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Bellows, Natchanart ***Applying Simulation Approach to Reduce Inventory***

Abstract

Company XYZ's current production system maintained a high level of inventory. Additionally, product flow was not effective throughout the current manufacturing floor layout. In each assembly process, there were long waiting times which had a direct impact on manufacturing costs and space utilization. When parts and subassemblies persist in the production system longer than necessary, for both raw material and WIP, the cost of holding inventory increases, causing a delay of return on investment.

The purpose of this study was to apply process mapping to identify wastes in the assembly processes, specifically the wastes that generate high inventory level and waiting time. The results from process mapping were then used to determine possible solutions. Simulation models were utilized to simulate and identify what can impact inventory levels, inventory holding time, and lead time to deliver products to customers. The results of this study identified improvement opportunities that Company XYZ can use for decreasing inventory without a negative impact on product delivery time. Based on this study results, smaller batch size tends to decrease inventory level. However, to prevent long delivery lead times, the company needs to hold some level of safety stock.

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Chapter I: Introduction

Company XYZ, a Midwest family business, was founded in 1949. It started by producing a small food supply equipment at local business. Today, the business has grown to manufacture variety of food serving equipment. The company operates out of an approximately 120,000 square foot facility and services a variety of customers including companies in the fast food, beverage, catering, hotel, and chain restaurant business. Its vision is to deliver products with honesty and passion as a global leader in technology of excellent quality serving products.

Company XYZ's diverse customer base has a variety of requirements which results in different designs and the use of many custom parts. Consequently, the company currently has over 5,800 part numbers in inventory to manage. Production demand is variable and orders can be as small as 50 to as large as 70,000 pieces. The company builds batch sizes larger than order quantities, holding the excess parts in inventory, to cover small order set-up costs. As a result, it keeps a safety stock of parts and sub-assemblies on the production floor at all times carrying an abundance of work in process (WIP) inventory and consuming a great deal of floor space. The company not only has a variety of parts to manage and overproduces to cover setup cost, but also carries increased inventory due to the existing process flow.

The current floor space layout was not ideal with parts traveling long distances from station-to-station creating non-value-added movement as well as inventory held at each station. Hence, the manufacturing system was a batch and queue process where parts were produced at each required station then placed into a container. Production needed to wait until the container was full before parts were transferred to the next process to decrease frequency of travel. As a result of holding the parts at each process waiting to fill the container, the parts stayed in the production system longer. Therefore, inventory level was increased throughout the process, increasing overall costs for the company to carry excess inventory which is considered waste. In order to remain competitive in the business, the management team has realized the need to make changes to the current process.

Statement of the Problem

Company XYZ's current production system holds a high level of inventory. In addition, product flow was not efficient throughout the current floor layout and there were long wait times, which had a direct impact on manufacturing costs and space requirements. When parts and subassemblies remain in the workstream longer than necessary, both as raw material and WIP, the cost of holding inventory increases, resulting in a delay of return on investment.

Purpose of the Study

The purpose of this study was to use process mapping to identify problems in the assembly processes and determine possible solutions. A simulation model was created and used to study inventory levels, inventory holding time, and lead time to deliver products to customers. The company may need to consider holding some level of safety stock to prevent long delivery lead times. The results of this study identified improvement opportunities that Company XYZ could utilize for decreasing inventory without a negative impact on product delivery time.

Assumptions of the Study

This study has three assumptions.

1. For this study, there are no labor constraints, meaning that all operators are cross trained available when production requires.
2. For ease of simulation, production operates only Monday through Friday on two shifts. The first shift works from 6:00 AM to 2:30 PM. The second shift works from 2:00 PM to 10:30 PM.

3. Raw materials required for production are always available.

Definition of Terms

The following terms and definitions are used.

Batch and queue. A production system where groups of parts are moved to the next process step before there are needed. The parts wait in a queue to be processed (Manos & Vincent, 2012).

One piece flow. **“**A situation in which products proceed, one complete product at a time, through various operations in design, order-tasking, and production, without interruptions, backflow, or scrap” (Womack & Jones as cited in Manos & Vincent, 2012, p. 246).

Order cycle time. Time from receiving customer order to delivery time is calculated from the time that the company has enough inventory for all components until the time finish final assembly.

Product cycle time. Time from starting work with the first component until the time finishing final assembly.

Work in process. “Incomplete products or services that are awaiting further processing prior to being forwarded to the customer as finished product or completed services” (Manos & Vincent, 2012, p. 393).

Limitations of the Study

There are two limitations applied to this study.

1. Company XYZ produces several products. This study focused on a randomly chosen product which is pump part number 83330.
2. Lead time for raw material ordering was not included in this study.

Methodology

In this study, process mapping was conducted and a simulation model built using Arena software to simulate different production setting scenarios. The process was analyzed in terms of batch size, equipment setup time, and transfer time between stations to minimize inventory level, product time, and order time. The outcomes of this study will be submitted to Company XYZ for future state improvements.

Chapter II: Literature Review

Company XYZ carries a high level of inventory which contributes to holding costs, delay of return on investment, and inefficient use of floor space. To minimize inventory, applying lean manufacturing principals could help the company eliminate unnecessary activities. In order reduce process waste at Company XYZ, there are several steps to be considered part of the process improvement. First, identify types of waste in the system and determine sources of problems including the opportunities for change. Process mapping is one tool that can be used to identify sources of waste. Second, evaluate opportunities to implement methods such as one-piece flow and single minute exchange of dies to reduce work in process (WIP) and travel time on the production floor. Finally, design of experiments and simulation can be used to examine the optimal solution for the future state.

Lean Manufacturing

Lean Manufacturing was first introduced by Toyota and is also known as the Toyota Production System. According to Earley (2016), lean should not be complicated. To be successful in implementing lean, there are several principles to comprehend. First, it is essential to know the customer and fully understand value from the customer perspective. Second, produce only what the customer ordered and ship the final product immediately. Furthermore, the process from receiving an order through shipping the product should be continuous flow (Earley, 2016). There is no stopping, no inventory waiting between processes or being held in a warehouse. Third, recognize and eliminate non-value-added activities or wastes throughout the operation (Earley, 2016; Maciej, 2014). Lastly, use proper tools to closely monitor and control the process to minimize process variation which results in eliminating potential sources of defective products (Earley, 2016). Successful implementation lean manufacturing can significantly reduce the amount of waste in a process.

Types of Waste

Manos and Vincent (2012) explained that in any type of business, work is comprised of three essential elements. First, actual work that adds value to the product or service from the customer perspective. Second, work required to be performed but does not add any value to the actual product or service. Third, work that is not necessary and does not add value to the product or service which is waste. Therefore, waste refers to any work activities that use resources and cause a product or service cost increase, but the customer is not willing to pay for (Manos & Vincent, 2012; Suárez-Barraza, Dahlgaard-Park, Rodríguez-González & Durán-Arechiga, 2016). Taiichi Ohno is the first person who identified the seven types of wastes (Liker, 2004). The seven wastes consist of over production, waiting or idle time, unnecessary transport, over processing, inventory, unnecessary motion, and defects. In addition, Adams (2006a) suggested an eighth waste exists which is the lack of utilizing people and their abilities. The following paragraphs define the eight types of waste and possible solutions for each.

The first waste is over production. This waste occurs when a company is producing more than what is needed at that time (Sutherland & Bennett, 2008). Manos and Vincent (2012) also described over production as the most significant of all wastes because it could lead to other types of waste such as excessive inventory. For instance, a company may build ahead for future orders per a demand forecast. Sutherland and Bennett (2008) described demand forecasting as a created demand that can impact inventory level. When a company forecasts too high, the production floor will be overproducing and the products become excess inventory. By the same token, Hill (2018) identified over production as the worst waste because it results in surplus inventory that waits for actual customer orders resulting in inventory holding costs.

To deal with over production, it may be necessary to decrease machine setup time to lower setup costs which allows flexibility of product change over and production of smaller lot sizes (Hill, 2018). Equally important is focusing on the orders that can be sent to a customer today, instead of preparing for future orders by adjusting the production rate to match customer demand (Adams, 2006b; Hill, 2018). When company produces at the same pace as customer demand, over production should not occur.

The second waste is waiting. This waste appears when a machine is idle waiting for product to arrive, an operator is idle waiting for a machine to complete work, or WIP is waiting to transfer to the next operation (Hill, 2018; Manos & Vincent, 2012). Waiting could be the effect of an unbalanced workload at each process step, or disconnection of production floor layout (Sutherland & Bennett, 2008). This type of waste not only occurs on a production floor, it also can happen in a supply chain system. Manos and Vincent (2012) describe the largest waste in time to deliver is the waiting time. When there is waiting time in the process, product stays in the system longer causing a delay of finish goods delivery.

To minimize waiting time, Manos and Vincent (2012) suggested the manufacturing team pay attention to balancing of workload throughout the whole process. Standardized processes should be established so everyone works the same manner which creates a consistency of work practice, and the time required for each process step will be stable (Hill, 2018). Additionally, the flow of processes should be smooth and continuous, thus, there is no buffer between process steps (Hill, 2018).

The third waste is unnecessary transport. Handling product or WIP moving long distances from one process to the next process step, or transferring material from warehouse to working area multiple times are considered transportation waste. This type of waste can be found in nearly all warehouses (Adams, 2006a). On the production floor, transferring WIP or material before it is needed also creates transportation waste. This waste could cause a delay of overall work processing because it increases waiting time and results in the product staying in the system longer. Moreover, unnecessary or multiple transfers can cause damage to product or raw material (Manos & Vincent, 2012).

To decrease transportation waste, the floor layout and flow of product or material may need to be revisited. Adams (2006b) recommended mapping the movement of each material from the time received until it is ready to ship out. From raw material to completed product, the process should be setup as a continuous flow to avoid back and forth transportation (Hill, 2018; Manos & Vincent, 2012).

The forth waste is over processing. This type of waste happens when activities performed to complete the product go above and beyond what is actually needed to satisfy the customer. For instance, producing a part holding a tighter tolerance than the customer provided drawing. Redundant processing is also considered over processing. For example, a manual visual inspection station setup for detection of the same defect as automated equipment. Adding more value to a product than the customer requires could increase production costs and increased handling may cause delays in the process including chance of creating defects (Adams, 2006b; Manos & Vincent, 2012).

Hill (2018) commented that over processing is not simple to capture and eliminate. However, this type of waste can be reduced by evaluating what is required in the process to meet customer requirements. Equally important, the company needs to ensure that the processes are simple enough and can deliver what the customer asked for and is willing to pay for.

The fifth waste is inventory. Staging or storing raw material, WIP, or finished product that is not required for use or shipment at the time of creating the inventory is waste. Keeping WIP or incomplete product between processes is also considered as inventory (Hill, 2018; Manos & Vincent, 2012). This type of waste is related to over production and waiting since they both can create excessive inventory. When product is produced faster than customer demand, inventory happens and demands more space for storage. Furthermore, high levels of inventory can hide defective product (Manos & Vincent, 2012). Consequently, the cost of quality may increase and cause delay of return on investment.

Eliminating inventory completely seems impossible because a company may require some safety stock to prevent long lead times to delivery. Minimizing inventory levels requires precise demand forecasts and appropriate reorder quantities (Adams, 2006b). Hence, a company should only bring in material when required, and produce the products only when there is a customer order to fill (Hill, 2018).

The sixth waste is unnecessary motion. This waste transpires when there is unnecessary movement of people to perform their work (Hill, 2018). Extra effort motion can be the result of poorly designed work stations or production floor layout. In the long run, the undesirable motion can cause health problems for operators. This eventually results in product quality issues, and decreased productivity (Manos & Vincent, 2012). Finally, wasted motion can increase cost of the product.

To minimize unnecessary motion, equipment and work station layouts should be properly designed (Hill, 2018). An ergonomic assessment will be required to establish an effective work station that can reduce physical health issues for operators (Manos & Vincent, 2012). Mapping diagrams can also be used to study and identify effective routes of movement. Utilization of some tools can help minimize unnecessary movement, for instance, using a conveyor to transfer parts to the next process.

The seventh waste is defect. Product that does not meet customer specifications are considered defects as well as product that needs to be reworked or scrapped are also considered defects (Hill, 2018). There are several possibilities that cause product failure to meet customer expectations. For example, there may not be a standard procedure or the procedure is not well explained, the process design is too complicated, equipment is not well maintained, or the product was not well designed for manufacturing (Manos & Vincent, 2012). High defect rates increase scrap cost, rework cost, material cost and labor cost which decreases overall company profit.

To minimize defective parts, product design may need to consider the processes required to produce it and design in methods to reduce production errors. The processes should be simple and effective to prevent production errors (Hill, 2018). Next, all operating procedures required must be clear and simple enough to follow. Then control charts can be utilized to monitor product quality during production. Last, historical data can be collected and analyzed to identify improvements.

The final waste is the underutilization of employees' skills**.** Adams (2006a) defined waste associated with people as not utilizing them to their fullest potential. Each employee has different strengths and weaknesses. Adams (2006a) suggests making a "skills matrix" (p. 38) to determine what areas are strong and where improvement is needed and put a training program in place to address the gaps.

Process Mapping

Process mapping is a widely used tool for process development and improvement. Westcott et al. (2014) gave the definition of process mapping as “a technique for designing, analyzing, and communicating work processes” (p. 359). Process mapping is a means of using a flowchart identifying in depth details of a process flow from start to the end. It has the flexibility to be used in different businesses as a tool to help envision the entire system leading to an improved understanding of a process.

Westcott et al. (2014) suggested that process mapping can be completed following steps outlined below:

1. Select the process of interest to perform the process mapping.
2. Set a goal of performing the process mapping.
3. Select process map format to be used.
4. Start process mapping by identifying process inputs and outputs, start and end of process, details of operations, details of actions, and people who are involved with the process.
5. Ensure that all required details of the process are included.
6. Ensure that process inspections, or product testing are included.
7. Verify the accuracy of mapping through process operators and with personnel that are subject matter experts for the process.
8. Update the process as needed.

White and Cicmil (2016) state that process mapping is an effective method for gaining knowledge about ones’ organization and also a good means of documenting this knowledge. In addition, process mapping can be used to improve existing methods by identifying areas of opportunity to increase process efficiency, utilization, product quality, reduce scrap and improve employee collaboration.

Performing process mapping can lead to productivity improvement and better utilization of people. Kumar and Phrommathed (2006) performed a study in a paper mill process in Thailand where they used process mapping and simulation to improve the process of sheet cutting. When the new process is implemented, the process is more efficient which reduces lead time and freed operators so they could focus more on product quality. Mapping is not only useful for identifying productivity problems, it also can identify causes of defective product and uncover waste.

Waiting time is a waste that should be eliminated. DeGirolamo et al. (2018) applied process mapping in emergency diagnosis to track patient interaction time with the care facility throughout their treatment. From this mapping, healthcare providers can conclude where there are large variations in treatment times that may need to be addressed and the possible impact they have on treatment results. Another form of waste is defective product which results in scrap cost. Scrap reduction can be identified using a process map and possibly lead to process or material intervention. Rybicka, Tiwari, Campo, and Howarth (2015) studied material scrap management by interviewing four manufacturers that use composite materials. The interviewer asked questions using a process flowchart that mapped material flow to find out causes of material scrap, the possibility to reuse or recycle that material, and the opportunity of implementing new processed that generate less scrap material. The results from this process mapping identified the gaps in manufacturing that generate material scrap and waste management process issues which led to new material development in the future. Not only can process mapping identify sources of productivity problems and waste, process mapping can also promote employee engagement and co-operation.

Process mapping can be used to generate ideas from employees and promote teamwork. The study of pollution prevention at a dairy processing facility found that the employees were interviewed using the process map to brainstorm suggested 41 potential areas of the operation for pollution prevention (Aikenhead, Farahbakhsh, Halbe & Adamowski, 2015). From this activity, the company used employee collaboration to establish a plan to minimize facility generated pollution.

Single Piece Flow

According to Li, Ni, Wnag, Shi, and Zhu (2012), single piece flow "is a concept of carrying one work piece at a time between two adjacent operations, which help the company to achieve true just-in-time manufacturing" (p. 996). In a single piece flow process, the system should be pulling forward one unit at a time to the downstream operation so that all product is moving through the process at the same rate (Beachum, 2005). In order to balance the line, bottlenecks need to be eliminated. Li et al. (2012) identified strategies for eliminating bottlenecks in a process through the use of several flexible cells over larger high output machines, using a Kanban, or a supermarket to balance flow.

There are many benefits of achieving single piece flow which include minimizing WIP, balancing process flow and quality improvement due to issues being discovered when they occur. Clayton (2007) demonstrated that changing from a batch and queue process to single piece flow cut the amount of floor space required in half, reduced operators from eight to three and increased overall capacity.

Single Minute Exchange of Die (SMED)

Dave and Sohani (2012) defined Single Minute Exchange of Die (SMED) as a streamlined method of changing over production quickly from one product to the next. The goal of SMED is to have a complete process change take fewer than 10 minutes, given that time starts after the last good part of the current lot is produced and ends with the first good part of the next lot (Shingo, 1985). The key to reducing changeover time is to determine and separate external from internal activities, changing as many tasks as possible to external. External activities may be completed prior to the equipment being shut down while internal activities require the equipment to stop production during the change.

Shingo (1985) recommended that SMED should be completed in four steps:

1. Learn about the current state of the process by observing change overs, interviewing operators and recording videos of change overs.
2. Identify external and internal setup tasks and when possible change tasks to external to reduce setup time.
3. Re-evaluate all change over tasks to verify that as many as possible were changed to external operations.
4. Optimize all steps of the changeover to perform them quickly, simply, and safely.

Quick changeover can help a company improve its productivity as well as increasing flexibility when demand fluctuates (Moreira & Garcez, 2013; Pinjar, Shivakumar & Patil, 2015). SMED allows production of smaller batch sizes and eliminates unfavorable effects of changeover processes by reducing downtime making it possible for setups to be completed more frequently as well as possibly increasing production output (Groote, 2006; Filla, 2016). In summary, SMED can help a company decrease overproduction, minimize WIP and reduce inventory.

Design of Experiment (DOE)

An experiment for process improvement, in several cases, only considers one factor at a time. However, there might be more than one factor that influences the process. Thus, the design of experiment becomes a major player because it can include many factors at several levels which could determine effects of interaction between or among important factors (Henderson, 2011; Montgomery, 2013). Design of experiment is widely used in many businesses. Montgomery (2013) defined DOE as a vital tool for new process design and process improvements that helps reduce development time and process variation, increase yield, and finally decrease overall manufacturing cost. Montgomery (2013) provided a guideline for designing experiments.

1. Experimenters need to understand and clearly define the problem. This step requires a team working together listing the problems or questions that need to be resolved. Then the objective of experiment should be determined which could be factors screening, to optimize the process, to verify consistency of the system after experiment, to discover somethings new, or to verify robustness of process when process conditions change.
2. Outcomes of the experiment are correctly defined. Experimenters need ensure that the outputs from the process experiment provide valuable information. It could be either an average or standard deviation, or sometimes both. The means used to measure the outcomes should be addressed to make sure that they are capable for the required measurements.

3. Experimenters select the interested factors that possibly influence the process. One tool that can help identify factors is known as fish-bone diagram. Then the levels and range of selected factors needs to be defined. This step requires process knowledge which can be from personal experience or theoretical study.
4. Select experimental design by defining the sample size, and run order. The experimental design also considers the use of empirical models for results explanation, or the use of main effects and interaction studies.
5. Experimenters perform the experiment. It is important to closely monitor and strictly follow the experiment plan. If there is an error, it may result in invalid experiment results.
6. Performing data analysis requires statistical knowledge. However, the knowledge about the process and some common sense can also help interpret results and lead to conclusions.
7. After completion of data analysis, the experimenter needs to draw conclusions and provide recommendations. A confirmation run may be performed to verify the accuracy of the conclusions.

Simulation

Kelton, Sadowski, and Zupick (2015) defined simulation as "a broad collection of methods and applications to mimic the behavior of real systems, usually on a computer with appropriate software" (p. 1). It is a well-known and effective tool used for examining and resolving complicated systems (Altiok & Melamed, 2007). Simulations can be used to imitate different combinations of scenarios and provide the optimal result. Process simulation has many purposes, for instance, it can help identify problems in a manufacturing system, measure the existing system performance, simulate process improvements to provide an optimal solution before decision making, and perform cost analysis of benefit (Altiok & Melamed, 2007; Kelton et al., 2015).

Examining operational performance of the current situation assists a company in understanding and identifying existing problems. A model can be developed to represent the existing production system which includes the equipment operator, transportation tools, material storage space and product (Kelton et al., 2015). Supsomboon and Vajasuvimon, (2016) developed a model representing current production at a job shop to verify the system performance indicators of daily throughput, equipment, and operator utilization before determining change strategies.

Simulation may provide a company an advantage to remain competitive in their business. Simulation can help develop a model representing an unusual situation or define improvement opportunities to increase productivity (Kelton et al., 2015; Supsomboon & Vajasuvimon, 2016). When product demand changes, re-configuring the current production may be necessary. Aqlan, Lam, and Ramakrishnan (2014) developed a model that simulated the current production process and recommended combining the line along with an updated transportation schedule to improve production system efficiency. Companies, many times, have assumptions and believe they already know what in the production operation should change to improve performance, even though it may not be right. Opacic, Sowlati, and Mobini (2018) used simulation to discover that replacing a piece of equipment would not provide any benefit, instead, the company should increase the number of operators and add a transportation conveyor which will improve throughput by 21%. This prevented the company from investing in incorrect information. On the other hand, the current manufacturing problem may have more than one solutions and simulation can provide the optimal change which results in the lowest manufacturing cost.

The cost of change can be evaluated before making a decision. When a company needs to understand the effect of a change, sometimes it cannot be done at the current production line due to cost concerns, high demand, or tight deliver time lines (Altiok & Melamed, 2007). Simulation is a good alternative in this type of situation. Zhang, Chiang, and Wu (2014) used simulation to study the effect of production rate, defect rate, and maintenance frequency on fixed and variable costs. These three production parameters are not practical to test in real production, especially defect rate, while production speed and maintenance frequency would take a long time to collect data. Simulation results helped suggest the optimal settings to minimize overall manufacturing cost.

Even though there are many benefits of using simulation, there are also risks associate with it. Aqlan et al., (2014) suggested that to build an accurate simulation model for the future state, the company requires good collection of historical data as well as precise demand prediction. Without those, the model may lead company to the wrong way. Altiok and Melamed (2007) also described that in order to design the simulation, the statistical knowledge is very important. If simulation experiment does not proper design in term of running replication and length, the model may not valid to use for measure system performance. In addition, the interpretation of simulation output is also extremely vital. The experimenter needs to understand the system very well. Otherwise, it will lead to inaccurate prediction and wrong decision making.

Conclusion

To establish an optimal solution for Company XYZ, several steps need to be taken to reduce inventory throughout the process. Recognizing all types of waste along with the use of process mapping will help identify sources of waste in the system. Working toward single piece flow could be a company best practice for decreasing inventory. Reducing changeover time will allow more production flexibility as well as a reduction of WIP. DOE and simulation models should be used to determine the ideal solution for company management to review and select the path moving forward.

Chapter III: Methodology

Management team at company XYZ realized that the current batch and queue production system was inefficient and contained too much inventory. The manufacturing floor holds high levels of inventory and the equipment layout is not ideal, consequently material flow throughout the plant is less efficient than it could be. When parts and subassemblies wait to be processed in the system longer, costs of holding inventory increase and extra space is required. However, the company probably needs to hold some level of inventory to prevent long delivery lead times. To investigate all options and obtain the best results for the company, the management team would like to explore possible solutions and predicted outcomes before making any changes. Thus, the intention of this study was to evaluate batch size, equipment setup time, and transfer time between processes to minimize inventory required while maintaining or improving order cycle time and product cycle time.

Subject Selection and Description

This study was performed for Company XYZ located in the Midwest which produces a variety of food serving equipment. The company contacted the University of Wisconsin Stout, Manufacturing Engineering Department, for assistance in identifying waste in the current production system and defining improvement opportunities. One product was randomly selected by the company for the purpose of this study.

Instrumentation

Process mapping was utilized to determine what elements of the process flow contribute to high inventory levels. Then the current state batch queue process and manufacturing floor layout was modeled using arena simulation. Process cycle time, batch size and transfer time information provided by Company XYZ was utilized to obtain baselines for work in process

(WIP) and inventory, total order cycle time, and total product cycle time. Refer to Appendix A-C for manufacturing information provided by Company XYZ. The current state model was then modified by manipulating the production system to find the optimal solution for the company. The floor layout re-arrangement decreased transfer time between operations so reducing transportation waste was simulated to verify work in process (WIP) and inventory level, order cycle time, and product cycle time. Then smaller batch sizes and single minute exchange of die (SMED) for decreased equipment setup times was simulated. The combination of production system changes was determined through full factorial design of experiments (DOE). Each of the parameters were evaluated at two levels. The baseline model and modified models were run to collect statistical data for each. For arena simulation, a warm up period was required for the model to arrive at steady state so it can be considered a reliable representation of the actual system. The rum length was determined to be 640 hours or four weeks using multiple replications for each production system combination. The simulations were completed using hours for the unit of time.

Data Collection Procedures

Upon completion of each DOE run using arena simulation, the model generates output of statistical data containing the quantity of WIP and inventory, the product cycle time, and total order cycle time. This data was then exported as an excel file for each run combination simulated. Finally, the results from each run was combined into one excel spreadsheet before transferring to Minitab for further statistical analysis.

Data Analysis

The information collected from process mapping was compared to the simulation of the current state and was used to identify problems and possible solutions. The collected data from the DOE simulation was evaluated using analysis of variance (ANOVA) to compare the modified production system combination with the current production system. The expectations were WIP and inventory of future state is lower while the product time and order time are comparable to or lower than the current state.

Limitations

There is limitation to this study. First, single minute exchange of die (SMED) cannot currently be performed at the actual equipment due to production schedule and downtime constraints. Thus, the SMED time used for this simulation was determined based on theory. After recommendation are made, the company still needs to test the new changeover method on the production equipment. Second, the proper sub-assemblies lot size cannot be determined with the current information provided by Company XYZ. Sub-assemblies may be used to produce different products that may have vary demand.

Summary

This chapter provided a detailed description of the instruments, data collection procedures, and data analysis performed of the process at Company XYZ. The data analysis outcomes from the simulation are used for recommending the optimal solution for Company XYZ to consider before making the decision to change the production system to the future state.

Chapter IV: Results

Company XYZ currently uses a batch and queue production system that is inefficient and contains several types of waste with the majority being inventory waste. The inefficient production floor layout effects material flow throughout the plant, consequently increasing material transportation as well as waiting time at each process step. When parts and subassemblies wait to be processed in the system longer, costs of holding inventory increase and extra space is required. A simulation model was developed to evaluate new production floor layout, batch size, and equipment changeover time. This chapter discusses the results of the process mapping and simulation used to determine possible improvements in terms of inventory.

Process Mapping Analysis

Based on process mapping in Appendix B, there are some problems that possibly delay assembly processes and create high inventory in the system. First, equipment that is used for more than one sub-assembly creates bottle necks in the process because the capacity is limited. The TH sub-assembly and CD sub-assembly processes both use common equipment which are MB34 and B10T. Both equipment require long setup time in order to produce either subassembly. The degreaser equipment is also used in most sub-assembly processes. However, there is only one BM34, B10T, and DG station available. When equipment is setup to produce one type of sub-assembly, the other sub-assemblies wait for equipment to become available. Equipment constraints can cause waiting time that results in holding high inventory levels, and can delay completion of customer orders.

Second, lot size for each sub-assembly is significantly different. The smallest lot size is 1,254 pieces which is the TB sub-assembly and TD sub-assembly. The largest lot size is FSS sub-assembly which is 25,000 pieces per lot. The unbalance lot size among sub-assemblies could create excess inventory in the system. In like manner, safety stock level is also significantly different among sub-assemblies. However, this may be because some sub-assemblies are commonly used for production of different final products.

Third, the travel distance between equipment varies from 13.5 feet to 319.5 feet. Under these circumstances, sub-assemblies transferring between equipment were accumulated into a transfer bucket before being sent to the next process in order to decrease travel time. The sub-assembly bucket transfer method between process steps creates waiting time and could result in high inventory levels at each process step.

Fourth, the final product combines with seven different sub-assemblies. Among those seven sub-assembly processes, cycle time to complete each sub-assembly is significantly different. The BV sub-assembly takes the shortest time at the rate of 90 pieces per hour while FSL sub-assembly can only be produced at a rate of 30 pieces per hour. As a result of the un-balanced process cycle time, the sub-assemblies that have shorter cycle times need to wait in the system creating high WIP and inventory.

New Production Floor Layout Analysis

The simulation provided results of product travel distance, cycle time, and total inventory that were compared between the current and new layout using ANOVA. When production operates for 640 hours or four weeks, the new layout provides 21.21% lower product travel distance compared to the old layout. From Figure 1, the new layout average product cycle time is lower than the old layout by 10.46%. By the same token, the new layout average order cycle time is significantly improved by 14.24%. This is possibly because the overall travel distance of the new layout is shorter resulting in components and sub-assemblies moving faster through the system to fulfill customer orders. However, overall inventory did not significantly change between the old and new layout. Thus, if the company only changes the layout, the overall inventory cost most likely would not be decrease.

Key Performance Indicators	**Current Layout**	**New Layout**	**Percentage Difference**
Travel Distance (ft.)			
1 Completed Product Route Travel Distance	2,286	1,919	16.05%
Travel Distance in 640 Hrs of Production	704,622	555,155	21.21%
Cycle Time (hrs.)			
Product Cycle Time	205.2	183.73	10.46%
1 Completed Product Transfer Time	0.14	0.12	16.11%
Transfer Time in 640 Hrs of Production	11.97	10.70	10.63%
Order Cycle Time	66.06	56.63	14.27%
Total Inventory (pcs.)			
BV Sub-assembly	47,095	48,389	-2.75%
TH Sub-assembly	47,967	46,858	2.31%
CD Sub-assembly	73,572	71,197	3.23%
FSL Sub-assembly	48,780	49,831	-2.15%
CA Sub-assembly	31,678	30,049	5.14%
BD Sub-assembly	44,249	44,634	-0.87%
FSS Sub-assembly	116,027	115,728	0.26%
TB Sub-assembly	23,315	23,237	0.34%
TD Sub-assembly	27,621	26,877	2.69%

Figure 1. New production floor layout simulation outcomes.

Batch Size and Setup Time Simulation Analysis

Figure 2 provides the simulation results of four production combinations according the DOE table in Appendix A. The four combinations of equipment setup time and batch size, product cycle time and order cycle time are not significant different in all combinations as shown in Figure 3.

The results define that lower equipment setup time does not provide significant improvement to either product cycle time or order cycle time because of unbalance of sub-assembly processes cycle times. Some sub-assemblies, especially FSL sub-assembly, have a high process cycle time while the current equipment setup time is already low. Hence, the final product assembly still waits for all sub-assemblies to be ready before the last process step can begin. In the same manner, smaller batch sizes do not provide significant improvement in product cycle time or order cycle time because of waiting time for the sub-assemblies that have higher process cycle times. On the other hand, average WIP and inventory level for all sub-assemblies are significantly lower when producing smaller batch sizes as shown in Figure 44 to Figure 122.

Production Combination	**Setting 1**	**Setting 2**	**Setting 3**	**Setting 4**
Key Performance Indicators	**Current Setup Time/ Current Batch Size**	**SMED Setup/ Current Batch Size**	**SMED Setup/ Small Batch Size**	**Current Setup Time/ Small Batch Size**
Product Cycle Time	183.73	180.44	182.94	181.75
Order Cycle Time	56.63	55.52	58.97	58.48
BV Sub-assembly	48,389	49,384	42,991	43,520
TH Sub-assembly	46,858	46,095	45,748	45,833
CD Sub-assembly	71,197	62,756	49,695	51,380
FSL Sub-assembly	49,831	46,427	41,393	41,589
CA Sub-assembly	30,049	28,685	21,758	21,932
BD Sub-assembly	44,634	40,664	38,885	38,928
FSS Sub-assembly	115,728	115,442	107,385	107,770
TB Sub-assembly	23,237	21,021	18,229	18,217
TD Sub-assembly	26,877	24,228	20,351	20,490

Figure 2. Batch size and setup time simulation outcomes.

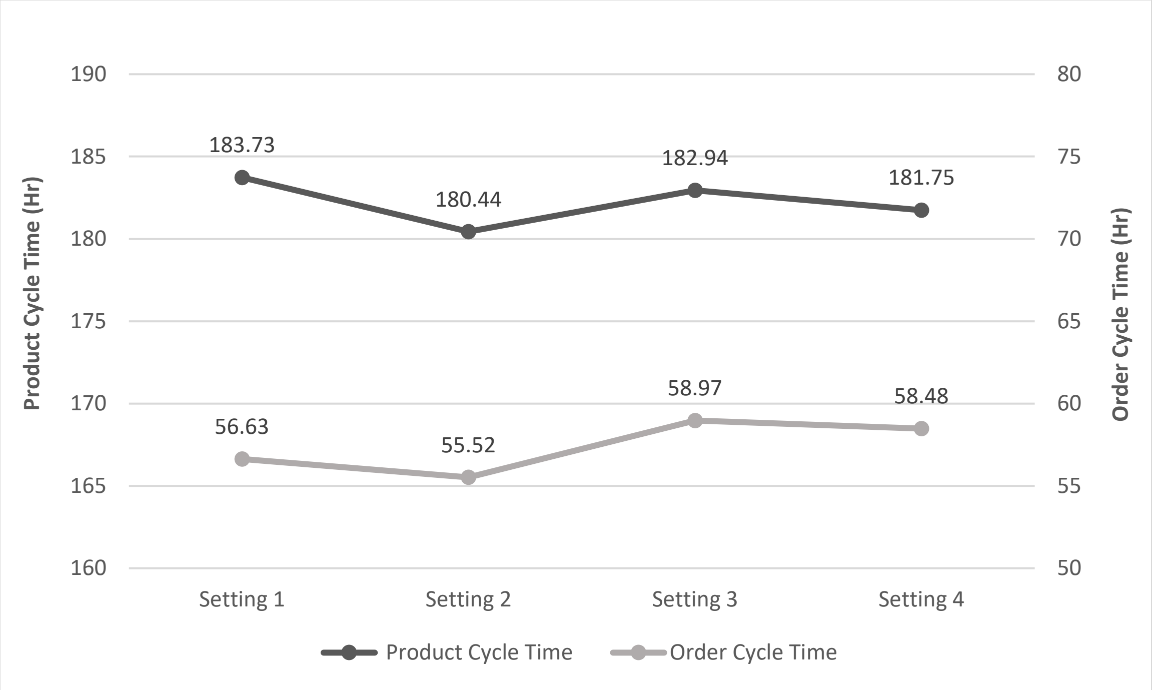

Figure 3. Cycle time.

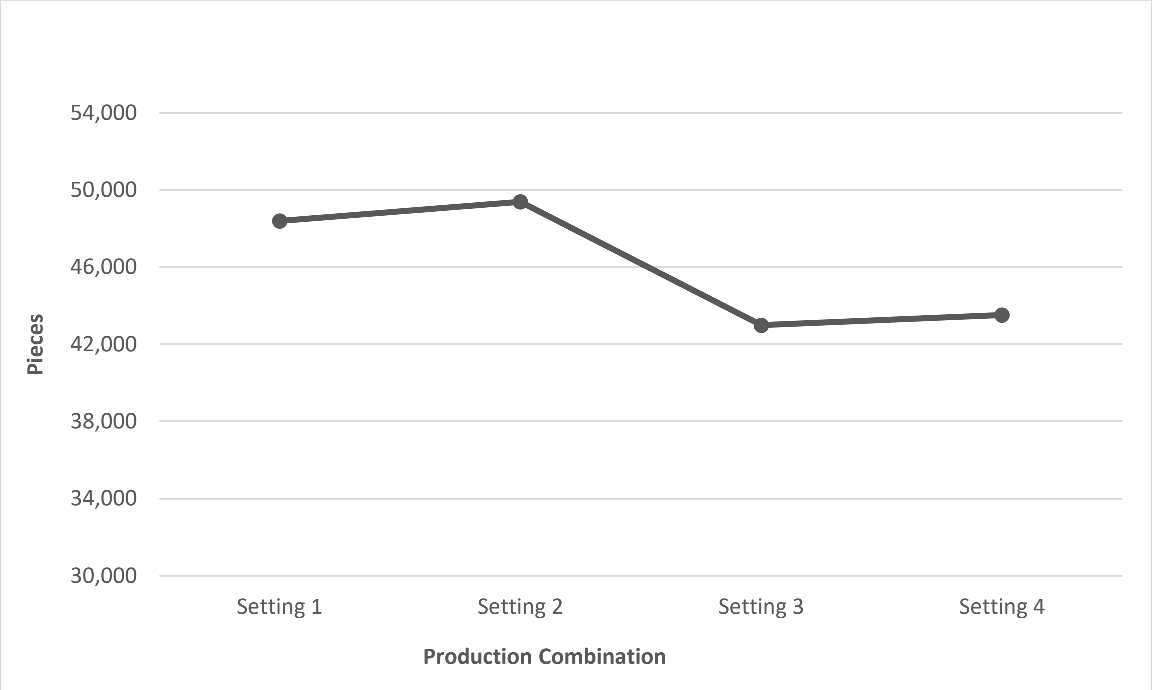

Figure 4. BV sub-assembly inventory.

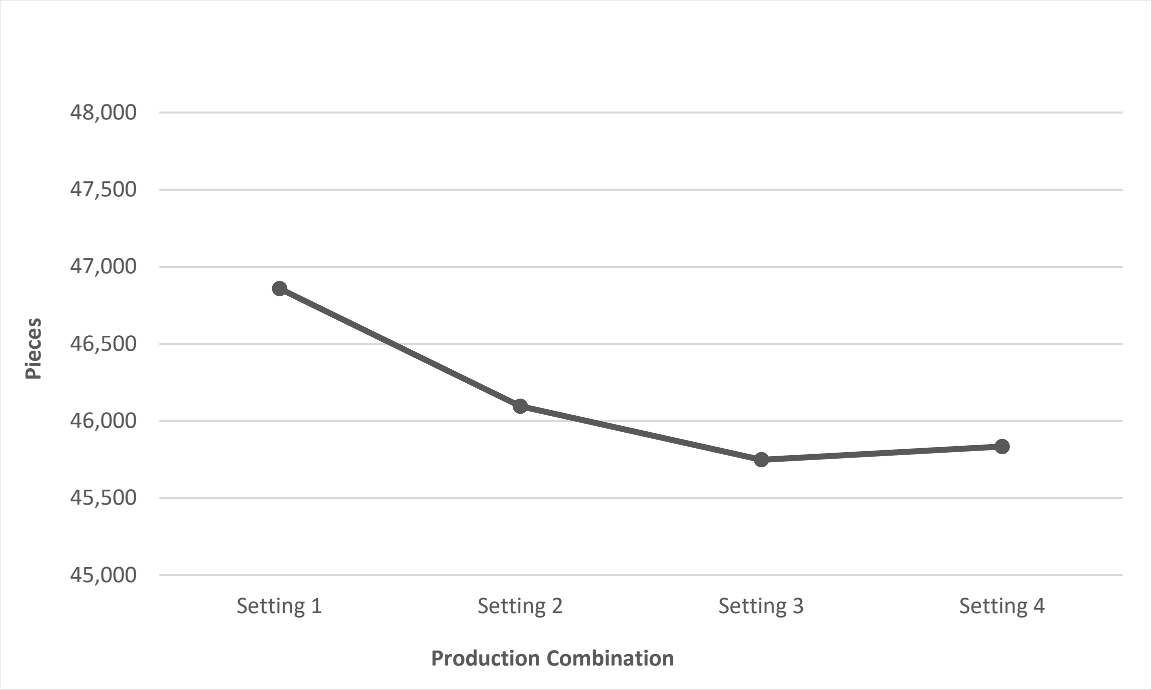

Figure 5. TH sub-assembly inventory.

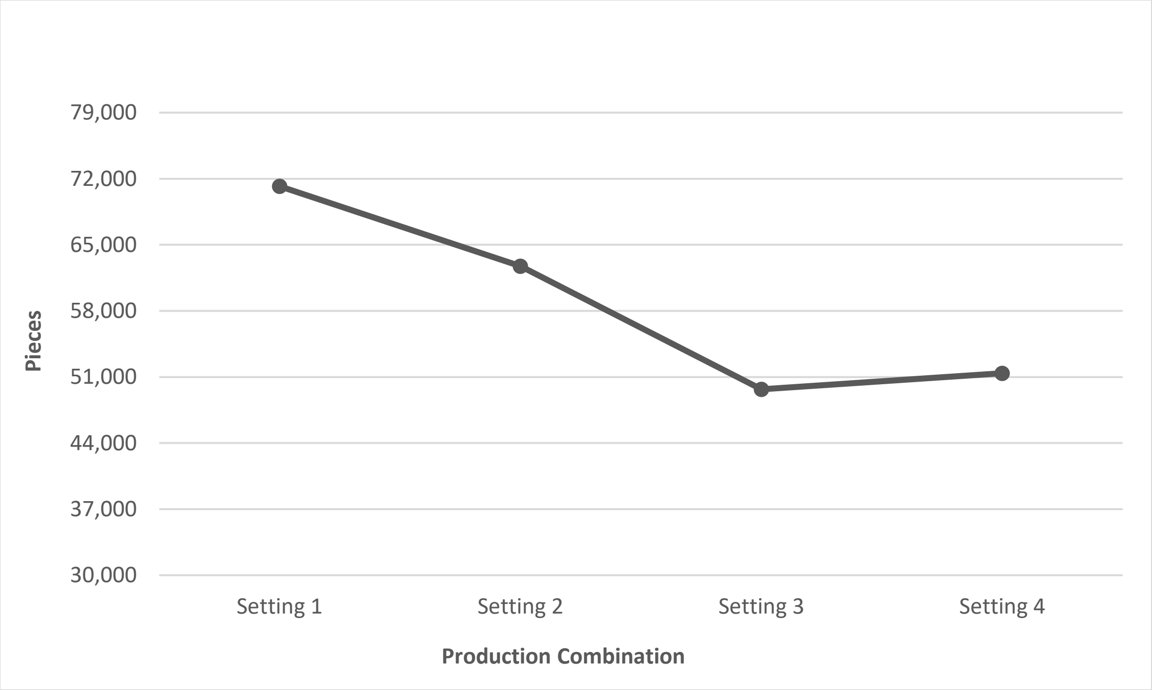

Figure 6. CD sub-assembly inventory.

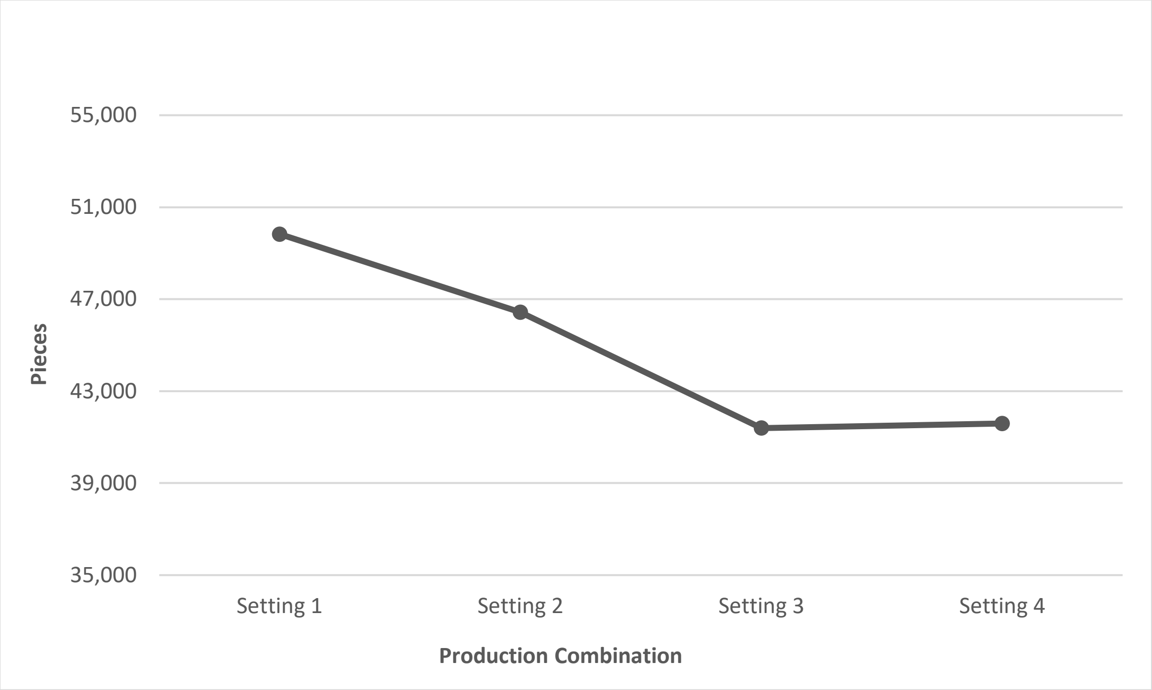

Figure 7. FSL sub-assembly inventory.

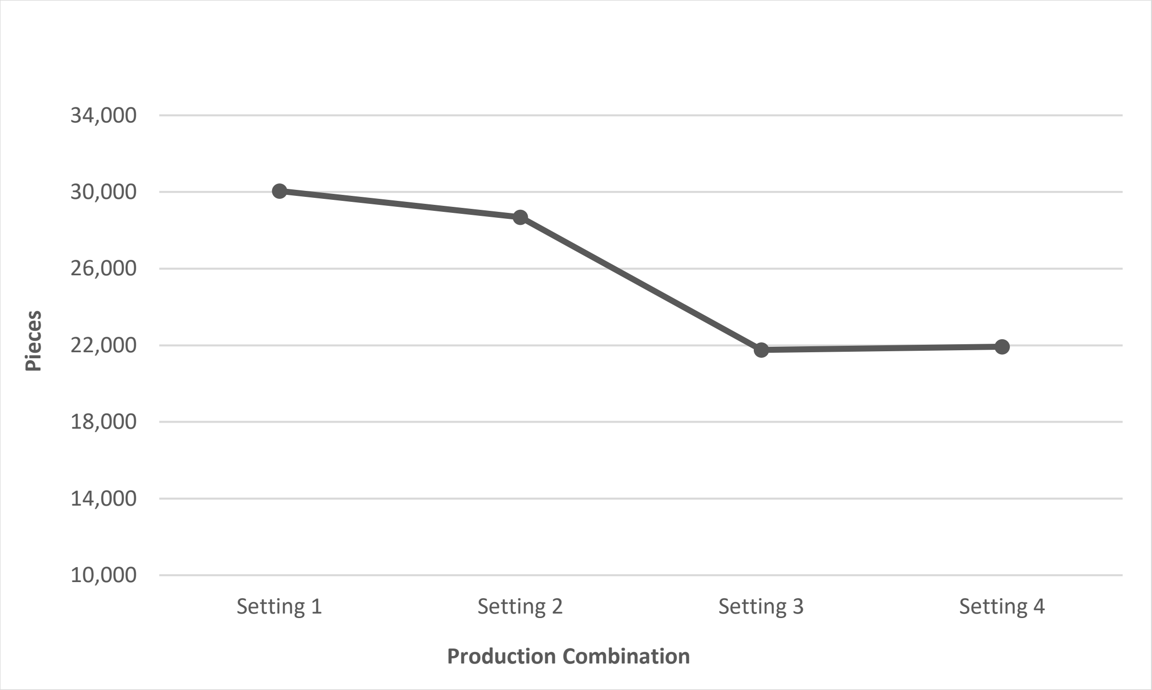

Figure 8. CA sub-assembly inventory.

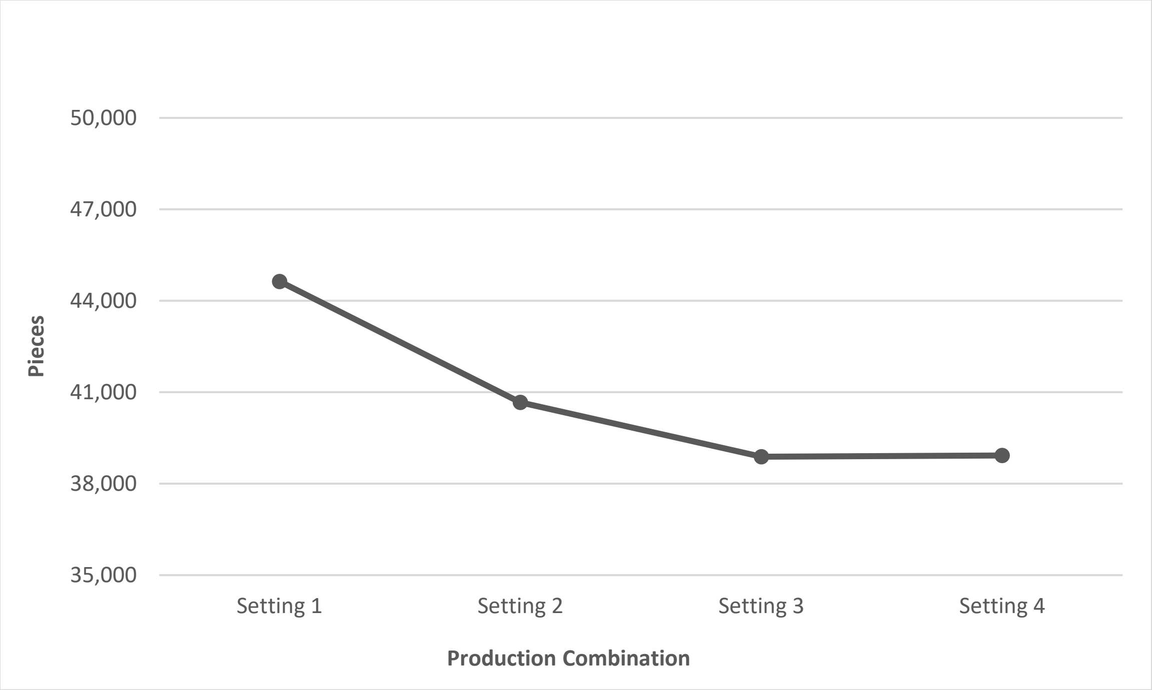

Figure 9. BD sub-assembly inventory.

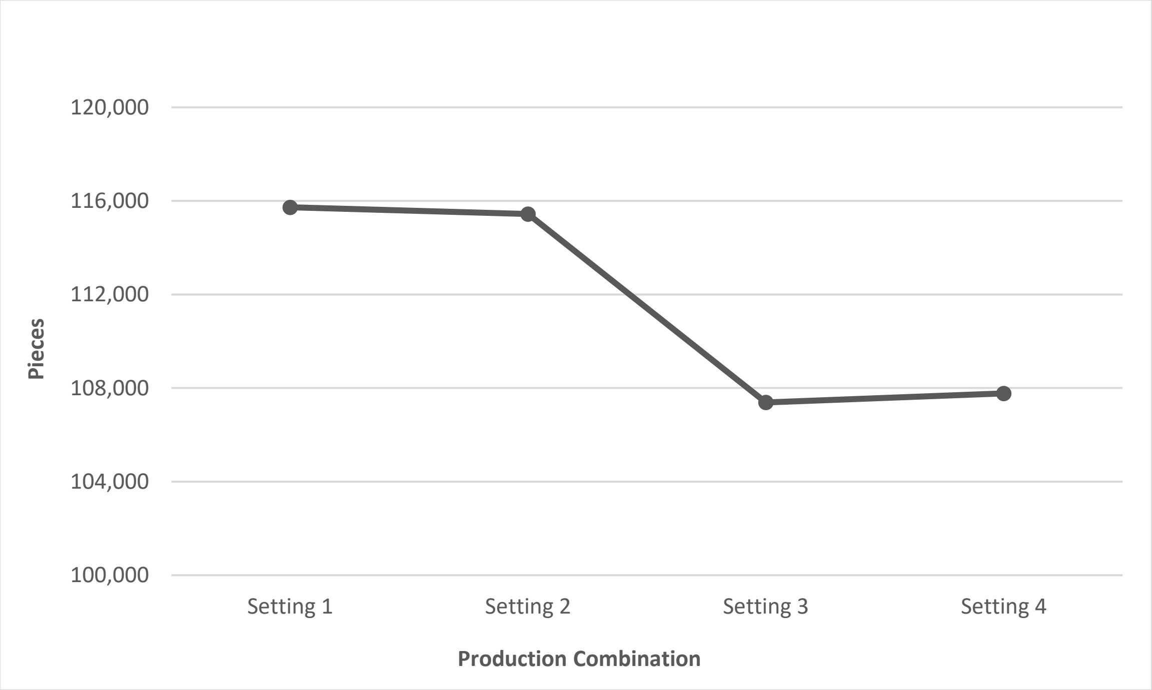

Figure 10. FSS sub-assembly inventory.

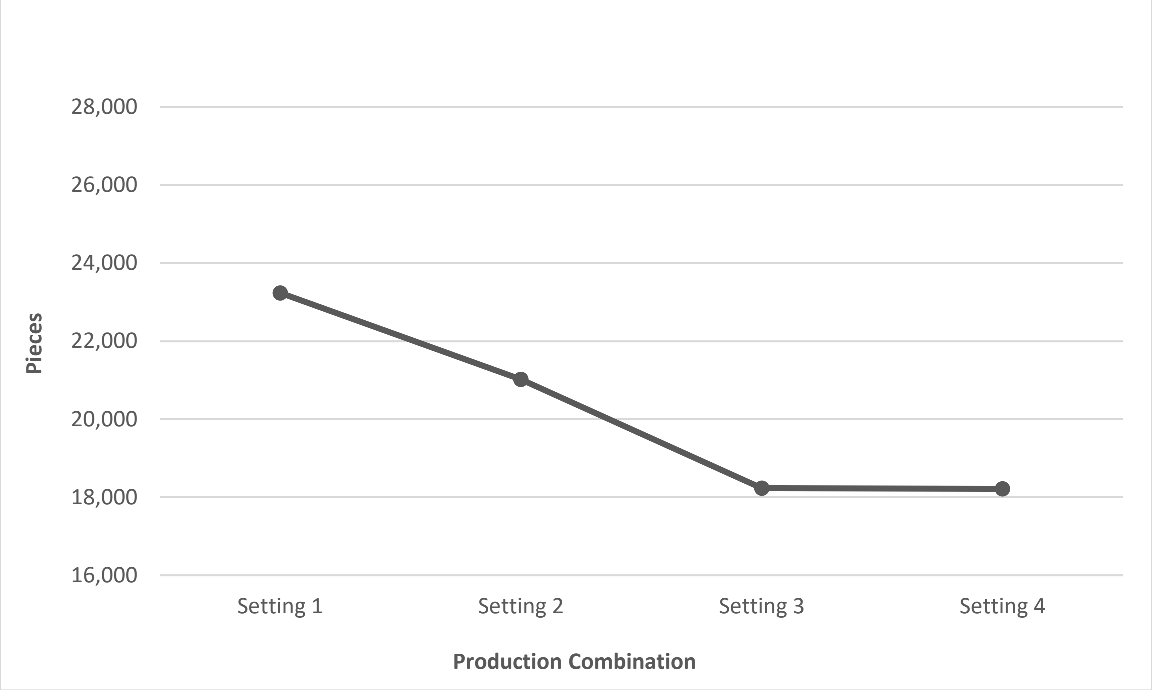

Figure 11. TB sub-assembly inventory.

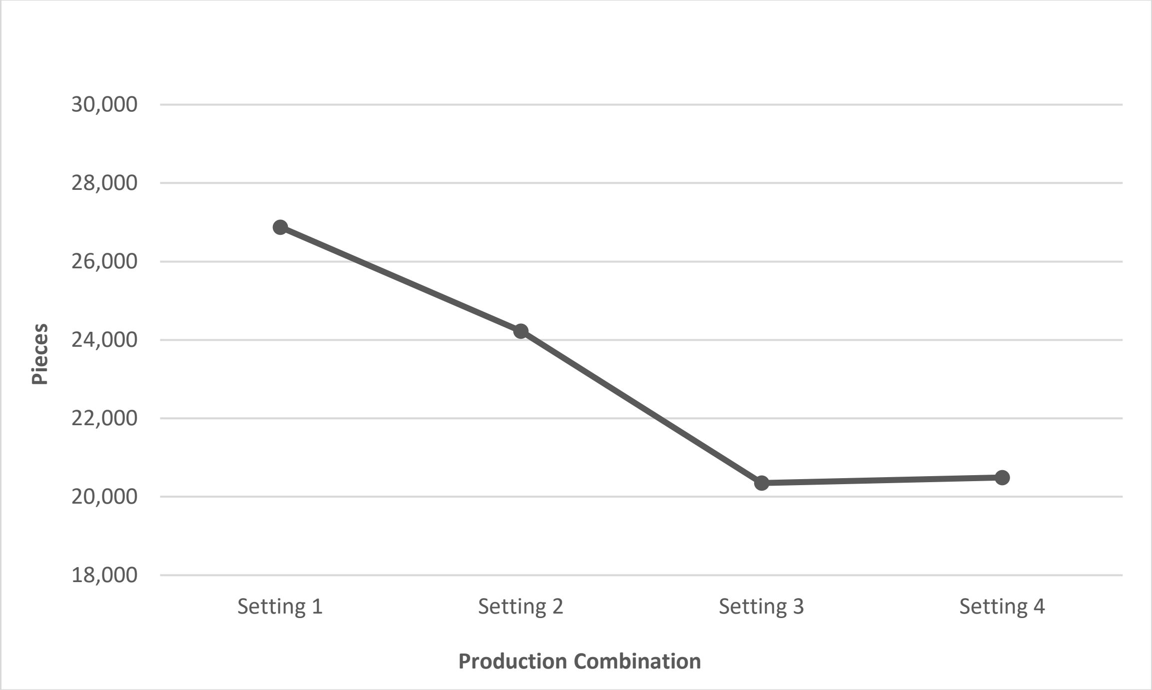

Figure 12. TD sub-assembly inventory.

Chapter V: Discussion, Conclusion and Recommendation

The purpose of this study was to utilize process mapping to identify problem areas in the assembly processes at company XYZ and determine areas of improvement. A simulation model was built and used to explain inventory levels, product cycle time, and customer order cycle time. The results of this study identified improvement opportunities that Company XYZ can use to decrease inventory without a negative impact on customer order cycle time.

Limitations

Although a smaller batch size tends to decrease inventory level, with the limitation of product variety and order history information, it is not possible to determine proper batch size for each sub-assembly.

Conclusions

Company XYZ holds high levels of inventory while the product flow is not efficient throughout the current floor layout and there are long wait times. Maintaining a high inventory had a direct impact on manufacturing costs and space requirements. When parts and subassemblies stay in the system longer than necessary, both as raw material and WIP, the cost of holding inventory increases. Process mapping results identified what and where in the process high WIP and inventory levels were generated. Simulation models were used to provide predicted outcomes of possible process improvements. Hence, the company can consider what changes would be a proper solution for the current situation.

Recommendations

Based on the simulation results, the following suggestions may be implemented. First, using smaller lot size or one-piece flow and a kanban system. Producing smaller lot sizes will reduce the waiting time and inventory levels when coupled with a kanban system that will send out a signal when the process needs to produce or reorder work in process items. However, with limited information for common components used across multiple Final Pump Assemblies, it is not possible to determine if lot sizes could be reduced.

Second, changing the production system from a “Push” system to a “Pull” System. Implementing the lean concept of a Pull system in the operation to produce when it is required will reduce the unnecessary inventory and WIP, which will result in less demand of cash flow and space. However, safety stocks need to be considered to prevent long lead-times for customer orders.

Third, the facility layout should be carefully analyzed. As part of the Lean implementation, 5S can help the company reduce unnecessary movement (non-value-added processes) and transportations. This will free up space and reduce the potential risk of miss-placed products, WIP, and inventory items. From the proposed new layout, there is potential for decreasing transportation waste. However, the equipment layout changes should be evaluated along with a kanban and Pull system. A conveyer system may be considered to eliminate the use of batch transfer buckets.

Fourth, equipment setup time should be evaluated. The longer equipment setup time required, the larger lot sizes tend to be in order to cover setup cost. Implementation of Single-Minute Exchange of Die (SMED) should be considered. Reducing machine set up time provides flexibility of quick equipment changeovers resulting in the ability to produce smaller lot sizes and can lower inventory levels. Equally important, grouping technology should also be assessed. During the process mapping, it was identified that there are similar parts that could be grouped together as one “interchangeable” item. This will reduce the machine set up time as well as simplifying inventory control.

Lastly, it is important for the company to focus on demand forecasting especially when it has a wide variety of final products. A business analytics study can be applied to determine the order pattern of each product family. When the company has an accurate demand prediction, it will be more effective in inventory control. In addition, a more reliable forecasting will help the company balance its operations to achieve a high utilization status.

References

Adams, J. (2006a). Stop wasting time, effort, money. *Supply House Times, 48*(11), 26-27.

Adams, J. (2006b). Muda II - Solutions to waste. *Supply House Times, 48*(12), 36-39.

Aikenhead, G., Farahbakhsh, K., Halbe, J., & Adamowski, J. (2015). Application of process mapping and causal loop diagramming to enhance engagement in pollution prevention in small to medium size enterprises: Case study of a dairy processing facility. *Journal of Cleaner Production, 102*(C), 275-284.

Altiok, T., & Melamed, B. (2007). *Simulation modeling and analysis with Arena*. Burlington, MA: Academic Press.

Aqlan, F., Lam, S., & Ramakrishnan, S. (2014, February). An integrated simulation-optimization study for consolidating production lines in a configure-to-order production environment. *International Journal of Production Economics, 148*, 51-61.

Beachum, D. (2005). Lean manufacturing beefs up margins: Pull systems, takt time, and one-piece flow benefit the operation of a powder coating system. *Metal Finishing, 103*(1), 20-25.

Clayton, Kiden. (2007). Demonstrating the value of one-piece-flow: One-piece-flow assembly challenges some of the most accepted production practices in foodservice. *Food Management, 42*(8), 30.

Dave, Y., & Sohani, N. (2012). Single minute exchange of dies: Literature review. *International Journal of Lean Thinking, 3*(2), 27-37.

Degirolamo, K., D'Souza, K., Hall, W., Joos, E., Garraway, N., Sing, C., . . . Hameed, M. (2018). Process mapping as a framework for performance improvement in emergency general surgery. *Canadian Journal of Surgery, 61*(1), 13-18.

Earley, J. (2016). *The lean book of lean: A concise guide to lean management for life and business*. Chichester, West Sussex, UK: John Wiley & Sons.

Filla, J. (2016). The single minute exchange of die methodology in a high-mix processing line. *Journal of Competitiveness, 8*(2), 59-69.

Groote, Y. (2006). More flexibility and productivity: SMED reduces changeover times. *Food Engineering & Ingredients, 31*(4), 32-35.

Henderson, G. (2011). *Six Sigma quality improvement with Minitab*. Hoboken, NJ: John Wiley & Sons.

Hill, K. (2018). Lean manufacturing: The seven deadly wastes. *Plant Engineering, 72*(2), 10-11.

Kelton, W., Sadowski, R., & Zupick, N. (2015). *Simulation with Arena*. New York, NY: McGraw-Hill Education.

Kumar, S., & Phrommathed, P. (2006). Improving a manufacturing process by mapping and simulation of critical operations. *Journal of Manufacturing Technology Management, 17*(1/2), 104-132.

Li, S. G., Ni, Y., Wang, X., Shi, L., & Zhu, L. J. (2012). Design of one-piece flow production system with mixed flows: A times process flow diagram-based approach. *International Journal of Computer Integrated Manufacturing, 25*(111), 996-1010.

Liker, J. (2004). *The Toyota way 14 management principles from the world's greatest manufacturer*. New York, NY: McGraw-Hill.

Maciej, P. (2014). Waste measurement techniques for lean companies. *International Journal of Lean Thinking*, 5(1), 9-24.

Manos, A., & Vincent, C. (2012). *The lean handbook: A guide to the bronze certification body of knowledge.* Milwaukee, WI: ASQ Quality Press.

Montgomery, D. (2013). *Design and analysis of experiments*. Hoboken, NJ: John Wiley & Sons.

Moreira, A., & Garcez, P. (2013). Implementation of the single minute exchange of die (SMED) methodology in small to medium-sized enterprises: A Portuguese case study. *International Journal of Management, 30*(1), 66-87.

Opacic, L., Sowlati, T., & Mobini, M. (2018, March). Design and development of a simulation-based decision support tool to improve the production process at an engineered wood products mill. *International Journal of Production Economics, 199*, 209-219.

Pinjar, M., Shivakumar S., & Patil, G. V. (2015). Productivity improvement through single minute exchange of die (SMED) technique. *International Journal of Scientific and Research Publications, 5*(7), 1-9.

Rybicka, J., Alvarez T., Campo, P., & Howarth, J. (2015). Capturing composites manufacturing waste flows through process mapping. *Journal of Cleaner Production, 91*(C), 251-261.

Shingo, S. (1985). *A revolution in manufacturing: The SMED system*. Cambridge, MA: Productivity Press.

Suárez-Barraza, M., Dahlgaard-Park, S., Rodríguez-González, F., & Durán-Arechiga, C. (2016). In search of "muda" through the TKJ diagram. *International Journal of Quality and Service Sciences, 8*(3), 377-394.

Supsomboon, S., & Vajasuvimon, A. (2016). Simulation model for job shop production process improvement in machine parts manufacturing. *International Journal of Simulation Modelling, 15*(4), 611-622.

Sutherland, J., & Bennett, B. (2008). The seven deadly supply chain wastes. *Supply chain management review, 12*(5), 38.

Westcott, T. R., Krivokuca, M., Marhevko, J., McCain, H., Sadler, K., Tucker, J., & Wood, D. (2014). *The certified manager of quality/organizational excellence handbook.* Milwaukee, WI: ASQ Quality Press.

White, G., & Cicmil, S. (2016). Knowledge acquisition through process mapping. *International Journal of Productivity and Performance Management*, 65(3), 302-323.

Zhang, R., Chiang, W., & Wu, C. (2014). Investigating the impact of operational variables on manufacturing cost by simulation optimization. *International Journal of Production Economics, 147*(C), 634-646.

Appendix A: Design of Experiment Table

Design Summary

Factors:	2	Base Design:	2, 4
Runs:	4	Replicates:	1
Blocks:	1	Center pts (total):	0

Production Combination	StdOrder	RunOrder	CenterPt	Blocks	Batch Size	Equipment Setup Time
Setting 1	2	1	1	1	Current Batch Size	Current Setup Time
Setting 2	4	2	1	1	Current Batch Size	SMED
Setting 3	3	3	1	1	Smaller Batch Size	SMED
Setting 4	1	4	1	1	Smaller Batch Size	Current Setup Time

Appendix B: Process Mapping