LEAN MANUFACTURING: SET-UP TIME REDUCTION IN SECONDARY WOOD MANUFACTURING FACILITIES IN NORTH AMERICA

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ABSTRACT

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ABSTRACT

Since the emergence and the subsequent evolution of lean manufacturing concepts, numerous enterprises of different scale and specialties have adopted lean tools and techniques in their facilities with varying success. In general, lean manufacturing related studies have been conducted on large manufacturing firms, such as the automotive industry. Yet, lean manufacturing tools and techniques are also suited for small enterprises. Thus, the main concern of this study is to investigate the success of set-up time reduction efforts (one of the steps needed to achieve "one-piece flow") in secondary wood products manufacturing facilities on four woodworking machines (moulder, shaper, table saw, and band saw) based on firm size.

The first objective of this research is to explore the results of the implementation of set-up time reduction efforts on selected woodworking machines in enterprises of varying size. It is assumed that company size is a major factor influencing the rate of set-up time improvements. To that end, the first hypothesis, which states that "Small firms are less successful in reducing set-up time through set-up time reduction efforts than are large firms," has been developed and supportive questions have been corresponding created. While statistical testing of the hypotheses created for this is not possible due to the limited number of participants, speculations about the possible outcome can be made. Thus, for hypothesis one, the data obtained does not show any sign of a relationship between a firm size and the success rate of set-up time reduction efforts.

The second objective of this study is to investigate how a firm's productivity is affected by set-up time reduction efforts as related to firm size. With regards to some of the weaknesses of typical small manufacturing firms (e.g. having limited budget and resources, intuitive management strategies including lack of strategic planning), large firms, by and large, are expected to be more successful in increasing productivity through set-up time reduction. To that end, the goal is to investigate results of the set-up time reduction efforts in terms of productivity improvement in manufacturing facilities. With this in mind, the second hypothesis was proposed, which reads “Small firms achieve lower productivity gains through set-up time reduction than do large firms.” For the second hypothesis, while no conclusive proof can be offered, no sign of a relationship between firm size and productivity gain through set-up time reduction could be found.

Another objective of this study is to explore the success rate of set-up time activities on the four types of woodworking machines in industry facilities considering the training activities provided by manufacturers. The aim is to compare set-up time improvement performance of manufacturers between enterprises which trained their workers/operators and enterprises which did not train their employees. To understand the relationship between the scale of firms (and/or facilities) and training activities to improve set-ups, the third hypothesis, which reads “Small firms are less concerned with set-up time reduction through training than are large firms,” has been developed. For the third hypothesis, while testing is not possible, it appears that there is no relationship between firm size and the level of concern for set-up time reduction through training activities.

The final objective of this research is to investigate whether the secondary wood manufacturing firms studied experienced a bottleneck in their production due to the long set-up actions of machines. In order to accomplish this objective, the final hypothesis, “In both, large and small firms, bottlenecks occur at machines with high set-up times,” has been developed. The final hypothesis cannot be accepted or rejected due to the limited number of responses obtained, set-up time was a frequently indicated explanation for the occurrence of production bottlenecks in secondary wood products manufacturing firms.

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1.INTRODUCTION

1.1. Research Motivation

Reducing the time spent to set-up machines in manufacturing facilities is critical to improving any company's competitiveness in today's global economy. To that end, companies are able to get several benefits from reducing set-up time, including increased capacity, reduced lead-time, increased customer responsiveness, reduced batch sizes, reduced inventory, less waste, and more flexibility for the production. According to McIntosh et al. (2007), high a frequency of changeovers, which can be achieved through reduced set-up time, are needed when companies desire to be more responsive and have more flexible manufacturing systems. Flexibility can be defined as the ability of a manufacturing system to respond efficiently and timely to changes in customer demand (Zammori et al., 2011; Wadhwa, 2012). These related advantages can be triggered with the improvement of set-up time in manufacturing facilities.

Set-up time is defined as the time between the last good item produced and the first good item produced after set-up of a new production batch by the machine (Trevino et al., 1993). Set-up activities are categorized into two types: internal and external set-ups. External set-up time is the set-up time spent on activities that can be performed while the machine continues its production run. Internal set-up, conversely, describes the set-up activities that require to stop the machine (also see **3.1.7.1. Set-up Concepts**) (Cakmakci, 2009; Monden, 2011). As mentioned before, manufacturers benefit from successful set-up time reduction efforts due to reduced lead time, reduced inventory and work in process (WIP), as well as through reduced lot sizes. These advantages can help companies increase their competitiveness including an ability to diversify their product lines and/or increase their production capacity.

INTRODUCTION

The term “Lean” is roughly defined as making manufacturing (or other) systems more effective and more efficient (Womack et al., 1990). Lean manufacturing techniques are rooted in the Toyota Motor Company’s the Toyota Production System (TPS) that started evolving in 1950s. The main idea of Lean is eliminating unnecessary tasks from work areas to reduce costs and increase productivity (Monden, 2011). Lean offers various tools to improve any given facility’s manufacturing systems including set-time reduction. Industries, such as the automobile industry, have been successful in implementing set-up reduction efforts. However, the implementation of Lean techniques in other industries needs further exploration. One of these industries is the forest products industry. This study intends to describe efforts by the U.S. secondary wood products industry to capture the benefits of set-up time reduction efforts. In particular, the study tries to quantify the estimated success rate of set-up time reduction efforts on commonly used basic woodworking machines in secondary wood products manufacturing firms. In particular, the following four pieces of equipment were investigated: moulder, table saw, shaper, and band saw. The underlying idea of examining secondary wood products manufacturing facilities is that, in general, these manufacturers produce various types of products on the same equipment and thus set-ups for the production of a new product are required frequently. To obtain insights into common practices, a survey was prepared based on the research hypotheses outlined in chapter 2.Research Statement. The survey then was conducted as a web-based survey among readers of one of the leading wood products industry trade magazines. The results of this study were used to describe current trends and successes of set-up time improvement efforts among secondary wood manufacturing firms in North America.

2.RESEARCH STATEMENT

This chapter provides an overview of the research hypotheses tested in this study. Data was obtained through an empirical study to test these hypotheses through the use of a survey instrument. Four hypotheses were proposed, and are shown below:

- **$H_0$1:** Small firms are less successful in reducing set-up time through set-up time reduction efforts than are large firms.
- **$H_0$2:** Small firms achieve lower productivity gains through set-up time reduction than do large firms.
- **$H_0$3:** Small firms are less concerned with set-up time reduction through training than are large firms.
- **$H_0$4:** In both large and small firms, bottlenecks occur at machines with high set-up times.

Since the emergence and the evolution of lean manufacturing concepts, numerous enterprises of different scale have adopted lean techniques in their facilities. However, little documented evidence of implementation efforts of lean manufacturing is available for small enterprises (Achanga et al., 2006). In general, lean manufacturing related studies have been conducted mostly for large-scale manufacturers, such as the automotive industry. Yet, lean manufacturing tools and techniques are also suited for small enterprises (Conner, 2001). Thus, this study is an effort to add to the body of knowledge concerning set-up time reduction in wood products manufacturing firms, where the main focus of this study is set-up time reduction on four woodworking machines (moulder, shaper, table saw, and band saw).

2.1. Research Hypotheses

Hypothesis one ($H_0 1$) is intended to obtain further insights about the use of set-up time reduction tools on woodworking machines in enterprises of the North American wood products manufacturing industry. It is theorized that there are varying success rates for set-up time improvements in different sized enterprises. Commonly, small manufacturing firms face capital limitations, and additionally, often lack management level support during lean implementations (Achanga et al., 2006). These characteristics can make small manufacturing firms less successful in regards to their set-up time improvement efforts. Also, due to small companies' capital restrictions, such firms may avoid hiring an outside expert on set-up time reduction efforts when this is advisable. Therefore, the first hypothesis seeks to answer the relationship between firm size and the success rate of set-up time reduction efforts.

The second hypothesis of this study is to investigate how productivity is affected by set-up time reduction actions on machines considering the size of a firm. As mentioned before, set-up time activities can be divided into two types: internal set-up activities (machine stopped) and external set-up activities (machine running). To that end, Monden (2011) noted that the most significant factor for successful set-up time reduction is converting as much of the internal set-up time to external set-up time. Thus, production continues with minimal stoppages. It was estimated that set-up time in a typical facility might represent 5-10 percent of the total processing time, showing the magnitude of the opportunity to increase productivity of individual machines (Illinois Manufacturing Excellence Center (IMEC). n.d.). In fact, thanks to successful set-up time reduction efforts, the 5-10 percent of the total productive time can be used for productivity increase thanks to successful set-up time reduction efforts. This estimated 5 – 10 percent proportion (increasing productivity) may be higher in large manufacturing firms than typical small manufacturing firms due to small firms' inherent weaknesses (Rose et al., 2009) e.g. having a limited budget and resources, and intuitive (without exploring reasons and facts) strategic decisions. Therefore, this study hypothesized that larger firms benefit more from set-up time reduction than do smaller firms.

The third hypothesis of this study is to explore the success rate of set-up time reduction activities on the four types of woodworking machines in relation to the training activities provided by each manufacturer. In general, small manufacturing firms are reluctant to provide formal training to their employees (Hill & Stewart, 2000). This situation can cause smaller firms to be less successful in reducing their set-up time in their facilities. This study will attempt to explore the relationship between training activities and set-up time improvement (on the four woodworking machines selected). Training can be an important method for employees to use their equipment more effectively. Training can allow employees to make quicker set-ups due to gaining skills and knowledge including how and where to place tools and parts for set-ups, and having more knowledge about their equipment.

The fourth hypothesis of this study is to reveal that if there is a relationship between production bottlenecks and long set-up activities of machines in wood manufacturing facilities or not. A bottleneck is described by Goldratt (1992) as *"Any resource whose capacity is equal to or less than the demand placed upon it (p.139)."* In a production system, a bottleneck can be explained as the condition when one machine runs full capacity and limits other machines' output and thereby lowers their capacities. Similarly, during a set-up of any machine in a production line, remaining machines may be needed to stop running; thus, limiting capacity and causing production bottlenecks. Eliminating bottlenecks can result in increased capacity of the entire manufacturing line (Markgraf & Media, n.d.). Therefore, it is hypothesized that the main reason for the bottleneck in manufacturing facility is the long set-up activities on the (bottleneck) machine.

3.LITERATURE REVIEW

3.1. Lean Manufacturing

3.1.1.Introduction to Lean

The term “Lean” first appeared in the book entitled *The Machine that Changed the World* by Womack et al. (1990) and was coined by International Motor Vehicle Program (IMVP) researcher John Krafcik. “Lean” was used as a term describing practices that make production systems more effective and more efficient (Womack et al., 1990). In the book, Womack et al. (1990) depict the results from a five-year study by the International Motor Vehicle Program (IMVP). IMVP was founded by the Massachusetts Institute of Technology (MIT) with help of the U.S. government in the 1980s to benchmark the global automotive industry in an effort to strengthen the competitiveness of U.S. automobile manufacturers (Womack et al., 1990). Womack et al.’s (1990) study revealed that the implementation of lean provides numerous benefits to manufacturers, such as improvements in productivity, on-time delivery, and cost reduction while it uses less of everything. In fact, Womack et al. (1990) stated that lean manufacturing requires

> *“… Half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product. Also, it requires keeping far less than half the needed inventory on site, results in fewer defects. And produces a greater and ever growing variety of products* (*p*.11).”

Therefore, adopting or using Lean helps companies be more successful and competitive. Toyota Motor Company is the most obvious example for the success of implementing lean manufacturing systems, making it the largest automobile manufacturer in 2012 (Organisation Internationale des Constructeurs d'Automobiles (OICA), 2013).

During the 1950s, lean techniques originated at the Toyota Motor Company under the umbrella of what Toyota refers to as the Toyota Production System (TPS). TPS was primarily developed by Taiichi Ohno, who is considered the pioneer of Lean (Womack et al., 1990). Ohno stated that to increase productivity and to reduce costs, he and his working group focused on the idea of eliminating unnecessary tasks in all areas of work, creating a fundamental principle of Lean (Monden, 2011). Thus, Lean is about being more productive while using less of everything. The following chapter includes more details about the Toyota Production System (TPS) and lean thinking.

3.1.2. Toyota Production System (TPS)

Development of the Toyota Production System (TPS) started in the 1950s and was initiated by Taiichi Ohno (Shuker, 2000). The main goal of the TPS is to eliminate all kinds of waste through continuous improvement in an enterprise (Monden, 2011). Additionally, according to Kasul and Motwani (1997), TPS is focused on *"Manufacturing the necessary quantity of the necessary item at the necessary time* (*p*. 274).*"* TPS has become synonymous and is broadly referred to as lean manufacturing (Herrmann et al., 2008). The elements of the TPS are illustrated by the Figure known as the TPS house, which is shown in Figure 1. The TPS house shows the roles of the various concepts in the system and underscores the importance of implementing TPS (Lean) as a holistic system in organizations (Lander & Liker, 2007).

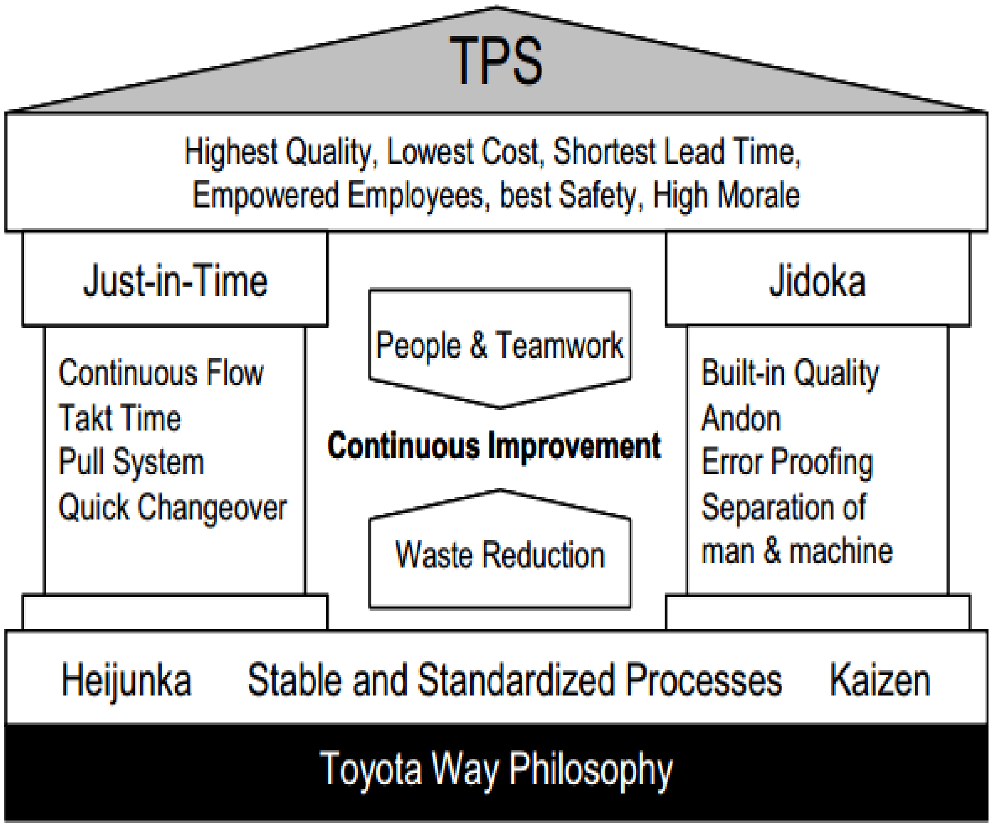

Figure 1: The TPS House (source: Herrmann et al., 2008).

The overall purpose of TPS is described on the top of the house in Figure 1, this is to produce the highest quality products with the lowest costs with short lead time while keeping individual employees' performances high. In this house-like figure, the pillars represent two main characteristics of TPS, Just-in-Time and Jidoka (anglicized as "Autonomation").

One of the main lean tools illustrated as the left pillar of the TPS House (Figure 1) is "Just-in-Time (JIT)" processing, which is considered a philosophy rather than a technique. In this case, Kisembo (n.d.) stated that JIT is a collection of tools and techniques to improve productivity. In essence, the JIT philosophy aims at reducing Work-in-Process (WIP) and finished goods inventory levels to a minimum by strict use of the minimum required quantity of parts or materials for every process. The ultimate target for the JIT philosophy is zero inventories, which would mean a complete elimination of all inventories (Fricke, 2010). In essence, JIT is about the right quantity of materials, in the right place, at the right time. Womack and Jones (1996) recall that *"Taiichi Ohno found this vantage point in the modern supermarket so stimulating that inspired him in 1950 to invent the new system of flow management we now call Just-in-Time* (*p.37)."* Ohno also realized that each process station has to be required to produce only the exact amount of needed parts that is pulled by the following station (or process). As a result, the Kanban System was developed to control production volume and flow. Kanbans carry a message (e.g., information indicating the need for a part) from the end user way back to all previous work stations involved. Various types of Kanban systems can be found; it might be a card, a Ping-Pong ball, or an electronic message (White, 2000).

The right-hand pillar of the TPS (Figure 1) describes another major tenet of the TPS and is called autonomation, or "Jidoka" in Japanese. The term can be defined as "human autonomation," or as "automation with a human touch (White, 2000)." According to White (2000), NUMMI (New United Motors Manufacturing Inc.) defines autonomation as "…*The quality principle or more specifically, taking care of quality issues at the source and not letting defects travel on to the next operation* (*p.9*)." Thus, Jidoka allows each employee having the power to stop production if a defect is found. In theory, Jidoka ensures that no defect will reach customers (Funston, 2013). The foundation of the TPS house, as shown in Figure 1, consists of four elements:

•Toyota Way Philosophy

•Kaizen (Continuous Improvement)

•Stable and Standardized Processes, and

•Heijunka (Production Leveling).

All other elements of the lean philosophy embodied in the TPS are built on this foundation listed above. These four lean tools (Toyota Way Philosophy, Kaizen, Stable and Standardized Process, and Heijunka) are crucially important as the foundation for the pillars (for Just-in-Time, and Jidoka) in this house analogy as they support the roof (highest quality, lowest cost, and empowered employees). Thus, the component at the bottom, the "Toyota Way Philosophy" is considered the most substantial element of the TPS as *"... It provides guidance for everyone in the organization regarding the direction the organization is taking and the way the organization wants to reach the goals* (Fricke, 2010, *p*. 13)."

Another fundamental principle of lean manufacturing is Kaizen or in other words the practice of continuous improvement. Kaizen is a systematic way to gradually, orderly, and continuously improve the business through focused, time-limited events involving a subset of the entire team (Abdullah, 2003). Kaizen, which Hettler (2008) describes as the link between improvement and lean manufacturing depends on the participation of all employees to provide continuous improvement with the purpose of eliminating all kinds of waste in an organization (Haak, 2006).

Another fundamental part of the TPS is an unwavering focus on stable and standardized processes. Standardized processes can be defined as a set of approaches to the documentation and application of best practices in a system (Ramalingam, 2008) and encompasses descriptions as to how tasks are completed, defined, and controlled. The underlying idea of standardization is creating a basis for improvement (Dennis, 2007), acknowledging the belief that more than one way to complete a job exist, and that workers related to that job are able to develop the best work design (Dennis, 2007). Additionally, because of efforts and resulting improvements to eliminate waste (Muda in Japanese), standards are continuously adapted to reflect improvements (Dennis, 2007). In this case, Ramalingam (2008) stated that standardized processes *"... Involve[s] determining the most effective work pattern, so that each team member can perform the work accurately and consistently until a better method is established* (*p*.16)." Therefore, standardization of work helps to achieve lean manufacturing goals including increased efficiency and effectiveness, worker participation, waste elimination, and improved quality.

The third element of the TPS foundation is Heijunka (production leveling). Heijunka ensures constant supply of customer demands/orders by sequencing the work; thus, production leveling allows the system to avoid overproduction when demand decreases unexpectedly (McLeod, 2009). In addition, production leveling balances the workload and prevents over-production of one item and under-production of another (Kasul & Motwani, 1997).

People, teamwork, and waste reduction are the elements of the TPS which are shown in the center of the house analogy (Figure 1). According to Sánchez and Pérez (2001), the goal of teamwork requires complementary skills of team members to transfer responsibilities to production workers and decrease indirect labor costs. Additionally, Taiichi (1988) gives an analogy that describes the importance of teamwork by stating that a soccer team may have talented players, however, it does not mean the team is going to win without teamwork. Another core element of the TPS (Figure 1), reduction of waste, can come in the form of standardization, which results in a more productive workforce, or production leveling, which leads to reduced inventory (Koole, 2005). The last element in the center of TPS (Figure 1), stability, *"... Is established through continuous improvement, an activity that is performed by everybody working* *for the company or supplying to the company* (Fricke, 2010, *p*.13).” Stability also refers to having reliable sources such as reliable equipment, workforce, machines, and material (D&I Partners, Inc., n.d.).

3.1.3. Lean Principles

According to Ramalingam 2008, five major principles of lean have been identified by Womack and Jones (1996) and are shown in Figure 2.

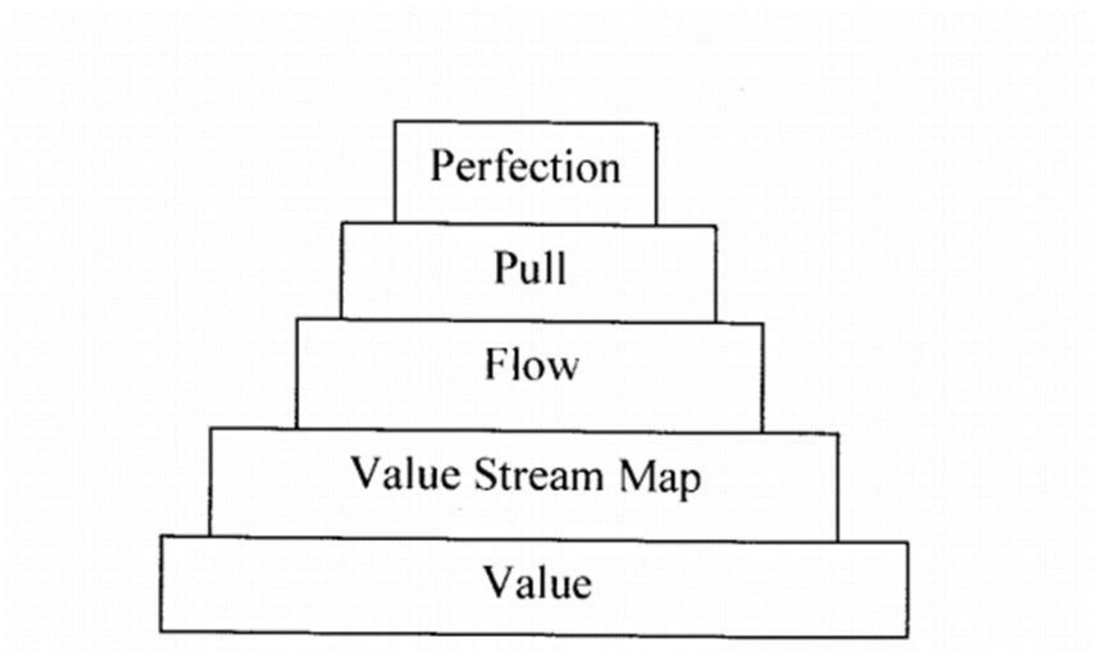

Figure 2: The five major lean principles attributed by Ramalingam (2008) to Womack and Jones.

3.1.3.1. Value

Various authors describe value as encompassing everything that customers are willing to pay for (Čiarnienė & Vienažindienė, 2012; Irani, 2011; Quesada-Pineda & Buehlmann, 2011; Todd, 1998); in contrast, waste is every activity that does not add value to the product or the service from a customer's perspective (Quesada-Pineda & Buehlmann, 2011). In fact, only a small amount of activities undertaken in today's organizations and production systems add value for the end customers (Čiarnienė & Vienažindienė, 2012). Therefore, understanding and producing to customers' desire and needs is critically important in the pursuit of creating value for customers. Thus, one should not establish customer value from the producers' perspectives (Ramalingam, 2008). Fernando and Cadavid (2007) correctly defined value as: "*What customers want, when and how they want it, and what combination of features, capabilities, availability, and price they will prefer* (*p*.72)."

3.1.3.2. Value Stream Map

Value stream mapping (VSM) is one of the lean tools that allows an organization to differentiate between value added and non-value added activities in all processes (Ramalingam, 2008). Thus, value stream mapping facilitates removing waste (e.g., removing all non-value adding activity) from the processes. Identifying the actions that are truly required for manufacturing a product based on the current status of technology, is the primary objective of any value stream map and these actions can be sorted as follows (Ramalingam, 2008, *p*.12):

- *"Actions which create value expected by the customer,"*

• *"Actions which do not create any value for the customer, but are required in the production system,"*

• *"Actions which do not create any value and those can be directly eliminated."*

The last type of activities from the list above and mentioned e.g., activities that do not create any value, are removed incessantly in a lean system. For example, rework on a defective product is a non-value added activity and needs to be eliminated through improving the processes to prevent defective products to occur in the first place.

As a base for improvement, the "current" value stream map is taken as a starting point to develop an "ideal" value stream map, which visualizes the production using only value added processes (Hettler, 2008). Figure 3 illustrates a current value stream map. According to Huang, (2008), a value stream map comprises data such as:

• Material and information flow from one process to another

• Inventory level at each process, including raw and work-in-process (WIP)

• Safety stock

• Supplier and customer information

• Conveyance of the product between processes

• IT and information flow

• Cycle time and Lead Time

• Quality level

• Downtime

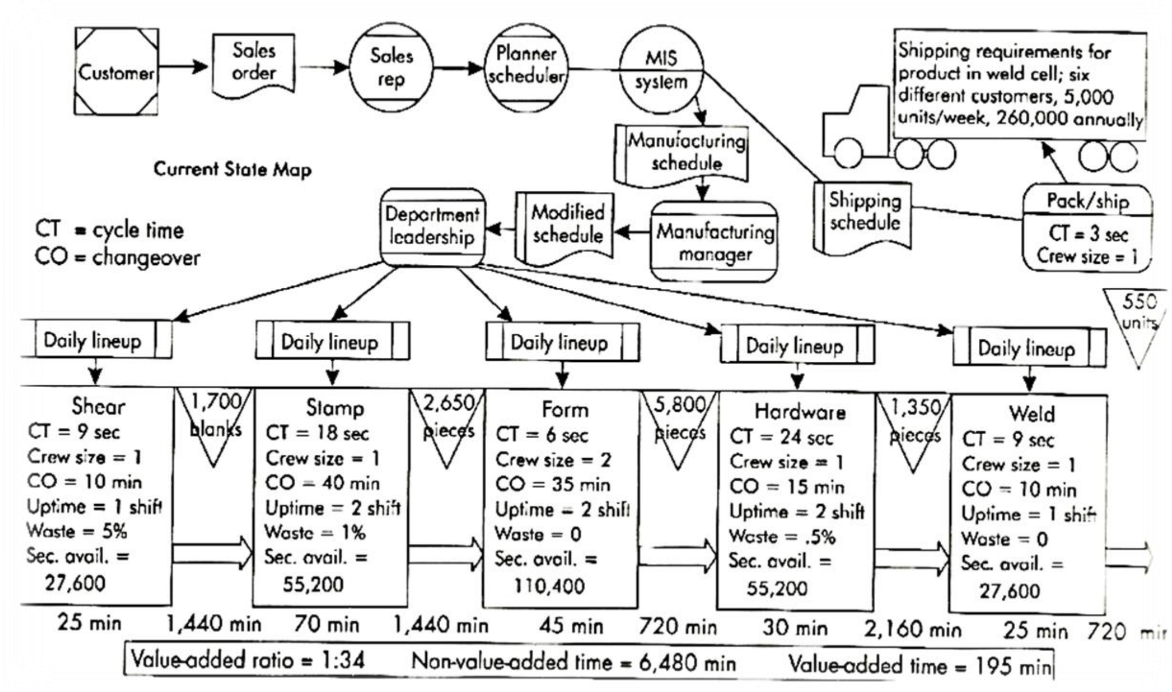

Figure 3: Example of a current state value stream map (source: Conner 2001).

As a rule, a team consisting of employees from a wide range of departments in an organization performs mapping activities (Ramalingam, 2008). The team collects data by tracking the product "…*As it is manufactured based on the existing conditions on the shop floor and not based on the old information* (Ramalingam, 2008. *p*.13)."

3.1.3.3. Flow

The power of "flow" is revealed by the application of continuous flow to the assembly line of Henry Ford (Morgan & Liker, 2006). Ramalingam's (2008) uses the concept of "flow" to describe the constant movement of materials through the manufacturing processes to produce customers' orders. Similarly, Liker (2004, *p*.88) stated that flow deals with the process of supplying raw materials needed for production stations that must start with a customer's order.

Actually, Liker (2004) stated that *"…Flow is the heart of the lean message that shortening the elapsed time from raw materials to finished goods (or services) will lead to the best quality, lowest cost, and shortest delivery time*."

3.1.3.4. Pull

"Pull" is a method that withdraws the parts needed for the current process from the preceding process (Monden, 2011). Pull begins with customer demand. Pull production is letting companies pull the value (products or services) by customers rather than pushing the products to the customers (Čiarnienė & Vienažindienė, 2012; Ramalingam, 2008). The inspiring idea of pull production derived from the replenishment of an individual item on supermarket shelves when the quantity of that item is low or out (Liker, 2004). Translating this idea to a manufacturing system, McLeod (2009) states that *"… Ohno utilized practices of Kanban inventory control, production smoothing, and set-up time reduction…* to facilitate pull (*p*.26)". Kanbans are physical or electronic elements that are used for conveying information that items are needed by the present process from the previous process (Čiarnienė & Vienažindienė, 2012).

3.1.3.5. Perfection

Upadhye (2010) stated that "*There is no end to the process of reducing effort, time, space, cost, and mistakes* (*p.*131)." Perfection is obtained by continuously removing waste from the system whenever and wherever waste is detected (Ramalingam, 2008).

The five major principles of lean for guiding the implementation of lean techniques (identifying value) are illustrated in Figure 4 (Lean Enterprise Institute, n.d.).

Figure 4: The five-step thought process for guiding the implementation of lean techniques (source: Lean Enterprise Institute, n.d.).

3.1.4. Liker's 14 Principles

In 2004, Liker categorized 14 principles under four categories (Table 1) to illustrate how to achieve success with the Toyota Production System (TPS). These four categories are: 1) *"Long-term philosophy,"* 2) "*The right process will produce the right results*," 3) "*Add value to the organization by developing people and partners*," and 4) "*Continuously solving root problems drives organizational learning"* (Liker, 2014). These 4 categories (4 Ps -philosophy, process, people, and problem solving) and 14 principles are illustrated in Table 1 and are explained in the following paragraphs.

The first category of Liker's principles, *Long-Term Philosophy*, includes only one of the fourteen principles. This first principle ("*Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals*, Liker, 2006, *p.*8") states that a philosophical sense of purpose is more important than making money. As an example, Liker (2004) states that Toyota, rather than firing its employees during a temporary downturn, keeps them employed and the employees work on projects supporting the company's long-term philosophical mission. The message in a philosophical sense is *"Do the right thing for the company, its employees, the customers, and society as a whole* (Liker, 2004, *p.* 72)." Having a philosophical mission is the starting point and the base for all the other thirteen principles. As part of the first principle, creating a philosophy requires a company to consider as to how they intend to generate value for the customer, the society, and the economy (Liker, 2004).

The second category of Liker's principles focusing on processes ("*The Right Process Will Produce the Right Results*, Liker, 2006, *p.*9*"*) includes seven of the fourteen principles of the Toyota way (e.g., the Toyota Production System (TPS)). The second principle ("*Create continuous process flow to bring problems to the surface"*) deals with problems of the process regarding the goal of achieving continuous process flow. Within the scope of the third principle ("*Use "pull" systems to avoid Overproduction"*), overproduction is prevented by the implementation of "pull." Production is triggered by Pull with the consideration of "*…What customers want, when they want it, and in the amount they want it* (Liker, 2004, *p.*37)." Liker (2004) states that principle four ("*Level out the workload or Heijunka"*) aims at *"… Eliminating overburden to people and equipment and eliminating unevenness in the production schedule* (*p.*37)." Principle five ("*Build a culture of stopping to fix problems, to get quality right the first time"*) calls for the prevention of the production of defective products. In this case, the Jidoka

Table 1: Liker's 14 management principles based on the Toyota Production System (adapted from Liker 2004).

Liker's 14 Toyota Way Principles
Category 1: Long-Term Philosophy
• **Principle 1:** Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.
Category 2: The Right Process Will Produce the Right Results
• **Principle 2:** Create continuous process flow to bring problems to the surface
• **Principle 3:** Use "pull" systems to avoid overproduction
• **Principle 4:** Level out the workload *(Heijunka).* (*Work like the tortoise, not the hare.)*
• **Principle 5:** Build a culture of stopping to fix problems, to get quality right the first time.
• **Principle 6:** Standardized tasks are the foundation for continuous improvement and employee empowerment
• **Principle 7:** Use visual control so no problems are hidden.
• **Principle 8:** Use only reliable, thoroughly tested technology that serves your people and processes.
Category 3: Add Value to the Organization by Developing your People and Partners
• **Principle 9:** Grow leaders who thoroughly understand the work, live the philosophy and teach it to the others.
• **Principle 10:** Develop exceptional people and teams who follow your company's philosophy.
• **Principle 11:** Respect your extended network of partners and suppliers by challenging them and helping them improve.
Category 4: Continuously Solving Root Problems Drives Organizational Learning
• **Principle 12:** Go and see for yourself to thoroughly understand the situation *(genchi genbutsu)*
• **Principle 13:** Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly (*nemawashi*)
• **Principle 14:** Become a learning organization through relentless reflection (*hansei*) and continuous improvement (*kaizen*)

concept, the second pillar of the TPS House (Figure 1), supports the application of this principle. Jidoka allows stopping machines and equipment when a defect on a product is found. Principle six ("*Standardized tasks are the foundation for continuous improvement and employee empowerment"*) aims to achieve continuous improvement and employee empowerment through standardization. In the lean philosophy, standardized tasks help reduce production related costs through the removal of waste within the system. In most organizations, large amounts of waste occur due to random activities and inconsistent methods. To eliminate waste in the system, variations in methods and processes need to be removed or minimized (Gao & Low, 2014.) Standardized work also is the foundation for "pull" and "flow" (Liker, 2004). With the standardization of tasks, predictability in the form of regular timing and output of a process are maintained (Liker, 2004). Principle seven ("*Use visual control so no problems are hidden"*) aims to reveal waste, problems, and unusual conditions in a process. Once problems are uncovered, they can be fixed. According to Liker (2004), the use of basic visual indicators accelerates the determination of where employees are in the progress of the production process, e.g., is there a deviation from the scheduled timeline or the standard? Liker's eighth principle ("*Use only reliable, thoroughly tested technology that serves your people and processes"*) can be described as a balance between technology and humans. According to Liker (2004) principle eight requires using reliable and tested technology to support employees rather than technology on its own. Using a new technology carries a risk of interrupting production processes. Liker (2004) also pointed out that new technology is usually unreliable and hard to standardize.

The third category of the Liker's principles (People - "*Add Value to the Organization by Developing People and Partners,* Liker, 2006, *p.*11*"*) comprises of three of the fourteen principles. This category refers to adding value to an organization through empowering employees and partners (e.g. suppliers). Principle nine ("*Grow leaders who thoroughly understand the work, live the philosophy and teach it to the others"*) aims to grow leaders in the organization rather than buying or hiring them from outside of the company (Liker, 2004). The leaders' assignments are not only about accomplishing given tasks, but also about being role models for the organization and its philosophy. For example, the Toyota Motor Company does not look for CEOs or presidents from outside of the company, but they grow their own leaders which assures more insight and understanding of the Toyota culture and philosophy. Principle ten ("*Develop exceptional people and teams who follow your company's philosophy"*) emphasizes that besides growing leaders in the organization, Toyota also grows *"…Exceptional people, and teams who follow your company's philosophy* (Liker, 2004, *p*.39)." This principle underlines the most important assets of any organization, which are its employees (Gao & Low, 2014). Principle eleven ("*Respect your extended network of partners and suppliers by challenging them and helping them improve"*) requires the company to consider partners and suppliers as an extension of the organization; according to Liker (2004), the firm challenge its partners and helps them to show their value and supports them in improving their operations and products

According to Liker (2004), category four (problem solving – "*Continuously Solving Root Problems Drives Organizational Learning*, Liker, 2006, *p*.13*"*) includes the last three principles of the Toyota Way. Those three principles are about building a culture of continuous problem solving in an organization. Principle twelve ("*Go and see for yourself to thoroughly understand the situation"*) advises all employees to go and see the problem at the source (called "Genchi Genbutsu" in Japanese, Arumugam et al., 2012). This principle allows for a better understanding of the problem in question, based upon which a better decision can be made. Principle thirteen ("*Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly"*) is defined as consensus-style decision making ("*nemawashi"*). Even though consensus style decision-making can be perceived as time consuming, when a decision is made, it is widely accepted and can be rapidly implemented. Principle fourteen ("*Become a learning organization* *through relentless reflection (hansei) and continuous improvement"*) focuses on creating "*... a learning organization through relentless reflection (hansei) and continuous improvement* (*kaizen*, Gao and Low, 2014, *p*.84)." Use "hansei" (Anglicized as "Reflection") to identify obstacles in a process and make provisions to not encounter these same problems again. In Lean organizations, hansei is also about taking responsibility for mistakes and explaining again with a written plan what is needed to be done so that the same problem will not be repeated (Liker & Morgan, 2006.) Liker (2004) quoted Bruce Browlee, a General Manager at the Toyota Technical Center, as saying:

> *"Hansei is really much deeper than reflection. It is really being honest about your own weaknesses. If you are talking about only your strengths, you are bragging. If you are recognizing your weaknesses with sincerity, it is a high level of strength. But is does not end there. How do you change to overcome those weaknesses? That is at the root of the very notion of Kaizen (continuous improvement). If you do not understand hansei, then kaizen is just continuous improvement. Hansei is the incubator for change – that whole process* (*p*.258)."

The fourteen principles discussed above can be interpreted as the way to Toyota's success, and these principles will guide companies to become lean organizations. Additionally, these principles clarify that everyone is a part of the solution and improvement while building a lean culture.

3.1.5. Waste

As previously mentioned, value is everything that customers are willing to pay for; in contrast, waste are all activities that do not add value to the product or the service from a customers' perspective (Quesada-Pineda & Buehlmann, 2011). Womack and Jones, in 1991, described seven types of waste and Liker in 2004 added an additional one. These eight non-value added activities in an enterprise are:

- "Overproduction" – when more items than needed are produced to meet current customer demand, it causes increased inventory and holding costs.
- "Waiting" – the time when machine do not produce or workers are waiting for material, maintenance crews, and tools to start production.
- "Unnecessary transportation" –transportation of items, data, or parts that are avoidable.
- "Over processing or incorrect processing" – unclear definition of process and project orders results in producing the wrong output.
- "Excess inventories" – costs are incurred for holding, waiting items between work-stations, and additional transportation is necessary.
- "Unnecessary movement" – excess walking and time spent during searching for equipment and tools by workers.
- "Defective products" – a product that does not comply with customers' expectations.
- "Unused employee creativity" – to eliminate this type of waste, managers and supervisors must listen to employees, obtain their ideas, benefit from their skills and learn about possible improvements.

Figure 5 shows how one can look at assets to find and eliminate waste (Čiarnienė & Vienažindienė, 2012).

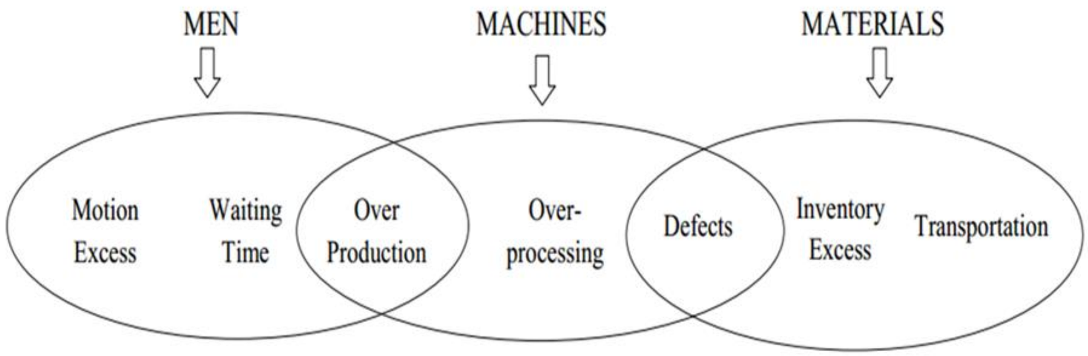

Figure 5: Wastes to be removed (source: Čiarnienė & Vienažindienė, 2012).

According to Ramalingam (2008), typically, less than 5% of all activities performed to make a product add value to a product. Thus, the elimination of non-value added activities allows the product to reach the end user without any interruption or delay.

3.1.6. Standardize Work

Whitmore (2008) mentioned what Taiichi Ohno's said in his article *"Without a standard, there can be no improvement* (*p.*171)." In this case, creating flow and pull is impossible without standardization of tasks, e.g., if each worker is allowed to choose their own work method and work sequence to complete the tasks, the outcome cannot be predicted and improvements cannot be made (Whitmore, 2008). Carrying out different work methods and work sequences by each worker means completing the same task with varying time requirements, which causes interruptions of flow. Therefore, differences for a same task are contrary to continuous improvement and must be eliminated by standardizing work in lean systems.

Standardized work can be described as the documentation and implementation of process/practices of methods on how tasks are defined, organized, and completed (Huang, 2008; Ramalingam, 2008). Each employee can perform the same tasks consistently in the same way until a better method is developed and be declared the new standard. Employee participation in the development of standards facilitates implementation and increases acceptance of the standard processes (Ramalingam, 2008.)

Several prerequisites are listed for standardization of work by Liker and Meier (2006), which are:

- *"The work task must be repeatable."* Description of a work cannot include *"if…then"* terms. As an illustration, if situation A occurs then carry out procedure B, if situation C occurs, carry out procedure D and so on. The condition above makes standardizing a work impossible unless it is described in a few simple rules.
- *"The line and equipment must be reliable, and downtime should be minimal."* One of the obstacles to standardization is the constant interruption of work and distraction of workers.
- *"Quality issues must be minimal."* Thus an employee does not struggle and loose time to fix poor quality issues.

3.2. Reduction of Set-up Time

Set-up time is described as the amount of the time taken between the production of the last good piece to the completion of the first good piece of the following run (Trevino et al., 1993). According to Enginarlar (2003), the main goal of set-up time reduction is to minimize machine downtime, minimizing losses of production capacity. Therefore, by minimizing set-up time, machine downtime and production capacity losses can be minimized and output of the production overall can be increased. However, as set-ups are indispensable for manufacturers of discrete products who produces multiple products, the negative impact of set-ups on production capacity needs to be held to a minimum (Coble & Bohn, 2005).

A higher frequency of producing different products by a manufacturing system increases the time spent for set-ups. In this case, reducing set-up time becomes a must to minimize the time loss caused by set-up activities. For example, in 1970, Toyota achieved to reduce the set-up time required for one of their 800-ton punch press for fenders and hoods from between two to three hours to three minutes (Monden, 2011). Such a single-minute set-up is widely known as SMED (Single-Minute Exchange of Die), and refers to a theory and technic that, optimally, set-up activities are performed within at most 9 minutes 59 seconds (a single digit number of minute, Shingo, 1985).

Monden (2011) explains that Taiichi Ohno realized that shortening the set-up time allows Toyota to reduce lot (batch) sizes. Thus, inventory of final and intermediate products can be reduced, hence, due to the shorter completion time of such smaller batches, producing in small batch sizes makes companies more responsive to customer needs and actual orders (Albert, 2004). Thus, smaller lot sizes reduce lead time and allows products to reach the customers with less delay. The Center for Industrial Research and Service (*CIRAS*, n.d.) lists the benefits of set-up time reduction, among others, as follows:

- Reducing lot sizes, leading to higher frequency of production of different models.

- Decreased lead time, which increases delivery performance leading to improved delivery.
- Improving documentation for set-up operations, resulting in improved quality.
- Reducing costs and inventory while achieving increased capacity.

According to Monden (2011), to shorten set-up time, four major concepts and six techniques for implementing these four concepts must be considered, as shown in Table 2 and explained in greater detail in the following sections.

Table 2: The four concepts and six techniques to shorten set-up time according to Monden (2011).

SET-UP CONCEPTS	CONCEPT IMPLEMENATATION
• **Concept 1:** Separate the Internal Set-up from the External Set-up • **Concept 2:** Convert as Much as Possible of the Internal Set-up to the External Set-up • **Concept 3:** Eliminate the Adjustment Process • **Concept 4:** Abolish the Set-up Itself	• **Technique 1:** Standardize the external set-up actions • **Technique 2:** Standardize only the necessary portions of the machine • **Technique 3:** Use quick fasteners • **Technique 4:** Use supplementary tools • **Technique 5:** Use parallel operations • **Technique 6:** Use mechanical set-up systems

3.2.1. Set-up Concepts

3.2.1.1. Concept 1: Separate Internal Set-up from External Set-up

Internal set-up is referred to as set-up activities that can be only performed when the machine does not run, whereas external set-up refers to set-up actions that can be performed while the machine runs (Cakmakci, 2009; Monden, 2011). Distinguishing the two types of set-up activity is easily done by answering the question: *"Do I have to shut the machine down to perform this activity* (Cakmakci, 2009, *p*. 170)?"

3.2.1.2. Concept 2: Convert as Much as Possible of the Internal Set-up to External Set-up

To achieve the goal of single-digit set-up time (SMED), converting as much of the internal set-up activities to external set-up activities becomes critically important (Cakmakci & Karasu, 2007; Monden, 2011). When changing internal set-up activities to external set-up activities, the machine can continue producing during the time that was switched from internal to external set-up activities. Monden (2011) gives an example that liners (spacers) can be used to standardize the die heights of a punch press or a molding machine to eliminate stroke adjustment. Thus, the process can continue to produce without stopping the punch press (or molding machine) to adjust its die heights. Figure 6 illustrates the example of using a liner to standardize die height.

3.2.1.3. Concept 3: Eliminate the Adjustment Process

Another concept to shorten set-up time is to minimize the adjustments necessary while setting up a machine/process, which usually comprise 50-70 percent of the overall internal set-up time required (Monden, 2011). As an illustration, Monden (2011) gives an example of a punch press producer who may produce a machine which is adjustable to diverse customers' (companies') die height requirements, however, each company may refrain from the stroke adjustment by standardization of its die height at a specific size.

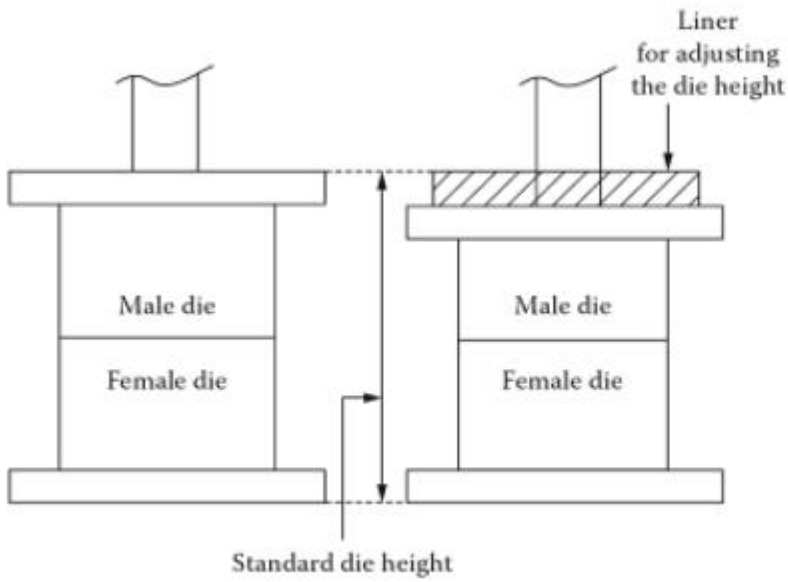

Figure 6: Using a liner to standardize die height (source: Monden 2011).

3.2.1.4. Concept 4: Abolish the Set-up Entirely

To remove the need for a set-up entirely, two approaches can be applied (Monden, 2011): 1 - Use uniform products in product design and the same parts for the production of various products (e.g. the same bracket for all products (Hopp & Spearman, 2011)). Or 2 - produce various products at the same time (e.g., stamping parts A and B in a single stroke and separating them later (Hopp & Spearman, 2011)).

3.2.2. Concept Implementation

3.2.2.1. Technique 1: Standardize the External Set-up Actions

To standardize the external set-up actions meant to turn the activities required by external set-ups into routines and standardize the operations necessary for preparing the dies, tools and materials (Monden, 2011).

3.2.2.2. Technique 2: Standardize Only the Necessary Portions of the Machine

Monden (2011) stated that standardizing the size/shape of all dies will result in reduced set-up time. However, the application of this type of standardization will be costly. Therefore, rather than standardizing all the machines, *"Only the portion of the function necessary for set-up is standardized* (Monden, 2011, *p*.192)."

One of the examples of these techniques is equalizing the dies' heights (Figure 6). Standardization of the die height and the die-holders allows elimination of the processes of removing and inserting of fastening tools, and adjustments. (Monden, 2011).

3.2.2.3. Technique 3: Use a Quick Fastener

Even though a bolt is one of the most frequently used fastening devices, fastening occurs only during the last turn of the nut, which can be loosened at the first turn. Therefore, fastening devices that allow fixation after only a single turn should be devised and used (Monden, 2011).

3.2.2.4. Technique 4: Use a supplementary Tool

The process of attaching a die to a punch press takes considerable time. Therefore, the attachment of the die to the punch press should be done in the external set-up stage; following this, the supplementary tool can be set in the machine at one touch in the internal set-up stage (Monden, 2011.)

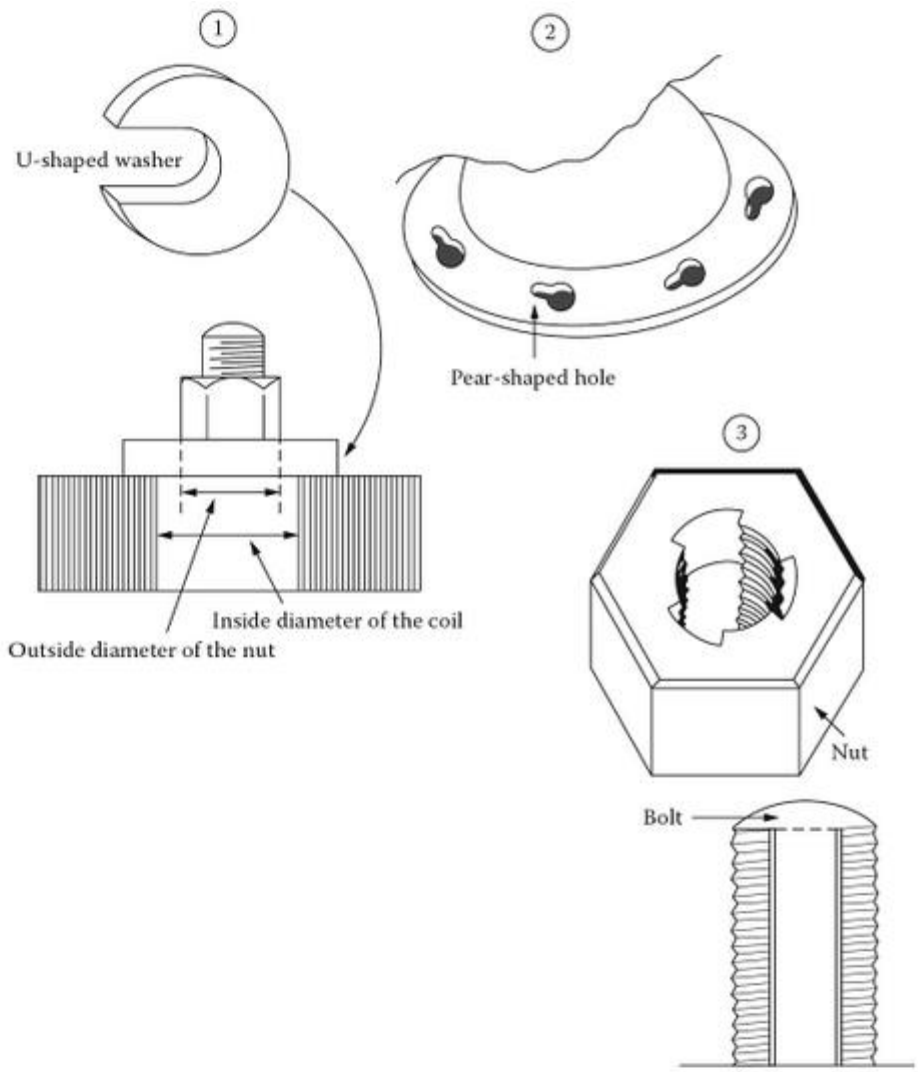

Figure 7: Several examples for of quick fasteners: 1- U-shaped washer; 2- Pear-shaped bolt hole; 3- nut and bolt with only corresponding portions grinded (source: Monden, 2011).

3.2.2.5. Technique 5: Use Parallel Operations

For some machines such as large presses, set-up actions will take a long time for just one worker. However, by using two or more workers for the set-up of such a machine (e.g. large punch press), wasteful movements can be eliminated or minimized. Even though total labor hours may stay the same for the set-up, effective operating time of the machine will increase (Monden, 2011).

3.2.2.6. Technique 6: Use a Mechanical Set-up System

Doing the attachment of the die, to fasten the die at several positions, oil or air pressure system could be beneficial. Additionally, electrically operated mechanisms can be used to adjust the height of a punch press. Even though these systems facilitate above adjustments, it may be an expensive investment for some manufacturers (Monden, 2011).

3.3. Documented Set-up Time Reduction Studies

Literature comprises of numerous studies relating to lean manufacturing in various areas/industries as well as to wood manufacturing. Studies of particular interest in wood manufacturing area, for example, Fricke (2010) who focused on lean manufacturing (and its tools) and is entitled *"Lean Management: Awareness, Implementation Status, And Need for Implementation Support in Virginia's Wood Industry."* Also, Erdogan 's (2015) paper *"Development of a Tool to Measure the Effectiveness of Kaizen Events within the Wood Products Industry*" researches the use of Lean tools by the wood products industry. However, the relevant literature does not include any study about the use of (Lean) set-up time reduction tools by the wood or the forest products industry while, however, numerous examples exist for other industries, such as:

Sheri et al. (2005), who wrote about "*Set-up time reduction for electronics assembly: Combining simple (SMED) and IT-based methods*." These authors present information about set-up time reduction for printed circuit board assembly (PCBA), an electronic component. In their study, the set-up time improvement achieved resulted in an 85 percent reduction of set-up costs while the reduction in internal machine set-up time per feeder was reduced to 11 seconds from1.7 minutes originally and total set-up time was reduced to 24 minutes from 158 minutes.

Yang et al., in 1993, published a study entitled *"Set-up time reduction and competitive advantage in a closed manufacturing cell"* examining the relationships between set-up time reduction, potential competitive benefits of manufacturing cells, and a projected cell performance by using a queuing model (M/G/1 model). Their paper revealed that with the reduced product set-up time, optimal product lot size, average and variance of average flow time can be decreased. Additionally, these authors found a link between set-up time reduction and potential competitive benefits for the firm in the market place in that the reduction of set-up time allows firms to increase delivery speed and to respond quicker to changes in the markets.

Bavuluri's (2012) paper entitled "*Set Up Time Reduction and Quality Improvement On the Shop Floor Using Different Lean and Quality Tools"* examined improving set-ups to reduce set-up time with an application of different lean techniques to reduce set-up time including 5S, SMED and FMEA (failure modes and effects analysis) in a semi-automated plant. Set-up improvements in the facility resulted in a nearly 50 percent reduction in inspection time, and loading and unloading time was reduced by 40 percent by using a newly designed handling for pump housing. At the same time, the cost of rework caused by alignment problems was eliminated and as a result approximately $13,000 are saved monthly.

Li in 2003, another paper related to set-up time reduction published "*Improving the performance of job shop manufacturing with demand-pull production control by reducing set-up/processing time variability."* This study was conducted as a simulation modelling experiment and explored the effects of set-up time reduction and processing time variability on the manufacturing performance of a job shop with demand-pull production control. This study revealed that using a Kanban system allows to minimize set-up time variability with appropriate layout of a job shop.

Above studies show that companies obtain several benefits from reductions in set-ups time in facilities,

including decreasing costs, improving flow time, faster response to customer demands, and facilitating employees work during set-ups. With respect to promoting findings from previous studies relating to set-up time, this study aims to reveal, set-up time reduction efforts and benefits from set-up time reduction in secondary wood manufacturing facilities.

4. METHODOLOGY

This study aims to reveal the success rate of set-up time reduction activities on woodworking machines (moulder, shaper, table saw, and band saw) in the secondary wood manufacturing industry of North America over the last decade (from 2005 to 2015). This ten-year period was chosen since some of the companies involved might not have undertaken any set-up improvement activities on their woodworking machines in recent years. Therefore, the ten-year period aims to increase usable responses from the survey and to help reveal general trends in set-up time reduction efforts in the industry. According to the Encyclopedia of Occupational Health and Safety from the International Labor Organization (n.d.) wood is typically processed in a regular facility "…*from rough planer, to cutoff saw, to rip saw, to finish planer, to moulder, to lathe, to table saw, to band saw, to router, to shaper, to drill and mortiser, to carver and then to a variety of sanders* (Woodworking Processes chapter, para. 4)." In this case, the machines listed below were chosen due to their widespread use in secondary wood products manufacturing enterprises.

- Moulder
- Table saw
- Shaper
- Band Saw

Some more advanced machines, such as CNC (computer numerical control) wood routers, are not included in this study. The main reason for excluding CNC machines and similar equipment is their complexity and the variability in set-up requirements. In this case, this variety makes it difficult to compare the set-up time reduction performance on CNC-routers between different facilities.

4.1. Data Sources

4.1.1. Population of interest

This survey targets industries which widely use moulders, band saws, table saws, shapers, and require frequent changes in set-up of these machines. Thus, the survey looks at members in the wood products manufacturing (NAICS 321) and furniture manufacturing (NAICS 337) industry segment (U.S. Census Bureau, 2012). However, not all the sub-categories of these two industries are within the scope of this study. For example, sawmills (NAICS 321113), wood preservation (NAICS 321114), and metal household furniture manufacturing (NAICS 337124) manufactures, among others, are of no interest to this study. Table 3 displays the NAICS categories targeted.

Table 3: The targeted NAICS industry categories of this study (sub-categories to main categories are represented as non-shaded areas to dark-shaded areas).

	2012 NAICS CODE	**NAICS Description**
1	(NAICS 321)	Wood Product Manufacturing
2	(NAICS 32191)	Millwork
3	(NAICS 321911)	Wood Window and Door Manufacturing
4	(NAICS 321912)	Cutstock, Resawing Lumber, And Planning
5	(NAICS 321918)	Other Millwork (Including Flooring)
6	(NAICS 337)	Furniture and Related Product Manufacturing
7	(NAICS 3371)	Household And Institutional Furniture And Kitchen Cabinet Manufacturing
8	(NAICS 33711)	Wood Kitchen Cabinet and Countertop Manufacturing
9	(NAICS 33712)	Household, Institutional Furniture Manufacturing
10	(NAICS 337121)	Upholstered Household Furniture Manufacturing
11	(NAICS 337122)	Nonupholstered Wood Household Furniture Manufacturing
12	(NAICS 337127)	Institutional Furniture Manufacturing
13	(NAICS 3372)	Office Furniture (Including Fixtures) Manufacturing
14	(NAICS 337211)	Wood Office Furniture Manufacturing
15	(NAICS 337212)	Custom Architectural Woodwork and Millwork Manufacturing

4.1.2. Online Questionnaire

The online survey questionnaire was created using the Qualtrics survey system (Qualtrics, 2005). A link of this web-based survey was shared in a trade magazine and its associated electronic newsletters. The link directed each respondent to the (web-based) survey, which was hosted on Virginia Tech's server (https://virginiatech.qualtrics.com/).

4.1.3. Mailing List

Possible respondents from wood manufacturing enterprises were reached through a trade publication (FDM&CM; http://www.fdmcdigital.com/). The underlying idea of cooperating with a trade magazine is to benefit from the magazine's network of industry professionals, hopefully resulting in an increased number of responses. The higher response rate increases the statistical validity of the findings of the study by collecting more data from the population (Great Book n.d.; UMEX 2002)

Other options for collecting responses would be surveying companies by mail, by phone or face to face. However, these two options were excluded, because conducting online surveys allows us to reach more companies and obtain more responses in a short time. Table 4 demonstrates the advantages and disadvantages of conducting an online survey. According to Sue and Ritter (2011), if a study requires a large sample size in a widely distributed geographical area, conducting online surveys will be a better alternative than surveying by mail and telephone. Additionally, web based surveys have the advantages of lower cost and quicker responses (fast data collection with internet) and higher response rate expectancy (Bonometti & Tang 2006, Van Selm & Jankowski 2006).

Table 4: Advantages and disadvantages of conducting an online survey (adapted from Sue and Ritter 2011).

Advantages	Disadvantages
Low cost	Coverage bias
Fast	Reliance of software
Efficient	Too many digital surveys, causing overload
Contingency questions effective	
Direct data entry	
Wide demographic reach	

4.2. Questionnaire Design

A copy of the final questionnaire can be found in Appendix A. The survey is divided into four main sections: Objective, Company Information, Set-up Time Reduction Efforts, and General Questions. The introductory part of the questionnaire comprises introductory information about the aim of this study and brief explanations of technical terms (set-up time, and external/internal set-up). The company information section includes the questions that were created as part of this study to reach the target respondents (e.g. plant/operations/production manager) and collect general information, including number of employment, type of facility, and locations. The set-up time reduction efforts section consists of questions related to the set-up time reduction efforts on selected woodworking machines. The final section, general questions, comprises questions that ask for information about the most successful set-up time reduced machine through set-up time reduction and (if any) the bottleneck causing machines in the respondents' facilities. Each section is discussed below.

4.2.1. Company Information

In the Company Information section, questions are asked to assure that the survey is answered only by suitable companies and by knowledgeable employees in individual enterprises. Knowledgeable employees include individuals serving as plant managers, production managers, operations managers, continuous improvement person, or maintenance crew members (Q1). This section also asks questions directed to obtain information about:

- ↳ The main product produced by their facility and whether the product type affects set-up time reduction in facilities (Q2).
- ↳ The geographical location of the respondent's facility (Q3, Q4, Q5, and Q6).
- ↳ To compare the set-up time reduction efforts in the secondary wood manufacturing firms based on their employment sizes (table 5, and Q7).
- ↳ During the period 2005 to 2015, did a respondent’s facility make any effort to reduce set-up time in their facilities (Q8)? Only answered in the affirmative, respondents from targeted facilities are allowed to continue the questionnaire.

In this study, the sizes of enterprises/facilitates are classified into four types as follows: - (1) Very small enterprises/facilities which employ fewer than 20 employees – (2) Small enterprises/facilities, which employ 20 to 99 employees – (3) Medium enterprises/facilities, which employ 100 to 499 employees – and (4) Large enterprises/facilities which employ 500 or more employees. This classification is also used in the Statistics of U.S. Businesses report (2015). Table 5 demonstrates the scales of enterprises/facilities based on their total number of employees.

Table 5: Classification of enterprises based on employment.

Company Category	Number of Employees
Very small enterprises/facilities	Fewer than 20 employees
Small enterprises/facilities	20 to 99 employees
Medium enterprises/facilities	100 to 499 employees
Large enterprises/facilities	500 or more employees

4.2.2. Set-up Time Reduction Efforts

The second section of this survey is called *Set-up Time reduction efforts*. In this section, the primary concern is to find out if companies have used active, directed set-up time reduction efforts in their facilities. If respondents have used active, directed set-up improvement efforts in their facility, follow up questions are asked about set-up time reduction efforts on two (of four) types of basic woodworking machines. The machines selected are: moulder, band saw, table saw, and shaper. For these four machines, the questions were developed to understand the effectiveness of a company's set-up time reduction with the following inquires:

- ↳ To ensure the respondents' facilities own (at least one of) the selected woodworking machines for this study (Q9, Q10, Q11, and Q12) and measure success rate of the set-up time reduction on these machines.
- ↳ Between 2005 and 2015, the rate of set-up time improvement (as a percentage) on the woodworking machines (Q13, Q23, Q31, and Q39). The reason for specifying the ten-year period is that in recent years, some companies might not have worked on set-up time improvement on these four woodworking machines.

- The single most important outcome achieved with the set-up time reduction (Q14, Q24, Q32, and Q40).
- The rank of increasing throughput (productivity) depending on the set-up time improvement on the woodworking machine (Q15, Q25, Q33, and Q41).
- To find out the most successful areas of the set-up time reduction related to the woodworking machine (Q16, Q26, Q34, and Q42).
- To understand the most time consuming part of their woodworking machines' set-ups (Q17, Q27, Q35, and Q43).
- To learn about how frequent their machines need set-up on a typical day (Q18, Q28, Q36, and Q44).
- To find out the success rate of the set-up time reduction between firms who trained their workers/operators on how to set-up the woodworking machine and who did not (Q19, Q29, Q37, and Q45).
- To understand the effect of the training provider types (e.g. manufacturer of the woodworking machine, and company personnel) on the set-up time reduction success on the woodworking machine (Q20, Q30, Q38, and Q46).

4.2.3. General Questions

The General Questions section (final section) of the survey is prepared to obtain information about where facilities were the most successful in their set-up time reduction efforts, and to learn more about their bottleneck problems in their facilities. The aim here is to reveal if there is a connection between the bottleneck and the machine for which the most effective set-up time reduction has been achieved. To that end, the following information was inquired about:

- The machine where the largest set-up time reduction was achieved in their facility (see Q47).
- The most rewarding outcome of the set-up time reduction effort for the respondent's company (Q48).
- The machine that creates a production bottleneck (if any) (Q49 and Q50) and the cause of this bottleneck (Q51).
- And what solution (if there is any) did they find for this bottleneck (Q52)

5. RESULTS

This chapter presents the data obtained from the web-survey and is divided into three parts according to the sections used in the questionnaire; *Company Information, Set-up Time Reduction Efforts* and *General Questions.*

The web-based survey conducted was accessible online for 73 days (October 06, 2015 – December 17, 2015). During this (approximately) two and a half months surveying period, 24 completed responses were received. 23 of these responses were considered valid and analyzed.

5.1. Company Information

Respondents were asked to indicate which job positions they held (Q1). Most survey participants were plant managers (eight of twenty-three total respondents), among the remaining respondents were seven owners, four continuous improvement persons, two operation/production managers, one process engineer, and one CEO (Table 6).

Table 6: The statistics on respondents' job descriptions.

Job Descriptions	Number of Participants
Plant Manager	8
Continuous Improvement Person	4
Operations / Production Manager	2
Owner	7
Process Engineering Manager	1
Pres/CEO	1
TOTAL	**23**

When asked about the main product produced by repondents' facilities. Six respondents indicated that they are Wood Kitchen Cabinet and Countertop Manufacturers (NAICS 33711), followed by four Household, Institutional Furniture Manufacturer (NAICS 33712), four

Millwork Manufacturers (NAICS 32191), and one Office Furniture (including Fixtures) Manufacturer (NAICS 3372). Additionally, eight respondents selected *Other* product types manufacturing (Table 7). Respondents who selected the *Other* product types manufacturing, specified their main product types as:

- Store fixtures,
- All of the above (note: means all the standardized answers of the question),
- Custom cabinets, furniture, millwork,
- Wood moulding,
- Cabinet Components,
- Custom wood products to customer specs,
- POP display,
- Custom AV related furniture.

When respondents were asked about the location of their facilities in North America, the most common answer was *the U.S*. Only one respondent indicated that the location of his/her facility is in Canada, while no response came from Mexico. Table 8 demonstrates the location of respondents' facilities by state/province.

When respondents were asked about employment sizes in their facilities, 14 of them indicated that their employment sizes are between *one to 19*, followed by six facilities with *20 to 99* employees, two facilities with *100 to 499* employees and one facility with the *500 or more* employees (Table 9).

Table 7: The main product category produced in respondents' facilities.

The main product category		Number of Response
Millwork		4
Wood Kitchen Cabinet and Countertop Manufacturing		6
Household, Institutional Furniture Manufacturing		4
Office Furniture (Including Fixtures) Manufacturing		1
Other		8
Other	1. All of the above	
	2. Store fixtures	
	3. Custom cabinets, furniture, millwork	
	4. Wood moulding	
	5. Cabinet Components	
	6. Custom wood products to customer specs	
	7. POP display	
	8. Custom AV related furniture	
TOTAL		**23**

Table 8: Locations of the facilities of respondents.

	States/Province	Number of Facilities
The United States	**CA** California	2
	GA Georgia	1
	IL Illinois	1
	IN Indiana	1
	ME Maine	1
	MN Minnesota	2
	NC North Carolina	3
	NE Nebraska	1
	NJ New Jersey	1
	NY New York	2
	OH Ohio	2
	PA Pennsylvania	2
	TX Texas	1
	VA Virginia	1
	WA Washington	1
	TOTAL	**22**
Canada	AB Alberta	1
	TOTAL	**1**
	TOTAL (USA&CANADA)	**23**

Table 9: Employement sizes in facilities of respondents.

Employment Size	Number of Facilities
1 to 19 employees	14
20 to 99 employees	6
100 to 499 employees	2
500 or more employees	1
TOTAL	**23**

5.2. Set-up Time Reduction Efforts

When asked about any coordinated, targeted set-up time reduction efforts in respondents' facilities between 2005 and 2015, 16 participants answered *Yes* while seven of the total 23 participants selected *No* (Appendix A). Participants who said *Yes* were allowed to see and answer the rest of the questions. Of those 16 participants, we inquired about two of four woodworking machines (moulder, table saw, band saw, and shaper) selected for this survey. Thus, we obtained data for set-up time reduction efforts on 11 moulders, 15 table saws, 3 shapers, and 2 band saws (Table 10).

Table 10: Numbers of specified machine types.

Machine Type	Number of Machines
Moulder	11
Table Saw	15
Shaper	3
Band Saw	2
TOTAL	**31**

5.2.1. Set-up Time Reduction Efforts: Moulder

This section presents the data obtained about set-up practices on moulders where set-up time reduction efforts have been undertaken based on 11 responses collected through the online questionnaire. When respondents were asked considering any moulder in their facility, how they rate their set-up time improvement results between 2005 and 2015 (Appendix A, Q13), four respondents stated that their set-up time improvement was between 5% to 9.9 %, followed by three respondents with 0 % to 4.9 % improvement, another three respondents with more than 15% improvement and one respondent with no improvement (Table 11).

Table 11: Set-up time improvement where set-up time reduction efforts have been undertaken on the moulder between 2005 and 2015.

Set-Up Time Improvement	Number of Responses
None	1
0-4.9 %	3
5-9.9 %	4
10-14.9 %	0
More than 15 %	3
TOTAL	**11**

When asked about the single most important outcome from reducing the set-up time for the moulder, five participants (corresponding to 46% of the total) answered *Improved responsiveness to customer demands*, followed by two (18%) *Reduced batch sizes*, two (18%) *Reduction of WIP/inventory*, one (9%) *Increasing productivity/capacity*, and one (9%) *outsourcing* (Table 12).

When respondents were asked how they rank the productivity improvement (in terms of increasing throughput) as related to the set-up time improvement on the moulders in question, seven participants answered *Little*, while four of 11 participants selected *A lot*.

When participants were asked in which area of a moulder's set-up requirements has been reduced, the most frequent answer was *Searching for tools and equipment while doing set-up* (four answers), followed by *Mounting and adjusting cutterheads* (three responses), *Converting* *internal set-up time to external set-up time* (three responses), *Adjusting cutting depths and widths* (two responses), *Cleaning activities* (two responses), and *Other* (two answers; Table 13).

Table 12: The single most important outcome achieved through set-up time reduction of moulders.

The Single Most Important Outcome	Number of Responses
Improved responsiveness to customer demands	5
Increasing productivity/capacity	1
Reduced batch sizes	2
Reduction of WIP/inventory	2
Other - outsourcing	1
TOTAL	**11**

Table 13: Areas where the set-up time was reduced the most (Moulder).

Areas/places	Number of Responses
Mounting and adjusting cutterheads (knives, cutter etc.)	3
Adjusting cutting depths and widths	2
Searching for tools and equipment while doing set-up	4
Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)	2
Converting internal set-up time to external set-up time	3
Other	2
TOTAL	**16**

When asked what is the most time consuming part of a respondent's moulder set-up, four responses were *Mounting and adjusting cutterheads*, followed by two *Adjusting cutting depths and widths*, two *Trial runs*, one *Searching for tools and equipment while doing set-up,* one *Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)* and one *Other*. The participant who indicated *Other* did not specify the most time consuming part of their moulder set-up (Table 14).

Table 14: The most time consuming part of a moulder set-up.

The most time consuming part	Number of Responses
Mounting and adjusting cutterheads (knives, cutter etc.)	4
Adjusting cutting depths and widths	2
Searching for tools and equipment while doing set-up	1
Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)	1
Trial runs	2
Other	1
TOTAL	**11**

All respondents indicated that they train their workers/operators on how to set-up their moulders. However, when asked about who trained their workers/operators, the most common answer was *Company personnel* (nine answers), followed by *Manufacturer of the moulder* (two answers) and *Experts from outside of the company* (two answers).

5.2.2. Set-up Time Reduction Efforts: Table Saw

This section presents the data obtained on table saws based on 15 responses collected through the online questionnaire. When respondents were asked considering any table saw in their facility and the respective set-up time improvement achieved between 2005 and 2015 (see Appendix A, Q23), six respondents (corresponding to 40%) indicated that the set-up time improvement was *0 to 4.9* percent, followed by three responses (20%) indicating improvement of *more than 15* percent improvement, two responses (13%) with a *5 to 9.9* percent improvement, and two responses (13%) with *no* improvement while two other respondents (14%) did not provide an answer (Table 15).

Table 15: Set-up time improvement where set-up time reduction efforts have been undertaken on the table saw between 2005 and 2015.

Set-Up Time Improvement	Number of Responses
None	2
0 - 4.9 %	6
5 - 9.9 %	2
10 - 14.9%	0
More than 15%	3
N/A	2
TOTAL	**15**

When asked about the single most important outcome from reducing the set-up time for the table saw, five participants (39%) answered *Increasing productivity/capacity*, followed by two participants (15%) *More frequent set-ups/improve flexibility*, two participants (15%) *Reduced batch sizes*, one participants (8%) *Reduced maintenance due to shorter cycles*, one participants (8%) *Improved responsiveness to customer demands,* while two participants (15%) selected *Other.* One of the participants who indicated *Other* specified his/her answer as "*We run all parts on a nested based CNC now. much faster"* while the other one did not specified any response (Table 16).

When respondents were asked as to how they rank the productivity improvement (e.g., increases in throughput) depending on the set-up time improvement on a specified table saw, four responded either *Little* or *Some*, while two participants responded *None* and another two responded *A lot*.

When respondents were asked as to how they rank the productivity improvement (e.g., increases in throughput) depending on the set-up time improvement on a specified table saw, four responded either *Little* or *Some,* while two participants responded *None* and another two responded *A lot*.

Table 16: The single most important outcome achieved through set-up time reduction of table saws.

The single most important outcome	Number of Responses
Improved responsiveness to customer demands	1
Increasing productivity/capacity	5
More frequent set-ups/Improve flexibility	2
Reduced batch sizes	2
Reduced maintenance due to shorter cycles	1
Other	2
TOTAL	**13**

When participants were asked in which area of the table saw set-up activities time has been reduced the most, commonly selected answers were *Searching for tools and equipment while doing set-up* (four answers) compared to *Adjusting cutting depths and widths* (three answers), *Mounting and adjusting cutterheads* (one answer), *Converting internal set-up time to external set-up time* (one answer) *Cleaning activities* (one answer), and *Other* (four answers). Participants who selected *Other* indicated:

- *"Set-up time between parts has been reduced. Our operation runs a mixed-model, one-piece continuous flow. Batch size of one"*
- *"Don't use saw much because of CNC,"* and
- *"Fixturing"*

When asked the most time consuming part of a respondent's table saw set-up, seven participants (54%) answered *Mounting and adjusting cutterheads,* followed by two (15%) *Trial runs*, two (15%) *Adjusting cutting depth and width* one (8%) *Cleaning activities*, and one (8%) *Searching for tools and equipment while doing set-up* (Table 17).

Table 17: The most time consuming part of a table saw set-up.

The most time consuming part	Number of Responses
Mounting and adjusting a circular saw or a combination cutter	7
Adjusting cutting depth and width	2
Searching for tools and equipment while doing set-up	1
Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)	1
Trial runs	2
TOTAL	**13**

Except one, all respondents stated that they trained workers/operators about the set-up of their table saw. When asked about who trained their workers/operators, the most common answer was *Company personnel* (twelve answers), followed by *Experts from outside of the company* (one answer).

5.2.3. Set-up Time Reduction Efforts: Shaper

This section presents the data about the shaper based on three responses collected through the online questionnaire. When respondents were asked considering any shaper in their facility and how they rate their set-up time improvement achieved between 2005 and 2015 (see Appendix A, Q31), two respondents answered *5 - 9.9 %* while one respondent indicated *More than 15%*.

When asked about the single most important outcome from reducing the set-up time for the shaper, one participant answered *Increasing productivity/capacity* one participant *More frequent set-ups/improve flexibility* and the other participant's answer was *Reduced batch size*.

When respondents asked how they rank the productivity (increasing throughput) depending on the set-up time improvement on a specified shaper, two responses were *A lot* and one response was *Some*.

When participants were asked in which area set-up time has been reduced, the most frequent response was *Adjusting cutting depth and width* (two answers) while the other participant indicated *Mounting and adjusting a cutterhead*.

Additionally, when asked on the training of workers/operators about the set-up of their shapers, two respondents answered *No* and one respondent answered *Yes*. Additionally, when asked about who trained their workers/operators, the respondent's answer who stated *Yes* was *Company personnel.*

5.2.4. Set-up Time Reduction Efforts: Band Saw

This section presents the data about band saws based on two responses collected through the online questionnaire. When respondents were asked considering any band saw in their facility as to how they rate their set-up time improvement between 2005 and 2015 (Appendix A, Q39), one respondent answered *None %,* while the other respondent answered *More than 15%.*

When respondents were asked how they rank the productivity increases achieved (e.g., increasing throughput) depending on the set-up time improvement on the band saw in question, one participant answered *A lot* while the other respondent did not provide an answer.

When participants were asked which activity reduced set-up time the most, both respondents answered *Other* and one explanation was "*Fixturing for cutting different components"* while the other respondent did not provide an answer. Similarly, when asked about the most time consuming part of a respondent's band saw set-up, one answer was *Mounting a blade in a machine* while the other respondent did not provide a response.

No answers were obtained as to the band saw training activities in their respective facilities.

5.3. General Questions

In the last section of the survey, the first question was about with which machine participants had achieved the largest set-up time reduction in their facilities; the most common answers were *CNC type machines* (five responses) and *Moulders* (five responses; Table 18).

Table 18: Machines that the largest set-up time reduction was achieved.

Machine Type	Number of Responses
CNC type machines	5
Molders	5
Point to Point Router	1
Cut-off saw	1
Gang Rip Saw	1
Rear load panel saw	1
Shaper (Unique 250 Door Machine)	1
TOTAL	**15**

When asked which set-up time reduction effort was the most rewarding for their company, seven respondent indicated *New equipment technology*, followed by four *Moving internal activities into external ones*, four *Searching for tools and equipment while doing set-up*, three *Adjusting cutting depth and width*, three *Cleaning activities*, and one *Mounting a blade in a machine* (Table 19). Three participants selected *Other* and provided the following explanations:

- *"Cut patterns are done remotely and saved to a dedicated server so operators just have to run the saw and load stock."*
- *"Creating unique ways to have parts ready and set our POD and Rail system to change over quickly from part to part."*

- One participant did not indicate his/her response.

Table 19: The most rewarding set-up time reduction effort in respondents' companies.

The Most Rewarding Set-Up Time Reduction Effort	Number of Responses
Moving internal activities into external ones	4
Adjusting cutting depth and width	3
Searching for tools and equipment while doing set-up	4
Cleaning activities	3
Mounting a blade in a machine	1
New equipment technology	7
Other	3
TOTAL	**25**

When participants were asked if they do have a machine that creates a production bottleneck in their facilities, seven respondents answered *Yes* while nine respondents' answered *No.* Follow up questions, (asking for the bottleneck machine, reasons for bottlenecks, and solutions for the specified bottleneck) were asked to the respondents who said *Yes.* Table 20 shows the data for those follow up questions.

Table 20: Bottleneck machines, reason for and solution to the specified bottleneck.

Bottleneck Machine	Reason	Solution
Drum Sander	Set up time required	Not specified
Ripsaw	Machine failures	Manufacturer engineered better parts
Door and panel clamp machines	Glue drying	Fans, and leave gaps between products for air flow
Moulder	Production needs	Overtime
Auto Drilling	Set up time required	SMED set-up reduction
Costa Sander	Speed of the machine	Purchased another machine
CNC	Speed of the machine	Highly scheduling issues, obtained second CNC

6. DISCUSSION

6.1. The Survey

The research survey on *Set-up Time Reduction in Secondary Wood Manufacturing Facilities*, was conducted from October 06, 2015 to December 17, 2015. Given the importance of the topic and with the support of one of the leading trade magazines in the U.S. (FDM&CM) promoting the study, one would have wished for a higher participation rate than the one obtained (twenty-three valid responses). This low response rate may be due to several reasons. One being that the response rate of a survey is closely associated with a topic and the time required to complete the survey (Fan & Yan 2010). Indeed, potential respondents may have avoided to participate in the survey due to the estimated time required to complete the survey (15-20 minutes). Also, targeting multiple job positions for participants of the survey may have led to a lower number of possible respondents as not all employees were able to answer all the survey questions due to a lack of knowledge. Thus, potential respondents working as sales employees, production employees, or safety employees, to name a few, might not have been able to participate. Also, a part of possible respondents may not be able to access the Internet during their work hours and they may not want to spend their personal time to take the survey. Furthermore, possible respondents may consider set-up time reduction efforts as not necessarily needed or beneficial for their facilities. Thus, it can be speculated that the *Set-up Time Reduction in Secondary Wood Manufacturing Facilities* survey might not have been of considerable interest to a majority of woodworkers. When consider the low number of responses by larger firms; possibly larger firms do not use shapers, table saws, and band saws as extensively as smaller firms while larger firms can be more likely to use moulders in their facilities than facilities of smaller firms.

Although only a limited number of participants participated in the survey (twenty-three participants), respondents were mostly employees in the targeted job positions (plant or production managers, continuous improvement persons), assuring that the responses obtained have been given by knowledgeable professionals. Thus, despite the low response rate, the findings from this study can be considered relevant. However, the conclusions drawn from this study only apply to the facilities of the survey participants and they do not represent the general North American secondary wood manufacturing population or subscribers of FDM&CM.

6.1.1. Discussion of Survey Answers

6.1.1.1. Employment Size and Location

In terms of company size by employees, mostly respondents from smaller facilities participated in the survey. Fourteen respondents out of the total of 23 indicated the employment size in their facilities to be under 19 employees, and six respondents indicated that they have between 20 and 99 employees, while two respondents indicated to work in facilities with 99 to 499 employees and one respondent indicated to work in a facility with 500 or more employees. Although the survey was designed to obtain answers from three countries (the U.S., Canada, and Mexico), with the exception of one respondent from Canada, all respondents (twenty-two respondents) indicated that their facility is located in the U.S. Possibly, potential respondents in Mexico may have been willing to participate if the promotion of the survey and the survey itself would have been presented in their native language and/or be advertised in their national woodworking magazine. Also, advertising the survey in an appropriate Canadian woodworking magazine may have increased the number of responses from Canada.

6.1.1.2. Frequency of Set-up Time Reduction Efforts

Two-thirds of the respondents (sixteen of twenty-three respondents) indicated that they made efforts to reduce set-up time in their facilities. Seven respondents (who indicated that they did not make any efforts to reduce set-up time in their facilities) were displayed a *Thank you* message and their survey was terminated. In facilities where respondents did not make any set-up time reduction effort, managers (of facilities/firms) may not aware of benefits of set-up time reduction, or managers may be satisfied with the set-up time spent in their facilities. However, more research is needed to make conclusions about why there were no set-up time reduction efforts in some facilities. Respondents who indicated that they did not make any set-up time reduction efforts were not asked any follow up questions (only facilities who made set-up time reduction efforts were surveyed).

6.1.1.3. Number of Responses for Machines

The survey asked questions about four machines (moulder, table saw, shaper, and band saw), where each respondent was asked only to respond for two machines. Most data was collected for table saws with 15 (of sixteen respondents) answering table saw related questions in the survey. For moulders, data was obtained from 11 of the 16 respondents who indicated to undertake set-up time reduction efforts. For shapers and band saw, we expected to obtain somewhat lower numbers of responses as due to the logic of the online survey (respondents were able to answer questions for two machines with moulder being presented first, then table saw, followed by shaper and band saw). Therefore, only a limited number of respondents were able to see the questions for shapers and band saws. To that end, data was collected from three respondents for shapers, and two respondents for band saws.

6.1.1.4. Set-up Time and Productivity Improvement

For moulders, only one out of a total of 11 respondents indicated their set-up time improvement result as *None,* while all the other respondents indicated that they achieved some set-up time improvement in their facilities thanks to their set-up time reduction efforts. Set-up time improvements (where set-up time reduction efforts have been undertaken) achieved ranged from *0 – 4.9%* in three facilities, *5 – 9.9 %* in four facilities of respondents, and *more than 15 %* in three facilities of respondents.

When respondents were asked about how they would rank the productivity gains (increasing throughput) related to the set-up time improvement on their moulder, seven respondents rated the gain as *Little,* while another four respondent rated the gains as *A lot.* Therefore, without any exception, all the respondents who undertook set-up time reduction efforts on their moulders indicated that they improved their productivity in terms of increasing throughput.

For table saws, only two out of a total of 13 respondents indicated that their set-up time improvement efforts resulted in no reduction of set-up time while the 11 remaining respondents indicated that they achieved set-up time improvement in their facilities. Set-up time improvement ratings ranged from *0 – 4.9%* in six facilities, *5 – 9.9 %* in two facilities, and, *More than 15 %* in three facilities, while two respondents indicated *None*.

When respondents were asked how they would rank the productivity gains based on the set-up time improvement achieved on their table saw (twelve responses were obtained), two respondents indicated *None* was achieved, while four respondents responded that *Little* improvement was gained, while another four respondents indicated that *Some* improvement was achieved and two respondents rated their improvement as *A lot*. Overall, a majority of respondents concerning their table saw set-up time reduction efforts (ten out of total twelve responses) indicated productivity improvements (in terms of increasing output) related with the set-up time improvement efforts on their table saws.

For shapers, for which only three responses were obtained, all participants indicated they achieved at least some set-up time improvement. Two out of the total of three respondents rated the set-up time improvement achieved between *5-9.9%* while another respondent rated the achievement as *More than 15%.* When respondents were asked to rate the productivity improvement achieved thanks to the set-up time improvement on their shapers, one respondent indicated that *Some* productivity was gained while another two respondents indicated that *A lot* of productivity improvement was achieved.

For bands saws, only two responses were obtained, and one respondent rated their set-up improvement as *None* while the other respondent rated their set-up time improvement result as *More than 15%.* When respondents were asked to rate the productivity improvement depending on the set-up time improvement achieved on their band saw the answer was *A lot* by the only respondent who achieved a set-up time reduction.

6.1.1.5. Time Spent

When we asked questions about the most time consuming area for specific machine set-ups, four of the 11 answers relating to the moulder were *Mounting and adjusting cutterheads (knives, cutter etc.)* and for table saws seven of the 13 answers were *Mounting and adjusting a circular saw or a combination cutter.* Table 21 demonstrates the number of responses given by participants for the most time consuming area for their machine set-ups.

With respect to the four different types of woodworking machines specified in this study (moulder, table saw, shaper, band saw), respondents indicated that the same activity (*Mounting and adjusting*) is the most time consuming activity during their set-up for 13 out of a total of 28 machines (Table 21). *Mounting and adjusting* is being reported as the most time consuming activity of all the set-up activities may also be related to qualifications of the employees and the condition of the machines used and their technology in particular.

Table 21: The most time consuming areas for their machine set-ups in respondents' facilities.

The most time consuming activity	Moulder	Table saw	Shaper	Band saw	**Total**
Adjusting cutting depths and widths	2	2	2	0	**6**
Cleaning activities	1	1	0	0	**2**
Mounting and adjusting cutterheads	4	7	1	1	**13**
Searching for tools and equipment while doing set-up	1	1	0	0	**2**
Trial runs	2	2	0	0	**4**
Other	1	0	0	0	**1**
TOTAL	**11**	**13**	**3**	**1**	**28**

6.1.1.6. Training

For moulders, all respondents (eleven) indicated that their employees were trained on moulder set-ups. One question in the survey asked who trained the employees and respondents were allowed to select more than one training source (including manufacturer of the moulder, experts from outside of the company, and company personnel). Therefore, 13 answers were collected from 11 respondents. Only two out of a total of 11 respondents indicated that their workers/operators obtained training on machine set-up by more than one source; one respondent indicated their workers/operators were trained by *Company personnel* as well as *Manufacturer of the moulder* while the other respondent with a two-folded training strategy indicated that their workers/operators were trained by *Company personnel* and by *Experts from outside of the company*. However, when considering the number of answers obtained for each type of training source, nine responses stated that *Company personnel*, two responses mentioned *Manufacturer of the moulder*, and two responses indicated that *Experts from outside of the company* were involved.

For table saws, except for one respondent, all 12 respondents indicated that their employees were trained on the table saw set-up. The following question concerning who trained their workers was answered by 12 respondents, who were allowed to select more than one training source (including manufacturer of the moulder, experts from outside of the company, and company personnel). Only one out of a total 12 respondents indicated their workers/operators obtained training of their machine set-up from more than one source; this respondent indicated that their workers/operators were trained by *Company personnel* and by the *Manufacturer of the table saw*. However, 12 responses (all respondents of the related question for table saws) indicated that training was done by *Company personnel,* and one response indicated *Manufacturer of the table saw*.

For shapers, only one out of a total of three respondents indicated that their employees were trained about the shaper set-up. The respondent also indicated their training source as being *Company personnel.*

For band saws, only one respondent indicated that their employees were trained for their band saw set-up, however, the training source/s was not specified.

Given the frequency of training performed by company personnel, it appears that manufacturers may be reluctant to outsource set-up training to experts from outside of the company. This may be because companies do not see a benefit to outsource or to invest their capital to improve their set-up practices.

6.1.1.7. The Single Most Important Outcome

When respondents were asked about the single most important outcome from their set-up time reduction efforts achieved on the machines specified (moulders, shapers, table saws, and band saws), five respondents out of the total of 11 who replied to this question for the moulders stated that the most important outcome was *Improved responsiveness to customer demands* while five of the 13 who replied for their table saws stated that it was *Increasing productivity/capacity* of their equipment. To that end, for different types of woodworking machines, respondents indicated different achievements as the most single important outcome (Table 22). For four of the five respondents for the moulders, who indicated the single most important outcome was *Improved responsiveness to customer demands,* employment sizes in their facilities were *1-19* while one respondent indicated an employment size of *20-99*. Similarly, for three of five respondents on table saws who indicated the single most important outcome was *Increasing productivity/capacity*, employment sizes in their facility was again *1-19* while two other respondents indicated *20-99* and *100-99*, respectively. Interestingly, smaller facilities (e.g., 1-19 facility's employment size) indicated the same outcome for the same type of machines while larger companies indicated varied outcomes (Table 22).

Table 22: Employment sizes and the single most important outcome through set-up improvement in respondents' facilities

The Single Most Important Outcome Through Set-up Improvement		Employment Sizes in Facilities of Respondents				
		1 to 19	**20 to 99**	**100 to 499**	**500 or more**	**Total**
Moulders	**Increasing productivity/capacity**	1	0	0	0	**1**
	Reduced batch sizes	0	2	0	0	**2**
	More frequent set-ups/Improve flexibility	0	0	0	0	**0**
	Improved responsiveness to customer demands	4	1	0	0	**5**
	Reduction of WIP/inventory	**0**	1	1	0	**2**
	Outsourcing	1	0	0	0	**1**
	Reduced maintenance due to shorter cycles	0	0	0	0	**0**
	Total	**6**	**4**	**1**	**0**	**11**
Table saws	**Increasing productivity/capacity**	4	1	0	0	**5**
	Reduced batch sizes	1	1	0	0	**2**
	More frequent set-ups/Improve flexibility	0	1	0	1	**2**
	Improved responsiveness to customer demands	1	0	0	0	**1**
	Reduction of WIP/inventory	0	0	0	0	**0**
	Reduced maintenance due to shorter cycles	0	0	1	0	**1**
	Other (please specify):	1	1	0	0	**2**
	Total	**7**	**4**	**1**	**1**	**13**

6.1.2. General Questions

6.1.2.1. The Largest Set-up Time Reduction Achieved On Any Machine in Facilities

When asked about on which machine respondents achieved the largest set-up time reduction in their shop, five out of the total 15 respondents to this question indicated *moulders,* and five respondents indicated *CNC* type machines (Figure 22).

6.1.2.2. Most Rewarding Outcome

When asked about the most rewarding set-up reduction effort undertaken in their facility (respondent were able to select more than one answer), the most frequent answer was *New equipment technology* (seven out of twenty-five total selections from seventeen respondents) followed by four responses for *Moving internal activities into external ones,* four responses for *Searching for tools and equipment while doing set-up*, three responses for *Adjusting cutting depth and width,* three responses for *Cleaning activities*, one response for *Mounting a blade in a machine* and three responses for *Other.* Respondents who indicated *Other*, specified their answers as *"Creating unique ways to have parts ready and set our POD and Rail system to change over quickly from part to part,"* and *"Cut patterns are done remotely and saved to a dedicated server so operators just have to run the saw and load stock,"* while other respondent did not specify the most rewarding set-up time reduction effort in their facility.

6.1.2.3. Bottleneck Machines

Seven responses were received about the question on the existence of a piece of equipment in their facility that creates a bottleneck. Each of the seven respondents specified a different type of machine, ranging from drum sander, ripsaw, door and panel clamp machines, to moulder, to name a few (Table 20). The follow-up questions then asked about the reasons for the bottlenecks on these machines. We speculated that a frequent answer would refer to the *set-up time required*. However, only two out of the total seven respondents indicated that *set-up time required* indeed played a role. Only one of these two respondents answered the question as to how they solved their bottleneck problem. This respondent stated that they used SMED set-up reduction efforts to reduce their bottleneck problem (Appendix B).

6.2. Referring to Earlier Literature

While no direct comparisons between this and similar studies about set-up time reduction efforts in the U.S. wood products industry are possible due to a lack of such studies, comparisons with findings from set-up time reduction efforts in other manufacturing industries are possible. The studies conducted by Bavuluri (2012), Yang et al. (1993), and Sheri et al. (2005), indicate benefits of set-up time reduction efforts and reveal numerous benefits that can be obtained by reducing set-up time. Yang et al. (1993) show that reducing set-up time allows firms to increase delivery speed, a finding similar to the one indicated by several participants of this study (especially for moulders, Table 12). Several respondents of this study on set-up time reduction efforts in the U.S. wood products industry presented in this thesis also indicated that the single most important outcome from their set-up time reduction efforts is the *Improved responsiveness to customer demands*. Also, several participants in the study discussed in this thesis also indicated the most successful area for their set-time reduction efforts to be *Mounting and adjusting cutterheads*; a finding similar to the one by Bavuluri (2012), who described a reduction of the loading and unloading time of products from a machine thanks to newly designed handling tools.

As Yang et al. (1993) mention in their study, reductions in cell flow time, in the variance of the cell flow time, and in the optimal product batch sizes obtained by set-up time reduction allows enterprises to accomplish increased delivery speed and reliability, quicker response to market changes, and higher flexibility to customization requirements. In the study at hand, in regards of increasing delivery speed, several respondents indicated that their set-up time reduction efforts resulted in *Improved responsiveness to customer demands.* However, when consider faster responses to market changes and increased flexibility for customer orders, only a few of respondents of the current study (two responses for table saws, and one response for shaper) indicated benefits in being able to conduct *More frequent set-ups/improve flexibility.*

Sheri et al. (2005) also mentioned that they conservatively estimated (due to not having hard data) that their set-up improvement efforts resulted in reducing the time for searching for parts (with the use of the feeder management system installed as part of set-up time reduction effort). Similarly, several respondents in this study indicated that they reduced their machine set-up time the most in the area of *Searching for tools and equipment while doing set-up.*

Thus, earlier studies such as Sheri et al. (2005) *Set-up time reduction for electronics assembly: Combining simple (SMED) and IT-based methods,* Bavuluri (2012) *Set Up Time Reduction and Quality Improvement On the Shop Floor Using Different Lean and Quality Tools,* and Yang et al. (1993) *Set-up time reduction and competitive advantage in a closed manufacturing cell* obtained similar results on the benefits of successful set-up time reduction efforts, including but not limited to reduced set-up time and increased delivery speed.

6.3. Future Research

To make more generalizable conclusions from this survey, more data points are needed to allow for statistical evaluation. However, this research serves as a valuable starting point to conduct further studies about set-up time reduction in secondary wood manufacturing enterprises. Should such a follow-up study become reality, some questions to consider should be:

Do secondary wood manufacturing enterprises use lean techniques in their facilities, if so how they approach set-up time reduction tools e.g., do they consider set-up time reduction as beneficial/useful or not needed?

Do secondary wood manufacturing firms use Lean techniques in their facility? Do they provide training to their employees to improve implementation of Lean techniques in their facility? What is the primary source of training and why do they choose this type of training (e.g., having limited budget may not allow to outsource training)? In which cases do companies outsource their training (e.g., installation a new production line, and acquiring new equipment)?

Possible problems (e.g., bottlenecks, long lead times, and less frequent set-ups etc.) can be caused by the set-up time required can be examined. If secondary wood manufacturing firms have encountered bottleneck problems related with set-ups, how have these problems affected their production, what was their solution? Also, efforts should be made to discover difficulties of applying the solutions (e.g., length of the time, the amount of the capital investments, providing training etc.).

Above questions can be varied and elaborated to conduct further studies to reveal more information about set-up time reduction efforts in wood manufacturing facilities. Additionally, results from further studies may allow wood manufacturing enterprises to obtain benefits from set-up time reduction applications more effectively.

In terms of widely used woodworking machines in the secondary wood manufacturing industry, this study intended to understand the set-up time reduction efforts and the benefits obtained thorough set-up time reduction efforts in North American enterprises. Even though too little responses were collected for a thorough statistical analysis, helpful insights were obtained. To that end, in general, participants indicated their set-up time reduction efforts were successful and resulted in quite sizable degrees of improvement (e.g., *5 – 9.9 %,* and *More than 15%* savings in time to set-up a particular piece of equipment). Participants also mentioned that their set-up time reduction efforts returned in the form of productivity gains with the corresponding increase in throughput. Undertaking successful set-up time reduction efforts and set-up training in wood manufacturing firms can be done inexpensively when using *Company personnel* for the improvement. As this study shows, the vast majority of participants acquired considerable benefits from their set-up time reduction efforts including *Increasing productivity/capacity*, and *Improved responsiveness to customer demands*.

7. CONCLUSIONS

The main idea behind this study was to explore the set-up time reduction efforts and its success rate relating to size of firms in secondary wood manufacturing firms in North America. To that end, four types of widely used woodworking machines (moulder, table saw, shaper saw, and band saw) were chosen. Based on the four types of woodworking machines, a web-based questionnaire was designed and released to members of the secondary woodworking industry to collect the data required. Invitations for the web-based questionnaire were mailed to industry participants and the survey was accessible for 73 days. During this time period, participation in this survey was disappointing low and only 23 respondents contributed valid answers. Among 23 participants, 16 participants indicated they made set-up time reduction efforts in their facilities. Unfortunately, the data obtained was insufficient to statistically test the hypotheses of this study. However, based on the responses obtained, the following observation can be made for the participating respondents.

The first hypothesis of this study wanted to test “$H_0$1: Small firms are less successful in reducing set-up time through set-up time reduction efforts than are large firms.” Even though limited data is available, no relationship between a facility’s employment size and the success rate of set-up time reduction efforts could be found. In fact, varying success rates for set-up time improvement were indicated by participants of all firm sizes.

The second hypothesis of this study reads “$H_0$2: Small firms achieve lower productivity gains through set-up time reduction than do large firms.” Unfortunately, not enough data points were collected to make statistical inferences about the relationship between facility size and productivity improvement. However, a majority of respondents indicated that they increased their productivity thorough set-up time improvement on their machines.

The third hypothesis of this study, which reads "$H_0$3: Small firms are less concerned with set-up time reduction through training than are large firms." While testing this hypothesis was not possible, the majority of participants from all size groups indicated that their employees are trained on making set-ups of their machines. Additionally, the majority of respondents indicated that they used company personnel to train employees. Based on the data obtained, it appears that the size of a facility was not a criteria influencing the training of employees on set-up time reduction.

The fourth hypothesis of this study stated "$H_0$4: In both large and small firms, bottlenecks occur at machines with high set-up times." Based on the limited set of responses to this question, it appears that set-up time was not a common reason for the occurrence of production bottlenecks. In fact, of seven respondents who answered the questions related to bottlenecks, only two respondents indicated that the cause of their bottleneck was the length of their machine set-ups.

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APPENDIX A: THE SURVEY QUESTIONS

Default Question Block

Intro.
Survey Questionnaire

Setup Time Reduction in Secondary Wood Manufacturing Facilities

Source: http://www.hoppings.co.uk/about-us.php

Virginia Tech
Department of Sustainable Biomaterials
Brooks Forest Products Center 0503
Blacksburg, VA, 24061
If you have any questions, please contact:
Enis Kucuk
Phone: 540-577-5369
E-mail: ekucuk@vt.edu

Intro.
Objective

The objective of this study is to investigate approaches to set-up time reductions among secondary North American wood products manufacturers. The responses given are **confidential** and no company information will be **disclosed** at any time. Filling out this questionnaire will take approximately 15 minutes. Your response will help us to better understand practices in the industry and will allow us to better target our support efforts. Participation is voluntary and questions can be left unanswered if preferred. If you wish to receive a summary of the results, please indicate so at the end of the survey. Your help and time is greatly appreciated. Thank you for your willingness to participate. Should you have any questions or concerns, please do not hesitate to contact me.

Note/Definitions

Setup time is defined as the time between the last good item produced and the first good item produced by the machine., e.g. starting production of a new product on the same equipment.

External/Internal Setup:

External setup time is setup activities that can be performed while the machine continues the production run. Internal setup time requires the production on the machine to stop to perform setup activities.

Q1. Please indicate your position (check one):

- Plant Manager
- Operations / Production Manager
- Continuous Improvement Person
- Maintenance Crew
- Other (please specify) :

Q2. Please check one of the following categories which describes **the main product produced** by your facility (check one):

- ○ Millwork
- ○ Wood Kitchen Cabinet and Countertop Manufacturing
- ○ Household, Institutional Furniture Manufacturing
- ○ Office Furniture (Including Fixtures) Manufacturing
- ○ Flooring
- ○ Other (please specify):

Q3. In which country is your facility located?
(If you are responsible for more than one facility please consider the most familiar facility to you.)

- ○ The U.S. 
- ○ Canada 
- ○ Mexico 
- ○ Other (please specify):

Note.

Unfortunately, this survey covers only the U.S., Canada, and Mexico.
(Please click the next ">>" button to end the survey)

Q4. In which state is your facility located?

Q5. In which province or territory is your facility located?

Q6. In which state is your facility located?

Block 10

Q7. Please indicate how many employees are currently employed in **your facility** and, if your company is a multi-facility operation, **in your country** (incl. your facility) and, if your company has international facilities, **worldwide** (incl. your country):

	Number of Employees			
	1-19	**20-99**	**100 - 499**	**500 or more**
In your facility (please indicate)	○	○	○	○
In your country (incl. your facility)	○	○	○	○
Worldwide (incl. your country)	○	○	○	○

Q8. Has your facility made any coordinated, targeted **setup time reduction efforts** during the last 10 years (e.g., formal training, technology investment, renewing machine/equipment and others)?

- ◯ Yes
- ◯ No

Note.

Unfortunately, this survey aims to obtain information about setup time improvement.
(Please click the next ">>" button to end the survey)

Q9. Is your facility using **moulders (molders)** to produce your products?

- ◯ Yes
- ◯ No

Q10. Is your facility using **table saws** to produce your products?

- ◯ Yes
- ◯ No

Q11. Is your facility using **shapers** to produce your products?

- ◯ Yes
- ◯ No

Q12. Is your facility using **band saws** to produce your products?

- ◯ Yes
- ◯ No

Setup Time Reduction Efforts

Note.
The following questions are asked to obtain information about what types of activities have been done to shorten setup time, and about the success rate of these activities on a particular machine in your facility.

Setup Time Reduction Efforts 1

Moulder Questions

Q13. Between 2005 and 2015, considering any **moulder** in your facility (where set-up time reduction efforts have been undertaken), how do you rate the set-up time improvement?

- ◯ None
- ◯ 0 - 4.9 %
- ◯ 5 - 9.9 %
- ◯ 10 - 14.9 %
- ◯ more than 15%

Q14. Given your success in reducing the setup time for **the moulder**, please check the **single** most important outcome from the list below?

- ○ Increasing productivity/capacity
- ○ Reduced batch sizes
- ○ More frequent set-ups/Improve flexibility
- ○ Improved responsiveness to customer demands
- ○ Reduction of WIP/inventory
- ○ Reduced maintenance due to shorter cycles
- ○ Other (please specify):

Q15.
How would you rank the productivity (increasing throughput) depending the set-up time improvement on this moulder?

	None	Little	Some	A lot
Change in productivity	○	○	○	○

Q16. How many spindles does this moulder have?

Number of spindles (in this moulder)

Q17. In which of the following areas has the set-up time reduced the most?

- ☐ Mounting and adjusting cutterheads (knives, cutter etc.)
- ☐ Adjusting cutting depths and widths
- ☐ Searching for tools and equipment while doing set-up
- ☐ Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)
- ☐ Converting internal setup time to external setup time
  External/Internal Setup:
  External setup time is setup activities that can be performed while the machine continues the production run.Internal setup time requires the production on the machine to stop to perform setup activities.
- ☐ Other (please specify):

Q18. Please indicate what is the most time consuming part of your moulder set-up?

- ○ Mounting and adjusting cutterheads (knives, cutter etc.)
- ○ Adjusting cutting depths and widths
- ○ Searching for tools and equipment while doing set-up
- ○ Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)
- ○ Trial runs
- ○ Other (please specify):

Q19. How often do you set-up the moulder on a typical day?

Number of times in 1 day (aproximately) ________

Q20. Have your workers/operators obtained training about *"how to set-up a moulder"* in your facility?

- ◯ Yes
- ◯ No

Q21. Who trained your workers/operators?

- ☐ Manufacturer of the moulder
- ☐ Experts from outside of the company
- ☐ Company personnel
- ☐ Other (please specify) : ________

Table Saws Questions

Q22. On which type of **table saw** have you tried to reduce set-up time in the facility (e.g. cabinet table saw, bench top table saw, contractor table saw, and hybrid table saw etc.):

The type of table saw is ________

Q23. Between 2005 and 2015, considering **any table saw** in your facility (where set-up time reduction efforts have been undertaken), how do you rate the set-up time improvement?

- None
- 0 - 4.9 %
- 5 - 9.9 %
- 10 - 14.9 %
- more than 15%

Q24. Given your success in reducing the setup time for **the table saw**, please check the **single** most important outcome from the list below?

- Increasing productivity/capacity
- Reduced batch sizes
- More frequent set-ups/Improve flexibility
- Improved responsiveness to customer demands
- Reduction of WIP/inventory
- Reduced maintenance due to shorter cycles
- Other (please specify):

Q25.
How would you rank the productivity (increasing throughput) depending the set-up time improvement on this table saw?

	None	Little	Some	A lot
Change in productivity	○	○	○	○

Q26. In which of the following areas has the set-up time reduced the most?

- ☐ Mounting and adjusting a circular saw or a combination cutter
- ☐ Adjusting cutting depth and width
- ☐ Searching for tools and equipment while doing set-up
- ☐ Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)
- ☐ Converting internal setup time to external setup time
  External/Internal Setup:
  External setup time is setup activities that can be performed while the machine continues the production run.Internal setup time requires the production on the machine to stop to perform setup activities.
- ☐ Other (please specify):

Q27. Please indicate that what is the most difficult (time consuming) part of your table saw set-up?

- ○ Mounting and adjusting a circular saw or a combination cutter
- ○ Adjusting cutting depth and width
- ○ Searching for tools and equipment while doing set-up
- ○ Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)
- ○ Trial runs
- ○ Other (please specify):

Q28. How often do you set-up the table saw on a typical day?

Number of times in 1 day (aproximately)

Q29. Have your workers/operators obtained training about *"how to set-up a table saw"* in your facility?

- ○ Yes
- ○ No

Q30. Who trained your workers/operators?

- ☐ Manufacturer of the table saw
- ☐ Experts from outside of the company
- ☐ Company personnel
- ☐ Other (please specify) :

Shaper Questions

Q31. Between 2005 and 2015, considering any **shaper** in your facility (where set-up time reduction efforts have been undertaken), how do you rate the set-up time improvement?

- ○ None
- ○ 0 - 4.9 %
- ○ 5 - 9.9 %
- ○ 10 - 14.9 %
- ○ more than 15%

Q32. Given your success in reducing the setup time for **the shaper**, please check the **single** most important outcome from the list below?

- ○ Increasing productivity/capacity
- ○ Reduced batch sizes
- ○ More frequent set-ups/Improve flexibility
- ○ Improved responsiveness to customer demands
- ○ Reduction of WIP/inventory
- ○ Reduced maintenance due to shorter cycles
- ○ Other (please specify):

Q33.
How would you rank the productivity (increasing throughput) depending the set-up time improvement on this shaper?

	None	Little	Some	A lot
Change in productivity	○	○	○	○

Q34. In which of the following areas has the set-up time reduced the most?

- ○ Mounting and adjusting a cutterhead (knife, cutter etc.)
- ○ Adjusting cutting depth and width
- ○ Searching for tools and equipment while doing set-up
- ○ Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)
- ○ Converting internal setup time to external setup time
  External/Internal Setup:
  External setup time is setup activities that can be performed while the machine continues the production run.Internal setup time requires the production on the machine to stop to perform setup activities.
- ○ Other (please specify):

Q35. Please indicate that what is the most difficult (time consuming) part of your shaper set-up?

- ○ Mounting and adjusting a cutterhead (knife, cutter etc.)
- ○ Adjusting cutting depth and width
- ○ Searching for tools and equipment while doing set-up
- ○ Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)
- ○ Trial runs
- ○ Other (please specify):

Q36. How often do you set-up this shaper on a typical day?

Number of times in 1 day (aproximately) ______

Q37. Have your workers/operators obtained training about *"how to set-up a shaper"* in your facility?

- ◯ Yes
- ◯ No

Q38. Who trained your workers/operators?

- ☐ Manufacturer of the shaper
- ☐ Experts from outside of the company
- ☐ Company personnel
- ☐ Other (please specify): ______

Band Saw Questions

Q39. Between 2005 and 2015, considering any **band saw** in your facility (where set-up time reduction efforts have been undertaken), how do you rate the set-up time improvement?

- None
- 0 - 4.9 %
- 5 - 9.9 %
- 10 - 14.9 %
- more than 15%

Q40. Given your success in reducing the setup time for **the band saw**, please check the **single** most important outcome from the list below?

- Increasing productivity/capacity
- Reduced batch sizes
- More frequent set-ups/Improve flexibility
- Improved responsiveness to customer demands
- Reduction of WIP/inventory
- Reduced maintenance due to shorter cycles
- Other (please specify):

Q41.
How would you rank the productivity (increasing throughput) depending the set-up time improvement on this band saw?

	None	Little	Some	A lot
Change in productivity	○	○	○	○

Q42. In which of the following areas has the set-up time reduced the most?

- ☐ Mounting a blade in a machine
- ☐ Adjusting cutting depth and width (e.g. guides and thrust bearing)
- ☐ Searching for tools and equipment while doing set-up
- ☐ Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)
- ☐ Converting internal setup time to external setup time
  External/Internal Setup:
  External setup time is setup activities that can be performed while the machine continues the production run.Internal setup time requires the production on the machine to stop to perform setup activities.
- ☐ Other (please specify):

Q43. Please indicate that what is the most difficult (time consuming) part of your band saw set-up?

- ○ Mounting a blade in a machine
- ○ Adjusting cutting depth and width (e.g. guides and thrust bearing)
- ○ Searching for tools and equipment while doing set-up
- ○ Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)
- ○ Trial runs
- ○ Other (please specify):

Q44. How often do you set-up the band saw on a typical day?

Number of times in 1 day (aproximately)

Q45. Have your workers/operators obtained training about "how to set-up a band saw" in your facility?

- ○ Yes
- ○ No

General Questions

Q46. In your shop, on which machine have you achieved the largest set-up time reduction? (Any machine in your facility)

Please specify the machine (e.g. CNC router, moulder, etc.):

Q47. Which setup time reduction effort was the most rewarding one for your company?

- ☐ Moving internal activities into external ones
- ☐ New equipment technology (e.g. slides,fastener, modules etc.)
- ☐ Mounting a blade in a machine
- ☐ Adjusting cutting depth and width
- ☐ Searching for tools and equipment while doing set-up
- ☐ Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)
- ☐ Other (please specify):

Q48. In your facility, do you have a machine that creates a production bottleneck? (e.g. any resource whose capacity is equal to or less than the demand placed upon on it)

- ○ Yes
- ○ No

Q49. On which machine does your bottleneck occur?

Please specify the machine (e.g. CNC, moulder etc.): ______

Q50. What is the main reason for this bottleneck?

- ○ Speed of the machine
- ○ Operator of the machine
- ○ Machine failures
- ○ Production needs
- ○ Set up time required
- ○ Production scheduling
- ○ Other (please specify): ______

Q51. What have you done to solve the bottleneck on this machine?
(If you did not take any action leave **blank**)

Please specify the solution (for the bottleneck): ______

End of the Survey

END. Please indicate if you would like to receive an email of a summary of this survey results?

- Yes, please send the results to the following email address:
- No

note

NOTE.
External/Internal Setup:
External setup time is setup activities that can be performed while the machine continues the production run.Internal setup time requires the production on the machine to stop to perform setup activities.

APPENDIX B: COLLECTED DATA, NUMBER OF RESPONSES, ANSWERS OBTAINED

Please indicate your position (check one):	Number of responses
Plant Manager	8
Continuous Improvement Person	4
Operations / Production Manager	2
Other = Owner	7
Oher = Process Engineering Manager	1
Other = Pres/CEO	1
TOTAL	**23**

Please check one of the following categories which describes the main product produced by your facility (check one):	Number of responses
Millwork	4
Wood Kitchen Cabinet and Countertop Manufacturing	6
Household, Institutional Furniture Manufacturing	4
Office Furniture (Including Fixtures) Manufacturing	1
Other	8
TOTAL	**23**

In which country is your facility located?	Number of responses
Canada	1
The U.S.	22
TOTAL	**23**

In which state is your facility located? In which province or territory is your facility located		**Number of responses**
USA	CA California	2
USA	GA Georgia	1
USA	IL Illinois	1
USA	IN Indiana	1
USA	ME Maine	1
USA	MN Minnesota	2
USA	NC North Carolina	3
USA	NE Nebraska	1
USA	NJ New Jersey	1
USA	NY New York	2
USA	OH Ohio	2
USA	PA Pennsylvania	2
USA	TX Texas	1
USA	VA Virginia	1
USA	WA Washington	1
USA	**TOTAL**	**22**
CANADA		AB Alberta
	TOTAL (USA&CANADA)	**23**

Please indicate how many employees are currently employed in your facility and, if your company is a multi-facility operation, in your country (incl. your facility) and, if your company has international facilities, worldwide (incl. your country):					
	1-19	**20-99**	**100 - 499**	**500 or more**	**Total Responses**
In your facility (please indicate)	14	6	2	1	**23**
In your country (incl. your facility)	14	4	2	2	**22**
Worldwide (incl. your country)	13	3	2	2	**20**

Has your facility made any coordinated, targeted set-up time reduction efforts during the last 10 years (e.g., formal training, technology investment, renewing machine/equipment and others)?	Number of responses
Yes	16
No	7
TOTAL	**23**

Is your facility using moulders (moulders), table saws, shapers, and band saws to produce your products?	Number of responses
Moulder	11
Table saw	15
Band saw	3
Shaper	2
TOTAL	**31**

Between 2005 and 2015, considering any moulder in your facility (where set-up time reduction efforts have been undertaken), how do you rate the set-up time improvement?	Number of responses
None	1
0 - 4.9 %	3
5 - 9.9 %	4
More than 15%	3
TOTAL	**11**

Given your success in reducing the set-up time for the moulder, please check the single most important outcome from the list below?	Number of responses
Improved responsiveness to customer demands	5
Increasing productivity/capacity	1
Reduced batch sizes	2
Reduction of WIP/inventory	2
Other (please specify):	1
TOTAL	**11**

How would you rank the productivity (increasing throughput) depending the set-up time improvement on this moulder?	**Number of responses**
None	0
Little	7
A lot	4
Some	0
TOTAL	**11**

In which of the following areas has the set-up time reduced the most?	**Number of responses**
Mounting and adjusting cutterheads (knives, cutter etc.)	3
Adjusting cutting depths and widths	2
Searching for tools and equipment while doing set-up	4
Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)	2
Converting internal set-up time to external set-up time	3
Other	2
TOTAL	**16**

Please indicate what is the most time consuming part of your moulder set-up?	**Number of responses**
Adjusting cutting depths and widths	2
Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)	1
Mounting and adjusting cutterheads (knives, cutter etc.)	4
Searching for tools and equipment while doing set-up	1
Trial runs	2
Other	1
TOTAL	**11**

How often do you set-up the moulder on a typical day?	**Number of responses**
Yes	11
No	0
TOTAL	**11**

Who trained your workers/operators?	Number of responses
Manufacturer of the moulder	2
Experts from outside of the company	2
Company personnel	9
TOTAL	**13**

On which type of table saw have you tried to reduce set-up time in the facility (e.g. cabinet table saw, bench top table saw, contractor table saw, and hybrid table saw etc.):	Number of responses
Cabinet type table saw	6
Sliding type table saw	4
Benchtop	1
n/a	4
TOTAL	**15**

Between 2005 and 2015, considering any table saw in your facility (where set-up time reduction efforts have been undertaken), how do you rate the set-up time improvement?	Number of responses
None	2
0 - 4.9 %	6
5 - 9.9 %	2
10 - 14.9%	0
More than 15%	**3**
N/A	2
TOTAL	**15**

Given your success in reducing the set-up time for the table saw, please check the single most important outcome from the list below?	Number of responses
Improved responsiveness to customer demands	1
Increasing productivity/capacity	5
More frequent set-ups/Improve flexibility	2
Reduced batch sizes	2
Reduced maintenance due to shorter cycles	1
Other (please specify):	2
TOTAL	**13**

How would you rank the productivity (increasing throughput) depending the set-up time improvement on this table saw?	**Number of responses**
None	2
Little	4
Some	4
A lot	2
TOTAL	**12**

In which of the following areas has the set-up time reduced the most?	**Number of responses**
Mounting and adjusting a circular saw or a combination cutter	1
Adjusting cutting depth and width	3
Searching for tools and equipment while doing set-up	4
Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)	1
Converting internal set-up time to external set-up time	1
Other (please specify):	4
TOTAL	**14**

Please indicate that what is the most difficult (time consuming) part of your table saw set-up?	**Number of responses**
Adjusting cutting depth and width	2
Cleaning activities (e.g. removing dirt, oil, saw dust etc. from the machine)	1
Mounting and adjusting a circular saw or a combination cutter	7
Searching for tools and equipment while doing set-up	1
Trial runs	2
TOTAL	**13**

How often do you set-up the table saw on a typical day? (Respondents answers)												
# 2	# 1	# 5	# 20	# 4	# 8	# 0.2	# 10	# 2	# 25	# 8	Up to 1,000 adjustments could be made during a reduction run	# 5

Have your workers/operators obtained training about "how to set-up a table saw" in your facility?	Number of responses
Yes	12
No	1
TOTAL	**13**

Who trained your workers/operators?	Number of responses
Manufacturer of the table saw	1
Company personnel	12
TOTAL	**13**

Between 2005 and 2015, considering any shaper in your facility (where set-up time reduction efforts have been undertaken), how do you rate the set-up time improvement?	Number of responses
None	0
0 - 4.9 %	0
5 - 9.9 %	2
10 - 14.9%	0
More than 15%	1
TOTAL	**3**

Given your success in reducing the set-up time for the shaper, please check the single most important outcome from the list below?	Number of responses
Increasing productivity/capacity	1
More frequent set-ups/Improve flexibility	1
Reduced batch sizes	1
TOTAL	**3**

How would you rank the productivity (increasing throughput) depending the set-up time improvement on this shaper	**Number of responses**
None	0
Little	0
Some	1
A lot	2
TOTAL	**3**

In which of the following areas has the set-up time reduced the most?	**Number of responses**
Adjusting cutting depth and width	2
Mounting and adjusting a cutterhead (knife, cutter etc.)	1
TOTAL	**3**

Please indicate that what is the most difficult (time consuming) part of your shaper set-up?	**Number of responses**
Adjusting cutting depth and width	2
Mounting and adjusting a cutterhead (knife, cutter etc.)	1
TOTAL	**3**

Have your workers/operators obtained training about "how to set-up a shaper" in your facility?	**Number of responses**
Yes	1
No	2
TOTAL	**3**

Who trained your workers/operators?	**Number of responses**
Company personnel	1
TOTAL	**1**

Between 2005 and 2015, considering any band saw in your facility (where set-up time reduction efforts have been undertaken), how do you rate the set-up time improvement?	**Number of responses**
None	1
0 - 4.9 %	0
5 - 9.9 %	0
10 - 14.9%	0
More than 15%	1
TOTAL	**2**

How would you rank the productivity (increasing throughput) depending the set-up time improvement on this band saw?	**Number of responses**
None	0
Little	0
Some	0
A lot	1
TOTAL	**1**

In which of the following areas has the set-up time reduced the most?	**Number of responses**
Other (please specify): N/A and Fixturing for cutting different components	2
TOTAL	**2**

Please indicate that what is the most difficult (time consuming) part of your band saw set-up?	**Number of responses**
Mounting a blade in a machine	1
TOTAL	**1**

In your shop, on which machine have you achieved the largest set-up time reduction? (Any machine in your facility)	**Number of responses**
CNC type machines	5
Moulders	5
Point to Point Router	1
Cut-off saw	1
Gang Rip Saw	1
Rear load panel saw	1
Shaper (Unique 250 Door Machine)	1
TOTAL	**15**

Which set-up time reduction effort was the most rewarding one for your company?	**Number of responses**
Moving internal activities into external ones	4
Adjusting cutting depth and width	3
Searching for tools and equipment while doing set-up	4
Cleaning activities	3
Other	3
New equipment technology	7
Mounting a blade in a machine	1
TOTAL	**25**

In your facility, do you have a machine that creates a production bottleneck? (e.g. any resource whose capacity is equal to or less than the demand placed upon on it)	**Number of responses**
Yes	7
No	9
TOTAL	**16**

On which machine does your bottleneck occur?	Number of responses
Drum sander	1
Ripsaw	1
Door and panel clamp machines	1
Moulder	1
Auto Drilling	1
Costa Sander	1
CNC	1
TOTAL	**7**

What is the main reason for this bottleneck?	Number of responses
Set up time required	1
Machine failures	1
Other (please specify):	1
Production needs	1
Set up time required	1
Speed of the machine	1
Speed of the machine	1
TOTAL	**7**

What have you done to solve the bottleneck on this machine? (If you did not take any action leave blank)	Number of responses
Manufacturer engineered better parts	1
Fans, and leave gaps between products for air flow	1
Overtime	1
SMED set-up reduction	1
Purchased another machine	1
Highly scheduling issues, obtained second CNC	1
TOTAL	**6**