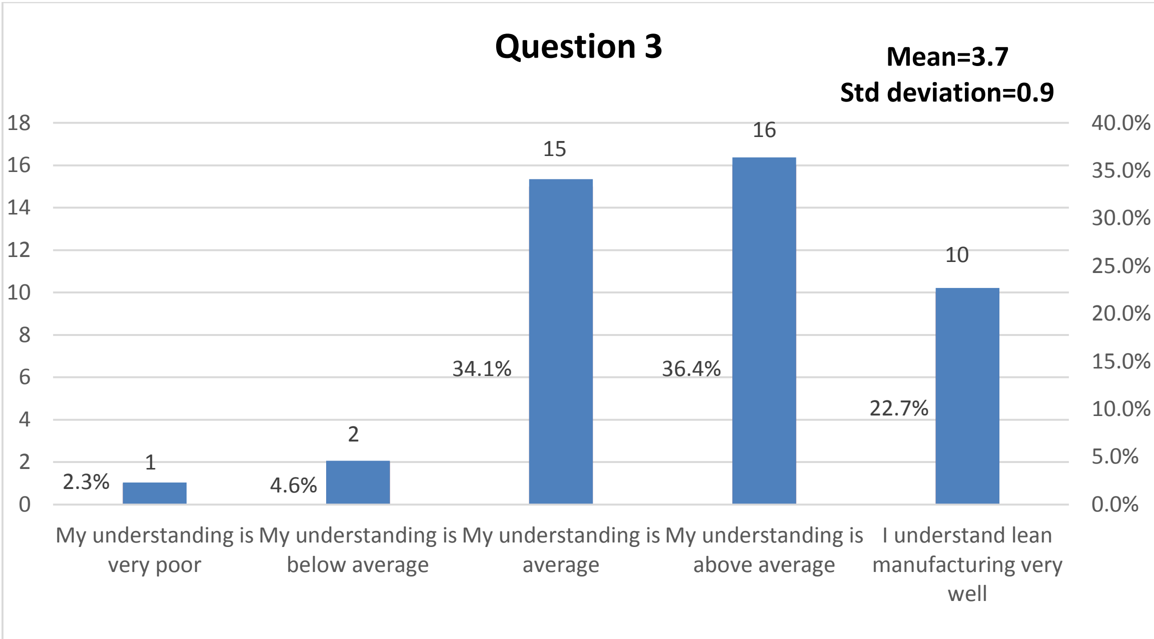

Figure 10. Responses to question 3: Respondents’ perception on their knowledge of lean-manufacturing.

The results indicated that thermoplastic-manufacturing industry practitioners perceived that they possessed knowledge of lean manufacturing since the mean was between average and above average, and 93% of the respondents chose average, above average and very well.

Result of Question 4

Question 4 of the questionnaire was as follows: In your opinion, what is your perception of how well your organization understands lean manufacturing? Forty-five respondents completed this question. As shown in Figure 11, 31.1% of the respondents perceived their organizations’ knowledge of lean manufacturing was above average;

however, equally, 31.1% of the respondents perceived their organizations' knowledge of lean manufacturing was below average, 28.9% of the respondents chose "average," 6.7% of the respondents chose "very well," and 2.2% of the respondents perceived their organizations' understanding of lean manufacturing was very poor. The mean for this question was 3.1, and the standard deviation was 1.

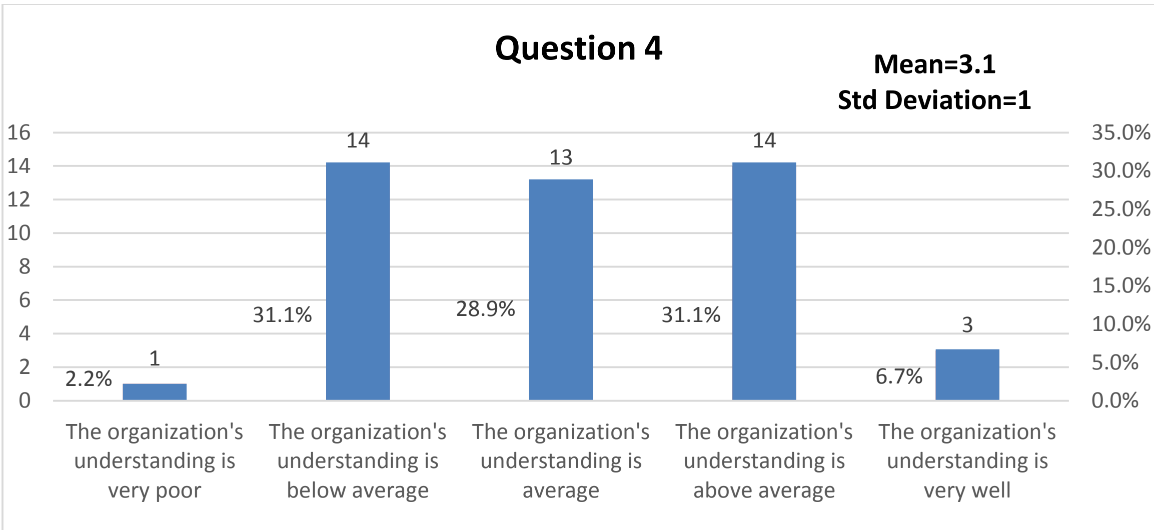

Figure 11. Responses to question 4: Respondents' perception on their organizations' knowledge of lean-manufacturing.

The result of the completed questionnaire indicated that the respondents perceived their organizations' understanding of lean manufacturing was above average since the mean was 3.1. However, it was much close to average, as 33.3% of the respondents in total chose below average and very poor. Therefore, it seems that thermoplastic-industry practitioners perceived their organizations as having knowledge of lean manufacturing, but the level of knowledge varied widely.

Result of Question 5

Question 5 was as follows: How often does your company use the following lean theories in manufacturing? The lean theories covered in the questionnaire included stability, standardization, employee involvement, customer focus, JIT, and Jidoka. The number of responses ranged from 41 to 45. Additionally, the question also had "Other" as an option, which enabled respondents to list lean theories not covered by the question. Seven respondents chose "other."

Lean theories perceived as used most often. As presented in Table 1, the lean theories that companies used more often are customer focus, employee involvement, standardization, and JIT. The mean of customer focus was 4, and the standard deviation was 1.1. For employee involvement, the mean was 3.8, while the standard deviation was 1.1. The mean of standardization was 3.6, and the standard deviation was 1.2. For JIT, the mean was 3.1, and the standard deviation was 1.3.

Table 1.

Mean and standard deviation of question 5: The usage frequency of lean theories

Theory	Mean	Standard Deviation	Response
Customer Focus	4.0	1.1	43
Employee Involvement	3.8	1.1	44
Standardization	3.6	1.2	44
JIT	3.1	1.3	45
Stability	3.0	1.2	44
Jidoka	2.4	1.3	41

The result of the completed questionnaire demonstrated that thermoplastic professionals perceived the usage of customer focus, employee involvement, and standardization as high. Based on Table 2, 86.1% of the respondents chose “often” and higher frequencies for their usage of customer focus, 84.1% of the respondents chose “often” and higher frequencies for the usage of employee involvement, and 77.3% of the respondents chose “often” and higher frequencies for their usage of standardization. All of the respondents perceived that they had used customer focus and employee involvement, whereas 95.5% of the respondents perceived that they had used standardization. By contrast, the mean value (3.1) for JIT was much closer to the mid-value, and the standard deviation (1.3) of JIT was also higher than that for the other theories, which indicated that many responses were not close to the mean. Only 55.6% of the respondents chose “often” and higher frequencies.

Table 2.

Percentages of question 5: The usage frequency of lean theories

Theory	Never	Sometimes	Often	Frequently	Everyday
Stability	11.4%	29.6%	22.7%	25.0%	11.4%
Standardization	4.6%	18.2%	18.2%	29.6%	29.6%
Employee Involvement	0.0%	15.9%	20.5%	29.6%	34.1%
Customer Focus	0.0%	14.0%	16.3%	30.2%	39.5%
JIT	8.9%	35.6%	15.6%	20.0%	20.0%
Jidoka	26.8%	34.2%	17.1%	12.2%	9.8%

Lean theories perceived as used less often. The respondents perceived that they had used stability, Jidoka, and other lean theories in a relatively lower frequency. In Table 1, the mean of stability is 3, and the standard deviation is 1.2; the mean of Jidoka is 2.4, and the standard deviation is 1.3; and the mean of other theories was 2.4, with a standard deviation of 1.3. However, only seven respondents provided other theories (the other responses were lean culture/continuous improvement and ergonomic movement and handling). Therefore, the mean and standard deviation of other theories cannot be compared with stability and Jidoka.

Although the mean of stability was below the mid-value, it was very close to it. Only 11.4% of the respondents perceived that they had never used stability, while 59.1% of the respondents chose “often” and higher frequencies for stability, i.e. they were even more than those who chose JIT (55.6%). By contrast, the usage frequency of Jidoka was much less. Sixty-one percent of the respondents chose “sometimes” and “never”, and 26.8% of the respondents perceived that they had never used Jidoka.

Result of Question 6

Question 6 of the questionnaire was as follows: How often does your company use the following lean tools in manufacturing? As shown in Table 3, based on the mean value, the frequently used lean tools from the most used to the least used were standard work, suggestion program, 5S, kanban, TPM, poka-yoke, takt time, VSM, and heijunka. The number of responses ranged from 39 to 44. Since there were only four responses for “other” (responses stated visual and metrics), this response cannot be counted. All the standard deviation values were relatively high, which might indicate a lack of general understanding of the implementation of lean tools among the thermoplastic professionals.

Table 3.

Mean and standard deviation of question 6: The usage frequency of lean tools

Tool	Mean	Standard Deviation	Response
Standard Work	3.3	1.4	44
Suggestion Program	3.3	1.5	39
5S	3.2	1.3	44
Kanban	2.8	1.4	43
TPM	2.7	1.3	44
Poka-Yoke	2.7	1.3	43
Takt time	2.4	1.3	43
Value Stream Mapping	2.3	1.2	44
Heijunka	2.1	1.2	43

Lean tools perceived as used most often. The lean tools that the respondents perceived that they had used most often are standard work, suggestion program, and 5S. As shown in Table 3, the mean of standard work was 3.3, and the standard deviation was 1.4; the mean of suggestion program was 3.3, and the standard deviation was 1.5; and the mean of 5S was 3.2, while the standard deviation was 1.3.

Based on Table 4, 61.4% of the respondents perceived that they had used standard work often or more frequently, whereas 11.4% of the respondents chose “never”; 66.7% perceived that they had used suggestion program often or more frequently; 18% chose “never”. Over 68% of respondents chose “often” and higher frequencies for the usage of 5S, and 13.6% perceived that they had never used 5S.

Table 4.

Percentages of question 4: The usage frequency of lean tools

Tool	Never	Sometimes	Often	Frequently	Everyday
5S	13.6%	18.2%	27.3%	20.5%	20.5%
TPM	18.2%	36.4%	13.6%	20.5%	11.4%
Standard Work	11.4%	27.3%	11.4%	22.7%	27.3%
Takt time	27.9%	34.9%	14.0%	14.0%	9.3%
Kanban	20.9%	30.2%	18.6%	11.6%	18.6%
Heijunka	41.9%	30.2%	16.3%	4.7%	7.0%
VSM	34.1%	25.0%	22.7%	13.6%	4.6%
Poka-Yoke	25.6%	23.3%	23.3%	16.3%	11.6%
Suggestion Program	18.0%	15.4%	18.0%	20.5%	28.2%

Lean tools perceived as used less often. In Tables 3 and 4, lean tools that thermoplastic-industry practitioners perceived they had used less often were kanban, TPM, poka-yoke, takt time, VSM and heijunka. The mean of kanban was 2.8, and the standard deviation was 1.4. The mean of TPM was 2.7, and the standard deviation was 1.3. The mean of poka-yoke was 2.7, and the standard deviation was 1.3. The mean of takt time was 2.4, and the standard deviation was 1.3. The mean of VSM was 2.3, and the standard deviation was 1.2. The mean of heijunka was 2, and the standard deviation was 1.2.

The means of kanban, TPM, and poka-yoke were close to the mid-value, which indicated that they were being regularly used by thermoplastic professionals. 48.8% of the respondents perceived that they had used kanban often and more frequently, whereas 20.9% chose “never”. Forty-five percent of the respondents perceived that they had used TPM often and more frequently, and 18.18% chose “never”. Fifty-one percent of the respondents chose “often” and higher frequencies on the usage of poka-yoke, whereas 25.6% perceived that they had never used poka-yoke.

On the contrary, the means of takt time, VSM, and heijunka were not close to the mid-value, which indicated that the usage frequencies of those lean tools were relatively low. Sixty-two percent of the respondents chose “sometimes” or “never” for the usage of takt time, and 27.9% perceived that they had never used takt time. Fifty-nine percent of the respondents chose “sometimes” or “never” on their usage of VSM, and 34.1% perceived they had never used VSM. Seventy-two of the respondents perceived that they had used heijunka less frequently than often, and 41.9% of the respondents perceived that they had never used heijunka.

Result of Question 7 and Question 8

Questions 7 and 8 of the questionnaire were the same question, which was: What are the outcomes of lean-manufacturing implementation at your company? The outcomes covered by Question 7 were response time, lead time, inventory, and cost since decreasing means positive result for the outcomes. The outcomes of Question 8 were quality and customer satisfaction since increasing means positive result for these outcomes.

As illustrated in Table 5, the mean of customer satisfaction was 3.7, and the standard deviation was 0.7; the mean of quality was 3.7, and the standard deviation was 0.7; the mean of inventory was 3.5, and the standard deviation was 0.8; the mean of cost was 3.5, and the standard deviation was 0.6; the mean of lead time was 3.4, and the standard deviation was 0.8; and the mean of response time was 3.1, and the standard deviation was 0.8.

Table 5.

Mean and standard deviation of questions 7 and 8: The outcomes of lean

Outcomes	Mean	Standard Deviation	Response
Customer Satisfaction	3.7	0.7	43
Quality	3.7	0.7	41
Inventory	3.5	0.8	43
Cost	3.5	0.6	43
Lead time	3.4	0.8	43
Response time	3.1	0.8	43

Over 51% of the respondents perceived that lean-manufacturing implementation had no influence on response time; 25.6% perceived that lean-manufacturing implementation decreased response time, but 18.6% chose “increase”. Forty-one percent of the respondents perceived that lean-manufacturing implementation had no influence on the lead time, and 44.2% perceived that the lead time decreased after lean implementation. Over 37% of the respondents perceived that lean-manufacturing implementation had no influence on the inventory, and 51.2% chose “decrease”. Forty-eight of the respondents perceived that lean-manufacturing implementation had no influence on the cost, and 46.5% chose “decrease”.

Table 6.

Percentages of questions 7 and 8: The outcomes of lean

Question 7	Significantly Increase	Increase	Average	Decrease	Significantly Decrease
Response time	2.3%	18.6%	51.2%	25.6%	2.3%
Lead time	2.3%	9.3%	41.9%	44.2%	2.3%
Inventory	2.3%	4.7%	37.2%	51.2%	4.7%
Cost	0.0%	2.3%	48.8%	46.5%	2.3%
Question 8	**Significantly Decrease**	**Decrease**	**Average**	**Increase**	**Significantly Increase**
Quality	0.0%	2.4%	39.0%	48.8%	9.8%
Customer Satisfaction	0.0%	2.3%	37.2%	51.2%	9.3%

Thirty-nine percent of the respondents perceived that lean-manufacturing implementation had no influence on the manufacturing quality, and 48.8% perceived it increased the quality. Over 37% of the respondents perceived that lean manufacturing had no influence on customer satisfaction, and 51.2% of the respondents perceived that customer satisfaction increased after lean-manufacturing implementation.

The results of Questions 7 and 8 indicated that thermoplastic professionals perceived that lean manufacturing offered positive outcomes. According to the mean values of the outcomes, response time, lead time, inventory, and cost all decreased, while quality and customer satisfaction increased. However, 18.6% of the respondents perceived that lean manufacturing implementation increased the response time, which might indicate that the implementation of the fundamental lean theories and tools was not enough.

The standard deviation of all the outcomes was relatively low. It indicated that most respondents seemed to agree that lean-manufacturing implementation had a positive influence on the outcomes.

Result of Question 9

Question 9 of the questionnaire was as follows: Which lean theories produced the best results after implementation? The lean theories that were covered by Question 9 included stability, standardization, JIT, Jidoka, involvement, and "other". Customer focus was inadvertently omitted from Question 9, and there were 41 counted responses.

In Figure 12, 78.05% of the respondents perceived that standardization produced the best results; 65.85% perceived that involvement produced the best results; 36.59% perceived that stability produced the best results; 12.20% perceived JIT as producing the best results; 4.88% chose Jidoka; and 4.88% chose "other" (defined as lean culture).

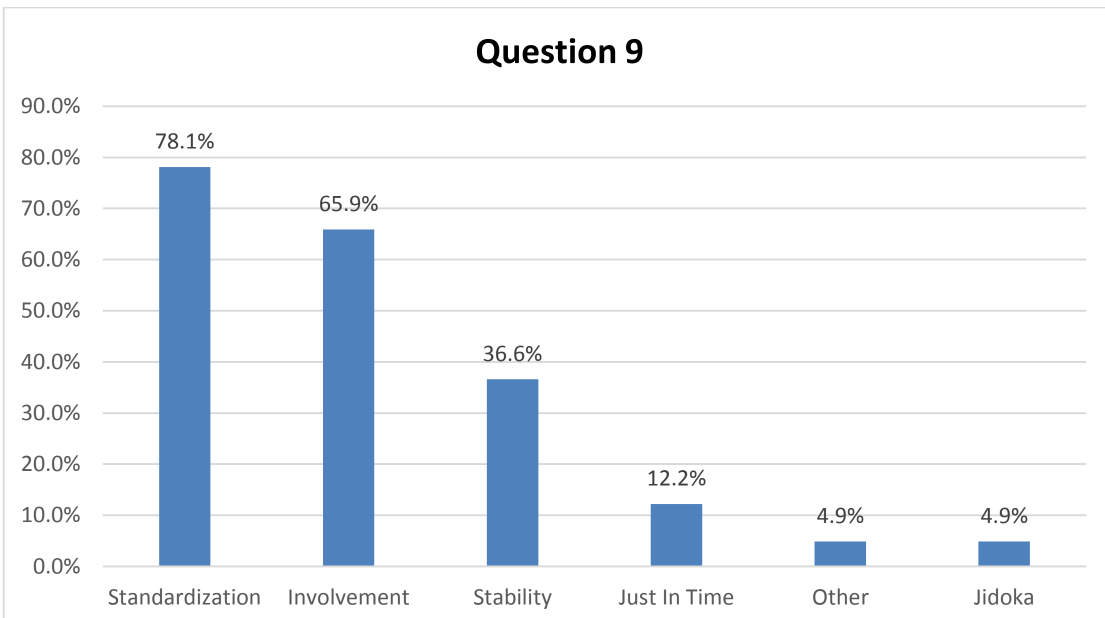

Figure 12. Responses to question 9: Respondents' perception on the result of lean theory implementation.

Result of Question 10

Question 10 of the questionnaire was as follows: Which lean theories produced the best results after implementation? The lean tools covered by Question 10 were 5S, TPM, takt time, heijunka, poka-yoke, suggestion program, and “other”. Standard work, Kanban, and VSM were inadvertently omitted from the question; and 41 responses were counted.

As shown in Figure 13, 67.5% of the respondents perceived that 5S produced the best results; 35% perceived that TPM produced the best results; 35% perceived that poka-yoke produced the best results; 25% chose suggestion program; 10% listed “other” as lean culture and SMED; and 7.5% chose heijunka.

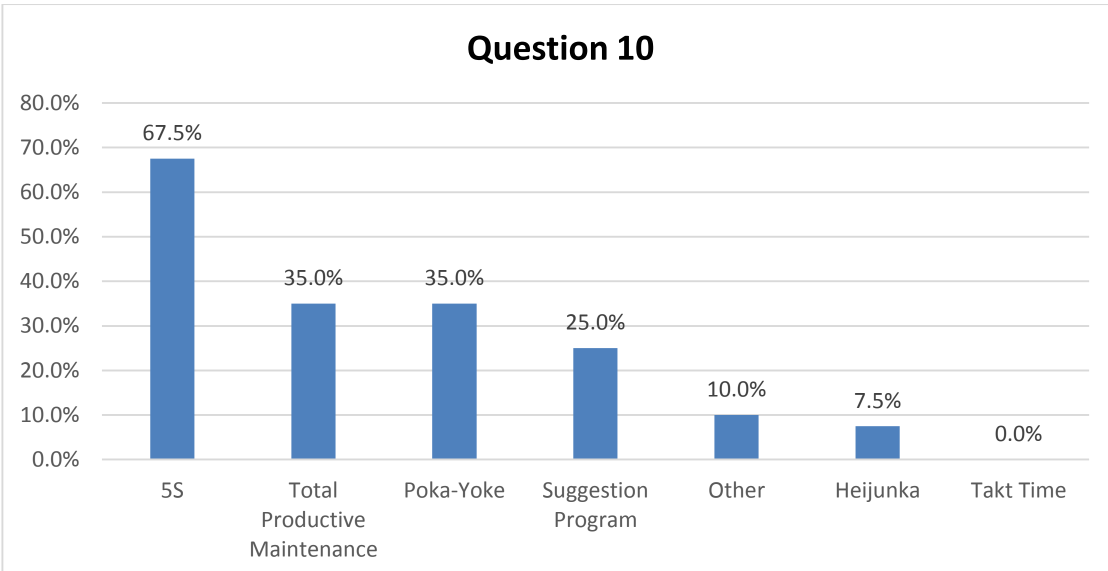

Figure 13. Responses to question 10: Respondents’ perception on the result of lean tool implementation.

Result of Question 11

Question 11 of the questionnaire asked respondents to add any additional comments on their perceptions of lean in the thermoplastic industry. The comments provided by the respondents follow and are shown verbatim:

- I believe you will find that the implementation of lean also varies by the segment of the thermoplastics industry you are studying. In my field (medical devices), there has been rapid implementation of lean manufacturing / toyota *[sic]* production system. The lean precepts align well with the regulations that govern our industry and enable organizations to systematically improve (from my personal observations). Finally, I would strongly recommend you read books on creating a lean culture. Lean is more than just a set of tools or eliminating waste: it's a systematic way of running a business, driving continuous improvement, respect for people, and people engagement. At a fundamental level you can't truly implement lean manufacturing without a lean culture. Best of luck with your dissertation.

- Experience cited related to extrusion compounding.
- "Thermoplastics Industry" is too broad a term. Lean Manufacturing (LM) is best understood when a plant produces a product with multiple components and/or processing steps. So much of our industry is like us, one step, shoot and ship. You will get better results if you sharpen your focus to multi-step, price sensitive components of the industry.
- To fully implement Lean, it is a high involvement process, many times interrupted by everyday normal activities, it has to be assumed as another everyday MUST and have the proper technical team of committed personnel to be in charge of implementation so they can follow up on the rest of the organization sectional goals and keep up the enthusiasm. If not, after a few months all the hard work, theories, meetings and initial success will fade away. You have to show the evidence of the progress and the positive results in order to maintain the sense that the effort is always worth the job done.

- In the automotive industry, where I have spent most of my working life, we used this system a lot. Now in the medical arena this is like going backwards.
- TOYOTA *[sic]* is a highly structured, very large, bureaucratic organization. As such everything needs to be formalized. Many companies in our field - at least us - are not so large (around 100 employees) and such a formalization would be more stifling, than helpful.
- The focus on employee participation and buy in to systems that are put in place by company directors is most important. We must have a ground to ceiling approach where the production floor is treated as the most important and all inputs by personal on the floor must be listened to and sometimes implemented because they are going to help in the long run to increase efficiency and quality.
- My understanding is that the major medical companies are using the theories and practices of lean manufacturing on a daily basis.
- In my job function, I visit many manufacturers in many industries. I have observed that those embracing lean manufacturing techniques are ALWAYS better than those that do not.
- In most cases the compounding community has not embraced lean manufacturing.
- We are a job shop show *[sic*] lean was difficult to implement in some areas, but we found good payback in the area of set up and packaging.

Conclusion

The primary purpose of the current survey research was to analyze the implementation of lean manufacturing in the thermoplastic-manufacturing industry based on thermoplastic professionals' perceptions. The instrument of this survey was a questionnaire that was created by the researcher through Qualtrics' website. The number of completed responses for each question ranges from 39 to 45.

Demographic Conclusions

The respondents' job titles were distributed among various levels of thermoplastic-manufacturing companies. Almost all of the respondents seemed to understand thermoplastic-manufacturing processes very well since 93% of the respondents had over 10 years' experience in the industry, and the average experience of the respondents was over 23 years.

Research Question Conclusions

Research question 1: Do Thermoplastics-manufacturing industry practitioners perceive they have knowledge of lean-manufacturing?

Thermoplastic-manufacturing industry practitioners perceived that they had knowledge of lean manufacturing and that the level of their knowledge was above average. Ninety-three percent of the respondents thought their knowledge of lean manufacturing was either average or above average.

Research question 2: Do Thermoplastics-manufacturing industry practitioners perceive their organizations have knowledge of lean-manufacturing?

The respondents perceived their organizations to have knowledge of lean manufacturing, but the level of the knowledge was slightly above average. In addition, almost one-third of the respondents perceived their organizations' knowledge of lean manufacturing was below average. Hence, it appears that the respondents' perception of their own knowledge of lean manufacturing was different from their perception of their organization's knowledge of lean manufacturing.

According to Figures 10 and 11, the respondents perceived that their knowledge of lean manufacturing was greater than their organizations' knowledge of lean manufacturing that indicated that the knowledge of lean manufacturing was not consistent across the respondents' organizations, which might be an obstacle for lean-manufacturing implementation. Lean implementation requires constant coordination of many cross-functional groups. If there is inconsistent understanding of lean manufacturing, lean implementation might lead to undesired outcomes that consequently prevent further lean-manufacturing implementation from happening.

Research question 3: What lean theories do practitioners perceive to have used in their manufacturing processes?

The lean theories that the respondents perceived to have used in their manufacturing processes are customer focus, employee involvement, standardization, JIT, stability, Jidoka, and others (lean culture/continuous improvement and ergonomic movement and handling). However, the usage frequencies of lean theories varied widely. Over a quarter of the respondents perceived that they had never used Jidoka.

Research question 4: What lean tools do practitioners perceive to have used in their manufacturing processes?

The lean tools that thermoplastic practitioners perceived to have used during manufacturing included standard work, suggestion program, 5S, kanban, TPM, poka-yoke, takt time, VSM, heijunka, and others (visual and metrics). The usage of the lean tools that linked with JIT (Kanban, takt time, VSM, and heijunka) and Jidoka (poka-yoke) was below average. A possible reason might be that thermoplastic companies lacked the skills to execute the implementation of JIT and Jidoka since their knowledge of lean was mixed, based on the respondents' perceptions.

Additionally, as presented in Table 3, TPM was perceived as used less often by respondents, which might lead to consequences, such as machine breakdowns and quality loss. Therefore, the thermoplastic-manufacturing industry should use TPM more often since it is a critical component of stability. Further implementation of TPM could help thermoplastic-manufacturing companies to further improve overall machine effectiveness.

Research question 5: What outcomes do practitioners perceive to have accomplished by the lean-manufacturing implementation?

The outcomes of lean-manufacturing implementation were all positive. Customer satisfaction and quality increased, whereas inventory, cost, lead time, and response time all decreased. However, the respondents perceived response time was neither increasing nor decreasing. There are many reasons that might have resulted in this perception. One possible reason might be the infrequent use of TPM and machine stability. An unstable machine causes delay, breakdowns, and speed loss, all of which increase response time. Another reason might be the lack of VSM implementation, as it is a waste-elimination tool that could help companies remove unnecessary processes. Without VSM, the manufacturing processes might have contained wasted processes that increased response time.

Research question 6: Which lean theories do practitioners perceive to have the best result after implementation?

According to the Figure 12, the respondents perceived that standardization, involvement, and stability produced the best results. Stability and standardization are the foundations of lean-manufacturing implementation since they are at the bottom of the house of lean. Stability and standardization could help companies stabilize their machines, work methods, materials, and employees. Therefore, it is logical that respondents perceived the implementation of those two theories to lead to the best results.

The involvement theory could help companies empower and motivate their employees, which could consequently increase employees' loyalty. Loyal employees should have less possibility to leave their companies. Hence, the involvement theory could also help companies retain man/woman stability. Companies could save on the cost of training new employees. Besides, well- motivated employees could be more productive, which might improve lead and response times.

Research question 7: Which lean tools do practitioners perceive to have the best result after implementation?

As illustrated in Figure 13, the respondents perceived that 5S, TPM, and poka-yoke produced the best results. 5S and TPM as lean tools were related to lean theory stability. As mentioned in Question 6, the respondents perceived that the implementation of the stability theory produced the best results. Therefore, it is valid that the respondents also perceived 5S and TPM to produce the best results. 5S could improve material stability, which could save the cost of missing parts and reduce the time that employees use to locate some parts or tools. TPM could improve machine stability, which could prevent incidents, such as machine breakdowns and quality losses.

By contrast, the theory that related to poka-yoke was Jidoka, and only 4.9% of the respondents perceived Jidoka to produce the best results; however, the fact that Jidoka could not lead to the best results does not reduce the possibility that poka-yoke could produce the best results. One reason might be that the implementation of Jidoka was not enough since the respondents perceived that they had used Jidoka less often. Another reason might be that the result of poka-yoke-implementation was more visible. For instance, if a company implemented a poka-yoke device that could detect defective products, it could immediately improve company's reaction speed to problems, which could reduce the cost of manufacturing more defective products and improve the overall quality.

Summary

The purpose of the current survey research was to understand the current status of lean-manufacturing implementation in the thermoplastic-manufacturing industry using the perception of the industry's practitioners and to identify appropriate lean theories and tools for the industry.

As illustrated in Figure 14, from the house of lean's perspective, the data indicated that the usage of the pillars of lean (JIT and Jidoka) was below average and JIT usage was slightly above average. The house of lean cannot stand without its pillars. Therefore, it appears that the thermoplastic industry's implementation of lean manufacturing was incomplete.

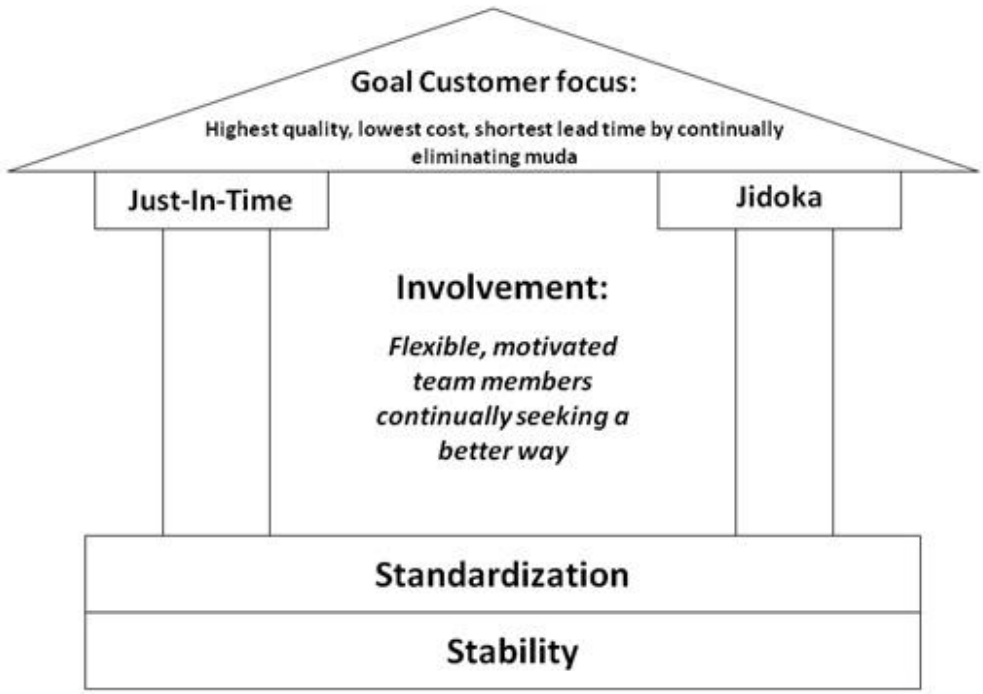

Figure 14. The house of lean. Reprinted from *Lean Production Simplified* (p. 19), by Dennis, 2007, Florida, FL: Taylor & Francis Group.

However, the respondents' perceptions also suggested that the lean-manufacturing implementation in the thermoplastic industry had a good foundation since the usage frequencies of lean foundation theories (stability and standardization) were above average overall. Consequently, with a stable 4M system (man/woman, machine, material, and method) and well-established standards, further implementation of lean using JIT and Jidoka could be possible. Additionally, the perceived usage frequencies of the interior (involvement) and roof (customer focus) were also above average, which indicated that thermoplastic-manufacturing companies might have engaged employees and had a clear goal (customer focus) in mind.

The thermoplastic-industry professionals should put more attention and efforts on the implementation of JIT and Jidoka. To fully implement JIT and Jidoka, thermoplastic-manufacturing companies should use the lean tools that relate to theories such as kanban, takt time, heijunka, VSM, and poka-yoke more often; they should also offer more training opportunities for their employees. Additionally, the thermoplastic-manufacturing industry practitioners perceived that the best lean theories for the industry were standardization, involvement, and stability, whereas they perceived the best lean tools to be 5S, TPM, and poka-yoke.

Recommendations for Future Studies

Recommendations for further researchers are the following:

1. As mentioned by one of the respondents in Question 11, lean implementations are not limited to lean theories. The creation of a lean culture is also quite important; therefore, future research could focus on the lean-culture creation aspect in the thermoplastic industry.
2. Future research could further narrow the scale of the current research. For instance, the research could focus on specific thermoplastic-manufacturing processes, product types, or a specific size of companies, which could lead to more accurate results.
3. Future research could also focus on other polymers in the lean-manufacturing industry, for instance, thermoset or elastomers.
4. Future research could further focus on the demographic aspect of the research to further explain the relationship of demographics and practitioners' responses. For

instance, the relationship between years of experience and responses and the relationship between job titles and responses

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Appendix A: The Questionnaire

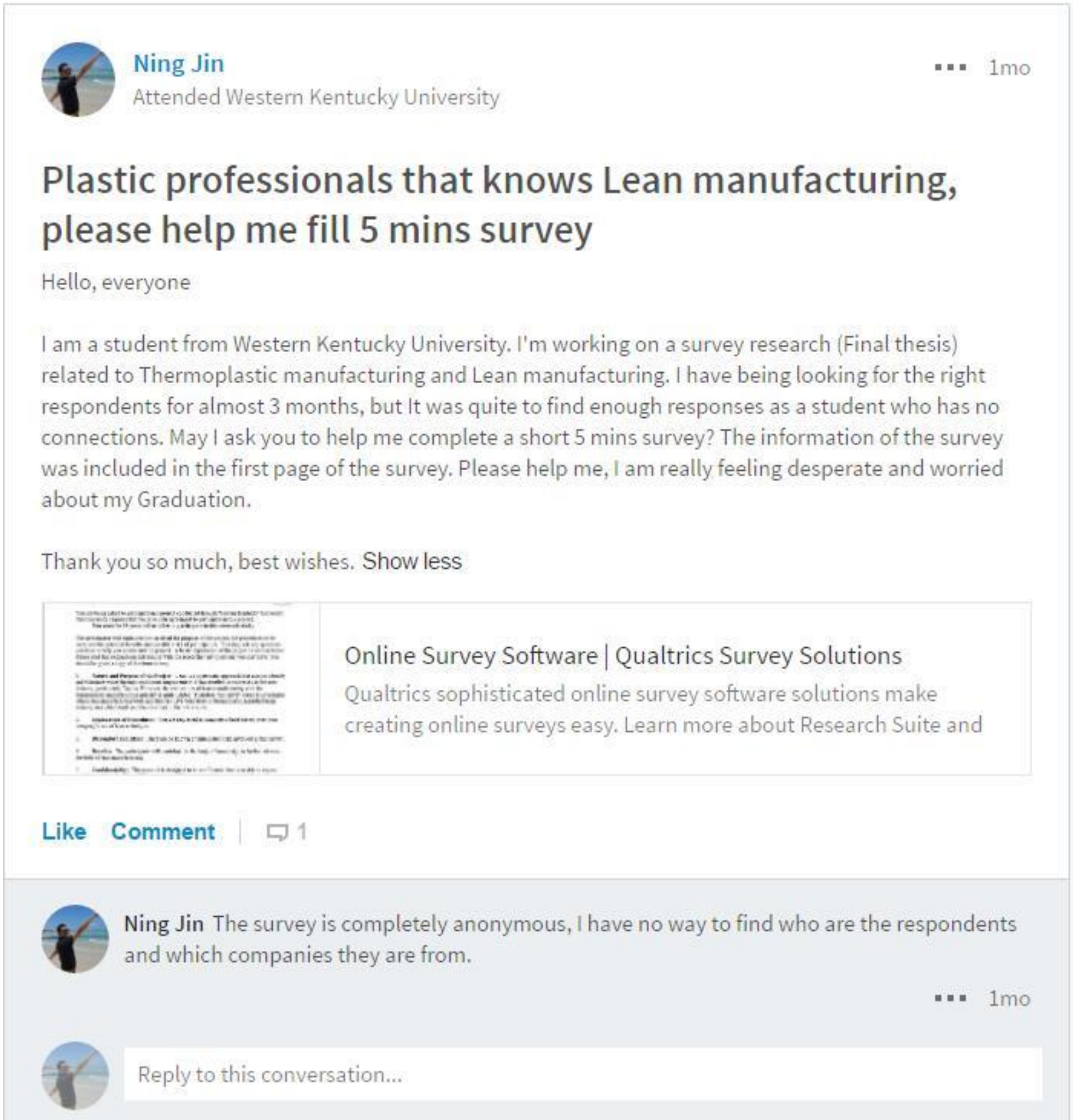

Figure A-1. Original message sent to LinkedIn.

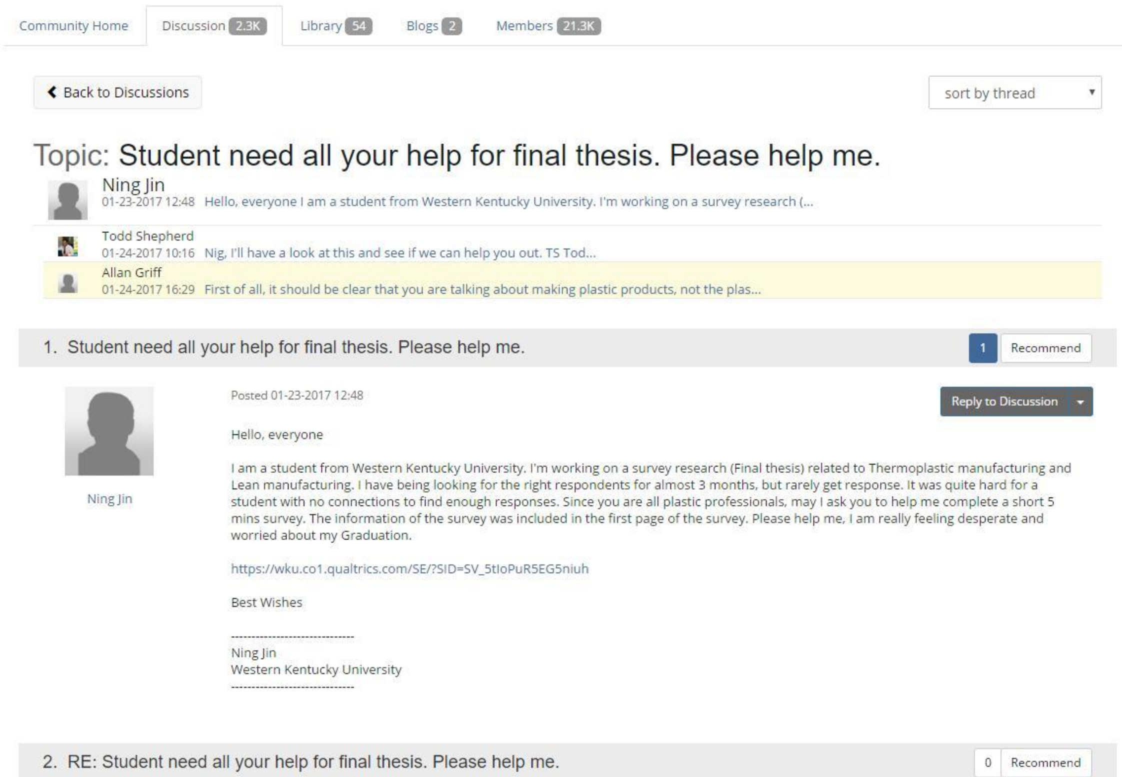

Figure A-2. Original message sent to SPE

INFORMED CONSENT DOCUMENT

Project Title: THE CURRENT STATUS OF LEAN THEORIES AND TECHNIQUES IMPLEMENTATION IN THEROMOPLASTIC MANUFACTURING
Investigator: Ning Jin, WKU, 786-303-9323

INSTITUTIONAL REVIEW BOARD WKU APPROVED

You are being asked to participate in a project conducted through Western Kentucky University. The University requires that you give your agreement to participate in this project.
You must be 18 years old or older to participate in this research study.

The investigator will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You may ask any questions you have to help you understand the project. A basic explanation of the project is written below. Please read this explanation and discuss with the researcher any questions you may have. You should be given a copy of this form to keep.

1. **Nature and Purpose of the Project:** Lean is a systematic approach that aims to identify and eliminate waste through continuous improvement. It has resulted in successes in the auto industry, particularly Toyota. However, the connection of lean manufacturing with the thermoplastic manufacturing industry is quite limited. Therefore, this survey seeks to investigate which lean manufacturing tools and theories have been used in thermoplastic manufacturing industry and which tools and theories lead to the best results.

2. **Explanation of Procedures:** You are requested to complete a brief survey over your company's use of lean techniques.

3. **Discomfort and Risks:** There are no known or anticipated risks involved in this survey.

4. **Benefits:** The participants will contribute to the body of knowledge to further advance the field of lean manufacturing.

5. **Confidentiality:** This research is designed to be confidential that is unable to expose participants' identity. Meanwhile, researcher will not make public any contact information related to participants.

6. **Refusal/Withdrawal:** Refusal to participate in this study will have no effect on any future services you may be entitled to from the University. Anyone who agrees to participate in this study is free to withdraw from the study at any time with no penalty.

You understand also that it is not possible to identify all potential risks in an experimental procedure, and you believe that reasonable safeguards have been taken to minimize both the known and potential but unknown risks.

Your continued cooperation with the following research implies your consent.

THE DATED APPROVAL ON THIS CONSENT FORM INDICATES THAT
THIS PROJECT HAS BEEN REVIEWED AND APPROVED BY
THE WESTERN KENTUCKY UNIVERSITY INSTITUTIONAL REVIEW BOARD
Paul Mooney, Human Protections Administrator
TELEPHONE: (270) 745-2129

WKU IRB# 17-125
Approval - 10/21/2016
End Date - 5/16/2017
Expedited
Original - 10/21/2016

Figure A- 3. Consent letter.

The application of lean tools and theories in thermoplastic manufacturing industry

Lean is a systematic approach that aims to identify and eliminate waste through continuous improvement. It has resulted in successes in the auto industry, particularly Toyota. However, the connection of lean manufacturing with the thermoplastic manufacturing industry is quite limited. Therefore, this survey seeks to investigate which lean manufacturing tools and theories have been used in thermoplastic manufacturing industry and which tools and theories lead to the best results. In order to participate in this survey, you must be working in the thermoplastics manufacturing industry. Your expertise and participation is very important to the research. The survey should about 15 minutes to complete. Your help is appreciated.

Q1. What is your job title?

Q2. How many years have you worked in the thermoplastic manufacturing industry?

Q3. What is your perception of how well you understand lean manufacturing?
- ❍ My understanding is very poor
- ❍ My understanding is below average
- ❍ My understanding is average
- ❍ My understanding is above average
- ❍ I understand lean manufacturing very well

Q4. In your opinion, what is your perception of how well your organization understands lean manufacturing?
- ❍ The organization's understanding is very poor
- ❍ The organization's understanding is below average
- ❍ The organization's understanding is average
- ❍ The organization's understanding is above average
- ❍ The organization's understanding is very well

Q5. How often does your company use the following lean theories in manufacturing?

	Never	Sometimes	Often	Frequently	Everyday
Stability: a theory that builds the foundation of improvement by stabilize man/woman, machine, material, and method	❍	❍	❍	❍	❍
Standardization: a system of using policies and common procedures to manage processes	❍	❍	❍	❍	❍
Employee Involvement	❍	❍	❍	❍	❍
Customer Focus	❍	❍	❍	❍	❍
Just In Time (JIT): a philosophy that has waste elimination as its ultimate objective, which can be achieved by only manufacturing and conveyance what is needed, when is needed, and in the amount needed	❍	❍	❍	❍	❍
Jidoka: combination of human intelligence with automation so that equipment is able to detect defects, alert personnel of the abnormality, and immediately stop production	❍	❍	❍	❍	❍
Other	❍	❍	❍	❍	❍

Q6. How often does your company use the following lean tools in manufacturing?

	Never	Sometimes	Often	Frequently	Everyday
5S: five words that begins with "S" (sort, set in order, shine, standardize, and sustain), they are the steps that can maintain an orderly, well-inspected, clean, and efficient working environment	❍	❍	❍	❍	❍
Total Productive Maintenance (TPM): an integrated sets of activities aimed at maximizing equipment effectiveness by involving everyone in all departments at all levels	❍	❍	❍	❍	❍
Standard Work: a detail description of each work cycle time, takt time, the work sequence, and the minimum inventory of parts needed to conduct the activity	❍	❍	❍	❍	❍
Takt time: the available production time divided by the rate of customer demand	❍	❍	❍	❍	❍
Kanban: a communication tool that ensures that every operation produce only the amount that will be used in the next step of the process	❍	❍	❍	❍	❍
Heijunka: a method of leveling production for mix and volume	❍	❍	❍	❍	❍

Value Stream Mapping: the process that drawing the value stream using icons that show the information and material flow of a process	❍	❍	❍	❍	❍
Poka-Yoke: a device or innovate that either detects abnormal before it happens or stops processes after abnormal happens	❍	❍	❍	❍	❍
Suggestion Program	❍	❍	❍	❍	❍
Other	❍	❍	❍	❍	❍

Q7. What are the outcomes of lean manufacturing implementation at your company?

	Increase significantly	Increase	Average	Decrease	Decrease significantly
1.Response time	❍	❍	❍	❍	❍
2.Lead time	❍	❍	❍	❍	❍
3.Inventory	❍	❍	❍	❍	❍
4.Cost	❍	❍	❍	❍	❍

Q8

	Decrease significantly	Decrease	Average	Increase	Increase significantly
1.Quality	❍	❍	❍	❍	❍
2.Customer Satisfaction	❍	❍	❍	❍	❍

Q9. Which lean theories produced the best results after implementation? (Check all that apply)

- ❑ Stability
- ❑ Standardization
- ❑ Involvement
- ❑ Just In Time
- ❑ Jidoka
- ❑ Other ____________________

Q10. Which lean tools produced the best results after implementation? (Check all that apply)

- ❑ 5S
- ❑ Total Productive Maintenance
- ❑ Takt Time
- ❑ Heijunka
- ❑ Poka-Yoke
- ❑ Suggestion Program
- ❑ Other ____________________

Q11. Please add any additional comments on your perceptions of lean in the thermoplastics industry.

Appendix B: Raw Data

Table B-1.

Question 1: Job title of respondents

Plant Manager
Sr. Consultant Engineer
Manufacturing Engineering Manager
President
Engineer
R&D Scientist
Rigid Packaging Market Manager
Retired plant manager
Associate Commodity Manager - Plastics -- formerly VP engineering at an injection molding company
New product development engineer
Composites Engineer
General Manager
President
VP Engineering
program leader - surgical materials in RDE
Engineering Manager
Process Engineer
Projecty Coordinator
Design & Development Mgr
President
Sr Process Engineer/ Injection Molding Tooling Manager
general manager
Director
Process Engineer
Research Leader
Project Mechanical Engineer
VP Manufacturing
Director
Processing Engineer
Production Manager
Vice President Sales & Marketing
President
Director - RD&E
Innovation and Engineering Director
Sr Engineer

Market Development Engineer
Project manager
President and CEO
Quality Manager
Sales Engineer
Manager
President
Manufacturing Process Engineer
President

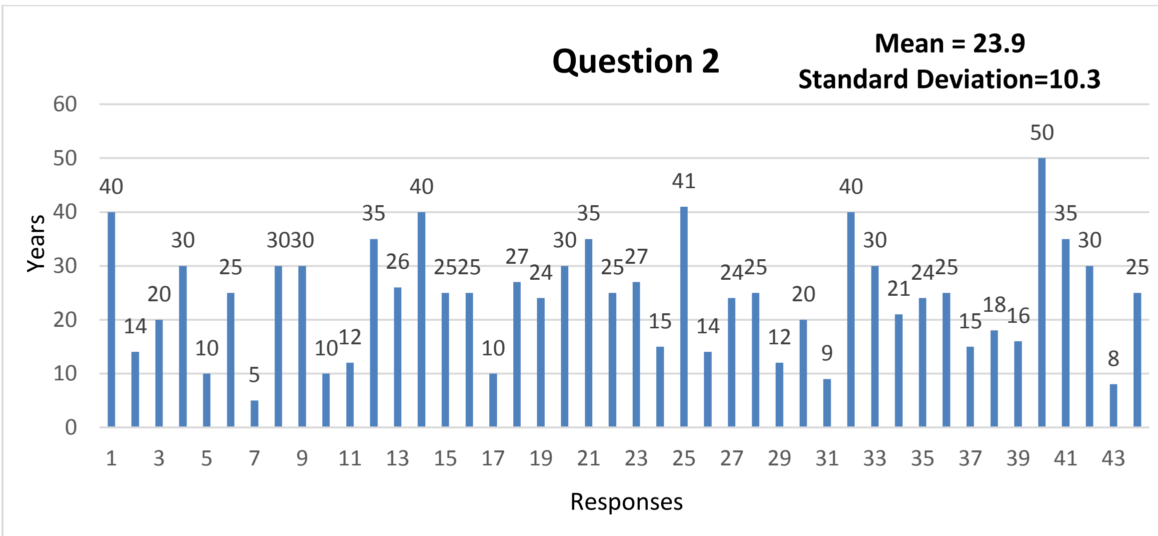

Figure B-1. Responses to question 2: Years of experience

Table B-2.

Question 3: Respondents understanding of lean raw data

#	Answer	%	Count
1	My understanding is very poor	2.27%	1
2	My understanding is below average	4.55%	2
3	My understanding is average	34.09%	15
4	My understanding is above average	36.36%	16
5	I understand lean manufacturing very well	22.73%	10
	Total	100%	44

Table B-3.

Question 4: Respondents' organizations understanding of lean raw data

#	Answer	%	Count
1	The organization's understanding is very poor	2.22%	1
2	The organization's understanding is below average	31.11%	14
3	The organization's understanding is average	28.89%	13
4	The organization's understanding is above average	31.11%	14
5	The organization's understanding is very well	6.67%	3
	Total	100%	45

Table B-4.

Question 5: Respondents' usage of lean theories raw data

Question	Never	Sometimes	Often	Frequently	Everyday	Total
Stability	11.4% (5)	29.6% (13)	22.7% (10)	25%1 (1)	11.4% (5)	44
Standardization	4.6% (2)	18.2% (8)	18.2% (8)	29.6% (13)	29.6% (13)	44
Involvement	0% (0)	15.9% (7)	20.5% (9)	29.6% (13)	34.1% (15)	44
Customer Focus	0% (0)	14% (6)	16.3% (7)	30.3% (13)	39.5% (17)	43
Just In Time (JIT	8.9% (4)	35.6% (16)	15.6% (7)	20% (9)	20% (9)	45
Jidoka	26.8% (11)	34.2% (14)	17.1% (7)	12.2% (5)	9.8% (4)	41
Other	42.9% (3)	28.6% (2)	0% (0)	0% (0)	28.6% (2)	7

Table B-5.

Question 6: Respondents' usage of lean tools raw data

Question	Never	Sometimes	Often	Frequently	Everyday	Total
5S	13.6% (6)	18.2% (8)	27.3% (12)	20.5% (9)	20.5% (9)	44
TPM	18.2% (8)	36.4% (16)	13.6% (6)	20.5% (9)	11.4% (5)	44
Standard Work	11.3% (5)	27.3% (12)	11.4% (5)	22.7% (10)	27.3% (12)	44
Takt time	27.9% (12)	34.9% (15)	14% (6)	14% (6)	9.3% (4)	43
Kanban	20.9% (9)	30.2% (13)	18.6% (8)	11.6% (5)	18.6% (8)	43
Heijunka	41.8% (18)	30.2% (13)	16.3% (7)	4.7% (2)	7% (3)	43
VSM	34.1% (15)	25% (11)	22.7% (10)	13.6% (6)	4.6% (2)	44
Poka-Yoke	25.6% (11)	23.3% (10)	23.3% (10)	16.3% (7)	11.6% (5)	43
Suggestion Program	18% (7)	15.4% (6)	18% (7)	20.5% (8)	28.2% (11)	39
Other	50% (2)	0% (0)	0% (0)	0.0%	50% (2)	4

Table B-6.

Question 7 and question 8: Outcomes of lean implementation raw data

Question	Increase significantly	Increase	Average	Decrease	Decrease significantly	Total
Response time	2.3% (1)	18.6% (8)	51.2% (22)	25.6% (11)	2.3% (1)	43
Lead time	2.3% (1)	9.3% (4)	41.9% (18)	44.2% (19)	2.3% (1)	43
Inventory	2.3% (1)	4.7% 2()	37.2% (16)	51.2% (22)	4.7% (2)	43
Cost	0% (0)	2.3% (1)	48.8% (21)	46.5% (20)	2.3% (1)	43
Question	Decrease significantly	Decrease	Average	Increase	Increase significantly	Total
Quality	0% (0)	2.4% (1)	39.1% (16)	48.8% (20)	9.8% (4)	41
Customer Satisfaction	0% (0)	2.3% (1)	37.2% (16)	51.2% (22)	9.3% (4)	43

Table B-7.

Question 9: Lean theories lead to best results raw data

Answer	%	Count
Total	100%	41
Standardization	78.1%	32
Involvement	65.9%	27
Stability	36.6%	15
Just In Time	12.2%	5
Other	4.9%	2
Jidoka	4.9%	2

Table B-8.

Question 10: Lean tools lead to best results raw data

Answer	%	Count
Total	100%	40
5S	67.5%	27
Total Productive Maintenance	35.0%	14
Poka-Yoke	35.0%	14
Suggestion Program	25.0%	10
Other	10.0%	4
Heijunka	7.5%	3
Takt Time	0.0%	0

Table B-9.

Question 11: Additional comments

I believe you will find that implementation of lean also varies by the segment of the thermoplastics industry you are studying. In my field (medical devices) there has been rapid implementation of lean manufacturing / toyota production system. The lean precepts align well with the regulations that govern our industry and enable organizations to systematically improve (from my personal observations). Finally, I would strongly recommend you read books on creating a lean culture. Lean is more than just a set of tools or eliminating waste: it's a systematic way of running a business, driving continuous improvement, respect for people, and people engagement. At a fundamental level you can't truly implement lean manufacturing without a lean culture. Best of luck with your dissertation.
Experience cited related to extrusion compounding.
"Thermoplastics Industry" is too broad a term. Lean Manufacturing (LM) is best understood when a plant produces a product with multiple components and/or processing steps. So much of our industry is like us, one step, shoot and ship. You will get better results if you sharpen your focus to multi-step, price sensitive components of the industry.
To fully implement Lean, it is a high involvement process, many times interrupted by everyday normal activities, it has to be assumed as another everyday MUST and have the proper technical team of committed personnel to be in charge of implementation so they can follow up on the rest of the organization sectional goals and keep up the enthusiasm. If not, after a few months all the hard work, theories, meetings and initial success will fade away. You have to show the evidence of the progress and the positive results in order to maintain the sense that the effort is always worth the job done.
In the automotive industry, where I have spent most of my working life, we used this system a lot. Now in the medical arena this is like going backwards.
TOYOTA is a highly structured, very large, bureaucratic organization. As such everything needs to be formalized. Many companies in our field - at least us - are not so large (around 100 employees) and such a formalization would be more stifling, than helpful.
The focus on employee participation and buy in to systems that are put in place by company directors is most important. We must have a ground to ceiling approach where the production floor is treated as the most important and all inputs by personal on the floor must be listened to and sometimes implemented because they are going to help in the long run to increase efficiency and quality.
My understanding is that the major medical companies are using the theories and practices of lean manufacturing on a daily basis.
In my job function, I visit many manufacturers in many industries. I have observed that those embracing lean manufacturing techniques are ALWAYS better than those that do not.

In most cases the compounding community has not embraced lean manufacturing. We are a job shop show lean was difficult to implement in some areas, but we found good payback in the area of set up and packaging