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The Benefit of Using Simulation to Improve The Implementation of Lean Manufacturing Case Study: Quick Changeovers to Allow Level Loading of The Assembly Line

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THE BENEFIT OF USING SIMULATION TO IMPROVE THE IMPLEMENTATION OF LEAN MANUFACTURING CASE STUDY: QUICK CHANGEOVERS TO ALLOW LEVEL LOADING OF THE ASSEMBLY LINE

By

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GRADUATE COMMITTEE APPROVAL

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BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Jack Jared McClellan in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

THE BENEFIT OF USING SIMULATION TO IMPROVE THE IMPLEMENTATION OF LEAN MANUFACTURING CASE STUDY: QUICK CHANGEOVERS TO ALLOW LEVEL LOADING OF THE ASSEMBLY LINE

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In today's competitive manufacturing environment, companies are constantly looking for ways to improve. Because of this, many companies are striving to become "lean" by implementing lean manufacturing, which is a difficult process. To aid in the implementation of lean manufacturing, simulation was used to reduce the trial-and-error period of lean manufacturing and find to optimum approach to implement the lean manufacturing principle. In this research, a case study of implementing level loading of the production schedule for BullFrog International, L.C. will be examined.

To make it possible to implement level loading, the thermo-former machine at the beginning of the operations was improved to allow quick changeovers. The changeover time was reduced by 60% and with a few additional changes changeovers could be

completely external. In order to be able to conduct simulation experiments to find the optimum production schedule, cycle times were gathered for each operation and a simulation model was developed of BullFrog International, L.C. current manufacturing operations. Historical data was gathered of previous month's sales orders and orders were divided into three different groups. Group 1 the spa orders are roughly 50% single-pump and 50% double-pump, group 2 the spa orders are roughly 60% or more single-pump spas and group 3 the spa orders are roughly 60% or more double-pump spas. Using historical data, level loading production schedules were developed using lean manufacturing principles by reducing lot sizes to the smallest possible and still preserving the correct ratios. All of these suggested production schedules were tested with the simulation model and through various experiments, the optimum production schedule were determined. The optimum production schedules were implemented and the results were recorded. The results were an average throughput increase of 49.1% in group 1, an average throughput increase of 58.7% in group 2 and an average throughput increase of 58.7% in group 3. These results support the hypothesis that level loading will increase throughput in a complex manufacturing system where there is a high mix and low volume production schedule. The results also support the hypothesis that the trial-and-error period was reduced by the use of simulation.

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1 Introduction

1.1 Background

1.1.1 Why Companies Are Converting to Lean Manufacturing

In an increasingly competitive world, many manufacturing firms are looking for an edge over their competition and for many manufacturing companies that edge is lean manufacturing. Implementing lean manufacturing is a difficult process that requires effort and determination. However, even though the transition is very difficult, the rewards earned by the transition make it worth the effort to change. Table 1.1 is the results of a survey of what advantages companies have realized by implementing lean manufacturing.

Table 1.1"*Selected Advantages Realized by Lean Companies*" [1]

Selected Competitive Advantages	Companies Realizing Advantage
Reduced customer lead time	63%
Steady or reduced pricing	63%
Increase market share	61%
Reduced time to lanch new products	39%
Increased product diversity	24%

Because of tremendous improvements experienced by the companies in this survey, they were able to do things that were not possible before. These same companies were surveyed again about what they did as a result of their productivity increases. The results of this survey are found in table 1.2.

Table 1.2 "*Actions Taken After Productivity Increases*" [1]

Action Taken After Productivity Increases	Companies Taking Action
Increased production and sales	69%
Guaranteed no layoffs due to increased efficiency in productivity	92%
Reduced overtime	73%
Reduced the number of temporary employees	33%
Reduced the nuber of employees through attrition	50%
Transferred displaced employees to improvement teams	38%
Used displaced employees for product development	13%

Given the dramatic productivity increases and what the companies were able to do because of the increases, it is not hard to see why so many companies are trying to convert their current operations to lean operations.

1.1.2 Why Companies Are Using Simulation

Simulation software has become increasingly popular over the past few decades and has given companies an edge to help them become more efficient and effective. Computer simulation is a powerful analysis tool that helps companies make effective changes because they can accurately predict the results of the changes prior to making them.

Companies use simulation software for various reasons and some of them are [2]:

- Work-flow planning
- Capacity planning
- Cycle time reduction
- Staff and resource planning
- Work prioritization
- Bottleneck analysis
- Quality improvement
- Cost reduction
- Inventory reduction
- Throughput analysis
- Productivity improvement
- Layout analysis
- Line balancing
- Batch size optimization
- Production scheduling
- Resource scheduling
- Maintenance scheduling
- Control system design

Although the initial investment for doing simulation is expensive, between $10,000 and $30,000, this cost can be recouped through the savings of the first few projects in which the company uses the software. After the initial expense, the operating expense of simulation software is usually between 1% and 3%. "The return on investment (ROI) for simulation often exceeds 1,000 percent, with payback periods frequently being only a few months or the time it takes to complete a simulation project." [2] There are many success stories of companies realizing tremendous savings because of the use of simulation in many different areas of their organization. Because simulation can offer such amazing results and can pay for itself in a quick time, it is not hard to see why so many companies are using simulation. However, many companies do not use it, because exact ROI and payback periods cannot be determined before hand. This should not be a reason for not using simulation, because "Most applications in which simulation has been used have resulted in savings that, had the savings been known in advance, would have looked very good in an ROI or payback analysis." [2]

1.1.3 Why Companies Should Use Simulation as a Lean Tool

In the traditional implementation of lean manufacturing, the use of simulation is discouraged. James P. Womack and Daniel T. Jones, who are two respected experts in the field of lean manufacturing, said in their book <u>Lean Thinking: Banish Waste and Create Wealth in Your Corporation</u>, "…don't bother with simulations to see about the 'what ifs.' We have studied one firm which had even developed a complex computer simulation package to predict what would happen if a single machine was moved anywhere in its production system. Because the predictions were always unsettling, the company never moved anything!" [3]. The reason why Womack and Jones discouraged the use of simulation is that it impeded the company from making any changes. Simulation is an analytical tool that is not perfect, but it is a very powerful tool if it is used correctly and in the right situations. Before placing faith in the results of a simulation model, the accuracy of the model needs to be verified to know how accurate the model is. With an understanding of the models accuracy, simulation can be used more effectively. Due to the many success stories of lean manufacturing, it is clear that lean manufacturing principles work. Using simulation to help implement lean manufacturing has great potential, because it can reduce the trial-and-error period of the implementation of lean manufacturing, it can help predict results of changes and forces companies to work through all the details necessary to make changes. By working through all the details, improvement projects are more likely to be implemented with fewer problems and in less time.

1.1.4 BullFrog International, L.C. Background

BullFrog International, L.C. was founded by David Ludlow in the late 1980's and is Utah's 4th fastest growing company. Because of the high quality and innovation of BullFrog's spas they have been able to capture market share faster than most small new companies usually do. Driven by a desire to provide better service to their customers by shortening their lead time, they decided to have some simulation studies done to improve operations and have been working on implementing lean manufacturing.

Each spa is custom built to each order, so the material flows through the factory in single piece flow. This is just one of a few lean principles that BullFrog International, L.C. is already practicing. The bottleneck of the system is the plumbing operation and there are three “floating bottlenecks” which are the drilling operation, the cabinet assemble operation and the final inspection station. Figure 1.1 is the current state work-flow diagram of BullFrog International, L.C. and has been provided to give a better understanding of the manufacturing operations.

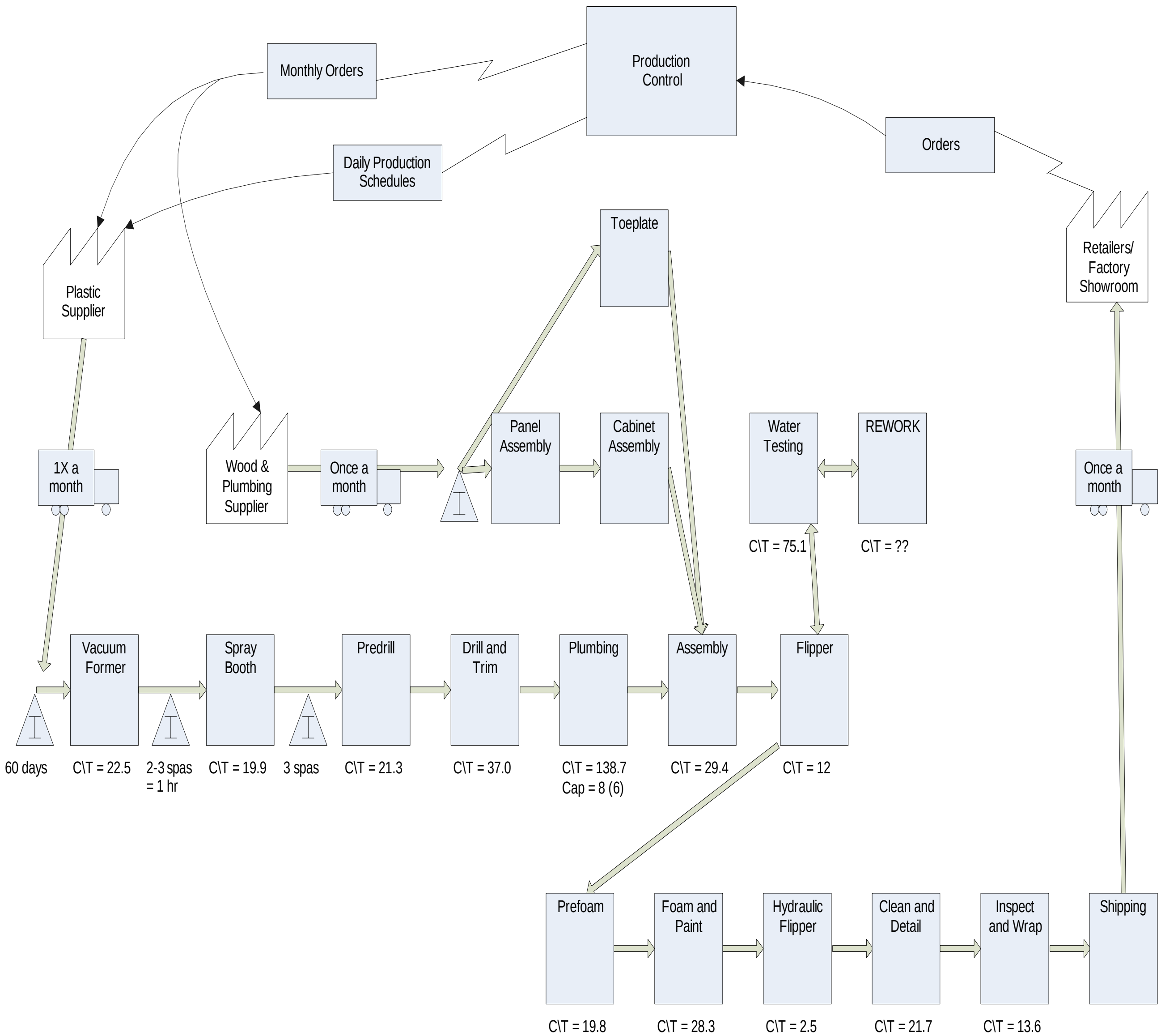

Figure 1.1 *BullFrog International, L.C. Current State Flow Chart*

1.2 Problem Statement

Lean manufacturing principles have been tested in many different companies around the world and these companies were rewarded with amazing results when they implemented lean manufacturing correctly, but implementing lean principles correctly is not always easy. To convert a company to lean manufacturing it requires determination to change for the better (this can be because of a crisis or because of the continual drive to improve in a company's culture) and it requires time to convert a company to lean manufacturing. The process for continual improvement given in the book Running Today's Factory and is shown in the circle diagram below.

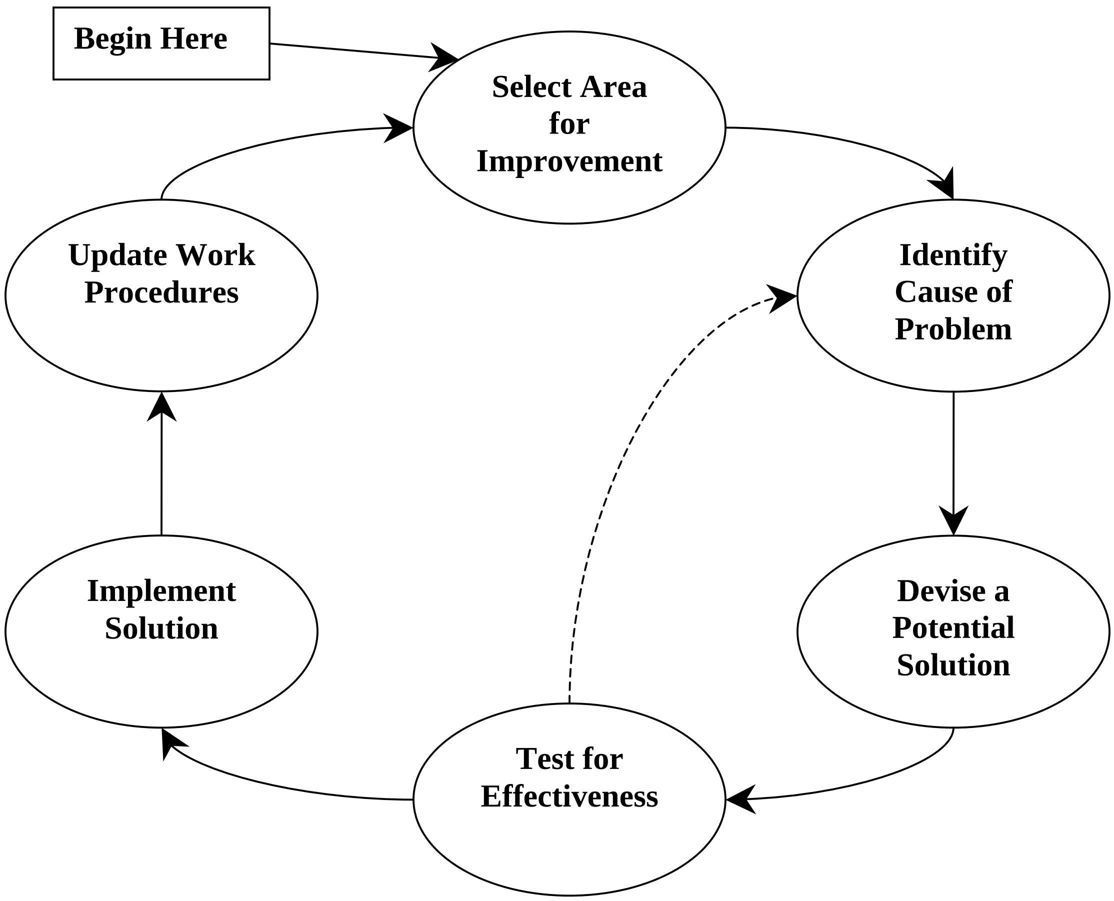

Figure 1.2 "*A Factory Improvement Cycle*" [1]

Each one of these steps requires time and effort. Another reason why converting a manufacturing firm to lean manufacturing takes time is because people resist change and working to overcome the resistance takes time. If a manufacturing firm can make the conversion quicker and smoother, they will be able to convert in less time and begin to reap the benefits of lean manufacturing sooner.

To implement lean manufacturing you must use the principles of lean manufacturing to guide your changes and then fine-tune the changes with a period of trial-and-error. The problem with this is "With the emphasis today on time-based competition, traditional trial-and-error methods of decision making are no longer adequate. Regarding the shortcoming of trial-and-error approaches in designing manufacturing systems, Solberg (1988) notes:

> The ability to apply trial-and-error learning to tune the performance of manufacturing systems becomes almost useless in an environment in which changes occur faster than the lessons can be learned. There is now a greater need for formal predictive methodology based on understanding of cause and effect."[2]

Simulation can help reduce the trial-and-error period significantly and thus help manufacturing firms make the leap towards becoming a lean firm quicker. The other issue that simulation can improve is the quality of the lean solution chosen. Many manufacturing systems are complex, and therefore choosing an optimum production schedule based on the cycle times of each process, the changeover times, and the variety of things to be produced, may not be obvious. Lean principles would suggest implementation of minimum batch sizes, for example; however, at a given point in time, minimum batch sizes might not result in optimal throughput.

1.3 Hypothesis

The hypothesis of this research is that using simulation will help reduce the trial-and-error period that occurs while implementing principles of lean manufacturing, while providing an optimal solution to the problem of production scheduling. The case study used for this research will center around improvement of a single production line in which multiple products with different levels of work content are manufactured. The effect of batch size on throughput was studied and an additional hypothesis for this research was formulated: namely, that level loading, or approaching a level-loaded production schedule, would improve throughput.

1.4 Methodology

To test the hypothesis, I did a case study at Bullfrog International, L.C. The traditional lean manufacturing method of mixed production will be compared to an optimal solution obtained using simulation. Some of the variables that will be studied include: implementation of quick changeovers on the thermo-former molds, variability in customer orders for spas (each spa is built to order), cycle time variability between spa types, and personnel variability.

The software that I am going to use to find the optimum mix of spa types to level load the production line is ProModel Optimization Software Suite (Student Version), because this simulation software possess the capabilities needed to conduct the case study and I have experience in using the student version of the software. Although some prefer using a hands-on approach to analyzing a factory, computer simulation will allow more variables to be accounted for without the need for a complex hands-on model and will provide valuable insights into the best production schedule.

Prior to choosing this case study of level loading the production line, I conducted a study of the entire operation and developed various possible improvements that would aid BullFrog International, L.C. to convert their operations to lean manufacturing. After evaluating the different possibilities, the level loading of the manufacturing line was selected for the case study.

To determine what things needed to be done to level load the production line, I collected the cycle time data on the various operations initially and then I set up a program to have the area managers record additional cycle times of each operation, which are necessary in order to run the simulation experiments. The cycle times were collected in accordance with a set of work instructions that I developed for the area managers. Once the case study was completed, the results were recorded and analyzed in my thesis.

1.5 Delimitations

The purpose of this research is not to use simulation to determine if lean manufacturing principles should be implemented or not, but to determine how lean principles could be best implemented using simulation. Simulation probably could benefit the implementation of various lean manufacturing principles; however, the focus of this research will be to determine the benefits of using simulation to level load a manufacturing line. Likewise, the goal of this research is not to determine which simulation software is the best for implementing lean manufacturing principles. The simulation software is a tool that was selected because it had all the capabilities needed to conduct this research and should aid with the implementation of lean manufacturing principles. The last delimitation for the purpose this study is that it is not to attempt to demonstrate how every lean initiative would benefit from simulation, but to attempt to demonstrate how simulation would benefit the level loading in a small factory with custom products.

1.6 Thesis Contribution

If this research shows that simulation can provide a solution to production scheduling that is not obvious using lean principles alone, it will support the argument that optimal lean solutions should be obtained by using simulation. So that the best lean solutions are discovered without physically experimenting with possible lean solutions, which will be quicker and less expensive.

1.7 Definition of Terms

Batch – The number of products being produced in a run.

Bolster – A bolster is the perforated plate in a punching machine on which anything rests when being punched.

Bottleneck – An operation with lowest capacity in the manufacturing system, which slows the rest of the operations.

Changeover – Changing the tooling, die or mold of a machine to make a different product.

Computer simulation – Computer simulation is an analytical tool that uses variability and interdependencies to predict the outcome of changes to a system.

CONWIP – Constant Work-in-process. A simulation system to mimic JIT and pull systems by the production being pulled by the final operation.

Cycle time – The amount of time that material spends in an operation.

Defect rate – The number of defects in a certain period.

Downtime – The time in which a machine or line is not operating due to machine failure, maintenance, break-time or any other reason that stops a machine or line from operating.

Drum buffer rope – A term coined in the book The Goal and is a method used in the Theory of Constraints or TOC to set the flow of materials through a production system.

External setup – Setup steps that can be preformed during the operation of the machine.

FIFO – First in first out.
Five whys – Five whys refers to a problem solving technique, in which the person who is solving the problem asks "why" five times or as many times as necessary to find the root cause of the problem.

Flow – The word flow in this case refers to the sequence in which operations are executed.

Flow chart – A flow chart is a chart that denotes how material moves through a system.

Hands-on approach – A hands-on approach refers to being physically and mentally involved in solving a problem or improving a system by trying new solutions.

Internal setup – Setup steps that must be preformed while the operation is not running.

Just-In-Time – Just-in-time is a lean manufacturing production philosophy in which just enough materials are ready at the right time and no more.

Kaizen – A Japanese word meaning small change, which is used in lean manufacturing to refer to the method used for continuous improvement. It is often referred to as a kaizen event. In a kaizen event, a team gets together and brainstorms on how to improve a process or fix a problem and then the solution is implemented in a trial-and-error situation.

Kanban – A Japanese word for "ticket", which is used in lean manufacturing to refer to a signal to produce another part.

Level loading – Level loading (also known as heijunka or mixed production) is a production scheduling technique used in lean manufacturing to set production to meet customer demand.

Little's law – Little's law is a mathematical proof named in honor of John D. Little who published the proof in 1961. Little's law is a mathematical equation to determine throughput. Little's Law = $Throughput = \frac{WIP}{Cycle\,Time}$

Lot size– Lot size refers to the number of products in one operation.

Poka-yoke (mistake-proofing) – Poka-yoke is a lean manufacturing initiative in which operations are made mistake-proof by adding checking mechanisms or making defective parts impossible to move down the manufacturing line.

Preventative maintenance – Preventative maintenance is a maintenance policy in which maintenance is performed in anticipation of possible failures.

Pull production system- Pull production system is a production system in which production is triggered by customer demand.

QDC – Quick die change

Rework – Defects in products that can be repaired through additional work.

Scrap – Defective products that cannot be repaired or used.

Single piece flow – Single piece flow is a production philosophy in which materials and products flow through the manufacturing system in single units.

Statistical Distribution – A statistical term to describe data collected.

Thermo-former – A machine that forms plastic parts through a process of heating a plastic sheet to its glass transition state and then is formed in a mold by a vacuum sucking the plastic sheet into the mold. This process is also sometimes known as vacuum-forming.

Throughput – The number of products made in a certain period of time.

Throughput per hour – The number of products made from a manufacturing system in one hour.

Throughput per minute – The number of products made from a manufacturing system in one minute.

Throughput rate – This term refers to the rate at which a product is completed and is removed from the manufacturing line.

Traditional lean manufacturing methods – Traditional methods that are used in a lean manufacturing system. For example pull control system, level loading, kaizen and kanban.

Traditional mass production – The traditional manufacturing system developed by Ford, in which efficiencies are maximized and products are made as fast and as many as possible.

Trial-and-error – Trial-and-error refers to the process of trying a new improvement or solution to a problem to see if it improves performance/ fixes the problem or not. If it does not improve performance or fix a problem, then a different improvement or solution is tried.

Variability – The randomness that is present in a manufacturing system or operation.

Work-flow – Work-flow is a word used to describe the route in which products are produced.

Work-in-progress (WIP) – The amount of inventory that is in the manufacturing system.

5-S – The term 5-S stands for the following five "S" words: sort, set in order, shine, standardize and sustain. 5-S is a lean initiative that involves cleaning and organizing workstations and the factory.

2 Review of Literature

2.1 Introduction

There are many relevant topics that will be covered in the review of literature, which are: a background to lean manufacturing, evaluating improvements, factory physics, examples of lean manufacturing advantages, problems in lean manufacturing implementation, reasons for simulation, using simulation for continuous improvement, manufacturing line flexibility, the effects of level loading on throughput and quick-changeovers. All of these topics will help create a better understanding of previous research, help guide and support this research.

2.2 Lean Manufacturing Background

Toyota Motors developed the Toyota Production System just after World War II, because Toyota management was not satisfied with Toyota's production level at the time. In 1950 Toyota had produced fewer automobiles since the company began producing automobiles than the Ford Rouge plant was producing in a single shift. There were only a few automotive plants in Japan in 1950 and they had to produce exceptionally diverse transportation needs for Japan. Toyota was producing cars, delivery vans, heavy trucks, light trucks, ambulances, limousines, and fire trucks. The automotive industry in Japan was faced with the challenge, especially Toyota, to manufacture a diverse product mix meeting customer demand and cost effectively. Foreign automakers wanted to enter the Japanese market, but the Japanese government imposed tariffs and prohibited foreign investment in Japan's automotive industry. This helped Japan's automotive industry domestically, but they were no match for their foreign competitors in other countries. [4] To add to this challenge of meeting Japans diverse automotive needs, "Ohno and others at Toyota estimated that American autoworkers were nine times more productive than their Japanese counterparts." [1] (Taiichi Ohno was a pioneer in the Toyota Production System.) The management at Toyota were not discouraged at their deficiencies in productivity; "Instead, Toyota concluded that the difference must be in the *system of production.* This led to Eiji Toyoda's historic pilgrimage to the Ford Rouge complex in Dearborn, Michigan. His objective was to learn the basis for American success and efficiency in automotive production, and to evaluate the feasibility of Ford's mass production system succeeding in Japan". [5] While touring Ford and visiting grocery stores the Toyota executive gained some of his biggest insights towards forming the Toyota Production System. Since then the Toyota Production System has evolved and expanded to many other companies. It is often referred to as "Lean Manufacturing".

2.3 Evaluating Improvements

It is important to understand how to measure a factory's performance and objectively analyze possible improvements to be made to the factory. Without measurements, there is no way to gauge factory performance and it is hard to know what improvements are needed in order to benefit operations, and not hinder performance. Knowing a company's performance level is vital to helping it become competitive in its industry. To illustrate the effectiveness of lean manufacturing principles, some well-established factory physics results will be used to give a scientific basis for these principles.

2.3.1 Evaluating Improvements

A table of factory physics equations that can help in demonstrating the advantages of operating a factory using lean manufacturing principles has been provided in the appendix. Some of these equations will be used in examples in the following section.

2.3.1.1 Examples of Lean Manufacturing Advantages

In this section, the advantages of single piece flow and level loading will be discussed.

- Single Piece Flow

To illustrate the benefits of single piece flow in throughput, the example in Running Today's Factory will be used. In this example there are four workstations and each workstation has a cycle time of 1 minute per piece. In this example the transportation time is being overlooked. Little's law will be used to calculate the effects of the batch size. Little's law is the following equation: $Throughput = \frac{WIP}{Cycle\,Time}$

Table 2.2 (found in the appendix) demonstrates the outcomes of the different batch sizes in overall cycle time, throughput in pieces per minute and throughput in pieces per hour. The outcome of this chart is often surprising to people in the manufacturing world, because for years it has been taught that larger batches are more efficient and result in higher throughputs. However, there is no difference in throughput in the different batch sizes; the only change is that the overall cycle time gets longer.

In the next validation test of single-piece flow, the throughput will be tested against the amount of WIP that is entered into the system. The same scenario applies as before in the chart where throughput and batch size were being compared and Little's law was used to calculate the throughput. Table 2.3 (found in the appendix) demonstrates what the outcomes in throughput would be if the WIP was fixed at different levels. It is easy to understand that since there are four workstations, the optimum level of WIP is four pieces. If the WIP level is lower it will result in a lower throughput and if the WIP level is higher, the only thing that will increase is the overall length of time the average piece spends in the system. There are graphs found in the appendix that show the difference from the "Worst Case" scenario (normal batching methods) and the "Best Possible Case" scenario (single-piece flow).

Other benefits that result from single-piece flow are lower variability and greater flexibility. "…the batch production example does have considerable variability! Remember, the variability to which we are referring is variability in processing time, The first item processed must wait until all others in its batch are processed before it can pass with its batch to the next station. So, even though it only takes 1 minute to process the first item, from the perspective of the first workpiece it requires 10 minutes. When 10 minutes have elapsed, not one but all items pass to the next workstation. Mathematically this is equivalent to 1 item requiring 10 minutes of processing time, and the other 9 items requiring 0 minutes. That is extreme variability!" [1] Operating the assembly line in a single-piece flow gives the assembly line more flexibility to meet the demands placed upon it.

- Level Loading Production Line

Level loading production (also known as heijunka or mixed production) is a production scheduling technique that reduces variability in the production schedule and sets production to meet customer demand. "Level production is achieved through means such as rapid machine set-ups/changeover and flexible, multi-machine manning strategies. Small lot or, preferably, mixed-model sequenced production scheduling is employed." [6] An example of this would be if a car manufacturing firm received an order for 100 compact cars, 200 mid-sized sedans. To level load this production line, the production schedule would be as follows: one compact car, two mid-sized sedans and this would keep repeating itself until those orders were met. If more orders were received, then they would be mixed in with the production schedule. Implementing heijunka does not always mean going to the minimum batch size, because changeover times do not always make minimum batch sizes the most efficient. An example of this is found in the book Lean Thinking: Banish Waste and Create Wealth in Your Corporation where a case study was examined at Bumper Works, changeovers had a maximum limit of 22 minutes and with the demand Bumper Works had it made sense for them to make only four changeovers during two shifts. [3] However, when changeovers are quick and easy, it is better to run smaller batch sizes. If a company implements mixed production, "The result is a production schedule that is thoroughly mixed. (Mathematically, this is equivalent to reducing the variability in the production schedule.) Practically speaking, the demands on suppliers and on the production operation are also evenly distributed, and variability in demand for materials, equipment, and effort is minimized." [1] More detail on level loading is given in the next section.

2.4 Heijunka or Level Loading

Level loading is a lean manufacturing principle, which is also known as mixed production or heijunka. Mixed production is a term that is used to denote the mixing of the production schedule to meet demand. "However, heijunka goes a step beyond the basic idea of mixed-production to match demand. It also incorporates the concepts of leveling and line balancing. Leveling is the term used to describe the effort to balance the work load to be performed to the capacity or capability of the process (machines and operators) to complete that work. Leveling also is focused on having each process use the same sequence of production as the preceding process. Heijunka incorporates the principles of line balancing by attempting to equate (balance) work loads (production rates) at each process to each other." [7] By implementing level loading at Bullfrog International it should balance the work load because the different spas require different amounts of work and by mixing the production schedule it should create a smoother flow of production because the work load will be more evenly distributed throughout the day. Because the work flow should be smoother, daily productivity should increase and thus increase the throughput each day. In the article Heijunka Transportation Measure: Development and Application the authors were able to conclude that because of the implementation of heijunka in transportation, the dock material handling labor productivity increased by 9.4%. [8] Although the application of heijunka was in transportation and not in production, the implementation should also increase productivity because heijunka would reduce the variability in the production scheduling.

2.4.1 Requirements to Implement Heijunka

To be able to achieve heijunka, the manufacturing system must meet certain requirements to be successful. Because mixing the production requires great flexibility, setup and changeover times need to be quick, easy and repeatable. Another requirement is that the employees are cross-trained and the employees must be flexible. Toyota rotates their employees through jobs during the shift to help them to be flexible and cross-trained. In addition, the workload must be balanced and all employees must have an equal workload. If the workload is unbalanced, employees will resist being rotated and will resist being flexible because more experienced employees will tend to take easier jobs and those who are forced to take harder jobs will complain that they are being treated unfairly because of their larger workload. To overcome this challenge workloads must be balanced as much as possible and policies should be implemented that make it advantageous for employees to improve processes and make workloads balanced. Other requirements are zero quality defects and the use of a kanban system. [7] It also requires companies to change how they buy from their suppliers and how interact with one another. [9]

2.4.2 Determining Lot Sizes in Heijunka

A lean manufacturing consulting company named Lean Advisors INC suggests the following on the best way to implement heijunka in a manufacturing environment. "Basically, we have to decide what kind of business we are (discrete mfg or high customization mfg) and balance based on the best strategy that supports the customer with little waste. In other words, some companies may be able to level the schedule to obtain a smooth production balance (such as automotive companies) while others will vary the labor and build toward immediate demand." [10] In the case of BullFrog International, L.C., they should build towards demand and vary the labor because they make a highly customized product. Once the implementation strategy has been defined, Jim Womack in his April 2004 news letter, stated that a company that implemented level pull should analyze"… actual customer demand, based on orders over the past several months, so it could stop using weekly forecasts and daily ship orders to schedule the plant." [11] In his news letter a company did this to level out production and this step was also suggested by Lean Advisors INC. After analyzing historical data, a level production schedule should be developed so production meets customer demand. When building a highly customized product, the historical data helps companies gauge how much inventory will be needed, but because everything is built to order, the final level production schedule needs to be developed with orders. With BullFrog International L.C., three general production schedules were developed but minor modifications were made depending on actual orders. The lot size is determined on the time it takes to perform changeovers. If changeovers require a considerable amount of time, then the lot sizes are larger. However, changeover times should be reduced if at all possible, to allow greater flexibility to meet customer demand and better level out production. If changeover time is negligible or very short, then the smallest lot sizes possible should be implemented.

2.4.3 Beneficial Effects of Heijunka

Heijunka has two main objectives, to reduce inventory levels because of mixed production and to level workload between operations and capacities. [7] However, there are more beneficial effects that take place because of it than just the two main objectives mentioned above. Lead times are reduced because products do not need to wait for entire batches to be finished and line stoppages because of part shortages and quality defects are minimized because the manufacturing line is not dedicated to a single product. So if a part shortage occurs or any problem, the manufacturing line can be changed over to another product without much effort. [7] This allows production to continue and minimizes the effects of the shortage or problem. Another advantages that are not so obvious is "… that having workers process each model virtually every day means that workers pay more attention to the process, and are inclined to fix problems more permanently. They don't simply patch a problem and forget it until next month." [7]

2.5 Problems in Lean Manufacturing Implementation

There are many possible problems that can occur while trying to implement lean manufacturing, "These barriers fall into the following categories:

- Executive issues
- Cultural issues
- Management issues
- Implementation issues
- Technical issues

" [12] Each one of these categories are important and if taken into consideration can reduce possible obstacles in the path to lean manufacturing. Executive issues occur when the company executives are not totally dedicated to making the conversion to lean manufacturing and a sufficient knowledge of lean manufacturing principles. The conversion process is difficult and if upper management are not on board, it become even more difficult. Cultural issues deal with the reaction to new concepts, responsibilities and procedures. It is in the nature of most people to resist change and that aspect of human nature often finds a way into company culture. Taking into account the cultural aspects of the company can help in planning and preparing for possible problems due to people resisting change. Management issues are closely related to executive issues because management needs to be dedicated to the conversion to lean manufacturing and have sufficient knowledge of lean manufacturing to bring about the change.

Implementation issues occur from poor planning, rushed solutions without a principled base, insufficient knowledge of lean manufacturing, dedication to continuously improving, etc… "…companies have an ad hoc approach to planning and then implementing their lean strategies and so despite their good intentions, they have only experienced mixed results." [13] Technology issues arise from misunderstanding of lean principles, approaching lean manufacturing in certain parts of the system instead of the system and implementation that is not base on theory. [12]

The article Lean Production: Implementing Problems also mentions some factors that need to be anticipated when reducing the WIP of the manufacturing line to make it a "pull flow". Those factors that need to be determined are to determine the number of kanbans to use, modification of material containers and one-piece flow operations. Each one of these factors needs to be considered carefully and the manufacturing firm needs to be prepared to operate in a "pull flow" system. To do this each machine has to be in good repair and have regular preventative maintenance. If a machine goes down it can be disastrous to the manufacturing line because all of the machines in a "pull" system are interdependent. A barrier to having reliable equipment is to having reoccurring problems. Reoccurring maintenance problems will always happen to a machine that has a problem and is repaired with a quick fix solution to get the factory up and running again. "If the machine breaks down again for the same reason, they repair it, but they do not ask the 'five whys' to determine the root causes of the repeated failures." [14] By determining the root cause, the maintenance problem will be solved and will not recur.

Another key to being able to create pull in a manufacturing system is that there must be a very low level of defects in the products, because there is not enough WIP in the system to cover defects. Quality is achieved by having each operator check their work or having the proceeding operator check the product before being his operation. "Poka-yoke (a mechanism to prevent defective work by putting various checking devices on the implements and instruments) will still help because a part will not be loaded into the succeeding operation." [14]

2.6 Reasons for Simulation

Simulation studies provide a helpful analysis for manufacturing and other situations. First, they help the people conducting the analysis to understand the details better. Next, they help the people conducting the analysis to understand the process being modeled better and the results give accurate predictions to what could happen if certain changes were made. The following quote was given in the introduction chapter of a simulation textbook as an introduction to how simulation is being used. "One area where simulation is finding increased application is in manufacturing and service system design and improvement. Its unique ability to accurately predict the performance of complex systems makes it ideally suited for systems planning." [2]

Simulation provides many benefits to organizations. "Rather than leave design decisions to chance, simulation provides a way to validate whether or not the best decisions are being made. Simulation avoids the expensive, time-consuming, and disruptive nature of traditional trial-and-error techniques. With the emphasis today on time-based competition, traditional trial-and-error methods of decision making are no longer adequate." [2]

Implementing lean manufacturing principles will involve many changes to the current manufacturing system to make the system lean. Because every company is different and has different needs, the changes made to each company will be different to suit their personal situation. Another reason why companies make changes to become a lean organization is that each lean expert has a slightly different outlook about how to become lean and will use creativity to implement the changes. Because creativity is a big part of implementing lean manufacturing principles, people have to fine tune the ways lean principle are implemented and this is done by trial and error most of the time. Lean principles can be implemented without simulation, but it will require a trial-and-error period to make sure the changes were optimally implemented. In fact James P. Womack and Daniel T. Jones, noted experts in lean manufacturing, said "… don't bother with simulations to see about the 'what ifs.' We have studied one firm which had even developed a complex computer simulation package to predict what would happen if a single machine was moved anywhere in its production system. Because the predictions were always unsettling, the company never moved anything!" [3] Womack and Jones discouraged the use of simulation in this statement because it impeded the firm that they studied from implementing any changes towards becoming lean. However, the point of this research is not to use simulation to decide if lean principles should or should not be implemented, but to see if simulation can benefit the implementation of lean principles. If simulation were used to help with implementation, the optimum solutions to each lean principle could be implemented without it being expensive, time consuming and disruptive.

In today society, it is essential that everything is done as effective as possible and simulation would help that happen. "With the importance in today's competitive market of 'getting it right the first time,' the lesson is becoming clear: if at first you don't succeed, you probably should have simulated it." [2]

Simulation is well suited for this case study because "…a *simulated* factory is often useful to help managers and shop floor workers understand the basics of factory dynamics. This can be done with computer simulation, but we usually prefer a hands-on approach. By studying the simulated factory the basic laws become apparent, and valuable insight is gained about the behavior of an actual factory." [1] Although some prefer using a hands-on approach to analyzing a factory, computer simulation will allow more variables to be accounted for without making a complex hands-on model and provide valuable insights about how the production mix should be.

Simulation is a very useful tool to have for making management decisions, but "Not all problems can be solved by simulation, nor should all problems that can be solved with simulation be solved with simulation." [15] This is true with using simulation to implement lean manufacturing principles, not all of the lean principles would benefit by the use of simulation in their implementation. Examples of some principles of lean manufacturing that probably would not benefit from the use of simulation are 5S, mistake-proofing and improving quality. When a company is trying to decide whether to use simulation, they should evaluate if simulation is the right tool needed or if the problem could be solved another way easier. "It is important to select the right tool for the task. For some problems, simulation may be overkill-like using a shotgun to kill a fly." [2] The case study being conducted in this thesis involves many different variables and has high variation in the various factory processes, so implementing level line loading correctly the first time would be virtually impossible.

Another important thing to remember about using simulation is that you need to have an understanding of manufacturing systems and management strategies. "Simulation can be expensive and time consuming if used incorrectly. One other precaution would be misinterpreting what the simulation results are saying." [15]

2.7 Using Simulation for Continuous Improvement

Simulation is a powerful tool in implementing lean manufacturing, because it allows companies to experiment with prospective changes before they make changes to their system. This approach reduces the need for trying something out to see if it will work and allows the optimum solution to be implemented right away.

Simulation can be used in the following seven steps to aid the continuous improvement process. "

- Step 1: Conduct assessment, define problem and set aggressive goal – One of the most obvious ways to use simulation in continuous process improvements is as an assistant to the champion in identifying problems in the manufacturing process. Several typical simulation metrics for identifying problems are large work-in-process, low machine and operator utilizations, excessive delays and 100% busy machines and operators. Armed with these problem areas, the champion can then prioritize the problems and select those with the greatest payoffs. As a result, the champion can provide the focus group with a specific goal.
- Step 3: Train focus group – It is well known that simulation is a valuable training tool. This is especially true since operators generally represent over one-half of a focus group.

- Step 4: Conduct critical assessment – The focus group can use simulation to evaluate the impact of various opportunities for improvement. Ideally the group can use the previous developed simulation model to evaluate the alternatives.
- Step 5: Document opportunities for improvement – The results of the simulation can be used by the focus group in documenting the opportunities for improvement.
- Step 7: Measure impact of improvements – Once a suggestion for improvement has been implemented, the simulation model can be modified to include the suggestions and then run to measure the impact."

[16] These steps are a good guideline for me to conduct my thesis, because this is a similar study to what I am working on.

The authors provide two case studies where simulation was used to make improvements in their factories and help illustrate the usefulness of simulation in continuous improvement. This article explained the usefulness of simulation in finding areas that need improvement in a factory to help the factory be more efficient. They did not use simulation to find the best way to implement lean manufacturing without a lengthy trial-and-error period, which is the purpose of this research.

The 1999 Winter Simulation Conference found simulation benefited continuous improvement process in the following ways:

- In the continuous improvement process, simulation is the most useful at the design stage, the assessment stage, and for presenting results to management. Simulation is a helpful analytical tool for doing continuous improvement, but cannot replace focus groups and do the actual implementation of the changes.

- The continuous improvement process can be done without simulation and be successful. Simulation can be best used if the models are developed, verified and validated as soon as possible. One benefit of simulation is that it makes decision making easier because it shows what needs to be improved and when it should be improved.
- Simulation models are the most effective when they contain detailed information like separating run time, setup and changeover times, downtime, break times, defect rates, and material handling. The more detailed information contained in the model, more insight can be gained.
- When dealing with new situations, a good way to start out is make a simple model. To help speed up the modeling time, it is helpful to make a few assumptions to simplify the modeling. These simple models show management the potential of each improvement and illuminate the real issues.
- Simulation is best used in a Kaizen event with a team member trained in simulation. This team member can test the various suggestions for improvement. Modifications to a single input variable are quick and easy, but major changes may take several hours.
- It is important to have a change management specialist that understands the company's situation and can interpret results for management. This

person explains suggested improvements to management and suggest what improvements should be done next.

- Tremendous insight can be given when a simulation model is overlaying a scaled layout of the factory floor because it makes the animation in the model more realistic to the focus group and they can see what actually happens or how the improvement would effect the operations.

This is a key article to my research because it gives me some good guidelines in how to set up my research and how I can use simulation better. My research is taking the foundation laid by the authors of this article and taking it to the next logical level of using simulation to find the optimum approach to implement improvements, specifically level loading of a production line. The contribution made by this research will save manufacturing firms time and money because they will be able to implement the most advantageous improvement tactics from the start. It will be helpful for me to remember that simulation is a powerful analysis tool, but you still need to have an understanding of manufacturing systems and simulation cannot replace focus groups or people from the process.

In an email received from Daniel T. Jones he gave the following counsel on the use of simulation and continuous improvement:

"I have seen a lot of use of simulation in system design and it is great fun and often helpful.

However it is also often misleading. A classic example is the Goldrat drum buffer rope stuff or CONWIP that says send the information as far upstream as possible and flow products back downstream in FIFO.

The problem in the real world is that FIFO is extremely difficult to sustain through many different steps - each of which are subject to considerable random variability - which end up with queues for shared facilities and separate decision points (often informal) and poor flow.

So simulation might tell you one thing - but in the real world subject to lots of variation (even in Toyota) the more you can avoid long strings of steps the better.

So it is no wonder that Toyota's systems are all very simple and robust and backed up with very quick detection of an incident and very good problem solving skills to prevent it happening again." [17] (For a full copy of the email, please see the appendix.) This advice illustrates the importance of a good understanding of manufacturing systems and principles, which will benefit in interpreting the results of a simulation experiment. Simulation models are only as good as the data that is in the model and since it is impossible to add data for every possible situation, simulation models can only give predictions of possible outcomes, not exact results. Due to people's inexperience with simulation and lack of understanding of the system being modeled, people have made mistakes which have caused results to be misleading and that has caused many to discourage the use of simulation. However, if simulation is used properly and the person conducting the simulation experiments has a good understanding of the system being modeled, the results will be helpful and not misleading.

There have been various simulation studies done about what is the least amount of kanbans needed to create a pull system, the smallest lot size, etc… In addition, there have also been simulation studies to compare different scheduling theories and simulation studies to quantify the benefits of a manufacturing firm converting to lean manufacturing.

However, there have not been simulation studies to find the optimal lean solutions, which is the purpose of this thesis. [6]

2.8 Manufacturing Line Flexibility

Many companies have been making the transition from traditional mass production methods to lean manufacturing methods because of the tremendous advantages that lean manufacturing has over traditional methods. This desire for change comes when manufacturers realize how much better their factories can be and what lean manufacturing can do for them.

Mass production has some advantages, like the high utilization of machines and minimal set-ups. "*Many companies produce goods in large lots simply because long changeover times make it too costly to change products frequently.*" [18] The attitude of changeovers is wide spread over the manufacturing world. However the disadvantages of mass production out weigh the advantages. Those disadvantages are "

- **Inventory waste:** Storing what is not sold costs money and ties up company resources without adding any value to the product.
- **Delay:** Customers must wait for the company to produce entire lots rather than just the quantities a customer needs.
- **Declining quality:** Storing unsold inventory increases the chance that it will have to be scrapped or reworked, which adds cost to the product." [18]

To achieve flexibility in a production line, one must be able to quickly changeover machines to be able to produce different products.

2.9 Quick-Changeovers

"Many generic manufacturing processes have to run in batch mode because the setup requires considerable time even when properly organized. Stamping, machining, injection molding, and cold heading are examples. The batch size is heavily dependent on the setup time. Poor setup discipline is a major reason for high WIP and poor quality" [14] By implementing quick changeovers, set up times are dramatically reduced making it feasible and not as costly to do changeovers. Some of the advantages of quick changeovers are "

- **Flexibility:** Companies can meet changing customer needs without the expense of excess inventory.
- **Quicker delivery:** Small-lot production means less lead time and less customer waiting time.
- **Better quality:** Less inventory storage means fewer storage-related defects. SMED also lowers defects by reducing setup errors and eliminating trial runs of the new product.
- **Higher productivity:** Shorter changeovers reduce downtime, which means a higher equipment productivity rate." [18]

Quick changeovers also allow for level loading the production line, which allows an even flow of work to flow smoothly through the manufacturing line.

In the article <u>Lean Production: Implementing Problems</u> it states many typical problems and requirements that are run into in quick setups, which are as follows:

- Personnel need to take care of external elements (external means setup procedures that can be done while the machine is operating) so that internal (procedures that can only be done while the machine is stopped) can be performed during downtime and not both external and internal.

- Personnel have difficulty obtaining supplies and equipment because they cannot find them.
- Equipment needs substantial maintenance.
- The mold/die has to be adjusted and readjusted because it is difficult to locate.
- The proper tools need to be readily available.
- The crew operating the machine should be the crew that does the setup/changeover because they are the ones who are most familiar with how the machine has been running.
- The crew operating the machine needs to immediately change the old setup to the new setup. [14]

To achieve quick-changeover/setups manufacturing firms use a few basic methods to help them avoid the time consuming operations that make changeover/setups so expensive. The first method used in quick-changeover/setup is to make the mold/die easy to retrieve and store. "Storage and retrieval facilities are key to any QDC program. What good are rolling bolsters, die carts, and quick disconnects if you can't find the die?" [19] The next method is to make the die/mold easy to transport to an from the machine, this can be done by die carts, cranes dedicated to moving the mold/die, adding wheels to the mold/die (assuming that it could still be positioned), etc… It is important to have the transportation method dedicated to that operation because sharing the mode of transportation could cause additional changeover time due to waiting. "After moving the die [mold] into the press [machine], locating and positioning on the bolster must be easy and accurate. Ball or flat rollers serve this purpose." [19] To make the positioning of the mold/die easy and accurate, the mold/die must be positioned in the same place every time and it should be mistake-proof. This can be accomplished by making the mold/die easy to move with ball or flat rollers and then using locating pins, stops and clamps to lock into place.   The last method for quick changeovers is to make the mold/die quick to connect/disconnect. All of these methods can be changed or adapted to suite the needs of the changeover/setup operation.

- Minimize the elements requiring changeover. The fewer to be changed, the faster they can be changed.
- Minimize all adjustments. Some may be required, but eliminate all that are not.
- Motorize any adjustments that can be powered. Make them programmable if possible.
- Reduce weight of all elements requiring change.
- Use quick disconnect mountings on all elements requiring removal. The mounts should incorporate automatic couplings/decouplings of utilities.
- Whenever possible, eliminate the need for utilities on tooling by incorporating a power takeoff through quick disconnect coupling.

" [19]

This is all significant to my thesis because the case study involves trying to implement quick changeovers to a production line with the intent to gain all of the advantages listed above and being able to level load the production line.

2.10 Conclusion

Using simulation to implement lean manufacturing principles would be beneficial because simulation predicts accurately the results of changes, it provides insights on possible problems that will occur because of changes, it requires all personnel involved to think through the details and it rapidly can figure out the optimum level of variables (inventory level, frequency of deliveries, etc…)

Quick changeovers make it possible for manufacturing firms to produce exactly what the customer needs, when the customer wants it. This flexibility allows companies to abandon mass production methods and raise their profits because of the benefits quick changeovers give them. Simulation is a powerful analytical tool that will help find the optimum mixture of spa types without being expensive, being time consuming and disrupting current operations. In today's business world, manufacturing firms need to be able to find the best solution as soon as possible. The trial and error approach of yesterday (used in lean manufacturing during kaizen events) should be reduced as much as possible. If a company can get improvement changes done right the first time, they will have a big advantage over their competitors. Simulation should help them to be able to get things done right the first time.

3 Research Procedures

3.1 Case Study Methodology

Prior to beginning this research, a study of the entire operation at BullFrog International, L.C. was conducted and various possible improvements that would help them to make their operations more efficient were developed. After evaluating the different possibilities, and observing that products where manufactured in large batches, the level loading of the manufacturing line was selected for the case study. Before implementing level loading or conducting simulation studies on level loading, data on cycle times had to be gathered, a base simulation model of the current performance had to be constructed and the thermo-former had to be adapted to be able to perform quick changeovers. Historical data of throughputs were gathered from two months prior to any changes and the production schedules were classified into three groups, which will be discussed later in this chapter. After that was accomplished, various simulation experiments were conducted testing traditional lean manufacturing suggested schedules and then experimenting with those ratios to find the optimum mix. Once the results of the simulation experiments of the optimum production mix had been determined, they were compared with the traditional lean manufacturing production mix ratios. The optimum solutions were then implemented and the actual results were compared with the simulation results.

3.1.1 Thermo-Former Quick Changeover Procedures

To develop improved changeover procedures, the current changeover procedures were observed and the cycle time of each changeover step was gathered. From the results of the observations and the analysis of the cycle time data, the most difficult and time-consuming steps were improved to lessen the time required to perform these step.

From the observations, the average mold changeover took 10 to 15 minutes. A target level of less than 5 minutes was chosen, because it takes 5 minutes to heat a sheet of plastic and changeovers could be external if the changeover time was less than 5 minutes, as a reasonable goal. Due to proprietary reasons, the changeover times gathered will be kept confidential. Instead, the cycle times will be expressed in terms of percentages of overall time. The following graph shows the percentages of time each changeover step requires on average.

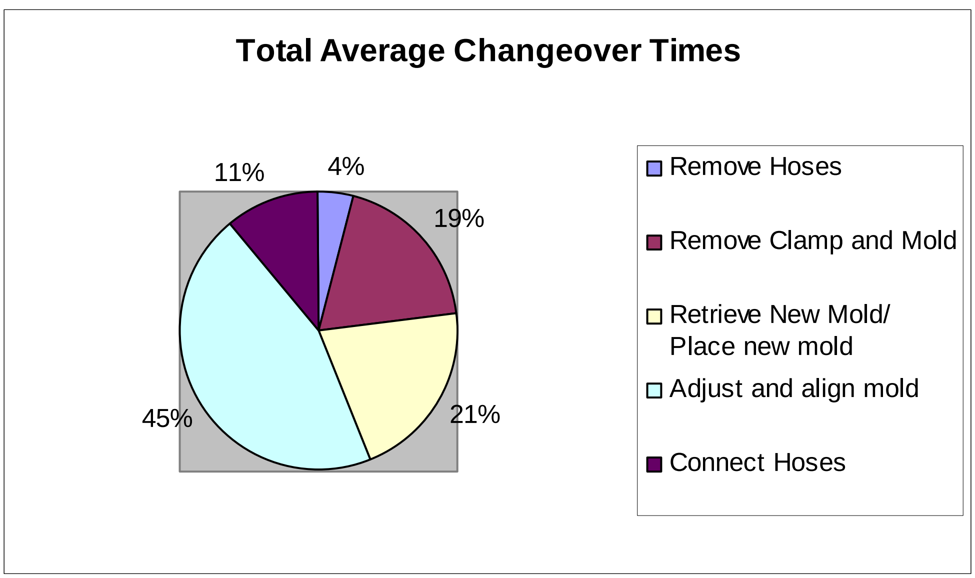

Figure 3.1 ***Total Average Changeover Times.***

After analyzing the data collected, the following areas were selected for improvement:

1. Mold adjustment and plastic alignment

2. Hose connection and removal

3. Mold clamping

No changes were made to the current changeover procedures until sufficient cycle times had been gathered. Due to proprietary information, the changes made to the thermo-former will be kept confidential. The improvements will be documented by comparing the new changeover times with the benchmark data gathered using the previous method.

3.1.2 Gathering Factory Cycle Time Procedures

The cycle times of each process in the factory were gathered to give a better understanding of the bottlenecks that might exist and of the work content at each station. Gathering detailed information on cycle times and work content in the plumbing area was especially important because prior to this study it was the suspected bottleneck of the entire operation. Using the gathered information, changes will be proposed to procedures and operating practices in the production area in order to increase daily throughput. Changes will include modifications to batch sizes within the current product mix. After the new batch sizes have been implemented, the results will be documented and compared to historical production results to determine if our suggestions resulted in better performance.

3.1.3 Performing Simulation Experiments

A base simulation model of the current operations was constructed and validated by the Production Manager, the Vice President of Manufacturing and the Materials Managers. The results of the base model were also tested against current operations data and were deemed sufficiently accurate to conduct this research. The simulation experiments will be performed to evaluate the best way to level load the production schedule; in other words, determine how much of each product should be produced between mold changes. Since BullFrog International, L.C. makes each spa to custom order, the production schedule will be broken into specific batch sizes for single-pump spas and double-pump spas, depending on the models to be produced with each category. This set of guidelines will give the theoretical best batch sizes of one pump and two pump spas in order to maximize throughput. Single-pump spas are smaller and therefore take less time to produce than double-pump spas, so the mixing of these two types should evenly load the manufacturing line.

3.1.4 Determine Traditional Lean Manufacturing Production Mix

If we were not using simulation, our inclination would be to implement a classic lean manufacturing solution, which is to minimize the batch sizes of each product. In order to determine this average minimum batch size, data on two months (March 2004 and April 2004) of spa orders was gathered. Using this data it was possible to identify three different single-pump to double-pump spa ratios: the average ratio or 50/50 ratio of single-pump to double-pump spas, the ratio of single-pump to double-pump spas where single-pump spas are 60% or more of the orders on a given day, and the ratio of single-pump to double-pump spas where double-pump spas are 60% or more of the orders on a given day. These three ratios were determined because there are days when there are more single-pump or double-pump spas scheduled for production, and then there are days when the production mix is relatively equal.

3.1.5 Implementing Results

After the best possible production mix schedules have been determined through multiple simulation experiments, they will be implemented and the effects in overall throughput and material flow through the production area will be documented.

3.1.6 Compare Actual Results vs. Simulated Results

When the results of the new production mix schedule have been documented, the actual results will be compared with computer-simulated results. Also, the actual results will be compared with the benchmark data that was gathered at the beginning of the study.

3.2 Data Collection

In order to perform the simulation experiments, cycle time data needed to be collected from each station in the production line. This was done by observing the operations at each station and taking an average of a number observed cycles. Area managers were engaged in collecting cycle times. In order to ensure that this work was done properly, the area managers were taught why gathering the cycle times was important and were given a procedure to follow for collecting the times. After the procedures agreed upon, the area managers were responsible for collecting cycle times for each operation in his area.

3.3 Evaluating Performance

Because of the nature of this case study, we will measure the effects of the improvements by two criteria: 1) changes in changeover cycle times, and 2) changes in throughput. Both of these measurements meet the requirements of the first guideline, because they are objective, precisely defined and are quantifiable. (It is important to note the assumption that all preventive maintenance has been done and that the changes on the thermo-former are functioning correctly.) The two measurements also meet the third guideline because they both promote appropriate behavior dictated by BullFrog International's goals of improving daily throughput in order to meet customer demand with less lead-time. By improving the cycle time on changeovers, it will allow the manufacturing line to be more flexible and to implement smaller batches.

3.4 Simulation Software Requirements

The purpose of this thesis is not to determine which simulation software is best for aiding implementation of changes, but the simulation software needs to have certain capabilities to conduct this case study. The simulation capabilities that I needed in order to conduct this case study are:

- The simulation software is suited for manufacturing circumstances
- Good animation capabilities (for showing results to management)
- Good data analysis capabilities
- The ability to model randomness and variability
- The ability to take raw data and fit it into a theoretical distribution.

The simulation software that was selected for this case study is ProModel. ProModel simulation software is an acceptable choice for this case study because of its following features: “

Features

- Quick-start modeling with an easy to use interface.
- Develop ‘what if’ scenarios quickly, easily and risk-free.
- Easily import and analyze data, with exportable results in Microsoft® Excel™ format.
- Capture system randomness and variability by utilizing over 20 statistical-distribution types, or directly import your own data.
- Distribute models to other divisions and departments with run-time licensing”

[20]

ProModel also has two supplemental software programs, which are “Stat-Fit” and “SimRunner.” Both software programs made ProModel a good choice of software because Stat-Fit can take raw data and put it into a theoretical distribution and SimRunner helps find optimum solutions through manipulating changeable variables.

3.5 Conducting Simulation Experiments

A base model of the current factory operations was constructed and validated to set as a benchmark. From the base model, the experiments will be done by changing the production schedule and inserting the new theoretical distribution of the cycle times for the mold changeover. Some manual experiments will be conducted (including the production mix determined by traditional lean manufacturing methods) and some experiments using “SimRunner” will be performed in order to find the optimum mix of spas in a production schedule. The results of each experiment will be documented and analyzed to see which production mixes yield the highest throughput and smoothest flow through the factory.

3.6 Comparing Results

The results of the simulation experiments will be compared to each other and the optimum solution for three different scenarios will be determined. The first optimum solution will be for the “average day”, where there is a 50/50 ratio of single-pump spas to double-pump spas. The second optimum solution will be for a “single-pump day”, where the single-pump spas make up 60% or more of the orders. The third optimum solution will be the opposite of the second optimum solution; the double-pump spas make up 60% or more of the orders. When these optimum solutions have been determined, they will be implemented in the factory and the actual results in throughput will be compared to the simulated results.

4 Data Analysis

4.1 Quick Changeover Time Results

Table 4.1 *Average Quick Changeover Time Results*

	Average Cycle Time
Old Changeover Time	10
New Changeover Time	4

In order to achieve our goal of evaluating the effect of level loading the production schedule, it was necessary to improve the changeover times at the thermo-former. After significant effort in determining what changes needed to be made, and in getting those changes implemented, we achieved a 60% reduction in the mold changeover time. This was accomplished by externalizing most of the mold changeover process, which means that the changeover can now be done largely while the machine is operating.

4.2 Traditional Lean Manufacturing Production Mix

The throughputs of each day of production in March 2004 and April 2004 were separated into the three different groups and the data were converted into averages, which produced the following results:

Table 4.2 *Historical Data Averages*

		Single-pump	Double-pump	Total
Group 1	Average Percentage	50.70%	49.30%	100%
	Spa Ratio	7.2	7.0	14.2
	Rounded Spa Ratio	7	7	14
Group 2	Average Percentage	66.92%	33.08%	100%
	Spa Ratio	9.5	4.7	14.2
	Rounded Spa Ratio	10	5	14
Group 3	Average Percentage	27.88%	72.12%	100%
	Spa Ratio	3.5	9.1	12.6
	Rounded Spa Ratio	4	9	13

The throughput averages for each group are for two normal shifts, which is 14 hours or 840 minutes of total production time. The averages of group 1 give a throughput per hour of 1 or in other words, they produce one spa every 60 minutes on average when the spa ratio is roughly 50/50. The averages of group 2 give a throughput per hour of 1 or in other words, they produce one spa every 60 minutes on average when 60% or more of the orders being single-pump spas. The averages of group 3 give a throughput per hour of 0.93 or in other words, they produce one spa every 64.6 minutes on average when 60% or more of the orders are double-pump spas.

4.2.1 Proposed Production Schedule

Using the historical data, we can formulate a production mix for each group using traditional lean manufacturing methods, which suggests that a minimum batch size for each type of spa is produced between changeovers. This production schedule, which can be replicated to produce an arbitrary number of spas, is shown in table 4.2.

Table 4.3 *Suggested Minimum Lean Manufacturing Production Schedules*

	Single-pump Made	Double-pump Made
Group 1	1	1
Group 2	2	1
Group 3	1	3

As an example, if 14 spas need to be produced using the Group 1 case, a single-pump spa is produced, followed by a two pump-spa, then a single-pump spa, etc.

4.3 Simulation Results

4.3.1 Base Model Results

The simulation results of the base model are as follows:

Table 4.4 *Base Model Simulation Results*

Average of 5 Replications of Base Model					
Name	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Max	% Utilization
Plastic Inventory	486.8	936.5	474.90	486.8	0.0
Vacuum Former	24.6	38.4	0.98	1	97.5
Spray Booth	24.4	36.8	0.93	1	93.0
PreDrill	24.6	37.1	0.95	1	94.5
Drill and Edge	24.4	37.5	0.95	1	94.8
Fitting and Plumbing	24.6	62.1	0.79	2	79.1
Cabinet and Shell assembly	23	15.2	0.36	1	36.5
Final Plumbing	23.2	21.7	0.52	1	52.5
Flip	45.4	10.2	0.48	1	48.1
Water Testing	23.6	37.9	0.23	3	23.4
Foam Trim Paint	22.8	13.0	0.31	1	30.8
Hydraulic Flipper	22	1.5	0.03	1	3.5
Clean Detail Final Assembly	22	8.1	0.19	1	18.8
Final Inspection	22.2	4.5	0.10	1	10.4
Wrap and Pack	22.2	6.5	0.15	1	14.9
Shipping	21.8	0.0	0.00	1	0.0

This simulation data shows that on average, BullFrog International produces 21.8 spas a day. This average is higher than the data shown in the previous section, but sales were slow during that month. The average throughput of May was 19.2, which is significantly higher and closer to the results in this base model. (The Director of Manufacturing gave the information of the average throughput of May, but no specific data was received)

The 21.8 spas produced in two shifts, which a total production time of 14 hours or 840 minutes gives a throughput per hour of 1.55 or one spa every 38.5 minutes.

4.3.2 Traditional Lean Manufacturing Methods Result

The simulation results of traditional lean methods in the three groups are as follows:

Table 4.5 *Simulation Results for Group 1*

Average of 5 Replications of Group 1					
Name	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Max	% Utilization
Plastic Inventory	22.6	42.6	1.00	1	0.0
Vacuum Former	22.6	42.6	1.00	1	100.0
Spray Booth	22.6	41.1	0.96	1	96.5
PreDrill	22.6	40.1	0.94	1	93.9
Drill and Edge	22.6	40.4	0.95	1	94.6
Fitting and Plumbing	23.2	75.2	0.90	2	90.5
Cabinet and Shell assembly	22.2	14.3	0.33	1	33.3
Final Plumbing	22.8	23.3	0.56	1	55.6
Flip	45.2	10.9	0.51	1	51.5
Water Testing	23.2	35.4	0.21	2.6	21.4
Foam Trim Paint	22.8	16.6	0.39	1	39.1
Hydraulic Flipper	22.6	2.0	0.05	1	4.7
Clean Detail Final Assembly	22.8	9.0	0.21	1	21.4
Final Inspection	22.6	6.0	0.14	1	14.1
Wrap and Pack	22.2	7.9	0.18	1	18.2
Shipping	22	0.0	0.00	1	0.0

Comparing Group 1 simulation results to the base model, we notice that there is an improvement of 0.9%. This improvement is not significant enough to warrant a change, because more replications would probably not make a big difference in throughputs and so implementing the traditional lean manufacturing method for group 1 probably would not change the throughput from current performance. The 22 spas produced in two shifts, which a total production time of 14 hours or 840 minutes gives a throughput per hour of 1.57 or one spa every 38.2 minutes.

Table 4.6 *Simulation Results for Group 2*

Average of 5 Replications of Group 2					
Name	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Max	% Utilization
Plastic Inventory	18.2	53.0	1.00	1	0.0
Vacuum Former	18.2	53.0	1.00	1	100.0
Spray Booth	26.6	34.3	0.94	1	94.0
PreDrill	26.6	34.6	0.95	1	94.7
Drill and Edge	26.6	34.9	0.96	1	95.6
Fitting and Plumbing	27.4	61.9	0.87	2	87.1
Cabinet and Shell assembly	26.6	21.2	0.57	1	57.5
Final Plumbing	26.8	28.3	0.78	1	78.4
Flip	52.4	11.5	0.62	1	61.8
Water Testing	27.2	41.6	0.29	3	29.0
Foam Trim Paint	25.4	17.7	0.45	1	45.2
Hydraulic Flipper	25	1.9	0.05	1	5.1
Clean Detail Final Assembly	25	9.5	0.25	1	25.0
Final Inspection	25	6.1	0.16	1	15.7
Wrap and Pack	24.8	7.5	0.19	1	19.4
Shipping	24.6	0.0	0.00	1	0.0

Comparing Group 2 simulation results to the base model, there is an improvement of 12.8% increase in throughput. The improvement of traditional lean manufacturing methods in group 2 is substantial enough to justify a change in the production schedule and if implemented probably would improve the throughput of the factory. The improvements caused by this change could be less or greater depending on defects and the type of spas ordered. The 24.6 spas produced in two shifts, which a total production time of 14 hours or 840 minutes gives a throughput per hour of 1.76 or one spa every 34.1 minutes.

Table 4.7 *Simulation Results for Group 3*

Average of 5 Replications of Group 3					
Name	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Max	% Utilization
Plastic Inventory	12	80.2	1.00	1	0.0
Vacuum Former	12	80.2	1.00	1	100.0
Spray Booth	23.4	39.6	0.96	1	96.1
PreDrill	23.4	40.2	0.97	1	97.4
Drill and Edge	23.4	40.0	0.97	1	97.0
Fitting and Plumbing	24.4	71.2	0.90	2	89.8
Cabinet and Shell assembly	23	12.3	0.30	1	30.1
Final Plumbing	23	20.0	0.49	1	48.7
Flip	46	11.1	0.53	1	53.4
Water Testing	23.8	34.5	0.22	2.4	21.5
Foam Trim Paint	23.8	14.4	0.36	1	36.0
Hydraulic Flipper	23.4	1.7	0.04	1	4.2
Clean Detail Final Assembly	23.6	9.2	0.23	1	22.6
Final Inspection	23.6	5.0	0.12	1	12.4
Wrap and Pack	24	7.6	0.19	1	19.0
Shipping	23.8	0.0	0.00	1	0.0

Comparing Group 3 simulation results to the base model, there is an improvement of 9.2% increase in throughput. The schedule suggested by the traditional lean manufacturing methods is a substantial improvement to merit a change in the production schedule and if implemented probably would improve the throughput of the factory. The improvements caused by this change could be less or greater depending on defects and the type of spas ordered. The 23.8 spas produced in two shifts, which a total production time of 14 hours or 840 minutes gives a throughput per hour of 1.7 or one spa every 35.3 minutes.

4.3.3 Optimum Mix Results

Multiple simulation experiments were conducted, in which the production schedule of 1-pump and 2-pumps were changed until the optimum throughput of each group was determined.

The optimized results of the three groups are as follows:

Table 4.8 *Optimum Production Schedule Suggested by Simulation*

	Single-pump Made	Double-pump Made
Group 1 Optimized	2	2

Table 4.9 *Simulation Results for Optimized Group 1*

Average of 5 Replications of Optimize Group 1					
Name	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Max	% Utilization
Plastic Inventory	13.4	72.1	1.00	1	0.0
Vacuum Former	13.4	72.1	1.00	1	100.0
Spray Booth	25.2	37.0	0.97	1	96.8
PreDrill	25.2	35.7	0.93	1	93.3
Drill and Edge	25.2	35.9	0.94	1	93.9
Fitting and Plumbing	26	60.1	0.81	2	81.3
Cabinet and Shell assembly	24.8	15.0	0.39	1	39.0
Final Plumbing	24.8	23.3	0.60	1	60.3
Flip	48.8	11.1	0.57	1	56.6
Water Testing	25.8	36.1	0.24	2.6	24.3
Foam Trim Paint	24.6	14.9	0.38	1	38.0
Hydraulic Flipper	24.6	1.8	0.05	1	4.6
Clean Detail Final Assembly	24.6	8.6	0.22	1	22.0
Final Inspection	24.6	5.9	0.15	1	15.0
Wrap and Pack	25	7.5	0.20	1	19.6
Shipping	24.4	0.0	0.00	1	0.0

Comparing the Optimized Group 1 simulation results to the base model, there is an improvement of 11.9% increase in throughput. This optimized schedule suggested a superior way over the traditional lean manufacturing methods. The improvement caused by the production schedule is substantial enough to merit a change and if implemented probably would improve the throughput of the factory. The improvements caused by this change could be less or greater depending on defects and the type of spas ordered. The 24.4 spas produced in two shifts, which a total production time of 14 hours or 840 minutes gives a throughput per hour of 1.74 or one spa every 34.4 minutes.

Through multiple simulation experiments, the results of the traditional lean manufacturing methods of group 2 and group 3 were the optimum solutions and will be the ones that will be implemented. The results of group 2 and group 3 are in the previous section.

4.4 Actual Results

The actual throughput numbers cannot be disclosed in this section due to the confidentiality of the information. However, the results will be presented in percentage of change in throughput from the historical data.

Table 4.10 *Actual Results of Implementing Production Schedules*

Date	Group 1	Group 2	Group 3	Single-Pump	Double-Pump	Percentage Increase
28-Jun	1	0	0	0.56	0.44	26.8%
2-Jul	1	0	0	0.58	0.42	83.1%
15-Jul	1	0	0	0.58	0.42	83.1%
16-Jul	1	0	0	0.54	0.46	83.1%
1-Jul	1	0	0	0.52	0.48	76.1%
13-Jul	1	0	0	0.56	0.44	76.1%
9-Jul	1	0	0	0.48	0.52	47.9%
28-Jun	1	0	0	0.50	0.50	26.8%
6-Jul	1	0	0	0.53	0.47	19.7%
7-Jul	1	0	0	0.59	0.41	19.7%
29-Jun	1	0	0	0.44	0.56	12.7%
8-Jul	1	0	0	0.58	0.42	33.8%
14-Jul	0	1	0	0.65	0.35	82.5%
19-Jul	0	1	0	0.61	0.39	82.5%
24-Jun	0	1	0	0.74	0.26	82.5%
25-Jun	0	1	0	0.60	0.40	42.9%
12-Jul	0	1	0	0.67	0.33	66.7%
30-Jun	0	0	1	0.35	0.65	58.7%
	11	5	1			
Avg Throughput	21.45	20.00	20.00			
Avg % Increase	49.1%	58.7%	58.7%			

Table 4.11 *Throughput Results for the Suggested Production Schedules*

Date	Throughput per Hour	Throughput Rate
28-Jun	1.29	46.67
2-Jul	1.86	32.31
15-Jul	1.86	32.31
16-Jul	1.86	32.31
1-Jul	1.79	33.60
13-Jul	1.79	33.60
9-Jul	1.50	40.00
28-Jun	1.29	46.67
6-Jul	1.21	49.41
7-Jul	1.21	49.41
29-Jun	1.14	52.50
8-Jul	1.36	44.21
14-Jul	1.64	36.52
19-Jul	1.64	36.52
24-Jun	1.64	36.52
25-Jun	1.43	42.00
12-Jul	1.50	40.00
30-Jun	1.43	42.00

On June 25, 2004 BullFrog International produced fewer spas than the other dates because there was only a single shift of production because the second shift was canceled. This was an 8 hour shift, but the total production time was only 7 hours or 420 minutes. This gave the throughput per hour of 1.43 or in other words, one spa was produced every 42 minutes. By extrapolating this data, it is possible that if they kept the same work pace, that BullFrog International could have produced twice the number of spas during two shifts.

4.5 Comparing Results

Table 4.12 *Comparing Actual Results with Simulation Results*

		Throughput % Increase	Throughput per hour	Throughput per minute
Group 1	Simulation Results	71.8%	1.74	34.40
	Average Actual Results	49.1%	1.51	41.08
Group 2	Simulation Results	73.2%	1.76	34.10
	Average Actual Results	58.5%	1.57	38.31
Group 3	Simulation Results	88.9%	1.70	35.29
	Average Actual Results	58.7%	1.43	42.00

The actual results were lower than the simulation results, but the actual results were significantly higher than the averages for March and April 2004. There was an average increase of 49.1% in throughput from the averages of March and April 2004 for group 1, which is significant. There was an average increase of 58.5% in throughput from the averages of March and April 2004 for group 2, while for Group 3 an increase of 58.7% was realized. The improvements can be attributed to the schedule changes, because no other changes were made with the exception of personnel where one employee was changed from night to day shift.

5 Conclusion and Recommendations

5.1 Conclusion

The results of the simulation experiments supports the hypothesis that the implementation of lean manufacturing will be improved from the use of simulation, because the results of the simulation suggested that there was a better production mix for group 1 than what would be suggested by lean manufacturing principles. The simulation experiment suggested a production ratio of 2 to 2, instead of the lean manufacturing ratio of 1 to 1, which gave an 11.9% increase over the base model and a 10.9% increase over the lean manufacturing suggest production schedule. The simulation results also validated that the production mix schedules for group 2 and group 3 were the best possible solution and provided motivation that they would be beneficial to implement. The actual results of implementing the different production schedules were a 49% average increase in throughput for group 1 and a 59% average increase in throughput for groups 2 and 3. Although the results of the simulation experiments did not exactly predict the throughputs that occurred in the factory, the use of simulation in implementing lean manufacturing was helpful. It allowed us to verify that two of the lean manufacturing production schedules we proposed were optimal solutions, while in a third case it provided a better result than the lean solution. By implementing our proposed production schedules, Bullfrog International, L.C increased their production throughput immediately and consequently had multiple record days during our observation period of one month. The data gathered from this case study supported two hypotheses that were the basis of this current work: 1) mixed, level loaded production schemes resulted in much better throughput than the large batch methods that were employed before the recommendations of the study were implemented, and 2) simulation can provide optimal solutions to the problem of production scheduling, while at the same time reducing the trial-and-error period that can be present during implementation of lean principles.

5.2 Recommendations

Although the data support the hypothesis, more experiment needs to take place before the hypothesis is confirmed. Also more case studies should be conducted in order to confirm that the use of simulation is beneficial in implementing lean manufacturing decisions where the answer is difficult to reach because of the complexity of the system. Making an accurate simulation model is very difficult because of the tremendous amount of factors that are a part of a normal manufacturing system. It would be helpful in studying factors or guidelines that can aid in creating a more reliable simulation model.

Converting operations to lean manufacturing is a difficult process and more research about making the transformation and what has helped others make the transition smoother. One possible way would be to develop Simulation software that guides you through making lean decisions, which could help companies make the lean transformation easier. Once a base model of the operations was created, the company could pick the areas or principles that they would like to implement first and then the simulation software could take them systematically through the process to help them to know exactly how to implement the change. This software could be an add-in software that could be purchased for companies trying to make the transition to lean manufacturing.

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7 Appendix

Table A. 1 (Equations taken from [1])

Little's Law	$Throughput = \frac{WIP}{Cycle\ Time}$	WIP = work in progress
Coefficient of Variation	$cv = \frac{\sigma}{t}$	σ = standard deviation t = mean time
Squared Coefficient of Variation	$scv = \left(\frac{\sigma}{t}\right)^2$	scv = squared coefficient of variation
	$\sigma_i^2 = t_i^2 \times scv$	σ_i^2 = Initial variance
Availability	$A = \left(\frac{m_f}{m_f + m_r}\right)$	A = availability m_f = mean time to failure m_r = mean time to repair
Effective Processing Time	$t_e = \left(\frac{t_0}{A}\right)$	t_0 = original processing time t_e = effective processing time
Effective scv	$scv_e = scv_0 + \frac{2m_r A(1-A)}{t_0}$	scv_e = scv for effective processing time
Utilization	$u = \frac{t_e}{t_a}$	u = utilization t_a = the mean time between arrivals of production work pieces
The Waiting Time	$CT_q = \left(\frac{scv_a + scv_e}{2}\right)\left(\frac{u}{1-u}\right)t_e$	CT_q = waiting time scv_a = scv for time between arrivals
The scv of Departure Time	$scv_d = u^2(scv_e) + (1-u^2)scv_a$	scv_d = scv of departure time
The Variance of Time Between Arrivals	$\sigma_a^2 = \frac{1}{\#\,jobs}(time)^2 - (t_a)^2$	σ_a^2 = variance of time between arrivals
scv of Arrivals if done in batches	$scv_a = k - 1$	k = number of pieces in a batch

Table A. 2 *Batch Production Performance*" [1]

Batch Size (WIP)	Cycle Time (minutes)	Throughput (pieces per minute)	Throughput (pieces per hour)
1	4	0.25	15
2	8	0.25	15
3	12	0.25	15
4	16	0.25	15
5	20	0.25	15
6	24	0.25	15
7	28	0.25	15
8	32	0.25	15
9	36	0.25	15
10	40	0.25	15

Table A. 3 "*Single-Piece Flow Performance*" [1]

Work-In-Progress (WIP)	Cycle Time (minutes)	Throughput (pieces per minute)	Throughput (pieces per hour)
1	4	0.25	15
2	4	0.50	30
3	4	0.75	45
4	4	1.00	60
5	5	1.00	60
6	6	1.00	60
7	7	1.00	60
8	8	1.00	60
9	9	1.00	60
10	10	1.00	60

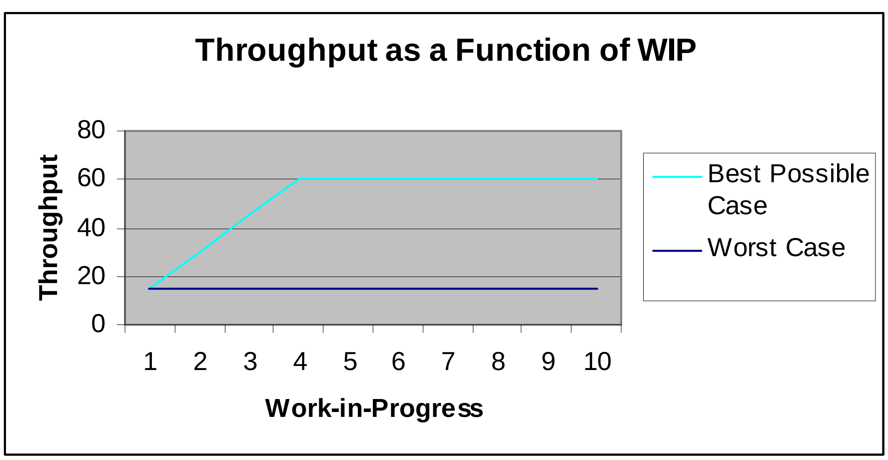

Figure A. 1 "*Throughput as a Function of WIP*" [1]

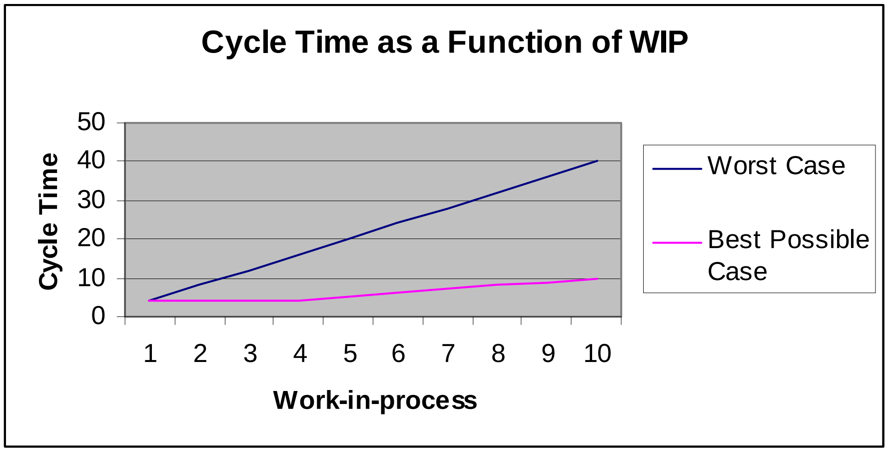

Figure A. 2 "*Cycle Time as a Function of WIP*" [1]

Entire Email from Daniel T. Jones
Dear Jack,

Thanks for your email.

I have seen a lot of use of simulation in system design and it is great fun and often helpful.

However it is also often misleading. A classic example is the Goldrat drum buffer rope stuff or CONWIP that says send the information as far upstream as possible and flow products back downstream in FIFO.
The problem in the real world is that FIFO is extremely difficult to sustain through many different steps - each of which bare subject to considerable random variability - which end up with queues for shared facilities and separate decision points (often informal) and poor flow.
So simulation might tell you one thing - but in the real world subject to lots of variation even in Toyota the more you can avoid long strings of steps the better.
So it is no wonder that Toyota's systems are all very simple and robust and backed up with very quick detection of an incident and very good problem solving skills to prevent it happening again.

I am sure there is lots of literature in the simulation world on this stuff - but you will find the answers to the Kanban issues in Creating Level Pull by Art Smalley available from LEI and LEA.

I hope this helps - best wishes
Daniel T Jones
Chairman
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Join us at the Lean Service Summit in Amsterdam on June 23-24.

-------------Forwarded Message-----------------

From: "Lean Enterprise Academy", INTERNET:info@leanuk.org
To: "Daniel Jones", danieltjones

Date: 10/06/2004 09:38 PM

RE: FW: Lean Manufacturing Thesis Question