THE IMPLEMENTATION OF A SYSTEMATIC METHOD FOR IDENTIFYING THE ROOT CAUSES OF MANUFACTURING NEGATIVE PROCESS YIELD IN A NORTH AMERICAN FASTENER MANUFACTURING FACILITY

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by

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ABSTRACT

Negative process yield is an unexplained expense that does have a significant impact on profits. As like most other manufacturing processes, there are multiple processing operations that a finished good can be exposed to during the course of the entire process. Negative process yield can occur during these known operations but without accurate reporting and data collection, it becomes a moot point. In order to investigate this unexplainable phenomena properly, understanding of what could possibly cause this from occurring must be achieved. In the case of the North American fastener manufacturing plant, missing pieces that are not accounted for through the normal scrap reporting process are often referred to as “negative process yield”. Loss of material from the various processes has been identified as a problem for the North American fastener manufacturing plant. The set of tools that assist in the identification and steady elimination of waste also referred to as lean principles and techniques must be used during the study. This study will examine and analyze the data collected and associated with the loss of unexplained production pieces throughout the production process and what the financial implications or effects have on margins or profits.

The Taguchi Design of Experiment (DOE) method is to be used for the experiment. Roy stated that the main focus of the application of DOE is to improve quality. The definition of quality varies widely depending on the applications, but it must be defined before any experimental technique can be produced with meaningful results. Taguchi offers a generalized definition for quality of performance. He regards performance as the major component of product or process quality. A reduced variation results in a reduction in scrap, less rejection of product, and fewer warranty returns, consequently reducing costs, and improving profits and improving customer satisfaction.

The result of the study indicated that the form tool was the most significant factor and the levels or grades of material used for those tools could have an effect on the machining process. There was also an indication that the drilling operation needed to be focused on and that the grade of material used, either carbide or high speed steel, be seriously considered based on the application and desired speeds and feeds of the drill depending on the substrate material of the fastener.

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I also would not be able to be in this position if it were not for my employer for the past twenty years. They proved to me that they believed in me by supporting in more ways than can be explained. Not only though the doctoral journey but also through other graduate pursuits. The financial assistance provided to me from them is priceless.

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INTRODUCTION

Overview

Manufacturing will always generate some form of scrap or waste during the various production processes and it will be at diverse levels, depending on the type of the industry and the respective organization. This will always have negative financial implications on the organization and it should be controlled as best as possible. Without understanding what type of scrap and what the cause of it is, will never allow the organization to continue to be as profitable as it potentially could be.

Manufacturing organizations have primarily been focused on positive output since the 18th century's Industrial Revolution and some have conveniently ignored the negative output such as scrap and other unknown production waste or a percentage of lost yields. By definition, negative process yield is considered to be the difference between the anticipated output and the actual output. The difference can be the result of not identifying or determining at what point in the production process where the loss or negative output occurred. When this loss of production pieces is calculated and ultimately reported to upper management of an organization, can become disturbing when the dollar amounts associated with the loss of output are reported. This unknown loss of potential revenue can be transferred to positive revenue by identifying the specific causes of the negative process yield during the manufacturing process and then reducing or ultimately eliminating it. Waste elimination is one of the most effective ways to increase the profitability of any business (McBride, 2003). Processes either add value or waste to the production of a good, or the provision of a service.

Lean Manufacturing is a well proven methodology of removing causes of waste and can be considered as a basis for this study to reduce or eliminate as much negative process yield as possible. By implementing those principles used within the lean manufacturing system will prove to be very beneficial for this exercise. In addition, Lean Manufacturing can be considered a business philosophy as well and has proven to be highly successful since it can reduce costs, eliminate waste, increase productivity, maintain high levels of quality and thus make a significant increase in an organization’s profitability. Lean Manufacturing derives from the Toyota Production System (TPS). The TPS consists of 14 principles and those are divided into distinct four sections. The fourth section is focused on continuously solving root problems that drives organizational learning. Within that section, it mentions that by identifying root problems and preventing them from reoccurring is considered a focus of the continuous learning in the TPS (Liker, 2004).

In the case of the North American fastener manufacturing plant, missing pieces that are not accounted for through the normal scrap reporting process are often referred to as “shrink” or negative process yield. Negative process yield is an unexplained expense that does have a significant impact on profits. As like most other manufacturing processes, there are multiple processing operations that a finished good can be exposed to during the course of the entire process. Negative process yield can occur during these known operations but without accurate reporting and data collection, it becomes a moot point. In order to investigate this unexplainable phenomena properly, understanding of what could possibly prevent this from occurring must be achieved.

Need for the Study

The North American fastener manufacturing plant has determined that it has a problem that it had never realized before. When it was discovered from a standard material usage report, that there were several thousands of expected production pieces that could and should have generated potentially good pieces could not be accounted for. And this was at an unexpectedly and unacceptable rate with respect to dollars, something needed to be done. So an investigation was conducted by a cross-functional team from Accounting, Manufacturing, Quality and Engineering to determine exactly how much was “missing” for the past five years. Table 1 is an example of how the negative process yield (NPY) would be calculated and reported over the past five years with respect to costs. This is a clear reason for why this should be addressed immediately at the North American fastener manufacturing plant.

Table 1. *Calculation of Negative Process Yield for the past five years*

	Est. # of Pcs. Produced	Est. Sales $	NPY	# of NPY pcs.	Est. COGS	Est. Cost of NPY
2013	275,600,000	$33,898,800	6. 44%	17,748,640	$0. 074	$1,309,850
2014	271,960,000	$35,898,720	4. 88%	13,271,648	$0. 079	$1,051,115
2015	260,000,000	$34,840,000	4. 99%	12,974,000	$0. 080	$1,043,110
2016	270,400,000	$38,126,400	4. 49%	12,140,960	$0. 085	$1,027,125
2017	285,000,000	$42,750,000	5. 77%	16,444,500	$0. 090	$1,480,005

The missing pieces, instead of simply referring to it as scrap, are now accounted for. But what was causing it and why? Therefore, it was determined by plant management that the causes for this unacceptable loss of material and production pieces, also known as negative process yield, should be analyzed, reduced and eliminated as much as possible. This will come in the form of narrowing down where the majority of the material's disappearance occurred through various types of data analysis. The use of proven problem solving techniques that will result in the reduction or elimination of what negative process yield could also be referred to as: waste. To eliminate or recognize waste, one must first understand it. Eliminating waste must be the business's first objective (Ohno, 1988), so that it can improve profitability and maintain its position in its current industrial marketplace.

One form of manufacturing waste with respect to lean can come in the form of negative process yield. Negative process yield is an unexplained expense that does have an impact on profits. An investment can be made in determining the specific factors that create the negative process yield or loss of material throughout the process before it is considered as a finished good.

For example, it was mathematically determined using an engineering calculation that a production work order would require 250 pounds of raw material (see Figure B6) to produce 25,000 pieces. The entire manufacturing process consists of the following general steps, tasks or processes: machining, cleaning, chip removal (see Figure B10) and deburring, heat treating (see Figure B9) zinc electroplating, and automatic video inspection and sorting (see Figure B12). These are the process variables that can have an impact on this unexplainable phenomenon. Specifically identifying the direct variables that impact this phenomenon the most can be challenging. However, at the end of the manufacturing process, the number of pieces was counted and there were only 23,250 pieces that were entered into finished goods inventory. This results in a 7% loss that affects net profits or the “bottom line”. There were no reported “scrap” pieces due to first pass quality inspections that could have deemed product defective or did not meet dimensional or visual acceptance criteria.

Manufacturing Process Analysis

As previously mentioned, this experiment is dealing with a batch-process operation. Manufacturing process can either be job shop, repetitive, batch continuous, or discrete. The manufacturing processing steps previously identified can be more clearly defined and understood through this more detailed description below:

Machining: The machining process consists of a 5-spindle screw machine (see Figure B1) that is fed with metallic bar stock. In this example, the bar stock is made from low carbon, lead-free steel. There are various different forms of tooling used within this machine. In addition, there are an enormous amount of moving parts in the machine such as gears, cams, motors, chains, spindles, holders, etc. Each type of part or fastener is designed with its own unique type of tooling and possibly different location within the machine. This is dependent on the diameter, length, and contour of the fastener. The machine is typically setup by designated setup personnel. These personnel usually have a large amount of experience with the troubleshooting and in-depth understanding of how the machine can make a good part and whether it made a bad part and why. The machine is setup and then an operator will run the machine. During the production order is where material can be lost or where negative process yield can occur. Setup scrap pieces are expected to happen to a certain degree. It needs to be kept at a minimum. However, during production is when discrepant parts (see Figure B2) can be produced when the variation of the machine presents itself in its truest form. A tool can fail, break, wear or slip. The pieces or parts that were produced during that time frame, which would be between the frequencies of inspection checks, are found and necessary adjustments to the machine. The majority of the time, the parts are sorted and not counted toward the final count at the end of the production order. Tooling enhancements are constantly being made in order to improve production efficiencies which have a positive impact on not producing as many discrepant parts as possible which have led to higher negative process yield rates in the past. Upon completion of the order, the number of parts is counted using a weight scale. An individual piece weight is initially calculated and then the number of pieces for the entire order is determined and recorded on the process router sheet and entered into the company's computerized Enterprise Resource Planning (ERP) system. The order is then moved to the next defined operation or process.

Parts cleaning / washing (see Figure B11): these closed looped (vacuum-proof work chamber) cleaning systems are designed to remove dirt, oil, and loose chips from the fasteners. Like all of the processes of this example, can be considered a bulk processing operation. During this operation, the parts are also subjected to ultrasonic cleaning and drying. If the proper sizes of baskets are not used during this operation is when the possibility exists that parts could be lost through the mesh of the baskets.

Deburring and chip removal (see Figure B10): deburring is a necessity when metal is removed from a steel slug of material because it creates sharp edges. Chip removal is required so that foreign debris is not included in the package that contains the parts. In addition, chips in the hole of the fasteners are not acceptable. The chip removal machine could lead to missing pieces due to the nature of its operation. Parts are fed into a hopper that leads to a vibratory mesh platform where air is blown at the proper predetermined setting. Chips are automatically discharged below the chip discharge hood, while clean parts drop from the parts delivery chute.

Heat treating (see Figure B9): is required for fasteners so that they become harder and stronger. In addition, their respective hardness is required when being pressed into a piece of sheet metal which needs to be softer for cold flow of the material into the self-clinching feature is accomplished. Self-clinching fasteners are designed to be installed into slightly softer materials. Heat treating is also a batch process operation. In this case, the type of heat treatment is carburization. Parts are layered on a belt that goes through the furnace. The parts are carburized in the main portion of the furnace and then the parts are dropped into a quench tank. A magnetic belt pulls the parts out of the tank and then they are fed onto another flat mesh belt that goes into a tempering furnace. The possibility of parts being lost in this operation exists as well, especially, in the bottom of the quench tank.

Electroplating zinc: This process is required to prevent corrosion and is a batch processing operation. Parts are loaded into various tanks throughout the process such as acid, rinse water, and the tank where the electrodeposition occurs. The possibility of losing pieces during this process is minimal due to the design of the tanks that do not allow the escape of the many different chemical involved.

Automatic video inspection and sorting (see Figure B12) system: this operation is at the end of the process and is where discrepant parts are detected based on the required dimensional specifications and other characteristics that are programmed into the machine’s software. This machine can detect if a fastener is too large or small in certain areas. It can detect if it has threads, chips in the hole or a mixed part that came from previous processing operations. There are some instances when individuals feel that this process could be the leading cause of the negative process yield because “bad” parts are deemed unacceptable by the machine. If that was true, then real root cause analysis is not being conducted. The parts were produced during the machining operation and apparently did not meet target values of a certain characteristic of the fastener.

The plan would be to investigate which one of the variable processes has the largest amount of impact on the negative process yield. Then implement a process improvement project to reduce or eliminate that variable and then the other subsequent processes or operations that will lead to higher profits and much more informed and optimal workforce.

Statement of the Problem

The negative process yield or scrap produced at the North American fastener manufacturing facility has not been able to be under any sort of control for the past few years based on recent reports. This unfortunate type of occurrence has a negative impact of the company's ability to become more competitive in the fastener industry's marketplace. It is known when a pre-determined amount of material is theoretically calculated to produce a specific number of fastener pieces for a production work order and the final count of pieces is less than it should have been, there is a problem. The operators who run the automatic screw machines (see Figure B1) make the necessary adjustments to make the parts as intended per the specifications. There are various types of tooling used and is not always guaranteed as being the standard operating procedure. If it is known as to what the optimal tooling might be in order to produce more defect free products that somehow get lost during production, should have a positive impact on reducing the negative process yield and putting more positive amount of pieces in the finished goods warehouse.

Background of the Study

The North American fastener manufacturing plant for this study is located in a city in the Southeastern part of the United States of America and is strongly supported by other manufacturing and technical facilities located throughout North America, Europe and Asia. It has enjoyed a sustained history as a global leader in the fastener industry since 1942. The company's leading brand has been recognized as the premier product in the thin sheet fastening industry for over 75 years. Today, the company continues to expand its portfolio of fastener designs and technologies continues to keep pace with the challenges presented by an ever-evolving marketplace.

Customers of this company gain the benefits accrued from the worldwide presence that is grounded in “local” access and, as a result, remains as the “go-to” fastening resources for virtually every industry, including the electronics, computer, and data/telecom, medical, automotive, aerospace and general manufacturing categories.

Obviously, the goal of the company is to produce 100% defect-free product. An adoption of a global manufacturing strategy is to practice defect prevention rather that defect detection. Statistical tools are used throughout the manufacturing process that monitors performance and assures quality control of each process step. However, unaccounted for material and piece loss has not been the primary concern for the company until now, since it has discovered as an opportunity to recapture some unknown amounts of lost profits. After this has systematically been determined and plans have been implemented to mitigate it is when the company will benefit from it and continue to be the world class manufacturing leader in globally producing internally and externally threaded fasteners for its respective industries served.

Significance of the Study

Loss of material from the various processes has been identified as a problem for the North American fastener manufacturing plant. The set of tools that assist in the identification and steady elimination of waste also referred to as lean principles and techniques must be used during the study. To recognize waste, the nature of it must be understood (Ohno, 1988). Production waste can be divided into several categories and for this study, the result of underproduction instead of overproduction, could be considered the primary focus of the problem. This study will examine and analyze the data collected and associated with the loss of unexplained production pieces throughout the production process and what the financial implications or effects have on margins or profits. The conclusion of the study will indicate how the other manufacturing plants of the company could benefit by implementing very similar programs that can assist them in reducing this form of waste and improve profits.

Statement of the Hypothesis

The negative process yield, loss of production pieces, or the percentage of negative process yields has been determined to be a detrimentally financial problem that needs to be held under better control. Currently, the problem stems from a lack of analysis over the years that unaccounted for pieces were costing the company up to a million dollars per year, potentially, in lost profits. The machine operators use the tools that they are equipped with and are expected to use per the tooling guidelines. This can become an issue when certain types of tools are either not recommended or are not available. Thus it is not known what effects the variation on the types of tooling have on the machined products that can cause too many pieces to be lost or discrepant when produced by the machining process (see Figure B1).

So, in order to effectively analyze the effects of the types of tooling material grades and brand of taps on the quality of the fastener that has somehow produced unknown pieces of scrap, the determination of what the optimal tooling must be identified and those relationships quantified. The relationship between the amount or rate of negative process yield produced in the screw machining process and the variables mentioned will be tested based on the following null hypotheses.

Null Hypothesis 1: There is no statistically significant difference in the percentage of negative process yield produced on the screw machine because of change in the form tool material.

Null Hypothesis 2: There is no statistically significant difference in the percentage of negative process yield produced on the screw machine as a result in the change of drill material type.

Null Hypothesis 3: There is no statistically significant difference in the percentage of negative process yield produced on the screw machine as a result in the change of the brand of taps.

Assumptions

For the purpose of this study, the following assumptions will apply:

Quality of the Raw Material (see Figure B6). The raw materials used for the machining operation are inspected upon receipt and the chemical and physical analysis reports are compared to the raw material specifications determined by the North American fastener manufacturer.

Accurate reporting of negative process yield during production. It has been determined that during production, that either inaccurate or non-reporting of negative process yield causes occur. It is very important that his does not happen during the course of this study.

Counting the number of bars of raw material (see Figure B6) before the production run begins. One of the primary reasons that unexplainable amounts of negative process yield are reported is when the machine operator does not match the number of bars with what is written on the raw material tag for a particular production order.

The operator uses the required type of tooling……… that has been defined during the experiments so that accurate data is recorded; this is very important dependent on this part of the experiment.

Standard operating procedures are followed as instructed. Deviations from any standard operating procedures are seriously discouraged during this experiment so that the data is not compromised and maintains its reliability for the successful completion of the study.

Limitations

The majority of the time, manufacturing organizations will experience difficulty when trying to find the appropriate time in which they would like to conduct experiments. In the case of this study, this will not apply. The only potential limitation would be that if the tooling that is required to conduct the experiment as originally planned were not available. This could potentially delay the experiment but there are contingency plans and alternate tooling in place that will be identified in advance that can be used if necessary.

Definition of Terms

Negative Process Yield: the production difference between what is planned versus what is actually made and placed into finished goods. The amount of material issued should produce a certain amount of product but after all of the processing events have taken place, the theoretical amount of pieces is not accounted for. The unit of measurement for negative process yield is a percentage of negative yield. For the purposes of this study, negative process yield is defined as the losses in production due to the creation of out of tolerance parts and does not include losses such as misplaced or stolen parts.

Automatic screw machine (see Figure B1): a lathe that is mechanically automated via cams and turns material symmetrical in shape. It can be used to drill holes and create threads.

Raw material – bar stock (see Figure B6): is a metal produced by a steel mill and is formed into a long continuous strip of various shapes and sizes.

Threaded fasteners: discrete piece of hardware that has internal or external screw threads

Batch processing: is a technique used in manufacturing, in which the object in question is created stage by stage of workstations, and different batches of products are made.

Lean manufacturing: a systematic method for waste minimization within a manufacturing system without sacrificing productivity.

Parts cleaning: This is an essential process and is considered a prelude to surface finishing and is design to protect the integrity of the part. Cleaning processes for this study are solvent based.

Automatic video inspection and sorting (see Figure B12): the machine used to perform this operation is capable of high resolution, multi-attribute, and 100% inspection at production rates or speeds. It improves production yield and quality, reduces containment issues and improves customer satisfaction.

Zinc electroplating: is a process of covering substrate materials such as steel and iron with a layer of protective coating of zinc to protect the substrate from corrosion. This system is considered a batch processing operation.

Heat treating (see Figure B9) process: this important operating process is used to alter the mechanical properties of a metallic alloy, thus manipulating properties such as hardness, strength, ductility, and elasticity.

Process router: a work flow diagram of sequential steps that describes the process in which a product is produced that are in-house and that are processed by an outside services supplier.

Enterprise Resource Planning (ERP) system: an integrated management of core business processes, often in real-time and mediated by software and technology. ERP systems track business resources such as cash, raw material, inventory, production capacity, purchase orders, etc.

CHAPTER 2

REVIEW OF LITERATURE

Overview

The previous chapter presented a brief introduction of the study that included the background of the study; the significance and need for the study and an analysis of the manufacturing process related to the study. In addition, the statement of the problem was identified with a statement of the hypothesis as it relates to the study. This chapter summarizes the literature relevant to this study starting with a brief introduction of problem solving methodologies, Lean Six Sigma, the reduction of manufacturing scrap or waste, lean manufacturing and continuous improvement, root cause analysis, and the use of various statistical process control methods used in manufacturing. And finally, it will cover how being a more lean thinking and efficient organization will generate the associated benefits that create profitability.

Problem Solving Methodologies

As a problem solving methodology or process improvement framework, there a series of well-defined steps used. Such as the definition of the problem, measurement of the problem, data analysis to discover the root causes of the problem, improvement of processes to discover the root causes of defects and controlling or monitoring processes to prevent the problem. This is also referred to as the DMAIC (Define, Measure, Analyze, Improve, and Control) methodology which defines lines of strategy and orientation in projects associated with Six Sigma. The Define step is where the problem is defined in conjunction with explaining what the project scope and goal should be. This is typically where you currently are with respect to the problem and objectives are clearly determined by the charter or from the project team. The Measure step is where the type of data to be collected is determined and how. The purpose of this is to establish process performance baselines. This baseline will be compared to the performance metric at the conclusion of the project to determine objectively whether significant improvement toward the goal has been achieved. The Analyze step is where the root cause for elimination has been undoubtedly identified. There will always be several potential root causes to choose from and those can be gradually eliminated in order to solely focus on the primary source for the variation or the cause for waste. The preliminary potential root causes that were identified will need to be listed and then prioritized based on their validity. There are several different statistical tests or methods that can help identify how certain process inputs affect the ultimate output(s). Such as p-tests, Pareto charts, and Histograms. For this study, a process map was constructed in order to help to ultimately determine one of the primary root causes and initially eliminate those that had no bearing on the outcome. Pareto charts help display the relative importance of problems or conditions in the form of a bar graph. It shows the distribution of items and arranges them from the most frequent to the least frequent. It shows where to put initial effort to get the maximum gain (Kumar, Mantha, Kumar, 2009). In order to make it easier to judge Pareto's "80/20 rule", Juran explained that he generalized Vilfredo Pareto's observation that 80% of income in Italy was limited to 20% of the population. Juran characterized the principle as the "vital few and trivial many” among manufacturing defects; 80% of defects in a process seemed to be accounted for by 20% of the causes (Wilkinson, 2006). The Improve step is where a solution is identified, developed and tested. Review of the process map and the data depicted in the Pareto analysis helps with cross-functional brainstorming, for example. The cross-functional make-up of the team can consists of the members from the various processing areas in order to represent itself in this brainstorming session and elimination of insignificant potential root causes. Brainstorming sessions provide the platform for person to person interaction, so the entire team is involved. It is also not a platform for debate or to criticize the ideas of other people. It only helps in building of ideas that leads to fantastic ideas. Once ideas are generated then it is displayed by using a cause and effect diagram or fishbone diagram. This provides a pictorial display of a list, in which one can identify and organize possible causes of problems or factors needed to ensure success of some effort. From this diagram, the user can define the most likely causes of a result (Kumar, Mantha, Kumar, 2009). The Control step is where monitoring and maintaining of the improved process takes place. Again, this is where a Six Sigma implementation is characterized where plans created in earlier phases can ensure ongoing compliance and be able to measure the process improvement resulting from the implementation. Monitoring it can come in the form of using basic shop floor statistical process control techniques. Quality control is the essential method for keeping the improvement process on track and in the right direction. This method also allows you to quickly spot trouble areas and fixes them quickly before they turn into larger problems. Standardization is one aspect of control, which allows a process to run as smooth as possible.

The reasons that lead any kind of organization to the use of this methodology are: improved efficiency of the organization, increase in profits, reduction of waste, improved customer service, and to gain a competitive advantage. Six Sigma methodologies is sustainable for manufacturing but is also applicable to organizational processes with some modifications, as in the areas of training, measurement, and the use of statistical tools. Three principles have to be considered to justify this application: all work occurs in a system of interconnected processes, all processes exhibit variation, all processes create data that explain this variation and our responsibility is to explain it and to develop strategies to reduce or eliminate it (Ferreira, Lopes, 2010).

Continuous Improvement

Continuous Improvement (CI) is a philosophy that Deming described simply as consisting of "Improvement initiatives that increases successes and reduces failures" (Jurgenson, 2000). Yet others view CI as either as an offshoot of existing quality initiatives like total quality management (TQM) or as a completely new approach of enhancing creativity and achieving competitive excellence in today's market (Oakland, 1999). Total quality can be achieved by constantly pursuing CI through the involvement of people from all organizational levels Kossoff (1993). CI can more generally be defined as a culture of sustained improvement targeting the elimination of waste in all systems and processes in an organization. Often, major improvements take place over time as a result of numerous incremental improvements. On any scale, improvement is achieved through the use of a number of tools and techniques dedicated to searching for sources of problems, waste, and variation, and finding ways to minimize them (Bhuiyan and Baghel, 2005).

With the rapid increase in global competition that many industry sectors worldwide have been facing over the past decade or more, associated with rapid technological changes and product variety proliferation, has led to a new scenario in which industries, to remain competitive, must continually implement management practices such as the continuous improvement approach (Carpenetti and Martins, 2001). Irrespective of the business domain, companies must focus on speed, efficiency and customer value to be globally competitive, and the long-term health of any organization depends on its commitment to continuous improvement. This type of vision helps companies remain competitive in the face of customers' constantly changing and evolving expectations (Singh, Singh, and Harwinder, 2017). Continuous improvement (CI) is an array of powerful techniques that has produced substantial improvements in numerous companies and organizations. CI provides perhaps the most central and universal component of TQM which itself has helped many companies achieve high quality and productivity (Zangwill and Kantor, 1998).

The Japanese concept of Kaizen (continuous improvement) bridges scientific and humanistic management philosophies by focusing on areas such as recognition, autonomy, training and the development of individuals. This concept, already put into action by major manufacturers, can be implemented into various sized manufacturing enterprises to improve their overall operational performance. Integrating various functional groups within a manufacturing organization can also improve both productivity and quality (Gunasekaran, 1994).

By simply implementing a continuous improvement initiative doesn't always guarantee success. Continuous improvement initiatives do put the necessary elements in place that will allow an organization to identify and implement improvements on an ongoing basis. Structured approaches to quality and process improvement started with TQM, and developed with Lean Manufacturing, Six Sigma, and Lean Six Sigma. Despite the benefits these can bring, some continuous improvement efforts that have reported to have a high failure rate (McLean, Antony, 2017). A systematic literature review was conducted for the most common failure factors associated with Lean Six Sigma. Even though the study was not purely focused on the manufacturing sector, the study did however identify the top five failure factors as lack of top management commitment, lack of training, poor project selection, lack of resources, and a weak link to the strategic objectives of the organization. It is also highlighted that manufacturing companies in particular lack the knowledge required of how to implement an improvement initiative, and that these organizations need a guide to successful implementation specific to their sector, especially if it is being started from scratch. In 2015, another systematic review was conducted that was focused on Lean Six Sigma in the manufacturing industry and the most common themes that led to a high failure rate were benefits, motivation factors, expectations, organizational culture and environment, implementation approach, employee involvement levels, and feedback and results (Albiwi, 2014).

Lean Manufacturing

Lean manufacturing, also known as lean production, was founded in Japan as a way that an entire system should think when it comes to improving a process and sustaining those improvements over time. It was initially created to eliminate waste and inefficiency in its manufacturing operations. The Toyota Production System (TPS) is Toyota’s unique approach to manufacturing and is the basis for the “lean production” trend over the last 30 or more years which have been very successful. Its success and incredible performance consistency can be attributed to and is a direct result of its operational excellence. This operational excellence is based in part on tools and quality improvement methods made famous by Toyota in the manufacturing world, such as kaizen (continuous improvement), just-in-time, etc. These techniques helped spawn the “lean manufacturing” revolution. But tools and techniques are no secret weapon for transforming a business. Toyota’s continued success at implementing these tools stem from a deeper business philosophy based on its understanding of people and human motivation. Its success is ultimately based on its ability to cultivate leadership, teams, and culture, to devise strategy, and to maintain a learning organization (Liker, 2003). In reference to a “learning organization”, Peter Senge wrote in his book, *The Fifth Discipline*, by defining a learning organization as a place where people continually expand their capacity to create the results they truly desire, where new and expansive patterns are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together (Senge, 1990).

As previously mentioned, the ultimate goal for lean is to eliminate waste or any non-value added components of a process. If implemented correctly, lean can lead to significant improvements in production efficiency, reduction of scrap and material costs, which will lead to lower costs and improved competiveness. Lean manufacturing is defined by Womack and Jones (*Lean Thinking,* 1996) as a five-step process: defining customer value, defining the value stream, making it “flow”, “pulling” from the customer back, and striving for excellence or perfection. Customer value is defined by what the customer’s specific needs are for a particular product. It can come in the form of when it is needed, how much will it cost, and the requirements and expectations with respect to quality. The value stream is all of the steps and processes involved in a transforming a product from a raw material and then delivering the final product to the customer. Value-stream mapping is a simple but eye-opening experience that identifies all of the actions that take a product through any process. The goal is to identify every step that does not create value and then find ways to eliminate those wasteful steps. Value-stream mapping is sometimes referred to as re-engineering but it leads to a better understanding of the entire process after the exercise has been completed. The flow of the value-stream must be smooth without interruptions, delays, or bottlenecks. The sequencing of events and the time between each event are tightened to ensure that the product flows smoothly down to the customer. This often requires the breaking down of a silo thinking culture and makes the effort to be become cross-functional across all departments, which can be one of the greatest challenges for lean programs to overcome. The “pull” system is successful with improved flow after the previous three activities have been completed. The time-to-market is dramatically improved. This will make it much easier to deliver products as needed, as in “just-in-time” manufacturing. The customer can “pull” the product as needed. Products do not need to be built in advance or stockpiled in anticipation that an order is coming in. This creates expensive inventory and is wasteful due to the fact that true value was not added to that inventory, until it is sold. Accomplishing excellence and perfection is the most important where making lean thinking and process improvement part of the organizational culture. Lean is not considered a static system and requires constant effort and vigilance in order to achieve that mode of excellence. Some experts say that a process is not truly lean until it has been through a value-stream mapping exercise more than a half-dozen times. In summary, lean manufacturing and lean thinking can improve overall business performance results in many different ways.

Reduction of Scrap or Waste in a Manufacturing Process

Lean Manufacturing philosophy is at the forefront in today’s operations management and quality improvement practices. It is characterized by its goal of maximizing productivity (Brown, 2008). Its primary focus is to minimize wastage, reduce variations in standards and to improve production quality. It also reduces cycle time, increases flexibility, and improves productivity

(Hobbs, 2004). Essentially, knowledge is distributed for all employees in the organization. It covers aspects of just-in-time, workflow management, culture of minimum waste as well as continuous improvement. The driving force of lean manufacturing is the process of continuous improvement through the elimination of waste or non-value adding activities (Burton and Boeder, 2003). There were eight types of waste categories that include defects were introduced in Burton's study. The scope of the defects encompasses generating scrap, rework or paperwork errors. The thrust to eliminate waste, especially defects, is therefore at the heart of lean manufacturing; described by (Womack and Jones, 1996) as one of his five principles of lean manufacturing's philosophy, namely the fifth principle, which requires companies to strive for perfection by constantly removing layers of waste. In order to eliminate wastage problems or scrap losses, one must recognize the root cause of the problem and attempt to solve the problem in a systematic way. In this regard, root cause problem solving (RCPS) can be considered as a structured problem solving approach using simple standardized tools to identify and resolve critical problems encountered in manufacturing operations. The use of this approach leads to the improved factory efficiency, improved quality, lower scrap, superior customer service, and an improved work environment. RCPS analysis tools commonly used to solve quality problems are cause-and-effect diagram, interrelationship diagram and the 5-whys analysis (Murugaiah, Benjamin, Marathamuthu and Muthaiyah, 2009). RCPS is a four-step process involving data collection, causal factor charting, root cause identification and recommendation generation and implementation (Rooney and Vanden Heuvel, 2004). Quality professionals naturally implement root cause analysis with corrective actions as remedial actions when faced with manufacturing problems in world-class organizations (Pylipow and Royall, 2001). The 5-why analysis emerged as a result of Taiichi Ohno's observation is his days I Toyota that when mistakes happen in the production or manufacturing environment people would blame one another. He realized that mistakes are inevitable and the best approach towards mistakes is to identify the root causes of the mistakes and act upon it (Ohno, 1988). His favorite tool to resolve problems at the manufacturing floor is the 5-why analysis.

In order to reduce waste in any given system, it is crucial to identify the different types of waste, as well as the potential causes and effects of each. Of the seven true types of lean wastes, only three or four actually apply to this study. Those will obviously include defects, excess processing, overproduction, and inventory excess can apply as well. Regardless of the industry, sub-par quality products will result in unsatisfied customers. This is why companies must pay close attention to detail of the product through an assembly line or machine production. Whether the process is producing defective parts or scrap, accompany will certainly have higher operating costs due to the need to reproduce or rework product. Assigning additional work on top of the base production line process can cause various problems in a system that is essentially already autonomous. Over processing also indicates when a system has not reached maximized efficiency. One of the most common tasks to be considered excessive processing is reworking a defective product. If the need to rework products could be reduced, a firm could save a tremendous amount of money. One of the worst types of waste is the act of producing more than what is in demand. Producing product before a customer needs it or simply producing too much of a certain product at any given time can cause a significant short-term financial loss (Byler, Griggs, and Macko, 2009). Retaining a large inventory can result in a financial loss and wasted space and the use of resources. Excess raw material, work-in-process, and finished goods that have not yet been sold to customers are all examples of supply stock (MacInnes, 2002). While some stock can act as a buffer for variation between production periods, it can also be very expensive.

Statistical Process Control Tools used during Manufacturing

The fundamentals of statistical process control were described by Shewhart. Statistical process control (SPC) techniques, in particular the control chart, have been widely used in the manufacturing industry (Krumwiede and Sheu, 1996). Usually, control charts are implemented for the purpose of process monitoring. When a process is considered to be out of control, an alarm is raised, so that engineers can look for assignable causes of variation and try to eliminate them.

Traditional control charts aroused in such a way that corrective actions are taken only after the occurrence of an out-of-control signal which indicates that the process performance has changed to a state significantly far away from the original. Hossain (1996) indicated that in this way, control charts function only as a reaction to a system deficiency. In many cases, it is more effective to take a proactive approach to prevent the occurrence of out-of-control situations allowing the process to be adjusted in a preventive way so that fewer non-conforming items will be produced (Xie, Goh and Cai, 2001).

The traditional SPC approach assumes that the process is not modified unless it is out of control. There are many examples for which constant adjustment and changes have to be made. For metal cutting processes, the cutting tool must be replaced regularly before it is totally worn out. System wear and tear is usually considered to be an assignable cause, but such a cause is difficult to remove. If we wait until the process is totally out-of-control, it might be too late to adjust the process and many non-conforming items will have already been produced. For processes with trend and regular adjustment, the first step is to develop a model that can accommodate an underlying trend in the process. If regular adjustments are performed, it should also be taken into consideration; traditional upper and lower control limits can still be derived; however, the process should be monitored based on the control limits and the specified adjustment procedure. When it is time for an adjustment, it is made. On the other hand, when a point is out of control, assignable causes should be looked for (Xie, Goh and Cai, 2001).

SPC widely employs various process monitoring charts for determining whether the process under consideration is performing within the specified limits are not. Process monitoring charts gives a graphical description of process performance. Process capability indices are the measure of efficiency of the process to produce the product within the specified dimensional tolerance limits. To be specific, *C*p is the process potential capability index. *C*p gives a measure of the variation and deviation in the process. The higher the *C*p value, the less variation and deviation in the process. *C*pk, on the other hand, is obtained from *C*pku and *C*pkl is considered the value of *C*pk. Elaborating on this, it can be said that centering of the process within the specification limits is done by *C*pk. It provides an indication whether the process is operating at the center of the specified tolerance zone or nearer to the upper and lower specification limits (Sharma and Rao, 2014).

Threaded fastener manufacturing can be considered somewhat of a batch process due to the nature of the size of the fasteners and the high volume and speed at which it is being produced. Even though one piece is made at a time and within seconds between each piece, they are all processed in large lot sizes. Monitoring the several dynamic processes involved in fastener manufacturing can be quite challenging. Batch processes can be characterized by their nonlinear behavior, finite duration, high conversions and recipe-driven nature. Monitoring batch processes is necessary for several reasons: safety, improving product quality and a better understanding of the process. Besides knowledge-based or state estimation approaches, multivariate statistical approaches can be used for monitoring batch processes (Ramaker et al., 2006).

The majority of literature that addresses batch manufacturing is usually associated with the chemical, pharmaceutical, and food industries. However, the theory of this can also be applied due to the complexity of the processes and sometimes the variables that have an effect on that process are sometimes unknown. There are many moving parts associated with the machine (automatic multi-spindle screw machine (see Figure B1)) and tooling that are primarily the probable causes for defects. Batch processing requires a type of sampling plan to be employed. The typical questions when initially designing a monitoring system for a process will be: when should it be monitored, how many samples, how frequently, etc.? Or a different approach can be taken. Hotelling (1947) was one of the first to introduce a multivariate approach to statistical process control to monitor a process of a multivariate nature. Jackson (1959) then applied principal component analysis

(PCA) to reduce the dimensionality of the multivariate data. Finally, Nokimos and MacGregor (1994) extended the concept of multivariate statistical process control using PCA to batch processes. This is called statistical batch process monitoring. Their approach to batch process monitoring is a purely data-driven approach based on linear multivariate analysis methods. The relevant variation of a process is captured in a dimension-reduced model. This is advantageous in terms of interpretability and comprehensibility. Two test statistics are derived from this model and both are monitored using control charts (Ramaker et al., 2006).

Profitability and Competitive Advantages associated with Lean

Increased global competition has fueled a growing interest in understanding the competitive strategies that make some organizations outperform their competitors. Meeting customer expectations and improving value creation requires organizations to implement different management approaches in light of creating competitive advantage. These approaches encompass a variety of philosophies, methods, and tools intended to increase an organization's performance with lean transformation being popular in recent times (De Souza and Carpinetti, 2014).

Lean can be defined as an operational strategy focused on improving competitive priorities such as quality, flexibility, cost, and delivery within organizations. However, case study literature also shows that organizations implementing lean have realized different levels of success or failure (Womack & Jones, 1996). Notably, the problem of failed lean transformations has been attributed to focusing on lean tools versus focusing on the underlying lean operational philosophy of the organization (Albliwi, et al, 2014). The failure to achieve an effective and permanent lean transformation remains a management problem of organizations being unable to capitalize on the benefits of lean (Kotter, 1995).

There are numerous strategies available for organizations attempting to gain sustainable competitive advantage. As an operational strategy, lean would appear to be a source of competitive advantage, as it can deliver greater value with fewer inputs than non-lean organizations. To create competitive advantage, organizations must often change the rules of the game by reinventing the means by which a product or service is made, sold, or delivered (Barr et al, 1992). In this regard, lean would appear to change the rules of the game in favor of creating competitive advantage based on how the value is created and delivered. However, a company can only outperform its rivals over time if it can establish a difference that it can preserve (Porter, 1996). This raises the issue of sustainable competitive advantage (Hallam et al, 2017).

CHAPTER 3

METHODOLOGY

Studying the reasons for why waste is generated in a production environment can be a very common problem or theme. Especially for those companies that have determined that there are reasons and needs for continuous improvement and have initially identified those areas that should be analyzed. For those founders and industrial leaders of lean manufacturing before us, they state that the reduction of, or the minimization of waste within a manufacturing system without sacrificing productivity, is a very important element for success.

The North American fastener manufacturing plant has implemented several different, but not very sustainable lean techniques and activities over the past several years. These activities were derived from various lean consultants and internal lean minded thinking personnel, but it was discovered that there is one area that was never a serious concern because it was difficult to define and also difficult to quantitatively capture. This fastener manufacturer had always assumed that there would be some sort of process fallout over the period of several processing operations and would absorb that amount as a “cost of doing business”. However, this amount of fallout of missing production pieces turned out to be a very costly mistake. After an initial cursory review of the processes involved in producing the fastener, it was determined that the machining operation is where the majority of the waste or negative process yield is being generated. This comes in the form of pieces that are made during the initial setup and the subsequent running of the production work order. During the machining operation there are opportunities where pieces are collected properly in the designated baskets and pieces that do not meet dimensional and visual specification could be improperly discarded and not accounted for per the standard operating procedures. This accumulation of pieces lead to the percentage of negative process yield that is reported after the material usage report is submitted for review. In the cross-functional team's opinion, the failure to use optimal tooling for certain types of product could be the leading cause of failure to meet the predetermined criteria that has been established by the fastener manufacturer.

Purpose of the research

The purpose of this research and the goal of the experiments associated with the research are to determine which of the identified contributing factors can lead to the minimization of the missing pieces during production. The research will lead to new process handling techniques, new tooling capabilities and other potential options for the machining operation.

Statement of the Problem

The negative process yield or scrap produced at the North American fastener manufacturing facility has not been able to be under any sort of control for the past few years based on recent reports. This unfortunate type of occurrence has a negative impact of the company’s ability to become more competitive in the fastener industry’s marketplace. It is known that when a pre-determined amount of material is theoretically calculated to produce a specific number of fastener pieces for a production work order and the final count of pieces is less than it should have been, that there is a problem. The operators that run the automatic screw machines make the necessary adjustments to make the parts as intended per the specifications. There are various types of tooling that can be used and that is not always guaranteed as being the standard operating procedure. If it is known as to what the optimal tooling might be in order to produce more defect free products that somehow get lost during production, should have a positive impact on reducing the negative process yield and putting more positive amount of pieces in the finished goods warehouse.

Design of Experiment (DOE)

There are many characteristics associated with good experiment design. An experiment should be as simple as possible to set up and carry out. It should also be straightforward in order to analyze and interpret, as well as easy to communicate and explain to others. It should include all of the factors or variables for which changes are possible. A well-designed experiment should provide unbiased estimates of process variables and treatment effects (factors at different levels). This will quickly filter out the factors that do not have a pronounced effect upon the percentage of negative process yield. In this study, determining what the reason or one of the primary reasons why production pieces during machining is not accounted for. It will also identify the best levels for those factors that do have a pronounced effect on the percentage of negative process yield. The experiment should plan for the analysis of the results, generating results that are free from ambiguity of interpretation. When analyzed, the experiment should provide the precision necessary to enable the experimenter to detect important differences between significant and insignificant variables. The analysis should produce understandable results that can be easily communicated to others interested. The experiment should direct the researcher in the direction of improvement to the process being analyzed.

The Taguchi Design of Experiment (DOE) method is to be used for the experiment. The main focus of the application of DOE is to improve quality. The definition of quality varies widely depending on the applications, but it must be defined before any experimental technique can be produced with meaningful results. Taguchi offers a generalized definition for quality of performance. He regards performance as the major component of product or process quality. A reduced variation results in a reduction in scrap, less rejection of product, and fewer warranty returns, consequently reducing costs, and improving profits and improving customer satisfaction.

A direct way to determine cause and effect is to run experiments. To study the influencing factors depends on the nature of the trend in influence of the factor or factors and its levels. Investigation of the influence of factors, one at a time, is a common practice among scientific professionals. When several factors are studied simultaneously, pursuing an economical experimental plan require more than common sense, it requires DOE.

There are several different numbers of levels and factors involved for this experiment, so there are many possible ways in which this experiment can be laid out. A number of standard orthogonal arrays (tables of numbers) should be constructed to facilitate the design of this experiment. Each of these arrays can be used to design experiments to suit several experimental situations.

The goal for using the DOE method is to determine the factor levels which will result in the ability to understand what the primary contributing factors that are causing the loss of production pieces. The use of orthogonal arrays was decided to be used because every test setting of a process parameter occurs or interacts with the other test settings the same number of times. Therefore, any two columns of an orthogonal array form a two factor complete factorial design.

A Taguchi design is a designed experiment that lets you choose a product or process that functions more consistently in the operating environment. Taguchi designs recognize that not all factors are called noise factors. Taguchi designs try to identify controllable factors that minimize the effect of noise factors. During experimentation, you manipulate noise factors to force variability to occur and then determine optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. A process designed with this goal will produce more consistent output. A product designed with this goal will deliver more consistent performance regardless of the environment in which it is used.

There are certain operating process parameters deemed fixed for this process: machine rate (cycle time), grade of raw material, skill level of the operator (do not want to replicate the Hawthorne studies), and the type of machining equipment. The result of the least amount of pieces lost determines which variable settings and combinations will either test negatively or positively and thus will either yield support for the hypothesis.

Controls required during the Experiment

During the machining operation, which is part of the focus of this study, it has been pre-determined that the primary loss of pieces occur during this operation. With that being said, there should be some stringent controls that are set into place before the experiment begins. Such as the need to control and maintain that each of the components that are involved in the machining remains constant throughout each trial run.

Type of product being produced: the North American fastener manufacturer produces and delivers hundreds of different fasteners for many different applications. The brand of fasteners utilize self-clinching, broaching, flaring, surface mount technology to provide strong, reusable, and permanent threads in thin sheet metal or P. C. boards. For this study, one of the most popular fasteners has been chosen. Thru-threaded, steel standoffs, which use the proven self-clinching design, provide ideal solutions for applications where mounting, spacing or stacking of panels or boards are required.

Type of machining equipment: there are several different types of screw machine options that can be used for the study in the North American fastener manufacturing facility. However, the preferred type or the original equipment manufacturer of the equipment to be used for the study will be *Davenport Machine*. It is a five spindle automatic screw machine (see Figure B1) that was originally designed and built in 1909. Its technology remains the same since then and has had the least amount of changes since its original construction.

Feed and speeds of the machining equipment: this refers to two separate velocities in machine tool practice and the effect that they have on the metal cutting process. Feed rate is the relative velocity at which the cutter is advanced along the work piece; its vector is perpendicular to the vector of cutting speed. There will be an optimum cutting speed for each set of machining conditions and the spindle speed (RPM) can be calculated from this speed. For this experiment, the RPMs will be 2,674.

Machine cycle time: the machine cycle time is the amount of time that it takes for the spindles to disengage and then rotate to the next operation in a five-position automatic lathe. The gross cycle time for the part to be manufactured during this study is 2. 4 seconds. This is directly associated with the optimal feed rates based on the size and length of the fastener.

Class and grade of material being used for the fastener: Low carbon steels are inherently easy to machine due to their softness and ductile nature. When strength is not a major concern, low-carbon steel is chosen because it is easy to handle and is fairly inexpensive. Surface hardness can be improved through carburizing which involves heating the alloy in a carbon rich environment.

Machine Operator skill level: this study will require that the Operator level will not be lower than an “A” certified machinist per the company training program.

Review of the Hypotheses

The following null hypotheses will be tested:

Null Hypothesis 1: There is no statistically significant difference in the percentage of negative process yield produced on the screw machine because of change in the form tool material.

Null Hypothesis 2: There is no statistically significant difference in the percentage of negative process yield produced on the screw machine as a result in the change of drill material type.

Null Hypothesis 3: There is no statistically significant difference in the percentage of negative process yield produced on the screw machine as a result in the change of the brand of taps.

Variables and Data Information

Form tool (s): Form or shave tools were designed to shape the exterior contour of a part, and in this case, a threaded fastener. The relative movement between the work piece and the cutting tool (also called the tool path) is controlled by the machine. Form tools can be made from high speed tool steel (HSS) or from carbide. Carbide form tools are typically used as inserts that can be easily replaced from the machine tool holder so that downtime is reduced. In addition, carbide tooling is typically found to be far superior in cutting due to the nature of the material. With that being said, it is usually the tooling of choice by the machine operator. However, it is not always available for certain part types or part numbers. In addition, carbide tooling is not always the perfect answer or optimal choice in machining metals. In the event that it is subjected to the workpiece as it was not intended, it could fracture more easily than its HSS counterpart. This could be due to the cutting speed and depth of cut and could have an inferior coating on its cutting edge. The bottom line is that tool wear is unavoidable. But if it is understood on what causes it and how it happens, will help in selecting the right cutting tools so that tool life is extended, wear is reduced and tooling costs are reduced as well.

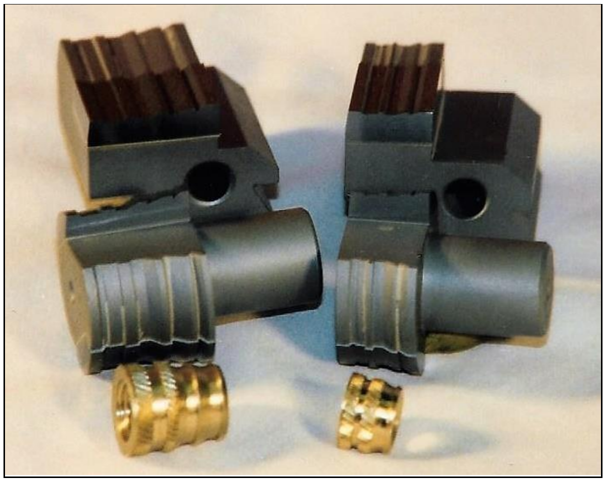


Figure 1: Carbide insert tool holders and High Speed Steel circular tools.

Drill(s): Drills (Figure2) are cutting tools that are used to remove material to create holes, almost always of circular cross-section. Drills, like forming tools, can come in various material types such as carbide and high speed steel. Depending on the material being drilled into and the size of the hole will sometimes dictate if either should be used or not. However, it has been proven that carbide drills (see Figure B7) are far superior to high speed steel drills (see Figure B8) based on the consistency of the hole size that is held and the durability that it can provide.

Figure 2: High Speed and Carbide Drills

Tap(s): Taps are tools used to create screw threads, which is called threading and can come in either the forming type or cutting type. A tap is used to cut or form the female portion of the mating pair of fasteners. The material used to make taps is typically the same type. However, taps can come in many different forms and shapes and with or without flutes. In addition, it has been proven that taps made by different manufacturers make a difference with respect to Quality and durability.

Figure 3: Thread cutting and forming taps

Design of Experiment for the Study and Data Collection

Roberts (1995) stated that statistically designed experiments could save an organization thousands of dollars in reduced development time, increased productivity and more reliable products and processes at lower costs. The experiment for the study was performed in a high-speed, high volume manufacturing setting using the Taguchi's (3 x 2 levels) Design-of-Experiment. The L8 design was chosen because of the small number of runs and dispersion of variables. Table 2 shows where Factors A and B were both set at level 1 for two trials, A was at level 1 and B at level 2 for two trials, A at level

2 and B at level 1 for two trials, and both A and B at level 2 for two trials. The same was also done for the settings in A and C, and in the setting in B and C.

Table 2.

Design matrix for Taguchi's L8 Design of Experiment for a three-factor, eight-run experiment.

Runs	Form tool(s) (A)	Drill(s) (B)	Tap(s) (C)	Response Y
1	1 (-)	1 (-)	1 (-)	Y1
2	1 (-)	1 (-)	2 (+)	Y2
3	1 (-)	2 (+)	1 (-)	Y3
4	1 (-)	2 (+)	2 (+)	Y4
5	2 (+)	1 (-)	1 (-)	Y5
6	2 (+)	1 (-)	2 (+)	Y6
7	2 (+)	2 (+)	1 (-)	Y7
8	2 (+)	2 (+)	2 (+)	Y8

Table 3 shows the actual levels and parameters that were used in the experiment. It can be stated that based on knowledge and experience of some of the cross-functional team members that suggested that carbide tools and drills (see Figure B7 and B8), and brand "B" of taps be part of this experiment.

Table 3: *Factors and parameter Levels of the 3 x 2 DOE.*

	Factors	Level 1 (-)	Level 2 (+)
A	Form tool (s)	High Speed Steel	Carbide
B	Drill (s)	High Speed Steel	Carbide
C	Tap (s)	"A"	"B"

Statistical Technique

JMP is a suite of computer programs for statistical analysis developed by the JMP unit of SAS institute and will be used to analyze the statistical data collected during the study. *JMP* helps businesses increase efficiency and improve quality through smart data analysis. It can analyze the data and present the report-ready and presentation-ready output and results with confidence. *JMP* allows the researcher or statistician to create robust parameter design that will identify controllable factors in the process that can minimize response variation that will make the product insensitive to change in noise factors. Taguchi designs include control factors, which are factors in the process that you can control, and noise factors, which are factors that you cannot control when the product or process is in use. *JMP* provides the two types (static and dynamic) and it will store the design information into a worksheet. A static design was chosen for this experiment because there is not a signal factor. Frequently, the goal of the experiment is to determine the settings of control factors that allow the response to remain close to a target value with minimal variation due to changes in the noise variables.

Setting the α (alpha) level

Before any statistical test or experiment is conducted, the alpha level must be determined, which is also referred to as the significance level. By definition, the alpha level is the probability of rejecting the null hypothesis when the null hypothesis is true. According to famed statistician R. A. Fisher, the majority of scientists use an alpha level of 0.05. If alpha equals 0.05, then the confidence level is 0.95. An alpha level of 0.05, there will only be a 5% chance of rejecting a true Ho. If the alpha is increased, the probability of incorrectly rejecting the null hypothesis and the confidence level both decreases. Decreasing the alpha from 0.05 to 0.01 increases the chance of a Type II (β) error which makes it harder to reject the null hypothesis. The alpha is the probability of making a Type I error (rejecting the null hypothesis when the null hypothesis is true). This value should be as small as possible so that the when the experiment is being planned the sample size will prove to be large enough.

CHAPTER 4

EXPERIMENT AND DATA ANALYSIS

The Experiment

The experiment in this study was designed using Taguchi's three factor two-level (L8 array) Design of Experiments. This design included all possible combinations of levels in an eight-trial experiment. The trials, which comprised of a two-level eight run designs, are listed in Table 4. The random order of run was selected by drawing numbers from a pool of eight slips of paper, as stated in the methodology. After the experiments, JMP statistical software was used in the statistical analysis of the experiment.

The experiment runs were performed according to the random order as noted in Table 4. Each run in the experiment produced a cell group of six production orders. A Production Standards report was generated for each work order and the negative process yield was calculated based on the number of pieces expected less the number of pieces that were actually placed into the warehouse. Six work orders were chosen in order to try and reduce the amount of known variability that can be exhibited with this type of equipment and respective processes. The mean negative process yield was calculated from those six runs and recorded in Tables A1 through A8 and summarized in Table 5.

Table 4.

Taguchi's three-factor two-level eight run design

Random order of Runs	Standard order of Runs	Factor A Material for Form tool	Factor B Material for Drill	Factor C Type of Tap	Response Y % Negative Process Yield
4	1	HSS (-)	HSS (-)	"A" (-)	
3	2	HSS (-)	HSS (-)	"B" (+)	
7	3	HSS (-)	Carbide (+)	"A" (-)	
5	4	HSS (-)	Carbide (+)	"B" (+)	
1	5	Carbide (+)	HSS (-)	"A" (-)	
6	6	Carbide (+)	HSS (-)	"B" (+)	
2	7	Carbide (+)	Carbide (+)	"A" (-)	
8	8	Carbide (+)	Carbide (+)	"B" (+)	

The Data

The data collected as a result of the experimentation from all of the combinations of the chosen factors and using each of the two factor levels are shown in Table 5. The coded factor levels ("-"and "+") are also placed next to the factor values to show the level variations used in the experiments. This information will be helpful during the running of the ANOVA.

Data Analysis

It has been stated that the data from the experiments will be analyzed using the JMP software. The steps in the data analysis are as follow:

Effects. The significant effects of the factors will be chosen from the graph or list.

Interactions and effects. When an interaction effect is present, the impact of one factor over another depends on the level of the other factor. That is part of the power of using an ANOVA because it has the ability to estimate and test interaction effects.

Analysis of Variance (ANOVA). The ANOVA will analyze the chosen model and the result will be viewed.

Model Graphs. The model graphs or figures will be used to visually interpret and evaluate the model including the effects and interactions.

In addition, the dependent variable (percentage of negative process yield) will be compared by the three designated independent variables and their groups or levels. As an example, the first independent variable (grade of form tool material) has two levels or groups (1 vs 2), etc. The ANOVA uses the F test, which allows researchers to make the overall comparison on whether group means differ. The F test is the ratio of two independent variance estimates of the same population variance. Considering an alpha of 0.05, if the calculated F-value is larger than the critical F-value after accounting for degrees of freedom, the null hypothesis (Ho) will be rejected. The results of the factorial ANOVA will be presented in the form of main effects and the interactions among study variables.

Table 5.

Experiment matrix in standard order with coded levels.

Random order of Runs	Standard order of Runs	Factor A Material for Form tool	Factor B Material for Drill	Factor C Type of Tap	Response Y % Negative Process Yield
4	1	HSS (-)	HSS (-)	“A” (-)	15.39%
3	2	HSS (-)	HSS (-)	“B” (+)	14.32%
7	3	HSS (-)	Carbide (+)	“A” (-)	12.50%
5	4	HSS (-)	Carbide (+)	“B” (+)	10.16%
1	5	Carbide (+)	HSS (-)	“A” (-)	10.14%
6	6	Carbide (+)	HSS (-)	“B” (+)	9.37%
2	7	Carbide (+)	Carbide (+)	“A” (-)	8.29%
8	8	Carbide (+)	Carbide (+)	“B” (+)	7.78%

Table 6.

Complete matrix, including interactions, with effects calculated.

Run	A	B	C	AB	BC	AC	ABC	AVG
1	-1	-1	-1	1	1	1	-1	15.39
2	-1	-1	1	1	-1	-1	1	14.32
3	-1	1	-1	-1	-1	1	1	12.5
4	-1	1	1	-1	1	-1	-1	10.16
5	1	-1	-1	-1	1	-1	1	10.14
6	1	-1	1	-1	-1	1	-1	9.37
7	1	1	-1	1	-1	-1	-1	8.29
8	1	1	1	1	1	1	1	7.78
Avg +	8.9	9.68	10.41	11.45	10.87	11.26	11.19	
Avg -	13.09	12.31	11.58	10.54	11.12	10.73	10.8	

A = Form Tool, B = Drill, C = Tap

The effects caused by interactions must be taken into consideration. The full-factorial design allows estimation of all three two-factor interactions (AB, AC, and BC) as well as of the three-factor interaction (ABC). Including the main effects (caused by A, B, and C), this brings the total to seven effects – the most you can estimate from the eight-run factorial design, because one degree of freedom is used to estimate the overall mean. Table 6 lists all seven effects. The main effects calculated earlier are listed in the A, B, and C columns.

The pattern of the coded factor levels for interaction effects is calculated by multiplying the parent terms. For example, the AB column is the product of A and B. The entire array exhibits a very desirable property of balance called “orthogonality.

The results are shown on the bottom line of Table 6. Notice that none of the interactions are significantly higher than the others but the form tool * drill interaction appears to have the most influence. In addition, the form tool is the highest value from the interactions and effects graphs (see Figures 5 and 6).

The absolute net effect results in a graphical display of a Pareto Chart (Fig. 4). Before plotting the effects, it helps the researcher by converting them into absolute values which is a more sensitive scale for detection of significant outcomes.

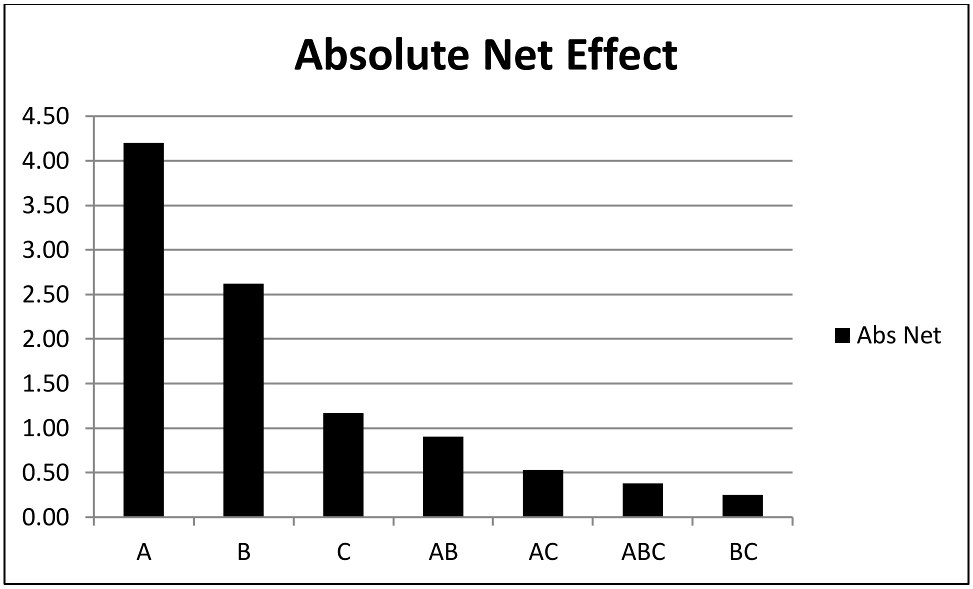


Figure 4. Absolute Net Effect

The absolute value scale is accommodated via a variety of normal paper called the “half-normal”, which is literally based on the positive half of the full normal curve. As before, the vertical (Y) axis of the half-normal plot displays the cumulative probability of getting a result at or below any given level. However, the probability scale for the half-normal is adjusted to account for the absolute values of the effect. There are seven (7) effects which mean each probability segment will be approximately 14.28% (7/100). The lowest weight will be plotted at 17.4%, which is the midpoint of the first segment. Table 7 shows this combination and all of the remaining ones.

Table 7. *Half-normal Probability.*

Point	Effect	Absolute Value of Effect	Cumulative Probability
1	BC	.25	7.14%
2	ABC	.38	21.43%
3	AC	.53	35.71%
4	AB	.90	50.00%
5	C	1.17	64.29%
6	B	2.62	78.57%
7	A	4.20	92.86%

Figure 5 plots the absolute value of the effect on the x-axis versus cumulative probabilities on the specially scaled y-axis on half-normal paper.

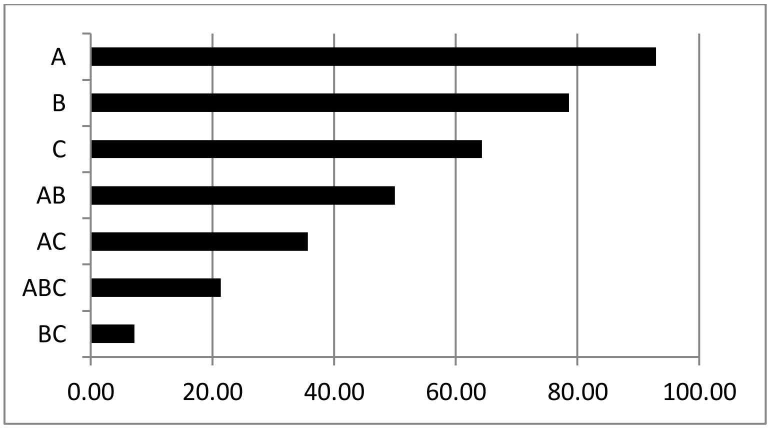


Figure 5. Absolute value of the effect on the X-axis.

The Effects Test report only appears when there is fixed effects in the model. The effect test for a given effect tests the null hypothesis that all parameters associated with the effect are zero.

Table 8.

Effects Test.

Source	DF	Sum of Squares	F Ratio	Prob > F
Form Tool	1	35.238	53.8756	0.0018*
Drill	1	13.755	21.0302	0.0101*
Tap	1	2.750	4.2037	0.1097

Figure 6 displays a cube plot. Cube plots display the predicted values for the extreme of the factor ranges. These values appear on the vertices of cubes. The vertices are defined by the smallest and largest observed value of the factor. It also shows the relationship between the factor and a response. In this case, when the tap is “B” brand (see Figure B5) and the form tool is made from carbide material, and the drill is made from carbide material, the screw machine should optimally perform and produce a quality fastener and reduce the amount of production negative process yield. The lowest number in the cube (7.78) considered achieving optimal status as opposed to a higher number with respect to the potential amount of negative process yield produced. On the other hand, 15.39 represents where the most percentage pf negative process yield was experienced when a high-speed steel tool and drill, and a “A” tap was used.

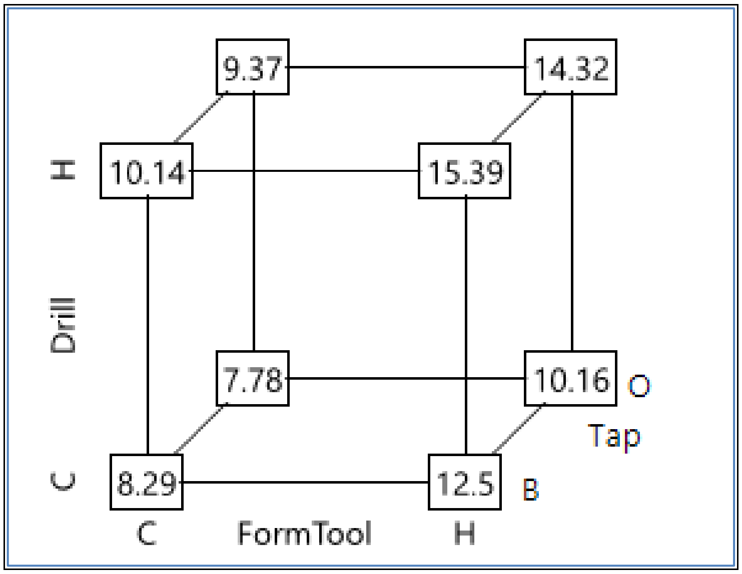


Figure 6. Cube Plot for predicted values for the factor ranges

The Interaction Graphs (Figure 7) are a visual way to see how changing one factor setting impacts the response as well as the impacts the other factors in the model. If there are cross-terms in the model and one term changes, the slope of another term helps to easily identify the interaction effects or cross-product effects in the model.

For example, in the left hand column, when the form tool is made from carbide material (C), the slope of the lines for the drill and tap both drop down close to “9”. If a High Speed Steel (HSS) form tool is used both interactions immediately increase to “12” or higher.

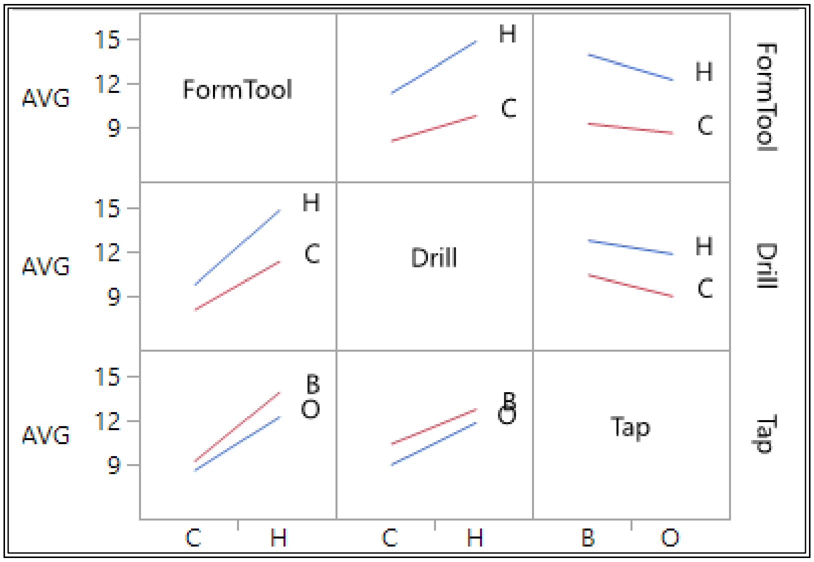


Figure 7. Interaction Graph.

The middle column displays how the interaction between any tap or form tool and the carbide drill (see Figure B7) generates a line that slopes downward close to “9”. However, when a HSS form tool is used with this interaction the effect if the worst of all interactions and is near “15”.

Analysis of Variance

Table 9.

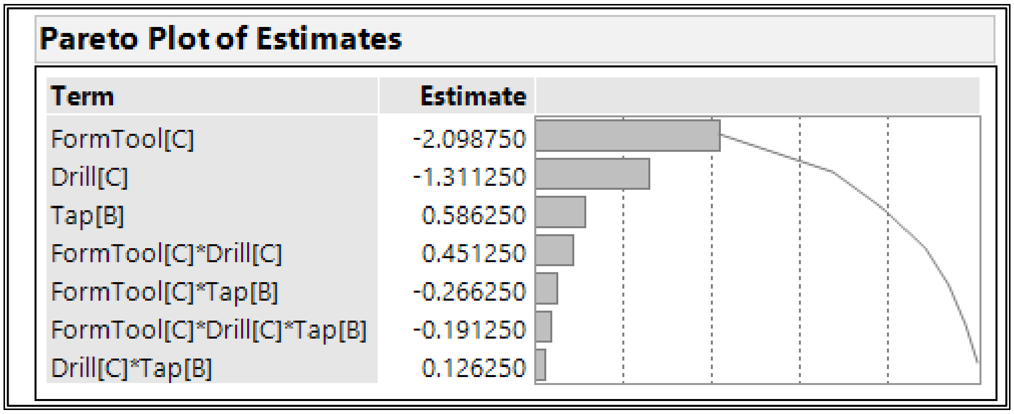
Analysis of Variance

Source	Sum of Squares	DF	MS	F (F-Critical = 21.2)	Prob > F	
Model	51.74	3	17.25	26.49	0.0043*	Reject Ho
A	35.24	1	35.24	54.12	0.0018	Reject Ho
B	13.76	1	13.76	21.12	0.0101	Reject Ho
C	2.75	1	2.75	4.22	0.1097	
Residual	2.6	4	0.65			
Corr Total	54.35	7				

As presented in Tables 8 and 9, the sum of squares of the three largest effects form tool (A) = 35.24, drill (B) = 13.76, and tap(C) = 2.75. When added together, the resulting sum of squares, which is 51.74 provides the actual beginning of the ANOVA. The next column in the ANOVA table is the degrees of freedom (DF), which is associated with the sum of squares. Each effect is based on two averages, high versus low, so it contributes 1 degree of freedom for the sum of squares. Therefore, there are 3 DF for the three effects in the model pool. The mean square, which is the sum of squares divided by the degree of freedom (SS/df) is equal to 17.25. The ratio of the mean squares (MS model/MS residual) forms the F value of 26.54 (Anderson & Whitcomb).

The Model F-value of 26.54 implies that the model is significant. There is less than 0.01% chance that a “Model F-Value” this large could occur. In other words, there is more than 99% confidence that the Negative process yield is significantly affected by the three factors chosen on the model. Values of “Prob>F” less than 0.0500 indicate model terms are significant. In this case, according to 8, the Form Tool and Drill are significant while the tap is not significant at the 0.05 level.

Figure 8 offers a simpler view of the relative effects via an ordered bar graph, also known as a Pareto chart, which serves as a graphic representation of the principle (also called the 80/20 rule). This becomes manifest by the vital few bars to the left of the graph towering over the trivial ones to the right.



Pareto Plot of Estimates

Term	Estimate
FormTool[C]	-2.098750
Drill[C]	-1.311250
Tap[B]	0.586250
FormTool[C]*Drill[C]	0.451250
FormTool[C]*Tap[B]	-0.266250
FormTool[C]*Drill[C]*Tap[B]	-0.191250
Drill[C]*Tap[B]	0.126250

Figure 8: Pareto Chart of Estimates

By definition, Residual = Observed – Predicted. The prediction of the factor is on the X-axis and the accuracy of the prediction is on the Y-axis. The distance from the line is how bad the prediction was for that value. Positive values for the residual (on the y-axis) mean the prediction was too low, and negative values mean the prediction was too high; 0, of course, mean that the prediction was nominal. Residual by Predicted plot (Figure 9) confirm that the residuals have a constant variance. In other words, the spread of the residuals should be approximately the same across all levels of the predicted values.

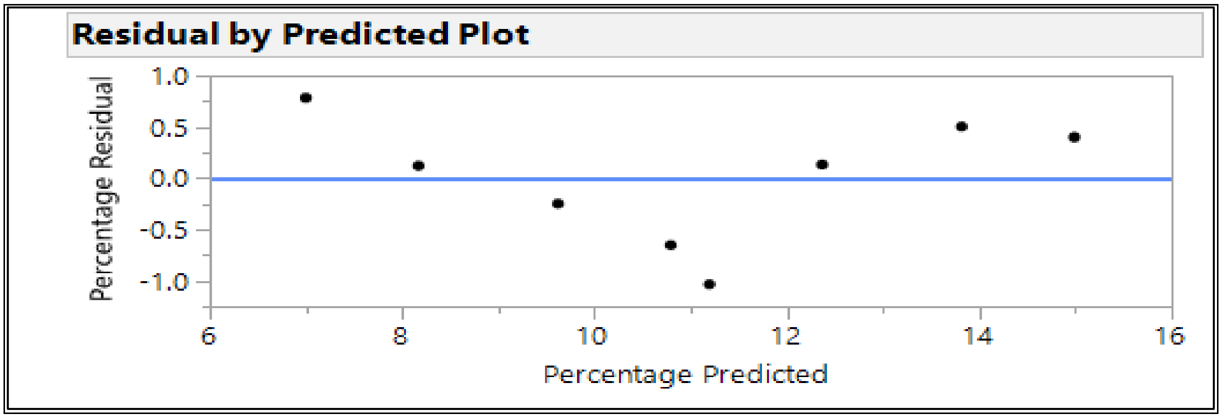


Figure 9. Residual by Predicted Plot

Interaction Effects

Figure 10 displays the absolute values of all effects, including their interactions plotted as squares on a normal probability plot. The interaction effects of these particular factors failed to produce significant effects as a noticeable gap is maintained between the individual effects and the interaction effects, which matched up near line zero. Ideally, this line will be a straight line, which indicates that there were no abnormalities. However in this case, the carbide type of Form Tool (C) and carbide type of Drill (C) exhibit some effect on the plot which indicates abnormality and those have an impact.

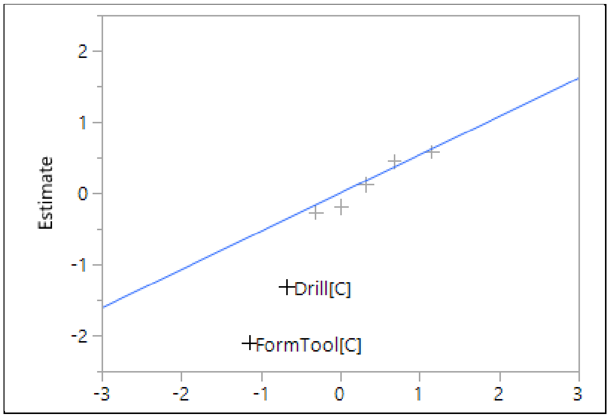


Figure 10. Normal Plot.

Testing the Hypotheses.

The testing of the hypotheses will be based on the ANOVA for the selected factorial models in Table 8 and Table 9. It has been stated earlier, from Table 9, that the Model F-value of 26.54 implies the model is significant. There is only a 0.01% chance that a “Model F-Value” this large could occur. Values of “Prob > F” less than 0.0500 indicate the model terms are significant. In this case, A, B are significant model terms. In Table 9, the “Model F-Value” of 26.49 from the interaction model implies there is a 0.43% chance that a “Model F-Value” this large could occur.

Since values of "Prob > F" less than 0.050 indicate the model terms are significant. In this case, form tool and drill are significant factors in the interaction model with "Prob > F" value of 0.0018 and 0.0101, respectively.

Result for Hypothesis 1.

The first hypothesis was formulated to examine the percentage of negative process yield produced on the screw machine based on the effects of the changes in the form tool material.

Null Hypothesis 1: There is no statistically significant difference in the percentage of negative process yield produced on the screw machine as a result of change in the form tool material.

Alternate Hypothesis 1. There is statistically significant difference in the percentage of negative process yield produced on the screw machine as a result of change in the form tool material.

Statistical Result. Table 9 showed that the Prob > F was equal to 0.0018 and less than 0.05. Therefore, the null hypothesis was rejected in favor of the alternate hypothesis, which means when carbide insert form tooling outperformed the high speed steel form tooling.

Result for Hypothesis 2.

The second hypothesis was formulated to examine the percentage of negative process yield produced on the screw machine based on the effects of the changes in the drill material types.

Null Hypothesis 2: There is no statistically significant difference in the percentage of negative process yield produced on the screw machine as a result in the change in the drill material types.

Alternate Hypothesis 2: There is no statistically significant difference in the percentage of negative process yield produced on the screw machine as a result in the change of drill material types.

Statistical Result. Table 9 showed that the Prob > F was equal to 0.0101 and less than 0.05. Therefore, the null hypothesis was rejected in favor of the alternate hypothesis, which means that the carbide drill outperformed the high-speed steel drill.

Result for Hypothesis 3.

The third hypothesis was formulated to examine the percentage of negative process yield produced on the screw machine based on the effects of the changes in the brand of taps.

Null Hypothesis 3: There is no statistically significant difference in the percentage of negative process yield produced on the screw machine as a result in the change of the brand of taps.

Alternate Hypothesis 3. There is statistically significant difference in the percentage of negative process yield produced on the screw machine as a result in the change of the brand of taps.

Statistical Result. Table 9 showed that the Prob > F was equal to 0.1097 and greater than 0.050. Therefore, the null hypothesis was not rejected and no difference was statistically detected between brand “A” and brand “B” of taps.

Table 10. *Best settings predicted for optimal performance on the Screw Machine.*

Factor	Name	**Optimal Level**	Factor Level (-)	Factor Level (+)
A	Form Tool	**Carbide**	HSS	Carbide
B	Drill	**Carbide**	HSS	Carbide
C	Tap	**“B”**	“A”	“B”

Validating the Result of the Experiment.

Table 10 describes what the optimal tooling was predicted to be before the experiment was conducted. During the experiment, these settings in the Optimal Level column were used to validate the experiment. The Operator was instructed to only use those settings for three consecutive production orders.

During the validation process runs, a total of 66,512 pieces were produced. Three consecutive production orders were used as part of the validation runs. Work order #s 1378366, 1407689, and 1419155 that all produced part # TSO-632-375ZI on the same machine. The expected number of pieces based on the amount of material issued was 69,207. This resulted in 3.89% negative process yield, or a percentage of negative process yield of 3.89%, by using the combination of a carbide form tool insert (see Figure B4), carbide drill (see Figure B7), and an “B” brand of tap (see Figure B5).

CHAPTER 5

SUMMARY, DISCUSSION, AND RECOMMENDATIONS

Summary

The primary goal of this experiment was to analyze the effects of the various combinations of types of tooling could have on the amount of negative process yield produced during a fastener manufacturing process. The primary process studied was where an internally threaded fastener was being produced on a multi-spindle screw machine (see Figure B1). The North American fastener manufacturer determined several years ago that it was losing at least a million dollars each year in an unknown “loss” of product that could not be accounted for. Thus a study was needed in order to get this under better control so that the manufacturer could become more profitable and continue to be the industry leader that it is today in the fastener manufacturing.

In addition, this study conducted a thorough literature review that covered very important areas that pertain to it such as Problem Solving Methodologies, Continuous Improvement, Lean Manufacturing, the Reduction of Scrap or Waste in a Manufacturing Process, and Statistical Process Control Tools used during Manufacturing. These topics were instrumental in developing methods and techniques that the North American fastener manufacturer will continue to use to identify causes of manufacturing negative process yield and being able to reduce it as much as possible.

The factors that were used as independent variables in the experiment came from several cross-functional meetings that were held to discuss the possible root causes of defective product made on a multi-spindle screw machine which could have led to negative process yield. This cross-functional team was primarily formed with members of that department and its respective team leaders. In addition, the team consisted of Process Engineers, Quality team members, and Production Supervisors. The study was conducted based on Taguchi's L8, three-factor, two-levels Design of Experiment. The statistical software chosen for the data analysis was the Tutorial version of JMP.

Discussion of the Result

The result of the experiment as stated in Chapter 4 showed that two of the three factors used in the experiments were significant enough to have an effect on the screw machining process in the North American fastener manufacturing facility. Figures 4 and 5 show that the most significant of the three factors was the Form Tool (A). The significance of the Form Tool is also evident in Effects Test for the Table 8, the ANOVA Table 9 and in Figure 10 Normal Plot. In the experiment, two values or levels of Form Tool was chosen, which were grades of material of either carbide or high-speed steel.

The second most significant factor in the experiment was the drill (B) being used, and is visible as shown in Figures 4, 5 and 10. The two separate material types for the drills used were high speed steel and carbide. In the set of Interaction graphs in Figure 7, when the drill and form tool interact, there is a significant effect as compared to the other combinations of interactions. In addition, the Sorted Parameter Estimates show that the form tool and drill have the highest Pseudo t-ratio than all of the other factors and various combinations of interactions.

Surprisingly, to the researcher, the tap was the least significant factor in the experiment based on the statistics. The levels of this factor were based on the manufacturer’s name brand of tap (“A” or “B”). However, the result of the statistics did reveal that the “A” performed superior in comparison to the “B” brand (see Figure B5). This is evident in Table 9 where it shows the Prob>F was equal to 0.1097 and greater than 0.050 and the null hypothesis was accepted. Coincidentally, Run #8 (Table B8) produced the lowest amount (optimal) amount of negative process yield (7.78%) as compared to all other possible combinations that were part of the Design of the Experiment using an “B” tap. This was confirmed or validated during the validation runs with three work orders that combined to only produce a total of 3.89% negative process yield

In summary, the differences detected between the various combinations of tooling in Ho_1, Ho_2, and Ho_3 were supported by the data analysis that was conducted. The first hypothesis focused on the material used for the form tool. The ANOVA suggests that the null hypothesis be rejected in this case because there was a significant statistical amount of difference between the grades of material during the experiment. The different grades of material were high-speed steel and carbide as previously mentioned. Carbide proved to be the optimal grade of material for this hypothesis (Ho_1). The same proved to be true for the drills as well (Ho_2). Surprisingly, based on the limited amount of experiences using “A” and “B” taps, “B” anecdotally seemed to be the superior brand of tap. On the other hand, it could have been someone’s subjective opinion.

However, the statistical analysis proved otherwise when other interactions were introduced or included in the experiment. Such as using the various combinations of grades of materials for form tools and drills. Additional formalized experimentation could be explored in the future based on comments from machine operators that have simply used taps in an unformulated situation during normal production.

Implications of the Result

Upon the completion of the experiment and after review of the results, it was determined that the form tool that used carbide material as opposed to high speed steel was the major factor in producing a quality fastener on a multi-spindle screw machine (see Figure B1). It was not mentioned, or it was not a factor in the final results of the experiment, but all of the carbide form tools (see Figure B4) used an exterior protective coating referred to as (TiN) or Titanium Nitride. There are numerous other coatings in the tooling (drills, form tools, cut-offs, taps, etc.) industry that some consider to be far more superior, but TiN was chosen for consistency purposes. The other coatings are Titanium Carbonitride (TiCN), Titanium Aluminum Nitride (TiAlN) and one of the more recent introductions to the coating offerings: FIREX ®. The testing of these types of coating could be considered for further research.

During the running of the experiments and as data was being collected, the cross-functional team that was aforementioned continued to meet and discuss other possible options as to how to reduce and prevent negative process yield. Upon completion of the study, it is obvious that this team will use the analytical data compiled and move forward with implementing the carbide form tool insert (see Figure B4), carbide drill (see Figure B7) when the appropriate application warrants it, and use the “B” brand of taps.

Sustainability of the Results of the Experiment

In addition, established policies and procedures that have been historically used over the many years were reviewed and are being enforced more as well so that a quality brand of fastener can be produced in the North American fastener manufacturing facility. The additional procedures and tasks are as follows:

1. Increase the frequency at which visual inspections of the fasteners occur. This is to prevent longer periods than normal where a discrepant failure would transpire and the machine would continue to run and produce “bad” product. If this was found earlier on, in comparison to 15 minutes versus 1 hour, negative process yield could be reduced that way.
2. Dedicate an Operator to one of the many machines consistently from day-to-day so that the familiarization with that machine and the product that it runs does not require re-adaptation each day or time, which could lead to ineffective or inefficient machining and not being concerned with known potential defects for that machine or that specific type of product.
3. Ensure that the optimal tooling as described in this experiment are readily available and used when it is required or necessary. An improved tooling management system could be a necessity in this case in order to not have tooling cost increase unnecessarily.

This North American fastener manufacturing facility has several hundred employees with the majority of them being a part of the machining department. During this study, purposely selected individuals were not chosen so that real data would be collected and not skewed and show that if an experienced Operator was aware that the study was being conducted that his or her behavior wouldn’t be different. The Hawthorne Effect wanted to be avoided by the researcher. By definition, the Hawthorne Effect is the inclination of people who are subjects of an experimental study to change or improve their behavior being evaluated only because it is being studied, and not because of changes in the experiment parameters or stimulus. One final note of consideration that needs to be mentioned is that production was never effected to where down time occurred due to the parameters established by the study.

REFERENCES

Albliwi, S. , Antony, J. , Abdul Halim Lim, S. and van der Wiele, T. (2014), *Critical failure factors of Lean Six Sigma: a systematic literature review*, International Journal of Quality & Reliability Management, Vol. 31 No. 9, pp. 1012-1030.

AR, Rahani and al-Ashraf, Muhammad. (2012). *Production Flow Analysis through Value Stream Mapping: A Lean Manufacturing Process Case Study*.

Barr, P. S. , Stimpert, J. L. and Huff, A. S. (1992), *Cognitive change, strategic action, and organizational renewal*, Strategic Management Journal, Vol. 13, No S1, pp 15-36.

Benjamin, Samuel and Marathamuthu, M. Srikamaladevi and Muthaiyah, Saravanan. (2009). *Scrap Loss reduction using the 5-whys analysis*. International Journal of Quality & Reliability Management. Vol. 27, No. 5.

Carpenetti,L. C. R. and Martins, R. A. (2001), *Continuous improvement strategies and production competitive criteria: some findings in Brazilian companies*, Total Quality Management, Vol. 12 No. 2, pp. 281-291.

De Souza, R. V. B. and Carpinetti, L. C. R. (2014), *A FMEA-based approach to prioritize waste reduction in lean implementation.* International Journal of Quality & Reliability, Vol. 31, No. 4, pp. 346-366.

Gunasekaran, A. (1994) *Improving productivity and quality in manufacturing organizations*, International Journal of Production Economics, Vol. 36 No. 2, pp. 169-183.

Hallam, Cory and Valerdi, Ricardo and Contreras, Carolina. (2017). *Strategic lean actions for sustainable competitive advantage*. International Journal of Quality & Reliability Management, Vol. 35, No. 2, pp. 481-509.

Hassan, Mohamed K. (2013). *Applying Lean Six Sigma for Waste Reduction in a ManufacturingEnvironment.* American Journal of Industrial Engineering.

Hossain, A. Choudhury, Z. A. and Suyut, S. (1996), *Statistical Process Control of an industrial process in real time*, IEEE Transactions on Industry Applications, Vol. 32, No. 2, pp. 243-249.

Kotter, J. R. (1995), *Leading change-why transformation efforts fail*, Harvard Business Review, Vol. 73, No. 2, pp 59-67.

Juergensen, T. (2000). *Continuous Improvement: Mindsets, Capability Process, Tools and Results*. The Jurgeson Consulting Group Inc. Indianapolis, IN.

Liker, Jeffrey K. (2004). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer.*

Liker, Jeffrey, K. (2004). *Becoming Lean: Inside Stories of U. S. Manufacturers*.

McBride, David (2003). *The 7 Wastes in Manufacturing*

Oakland, J. (1999). *Total Organizational Excellence: Achieving World Class Performance*, Butterworth-Heinemann, Oxford.

Ohno, Taichi (1988). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer.*

Porter, M. E. (1996), *What is Strategy? On Competition?*, Harvard Business Review, Vol. 74 No. 6, pp. 61-78.

Pylipow, P. E. and Royall W. E. (2001), *Root cause analysis in a world-class manufacturing operation*, Quality, Vol. 40, No. 10, pp. 66-70.

Roberts, G. (1995). *Quality Planning, Control, and Improvement in Research and Development.* New York, NY. Marcel Dekker, Inc.

Rooney, J. J. and Vanden Heuvel, L. N. (2004), *Root cause analysis for beginners*, Quality Progress, Vol. 37 No. 7, pp 45-53.

Senge, Peter M. (1990). *The Fifth Discipline*.

Sharma, G. V. S. S. and Rao, P. Srinivasa. (2014) *A DMAIC approach for process capability improvement an engine crankshaft manufacturing process*. Journal of Industrial Engineering.

Sraun, Jagdeep and Singh, Harwinder. (2017). *Continuous Improvement strategies across manufacturing SMEs of Northern India*. International Journal of Lean Six Sigma. Vol. 8, No. 2, pp225-243.

Wilkinson, Leland. (2006). *Revising the Pareto Chart.* The American Statistician, Vol. 60, No. 4

Xie, M. , Goh, T. N. , Cai, D. Q. (2001). *An integrated SPC approach for manufacturing processes*. Integrated Manufacturing Systems.

Zangwill, W. I. and Kantor, P. B. (1998), *Toward a theory of continuous improvement and the learning curve*, Management Science, Vol. 44, No. 7, pp. 910-920.

APPENDIX A: RUN OF EXPERIMENTS

Table A1: Run 1 Experiment

Carbide form tool HSS Drill "A" Tap

Mean Negative Process Yield = 10.14%

WO #	Part #	A	B	C	Y
1241236	TSO-6M3-600ZI	+	-	-	4.13%
1231639	TSO-632-187ZI	+	-	-	18.41%
1241237	TSO-6M3-600ZI	+	-	-	21.72%
1249223	TSO-256-500ZI	+	-	-	2.87%
1251524	TSO-6M3-600ZI	+	-	-	11.19%
1252262	TSO-256-437ZI	+	-	-	2.52%
					10.14%

Table A2: Run 2 Experiment

Carbide form tool Carbide Drill “A” Tap

Mean Negative Process Yield = 8.29%

WO #	Part #	A	B	C	Y
1296939	TSO-632-375ZI	+	+	-	3.27%
1293028	TSO-256-312ZI	+	+	-	4.88%
1287573	TSO-632-312ZI	+	+	-	8.80%
1298433	TSO-6440-187ZI	+	+	-	26.18%
1313067	TSO-632-250ZI	+	+	-	3.16%
1313822	TSO-632-375ZI	+	+	-	3.45%
					8.29%

Table A3: Run 3 Experiment

HSS form tool HSS Drill “B” Tap

Mean Negative Process Yield = 14.32%

WO #	Part #	A	B	C	Y
1105214	TSO-6440-187ZI	-	-	+	17.24%
1110569	TSO-632-250ZI	-	-	+	15.58%
1110572	TSO-632-250ZI	-	-	+	14.78%
1110573	TSO-632-250ZI	-	-	+	14.07%
1137957	TSO-632-250ZI	-	-	+	13.84%
1129208	TSO-632-312ZI	-	-	+	10.38%
					14.32%

Table A4: Run 4 Experiment

HSS form tool HSS Drill “A” Tap

Mean Negative Process Yield = 15.39%

WO #	Part #	A	B	C	Y
1071393	TSO-632-312ZI	-	-	-	9.57%
1070256	TSO-6M3-400ZI	-	-	-	28.02%
1085852	TSO-632-500ZI	-	-	-	20.37%
1085853	TSO-632-375ZI	-	-	-	6.33%
1090010	TSO-6M3-600ZI	-	-	-	17.95%
1101024	TSO-6440-375ZI	-	-	-	10.08%
					15.39%

Table A5: Run 5 Experiment

HSS form tool Carbide Drill “B” Tap

Mean Negative Process Yield = 10.16%

WO #	Part #	A	B	C	Y
1135179	TSO-632-437ZI	-	+	+	18.13%
1148396	TSO-6M25-1000ZI	-	+	+	1.60%
1187296	TSO-6M3-600ZI	-	+	+	5.89%
1196908	TSO-6M3-600ZI	-	+	+	6.84%
1198673	TSO-6M3-600ZI	-	+	+	12.67%
1218956	TSO-6M3-600ZI	-	+	+	15.83%
					10.16%

Table A6: Run 6 Experiment

Carbide form tool HSS Drill "B" Tap

Mean Negative Process Yield = 9.35%

WO #	Part #	A	B	C	Y
1296062	TSO-632-375ZI	+	-	+	11.45%
1297668	TSO-M3-1200ZI	+	-	+	2.86%
1272759	TSO-440-250ZI	+	-	+	7.16%
1298322	TSO-256-187ZI	+	-	+	18.11%
1302668	TSO-632-187ZI	+	-	+	9.46%
1300966	TSO-M2-1200ZI	+	-	+	7.06%
					9.35%

Table A7: Run 7 Experiment

HSS form tool Carbide Drill "A" Tap

Mean Negative Process Yield = 12.50%

WO #	Part #	A	B	C	Y
1137200	TSO-632-312ZI	-	+	-	17.15%
1144683	TSO-632-375ZI	-	+	-	12.03%
1157627	TSO-6440-187ZI	-	+	-	10.40%
1161627	TSO-632-500ZI	-	+	-	10.24%
1191800	TSO-6M3-600ZI	-	+	-	10.32%
1191801	TSO-6M3-600ZI	-	+	-	14.85%
					12.50%

Table A8: Run 8 Experiment

Carbide form tool Carbide Drill “B” Tap

Mean Negative Process Yield 7.78%

WO #	Part #	A	B	C	Y
1313068	TSO-632-250ZI	+	+	+	11.07%
1313977	TSO-M3-400ZI	+	+	+	15.50%
1316981	TSO-256-187ZI	+	+	+	6.35%
1305352	TSO-832-125ZI	+	+	+	1.62%
1307030	YTSO-45285-ZI	+	+	+	8.40%
1316982	TSO-256-187ZI	+	+	+	3.75%
					7.78%

APENDIX B: VARIOUS FIGURES ASSOCIATED WITH THE EXPERIMENT

Figure B1: Multi-Spindle Screw Machine

Figure B2: Fasteners being sorted due to a defect found during machining.

Figure B3: Circular High Speed Steel Form Tool

Figure B4: Carbide insert Form Tool

Figure B5: “B” Brand of Tap

Figure B6: Bundles of steel rod material.

Figure B7: Carbide material drills

Figure B8: High Speed Steel drills

Figure B9: Carburizing Heat Treat Furnace

Figure B10: Chip Removal Equipment.

Figure B11: Automatic Parts Washing Equipment

Figure B12: Automatic Video Sorting Equipment.