Walden University

COLLEGE OF MANAGEMENT AND TECHNOLOGY

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Antonio DePaolo

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Abstract

Implementing Work Practices and a Training Protocol in a

High-Technology Manufacturing Environment

by

Antonio DePaolo

M'Eng., University at Buffalo, 1998

BSIE, University at Buffalo, 1997

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Applied Management and Decision Sciences

Walden University

December 2012

Abstract

Many companies strive to improve performance but are unable to quantify the impact of training on performance. The purpose of this quantitative study was to determine the gains in performance achieved by implementing standard work practices and a specialized training plan in an environment where quality is critical. To achieve this purpose, an experiment was performed where training treatments were applied over 3 time intervals to the exact same group of workers. The dependent variables of quality and productivity were measured before the first training and following each training treatment. The theoretical framework of this research was based on the principles of scientific management which link methods improvements, formal industrial training, and change management to influence worker behavior. The research question addressed whether the 3 trainings affected quality and productivity scores. The 3 trainings represented the multilevel independent variable; performance scores were conceptualized in the areas of foreign material contamination, product handling practices, and equipment readiness. A repeated measures MANOVA was used to determine whether the group of workers (N = 108) improved over time following each training. From the results, which showed significant improvement in quality scores and insignificant gain in productivity scores, one can determine the return on investment of utilizing a repeated training design. The positive social change implications of this research are to provide quantifiable benefits of training to improve employee readiness and reduce cost in a manufacturing firm, which will lead towards improved job stability within the local community.

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Dedication

For my wife Tabitha, I thank you for your love, support, and encouragement which has helped me stay on the path of completing this major milestone in my life. For my children Amelia, Gabriella, and Antonio Jr., may you see this work as proof that you can come from humble beginnings and achieve great goals by staying focused, striving for excellence, and never giving up. All of you provide a solid foundation in my life built on unconditional love, uncompromised faith, and family. Thus, I dedicate this work to you.

Acknowledgments

This study is a culmination of work over the past fifteen years of my life in the field of continuous improvement. Many of my professional peers, both past and present, have guided my learning along the way and had led me to this dissertation. I truly stand on a foundation built by others and hope this work adequately reflects their contributions to my learning.

I owe my wife, Tabitha a debt of gratitude for her continual and unrelenting support, and her help in editing my work. I would like to thank Dr. Christos Makrigeorgis for chairing my committee and providing a solid foundation for scholarly learning and inquiry. His guidance over the last four years has shaped the way I objectively approach research. I would like to thank Dr. Jeffrey Prinster for sitting on my committee and adding value to my work. I would also like to thank Dr. Walter McCollum as the URR on my committee for helping me understand and exceed Walden requirements as a scholar practitioner.

Finally, I would also like to thank Walden University and its staff for providing an advanced degree program that intermingles philosophical reasoning with real world application and social responsibility. The impact of Walden's program, both professionally and personally, is the cornerstone for the next phase of my life.

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Chapter 1: Introduction to the Study

Introduction

On a high-technology manufacturing line, the measurements of product quality include process yield, productivity, on-time delivery, and warranty expense. The quality metrics are, in turn, affected by a number of factors, such as product processing errors, material quality, equipment quality, and the work environment (Crosby, 2008; Graupp & Wrona, 2011). The management and control of these factors aims at reducing variability in the quality of the manufactured product, which in turn improves the process quality outputs. One set of variability factors that has yet to receive research attention are work practices aimed at controlling the introduction of foreign material, improving product handling, and preventing equipment malfunctions.

In order to identify the work practices stated above, I consulted with subject matter experts, B. Vanbrunt and D. Jurena (personal communication, June 14, 2011), at a high-technology manufacturing company. These three work practices are key to improving the quality at the high-technology manufacturer used for the study. In this study, I contend that these three work practices can be influenced using targeted, advanced training to control foreign material introductions, improve product handling, and prevent equipment malfunction.

Thus, the purpose of this quantitative research was to use a repeated measures MANOVA to study the statistical significance of these three treatments on two group outputs, productivity and quality. A repeated measures MANOVA is well suited for this problem because of its ability to consider the three training treatments administered over time to the same group of subjects and because of its ability to consider multiple outputs.

The study is significant because understanding which of the three work practices is most and least significant to improving product quality is important because it allows money to be spent where it has the most impact. Second, improving product quality leads to improved profitability and improving profitability improves company stability in a competitive market.

Background of the Study

The focus of the study was to address the need to implement specific standard work practices and an improved training protocol to improve employee performance in a high-technology manufacturing environment. Improving the way people are trained is a significant applied business problem because (a) variation in work practices leads to errors and costs the company money, (b) too many mistakes can cost workers their jobs, and (c) making scrap in a process with long lead times causes extensive inefficiency within the production environment. Improved work practices and behaviors on the job provide the manufacturer with higher product quality, thus improving on-time delivery and customer satisfaction, and reducing business costs by reducing scrap and rework. Further, without standardized work practices, workers stay in a reactionary mode, constantly working to repair mistakes instead of operating in a prevention mode where there is room to concentrate on process improvement.

To understand the problem, I reviewed the literature across the fields of scientific management, industrial training, behavior modification, and quality management. Each field paid secondary attention to the combining of both training and methods improvement into one cohesive methodology. Thus, this study adds to the existing literature by addressing the need for both continual improvement in operational performance and improved training practices. Older research studies, such as Allen (1919), centered on a training protocol and a standard method but did not consider ongoing methods improvement as a natural part of the training protocol. Similarly, Taylor (1911) answered the methods questions with scientific management but did so from a top-down management perspective and thus caused disruption in the work environment. Gilbreth (1909) suggested the need for developing improved work practices (from a worker's perspective) but lacked the training aspect to sustain the improvements made to the workplace. From these early works, the United States government established a training program during the 1940's designed to provide industry leaders with a methodology for ensuring productivity and quality when training new and inexperienced manufacturing employees. However, the goal was to shorten the learning curve of new employees rather than focusing on improving well established processes. Throughout the last fifty years various aspects of standard work have been implemented across several industries. Much more recently, Graupp and Wrona (2006) revived the Unites States government training program for improving work practices through training. However, recent research on this subject suggests that standard work practices and training are one-time events and there is not a strong enough perspective on continuous improvement.

In addition to discussing industrial training and the principles of scientific management, this study covers performance improvement, which is significant for both the worker and the manufacturer. According to Amigo (2008), Bentley (2004), Collins (2002), Cooper (2005), Crosby (2008), Kimura (2009), and Park (2004), the primary behavioral inputs of worker performance in a workplace setting are values, communication, and collaboration. Each of these inputs is a necessary part of improvement and provides structure to the treatments within the experiment. Also, these inputs are necessary when implementing standard work practices in the workplace.

Several companies, including Toyota, Bell, IBM, and Ford, have implemented standard work practices to reduce product variation and improve product quality. However, as the manufacturing base for standard products continues to decline in the United States, many U.S. based companies are switching their business models to focus on custom high-technology product offerings that are difficult to manufacture. There is little understanding of how well these techniques work in a custom, high-technology manufacturing environment. This research used an experimental design by administering a series of treatments to the workers to determine if focusing on standard work practices and improving training protocol would improve performance in a high-model mix, low-volume workplace. More specifically, the experiment highlighted which of the three treatments was most critical to ensuring that the company achieves productivity and process yield targets. Knowing how standard practices and proper training influences worker performance, I hope to publish a related work that provide today's highly complex manufacturers with a new avenue for workplace improvement.

Problem Statement

There is an ongoing need to improve work practices and training protocols to meet or exceed customer requirements. Myer (2003) wrote that understanding customer needs and then transforming those needs into action is essential for creating value for the customer. Based on my experience in several different industries, the common expectations among customers include on-time delivery with good product quality at a reasonable cost. In those companies where I have worked, management teams dealt with variation in on-time delivery by working overtime, weekends, and holidays. They used an all hands approach to achieve the revenue targets. When dealing with variations in quality, they conducted reviews and issued corrective actions. Companies also conducted budget reviews, questioned variances on the financial report, and enacted cost-cutting measures. However, all of this nonvalue-added work did not address the fundamental need to continually improve goods and services from the operator-process point of interaction. Rather than cutting training expenses, there is a need to explore how to make training more effective. Further, when addressing problems, the corrective actions only address the symptoms of the work and not the work practices themselves. Thus, improving work practices through focusing on how operators interact with processes is an essential activity in the workplace on an ongoing basis.

The goal of this research was to understand the statistical significance of contamination control, material handling practices, and equipment malfunction prevention on the quality measures of process yield and productivity. This was done using repeated measures MANOVA.

Purpose of the Study

The purpose of this study was to quantitatively determine if performance can be improved by using a robust training plan to improve work practices. The training plan consisted of three trainings predefined by subject matter experts. The three trainings are entitled contamination control, material handling practices, and equipment malfunction prevention.

In repeated measures MANOVA language, each of the three trainings occurs at specific points in time and represents the three levels of the independent variable. That is, this research administered three levels of the independent variable, called *training type*, at three distinct points in time. Level 1 was the training administered at time t_1 and designed to minimize the introduction of foreign material by an employee. The first training trained the employee to follow the required procedures and ensure no foreign materials entered the clean room area and into the product. Level 2 was the training administered at time t_2 and designed to minimize poor quality due to improper product handling. The second training trained the employee to follow the specified handling procedures. Level 3 was the training administered at time t_3 and designed to minimize poor quality from equipment malfunction. The third training trained the employee how validate equipment readiness before production runs. The researcher tracked the participant participation of each of the three levels of categorical data before and after each treatment on a *yes* or *no* basis.

Dunn and Clark (1987) referred to the independent variable (the repeated factor) as a *within-subjects factor*, because the independent variable makes comparisons *within* a subject rather than across (between) groups of subjects. Thus, the specific MANOVA used was a within-subjects factor repeated measures MANOVA.

There are two dependent variables in this study: process yield and productivity. The definition of process yield is a ratio of the number of good units produced divided by the total units produced. For example, in a work cell producing 100 units, if 20 are defective, then the process yield is 80%. I used the prior 12 weeks of data to determine the baseline and then measured the quality ratio after each successive treatment. The process yield was a percent, thus, it could be any value from 0 to 100. The subject matter experts listed above deemed each treatment level of the independent variable as critical influencers of the dependent variables.

Productivity is a ratio of the number of units produced divided by the total number of labor hours to produce them. For example, a work cell with 5 people working 7.2 hours a shift making 100 units per shift equals 2.77 units per labor hour. I used the prior 12 weeks of data to determine the baseline and then measured the productivity after each training. The productivity number is a continuous value equal to or greater than zero.

In summary, each treatment of the independent variable provided a balanced representation of the workplace under study. I obtained a baseline measurement denoted as t_0 for each of the variables before the experiment begins. Once I established the baseline, I introduced three separate treatments to the workforce that addresses the three major quality issues in the workplace. Post treatment observations then took place to determine the effects of each intervention. This study utilizes a repeated measures MANOVA statistical technique to determine the relationship between improving work practices to worker performance. To achieve a 95% confidence level, the sample size for this study was a minimum of 86 people.

I hypothesized that each of the levels of the independent variable would have an effect on the dependent variables. By using a repeated measures MANOVA design, the research was expected to point to the relative strength of each level on the two dependent variables. Further information on repeated measures MANOVA is given in Chapter 2.

According to Singleton and Straits (2005), a pretest-posttest within-group design was the method of choice for this issue because it was a true experimental design that accounted for improvement over time. This design measured the group before and after the treatment to determine its impact on performance. The participants in this study were shop-floor workers in a high-technology manufacturing environment. A panel of subject matter experts in the same company predefined the treatments as foreign material control, product handling, and equipment malfunction prevention. The dependent variables were measures of quality and productivity. Archival data for both quality and productivity provided the baseline for this study. Each of the three treatments of the independent variable predicted the total effect on each of the two dependent variables.

One of the most important social change topics in the United States today is sustainable employment (Bernstein & Lazonick, 2011). Sustainable employment provides for the basic needs of a worker's family. Thus, altering work practices to improve performance directly reduces costs to the business and thus enables sustainable employment. There is equal benefit from learning how improving work practices leads to sustained change within an organization. This study validated the need to standardize and improve work practices, regardless of size or product produced.

Nature of the Study

This study used a repeated measures design where the same measures were collected several times for each subject after each treatment was administered. A MANOVA technique was used to determine the main effects of the independent variable (*IV*) treatment, the interaction among each training type, the importance of each dependent variable, and the relative strength of association.

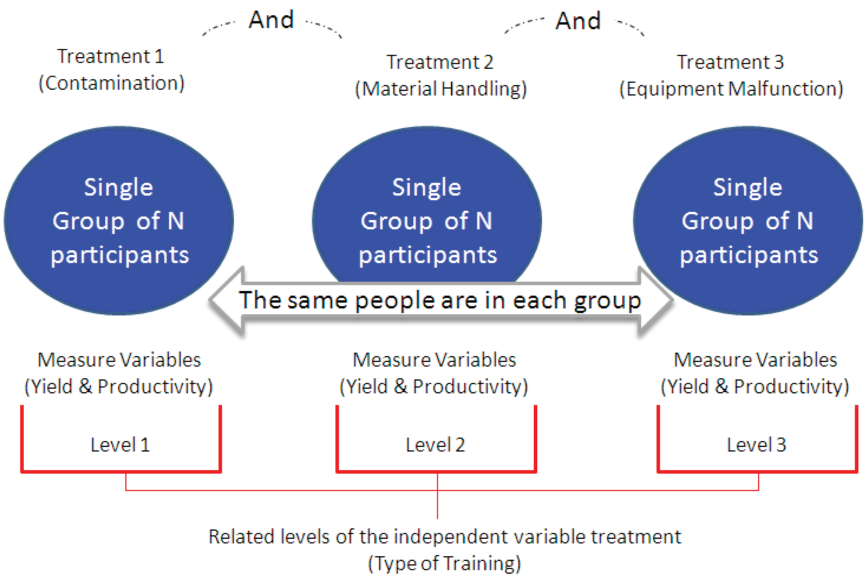


Figure 1. Schematic of the within-subjects factor repeated measures MANOVA.

Figure 1 shows an experimental design in which a series of work practices and training treatments is given to a group of workers. The experiment provided treatments to one group of at least 86 workers to be 95% confident that the sample properly represents the population. The first treatment involved training on contamination control in the work environment. The second treatment involved proper material handling techniques to protect the product. The third treatment involved training on equipment maintenance at the operator level. I took a baseline measurement prior to the first treatment to document the key process indicators of productivity and quality. Further, I took a posttest measurement after each treatment to determine which work practices and training methods improved the outputs of quality and productivity.

Regression analysis was not the chosen method because it would require multiple regression analyses to handle two dependent variables. Correlation analysis was not chosen because it is primarily a technique to determine the correlation between two variables. With multiple independent and dependent variables, this approach would also require several dozen runs to capture all of the combinations. Factor analysis was not chosen because it looks for and synthesizes variables in a way to determine the significant few factors that describe a single output (Brown, 2006). Further, according to Brown (2004), a factor analysis experimental design requires different groups each of which is given the same or different treatments to help determine significance. However, the regulated workplace in which this experiment took place required the entire group to be trained on the same procedures. Thus, factor analysis would prove cumbersome and cause a significant delay. An ANOVA is a univariate analysis of variance often used in experimental designs to study the effects on one dependent variable (Dunn & Clark, 1987). According to Dunn and Clark (1987), this approach can also encompass two-factor or multifactor designs to determine the effect on a single output variable. However, an ANOVA does not account for multiple output variables. Because of its ability to meet all of the study's requirements and characteristics, I chose MANOVA, which provides the ability to handle multiple outcomes (Weerahandi, 2004). I administered a series of three trainings to give depth to the study and to ascertain the impact of each treatment on a single group.

Research Questions and Hypotheses

A simple MANOVA has three sources of variance: between groups, error/residual (which includes the within-groups variance), and total. A repeated measures MANOVA adds another source of variance: between measures (i.e., treatments). The ability to identify the between-measures variation (i.e. treatments) led to the choice of the repeated measures MANOVA technique and was the key to the research questions (RQ's):

RQ1: What impact, if any, do the three training treatments have on the two outcomes (Q = Quality and P = Performance)?

RQ2: Which training has the biggest impact on the two outcomes?

RQ3: Which outcome is affected the most by which training?

The first RQ (RQ1) can be operationalized into two distinct within-subjects factors Repeated Measures MANOVA hypotheses (H):

H01Q: The means of the quality metric for the three repeated measures are the same.

H01P: The means of the productivity metric for the three repeated measures are the same.

RQ2 and RQ3 require post-hoc analysis, specifically, the application of the Scheffe interval and Tukey HSD post-hoc statistical tests. They can be used to identify which measures (which of the three training regiments) differ from one another in terms of quality and/or performance. These tests are performed only after the MANOVA F-test indicates that significant differences do exist among the measures (the training regimens) and thus are only examined if both H01Q and H01P are rejected. I discuss the specifics in Chapter 3.

Theoretical Base

This research synthesized studies in industrial training, scientific management, change management, and quality management to develop an alternative method to improvement. Allen (1919), Gilbreth (1909), Taylor (1911) and Graupp & Wrona (2011) provided for the evolution of industrial training and methods improvements within a manufacturing setting. They provided the base for this study.

There is a vast amount of published work that discussed the theories of scientific management, industrial training, and how change management can alter worker behaviors. However, these studies are decoupled from quantifying the effect of training on productivity and quality, which are the two critical metrics in a high complexity, low volume environment. Thus, to the best of this author's knowledge, there is no experimental blueprint for this study. A consideration was given to applying the Theory of Constraints to identify the weakest link in improving quality and performance, however in an environment characterized by high complexity and low volumes, people readiness is the key to improved outcomes. The author's prior experience to identify bottlenecks and implement kaizen events has yielded little quantifiable benefits to quality while this training regiment has been largely unexplored.

Given the aforementioned high level discussion, the research underpinnings were focused on industrial training and improvement. Specifically, in order to understand how change management factors into the experiment, the works of Park et al. (2004), Kimura et al. (2009), and Amigo et al. (2008) provided a general understanding of both productive and counterproductive behavioral characteristics within the workplace. Next, successful change requires a transition to take place from the old method to the new. Kegan (1982) and Bridges (2003) explored the transition dynamic that must take place for a change to sustain itself. Further, the work of Skinner (1953) provided a high level discussion on behavior and how to modify during a treatment. Thus, each work pointed to the need to perform the proper experimental setup to demonstrate improved quality and performance over the three treatments thus providing a legitimate avenue for further quality improvement. Doing so validates from an empirical point of view, the works of the aforementioned authors.

In addition, this study incorporated the works of Deming (2000) and Juran (1970) with a focus on quality in the workplace. Deming's (2000) fourteen points highlight how to develop a system focused on variation reduction in the workplace. Several of these points discussed the behavioral attributes as necessary to employ a sense of ownership, and accountability in the workplace. Juran (1970) took Deming's work a step further and concentrated his efforts on linking the staff employee with management. Thus, Deming (2000), Juran (1970), and He (2008) provided both a behavioral and a variation reduction aspect to industrial training. In summary, this research targets industrial training, methods improvement, change management, quality management, and continual improvement.

Definition of Terms

ANOVA: A statistical technique used to compare two or more group sample means to see it there are any reliable differences among them (Carey, 1998, p. 1).

Antecedents: Inputs already in place to adequately assess the risk of performance issues before the target behavior occurs (Kearney, 2008, p. 31).

At Risk Behavior: Also known as maladaptive behavior, at risk behavior is considered outside the normal operating parameters of the environment (Kearney, 2008, p. 28).

Behavior: Any observable and measureable act of an organism due to a combination of physiological, environmental, or inheritance factors (Kearney, 2008, p. 23).

Behavior analysis: A scientific observational approach to changing behaviors that are more useful to the social environment (Kearney, 2008, p. 19).

Common cause variation: In reference to a stable system, the variation exhibited by a process during normal operating conditions (Deming, 2000, p. 310).

Consequences: The positive or negative effect of a behavior within the environment (Kearney, 2008, p. 36).

Customer focus: The satisfactory fulfillment of fulfilling requirements and adding value for the consumer of goods (Deming, 2000 p.141).

Human motivation: The driving force of people linked to character formation and the satisfaction of needs (Maslow, 1954, p. 36).

MANOVA: A generalization of ANOVA to a situation in which there are several dependent variables (Carey, 1998, p. 1).

Productivity: A measure of the efficiency of a person, machine, factory, system, etc., in converting inputs into useful outputs. Productivity is computed by dividing average output per period by the total costs incurred or resources (capital, energy, material, personnel) consumed in that period. Productivity is a critical determinant of cost efficiency (www.businessdictionary.com).

Process yield: A ratio of the number of good units produced divide by the total number of units produced. Process yield is segment of a larger metric known as rolled throughput yield (Brue, 2006, p. 55).

Special cause variation: In reference to an unstable system, the variation exhibited by a process outside the normal operating parameters (Deming, 2000, p. 310).

Total quality management: A combination of a number of organizational improvement techniques and approaches including the use of quality circles, statistical quality control, statistical process control, self managed teams, and employee participation and empowerment (Myers, 2003, p. 7).

Values: Important and enduring beliefs or ideals shared by the members of a culture about what is good or desirable and what is not. Values exert a major influence on the behavior of an individual and serve as broad guidelines in all situations. (htt[://businessdictionary.com).

Assumptions, Limitations, and Scope and Delimitations

Assumptions

1. The archived data for process yield and productivity are correct.

2. The senior leadership team provides a supporting environment for implementing standard work practices and training method improvements in the workplace.
3. Workers know and adhere to the values of the organization—the foundation of their workplace behavior.
4. Supervisors communicate in a professional manner, without assigning blame, in order to focus on workers as part of the operating system.
5. Supervisors deal with maladaptive behaviors through normal Human Resource policies and procedures and any disciplinary actions are assumed to have no impact on the outcomes of this study.

The assumption is that supervisors will continue to focus on the worker as part of the ongoing operating system to ensure sustained improvement. As with any company, the workforce is dynamic and thus new or transferring employees may eventually work in the area of focus which could lead to reintroducing old or unwanted work practices. I assumed that all new and transferring employees receive adequate training to adjust to the work environment. Further, I assumed that once the standard practices are established, the trainers working in the area supply adequate reinforcement on the proper operating conditions and that management support their efforts to sustain the improvement.

Limitations

1. The ability to generalize the data outside the scope of a customized high-technology manufacturer was a limitation of this study. While it is noted that

standard work practices can be utilized in any company for any process, this study was limited to one company in the high-technology electronics field.

2. Model mix, volumes, the movement of resources and so forth added to the complexity of this study because conducting a repeated measures study requires a level or steady state to determine if my research had an impact in outcomes. I discuss these limitations as part of the discussion section.
3. The measurement system worked to correlate the improvement in work practices to performance improvement. The confounding effects of performance improvement based on focus and awareness placed on a specific area could provide a Hawthorne effect (Vandersluis, 2005). Thus, further discussion is required to determine the long-term applicability of using standard work practices approach to modify worker behavior in a manufacturing setting.
4. Ongoing leadership is a potential weakness. The literature suggested that the proper leadership needed to be in place to ensure effective change in performance (Kotter, 1996). Also, combined with leadership, the relative position of the person performing the intervention is important (Fiedler, 1967). Thus, an effort was made to ensure that the leadership and position of power did not affect the output by maintaining the leader assignments during the study.

Scope and Delimitations

The bounds of this study provide a range of coverage, both positive (what's included) and negative (what's excluded), and include:

1. The processes that supply the area of study are considered out of scope.
2. Machine capability outside the operators control was not considered as part of this study. This study primarily addressed operator-influenced errors and not causes due to machine capability.
3. The entire population in the area of study made up the sample. Each person working in the process received the training to determine the effects of the independent variables on the dependent variables.
4. Worker satisfaction and worker fatigue surveys were not studied even though the research suggested that improvements made by implementing standard work practices and training may impact such survey scores. The reason for excluding satisfaction and fatigue surveys was due to the time and resources allowed within the manufacturer for this study.
5. Changes in model mix and demand patterns were normalized to ensure the metrics of quality and productivity did not skew the results. Product quality is a ratio of good pieces over the total pieces produced. Likewise, productivity is a ratio of the number of units per labor hour. I normalized the metrics to work load and model mix on an ongoing basis.

6. The temperature and humidity are controlled within the factory. Thus, there were no known noise effects in the study. All other environmental factors were considered.
7. The study took place over several weeks. Thus, any disruption or work stoppage due to missing parts or other factors not influenced by the operator were considered out of scope and irrelevant to this study.

Significance of the Study

The significance of the study is articulated in terms of its attempt to reduce known research gaps, its application to professional practice and its overall implications to social change and specifically its business value proposition. This section will highlight the gaps within the existing body of knowledge to show how the research problem was motivated and developed. Exploring the gaps through application in a real work setting will help to ascertain the effectiveness of the study and provide insight into the challenges of applying the approach. The social implications provide a link to how the research will further help shape the work environment in the future.

Reduction of Gaps

This study adds to the existing body of literature by applying the principles of industrial training, scientific management, change management and quality management to improve worker performance in the workplace. The existing literature focuses on improving instructional process and has assumed that human beings can do their jobs without requiring the treatments discussed above. This study is important because workers need continuous training and my study provides a quantitative way to address continuous training on work practices and behavior in the workplace. Its effect is to improve performance in order to improve operating costs.

The outcome further provide a methodology to utilize when addressing improvement in the workplace, provide insight into the applicability of using standard work practices in a high-technology manufacturing environment, and provide an improved approach to variation reduction related to operator influenced errors. The metrics are process yield to determine quality performance, and productivity to determine the efficiency. Each metric provided a balanced view into the overall affectivity of the workplace. Additionally, each metric provided an indication if focusing on standardized work practices to improve quality performance was effective.

Professional Application

The literature noted the application of standard work practices and methods training in many manufacturing environments except for custom products. However, when operating in a highly custom niche market with low volumes, there is no known literature on the applicability of utilizing standard work practices. Many subject matter experts in the high-technology manufacturing industry suggested that the results would be minimal at best because more complicated problems arise in today's high-technology manufacturing environment. Thus, my study contributes to the body of knowledge by providing standard practices research in a customized shop.

There is a wide use of variation reduction initiatives in the workplace. However, improvement efforts seem to be short term and hard to sustain. When making incremental improvements to the current culture of the workplace, the workplace has a tendency to slip back to the culture from where it came. The training approach used by this study was intended to create a permanent shift in worker practices and behavior and thus yield longer-term improvement.

Implications for Social Change

The implications for social change are based on job stability within the local community through cost reduction efforts in manufacturing. The manufacturing industrial sector in the United States has experienced a push to move high volume standard products to lower cost nations to improve corporate margins. The high-technology manufacturer is also experiencing a push to find lower cost manufacturing alternatives. The effect of these outsourcing decisions on individual communities affects workers who struggle to learn a new trade while maintaining a higher standard of living for their families. If costs are kept down, the need for outsourcing is reduced, jobs stay in the community, and greater economic stability is achieved.

Summary and Transition

Chapter 1 provided an overview of the study that emphasizes the use of standard work practices and improved training protocol to improve worker performance within the workplace. Worker competency is not enough to ensure customer satisfaction. Work practices that modify workers actions are the core elements of improving customer focus within a manufacturing setting. Thus, there was a need to research worker training and change management within the workplace.

The literature reviewed suggested that standard work practices have primarily been geared towards education and training, nursing, and other service oriented industries where the customer and supplier are interacting. The literature further suggested that manufacturing leaders have incorporated standard work practices into companies producing standard products. However, there is a gap in the literature on standard work for custom products. Further, there is a need to determine which standard work practices would have the biggest impact on product quality. The result would determine whether standard work practices help to improve key performance indicators in a highly customized low-volume workplace.

In Chapter 2, the literature provides a theoretical foundation of scientific management. The review continues with the principles of standard work, and methods improvements. I then discuss industrial training and the adult learner to provide an approach to the research. Change management from a worker behavior perspective is discussed next to ensure the treatments in the study to effectively handle the change process. A discussion of quality management and the principles of variation reduction provide the research with a focus to address the problem. A review of MANOVA provides an in-depth understanding of its use in experimental research. Finally, Chapter 3 will discuss the methodology to complete the research while Chapter 4 displays the data and results of the research and Chapter 5 synthesizes and summarizes the results.

Chapter 2: Literature Review

Introduction

The purpose of this quantitative study was to see whether gains in performance were achieved by implementing standard work practices and a specialized training plan in an environment where quality is critical. The purpose of Chapter 2 is to provide a review of the known literature on the topic of improving work practices through improvements in training. Chapter 2 is organized by four themes: (a) scientific management and methods improvement, (b) industrial training and adult learning, (c) change management and behavioral characteristics, and (d) MANOVA.

The first theme includes Taylor's (1911) principles of scientific management, followed by a more detailed discussion of Gilbreth's methods improvement (1909). To link methods improvement as a basic component of training in an organization, Deming (2000) and Juran (1970) are used to provide key insights into the management of work as well as the need to focus on the behavior of workers.

To gain insight into a proven industrial training technique, the second theme includes an exploration of Allen's (1919) work on industrial training. A brief review of Knowles' (1984) work on andragogy was used to ensure that the experimental design accounts for the adult learner. To provide a basis for this experiment in the workplace, more recent works on industrial training will then be discussed.

The third theme includes a look at change management and the behavioral characteristics of people to ensure that the methodology accounts for shifting worker behavior. Thus, the transition from one stage to the next is discussed, based on the work of Kotter (1996) and Kegan (1982). Further, based on the work of Park et al. (2004), Kimura et al. (2009), and Amigo et al. (2008), a general understanding of both productive and counterproductive behavioral characteristics will ensure that the treatments in the experiment were set up properly to maximize the effectiveness of the training.

The fourth theme includes a discussion of the use of repeated measures MANOVA to provide statistical evidence of the connection between (a) work practices and behavior and (b) employee performance. A high-level overview of the statistical technique will be covered below. A review of specific research where MANOVA has been applied will highlight both the strengths and weaknesses of the approach. Finally, because a time series of treatments will be used to account for continual improvement, a brief explanation of the repeated measures MANOVA design will be discussed.

Literature Review Strategy

In compiling the data for the literature review published primarily in the past 5 years, the following databases were used: Academic Search Complete, Business Source, ProQuest Central, ProQuest Dissertations & Theses Database, and SAGE. The following search terms were used: *industrial training, quality control, change management, scientific management, multilevel modeling, hierarchical linear modeling, growth modeling, student achievement, student success, testing, standardized testing, assessment, school accountability, teacher accountability, No Child Left Behind (NCLB), measurement, validity, power, sample size* and *MANOVA*.

Three approaches were used in the search. First, a keyword search was conducted. Second, the reference lists of the selected articles were reviewed for additional articles. Third, a review of article references was completed to determine if there were other recent works that lend insight to my study.

Theoretical Foundation

There is a vast amount of published work that discusses scientific management, industrial training, quality control, and how change management can alter worker behaviors. However, these studies are decoupled from quantifying the effect of training on productivity and quality, which are the two critical metrics in a high complexity, low volume environment. Thus, to the best of this author's knowledge, there is no experimental blueprint for this study.

To construct the model for this study, I pieced together the concepts of scientific management, methods improvement, and industrial training into a cohesive framework. From this point, the theoretical foundation was used to explore the concepts of change management and worker behavior to ensure the critical variable of human behavior was understood before developing the experimental design. Finally, I provide a brief summary for the use of repeated measures MANOVA as the statistical technique of choice in this experiment.

Scientific Management and Methods Improvement

According to Taylor (1911), the objective of management is to maximize the prosperity for both the employee and the employer. He wrote, "Maximum prosperity can exist only as a result of maximum productivity" (p. 2). One of the tenets of Taylor was to ensure maximum prosperity, a high degree of quality and a high degree of productivity was necessary. In this study, I used metrics for quality and productivity as the dependent variables in alignment with Taylor's work. He expanded his earlier concepts of one time improvements to focus on maximizing output through continual improvements. Using a scientific approach, Taylor broke down the process into its simplest components and worked to remove the waste from the individual steps. However, companies that implemented Taylor's ideas without including the shop floor worker in the process of developing changes often enflamed resentment and alienated the worker. His work suggested there is a need for a collaborative approach to achieve maximum prosperity.

Another pioneering approach to methods improvements came from Gilbreth (1909). When working as a layman bricklayer, Gilbreth noticed three distinct bricklaying methods: the normal method, the method used to hurry up to finish a job on time, and the method used to slow down to take up any idle time in the day. As a worker, Gilbreth used this insight of working the job to develop the best way to lay bricks. Further, Gilbreth realized that collaborating with his fellow peers to develop the best way was the correct approach to making changes on work methods. He did not just find the best method, but he developed a proven technique that was superior in terms of quality, cost, and timely completion for the customer. He set out to acquire his own bricklaying work and was able to compete effectively with other brick laying providers because of the methods used. After spending time with Taylor (1911), Gilbreth established that the people in the process must be a part of creating new methods. More recent researchers (Bridges, 2003; Graupp & Wrona, 2006; Kotter, 1996; Kouzes & Posner, 2003) also suggested that engaging the employees before, during, and after the training treatments was necessary for the successful transition of the worker from the old method to the new method.

Quality management. Deming (2000) expanded the work of Taylor (1911) and Gilbreth (1909) to develop a quality approach to business. Deming developed 14 points of management, shown in Table 1 below, that demonstrate the need to reduce variation in a process. Deming (2000) suggested that there is a need for leadership. Deming further suggested the need to replace the firefighting that is normal and typical in the work environment with a long term improvement strategy. Part of this point was about creating a vision for all to strive for in their daily work. In my study, the vision must be communicated before the treatment begins to ensure the workers know why there was a need for change.

In his second point, Deming discussed a new way to manage or lead workers. Deming suggested managers must learn to think differently to make room for a new way. In many instances, management is the problem when it comes to improvement. I have experienced that a workforce is willing to find new ways, but leaders sometimes fail to recognize they are not willing partners in the need for improvement. Ng et al. (2010) validated the need for leadership as the main driver of workplace culture and environment thus allowing the workforce to achieve effective performance. Further, both Raja et.al (2011) and Hill et. al (2008) found that top management commitment is the most important variable when implementing quality management. While it is outside the scope of this study, the management team in the area of the study received communication on the need for commitment to the new training protocol.

Table 1

Deming's 14 Points

	Deming's 14 Points
Point 1	Create a contancy of purpose
Point 2	Adopt a new philosophy
Point 3	Cease dependence on inspection
Point 4	Do not award business based on price tag alone
Point 5	Improve constantly the system of production and service
Point 6	Institue training
Point 7	Adopt and institute leadership
Point 8	Drive out fear
Point 9	Break barriers among staff areas
Point 10	Eliminate slogans, exhortations, and targets
Point 11	Eliminate numerical quotas
Point 12	Remove barriers
Point 13	Institute a program of education and self improvement
Point 14	Take action to accomplish the transformation

Note. From "Out of The Crisis," by W.E. Deming, 2000, p. 248-275.
http://lii.net/deming.html.

The points 4, 5, and 6 address variation reduction, another theme in Deming's (2000) work. However, in Point 6, Deming specifically discussed the need for adequate training to ensure all workers are doing the job in the same sequence as a way to reduce variation. Reducing training through variation reduction and developing a single best method was a central theme of this experiment. Points 4 thru 6 were validated by Ubani (2011) whose work determined the need for employee training as a central tenet of quality management. I hypothesize that I will validate Ubani's argument that the current training method is inadequate for the workplace and the reason for poor performance is related to inadequate training.

Continual improvement is a third theme within Deming's (2000) work. Deming believed that companies need to maintain a forward motion and continually reduce variation as a standard business practice. Many of Deming's points highlight a shift in behavior to ensure the improvement continues over time. Khalid et al. (2011) found that many companies stop at the point of implementing a quality system and becoming certified. Khalid et al. suggested that companies must go beyond the implementation of a quality system and focus on quality improvement. The organization within this study has current certifications for their quality system and recently received perfect audit scores from outside auditors. However, the quality of product is considered too low by the management team. Thus, the organization used in my research is an example of Khalid's findings that there is a need to stretch beyond implementing a quality system to gain improvement in performance.

Juran (1970) concentrated on linking the staff employee with management. Juran believed that cultural resistance was at the core of product quality improvements. Thus, to change behavior within the workplace, Juran advocated the use of quality circles, a concept he learned while studying in Japan. The concept of quality circles means that organizations contain all the necessary elements of teamwork, communication and feedback, and a values driven organization. The purpose of quality circles is to drive ownership and accountability for quality to the shop floor employees. Chin et al. (2011) validated the relationship between human capital and effective quality management through a review of recent literature. Chin et al. further suggested a model that integrated human capital into the quality management system that will aid in the reduction of resistance to change. The organization within this study has tried and failed at implementing quality circles. I believe this was due to the inadequate training protocol that facilitates the existence of poor quality. Proper training is foundational and must be in place before venturing into such concepts as quality circles.

Incorporating quality into daily work. Quality initiatives or programs have been widely used in industry. There is a gap within the literature in addressing the workforce characteristics that are required for successful execution. While research related to reliability improvement in hospitals and student educational quality in schools (Copper et al., 2005; He, 2008; Miller et al., 2009) exists, researchers have suggested that analyzing behavior as a key component to quality within the workplace is a gap that needs to be addressed. Walton (1986) suggested that Deming's (2000) 14 points highlighted a need for a level of behavioral improvement along with improvements in management, systems, and variation reduction in order to achieve improvements in product quality. It is hypothesized that these aspects can be incorporated into the training practices, thus providing a stronger foundation for the worker.

Myers (2003) used a survey instrument developed by Kontoghiorghes and Dembeck (2001) to determine if the critical predictors of quality performance are correct in a technical services environment. The results of Myers work on the critical predictors of quality performance suggested that feedback, measurement systems, interrelationships, and teamwork are the primary drivers of quality. According to Myers's (2003), the critical predictors of quality performance are validated within the literature that using a scientific approach to work practices will help bridge the gap between the empirical evidence suggested within the literature review.

The philosophy of Deming (2000) and Juran (1970), along with Myers' insights (2008), provide a review of quality principles for the workplace. My experiment changed the current method of worker training during the experimental period. Thus, I considered each of the quality principles in this section to ensure the training protocol was adequate. To gain further information on the proper training protocol, an examination of industrial training was required and reviewed next.

Industrial Training and the Adult Learner

Allen (1919) broke down training into technical knowledge and auxiliary knowledge. Technical knowledge is the skill required to run a machine or to conduct a work assignment. Auxiliary knowledge is general knowledge. For example, knowing how to work safely and how to care for the work tools are considered auxiliary knowledge. While there is a need for technical knowledge on the job, my research was primarily focused on interweaving auxiliary knowledge and technical knowledge together to reduce variation within the workplace. Auxiliary knowledge relates to all jobs in all situations. Thus, Allen's work provided key insights into my study.

Before casting doubt on training as a strategic objective of a manufacturing company, Allen (1919) suggested a company must look at the difference in overhead costs between a properly trained person and a poorly trained person. Allen further suggested that a person who is trained properly was less likely to quit, less likely to make scrap, quicker to achieve the required production, and is overall more productive. Allen wrote, “Overhead cost will be cut according to the degree to which the training work is organized and operated according to the definite principles that underlie efficient training work” (p. 10). There is a strategic need for a training protocol that reduces variation, overhead costs, and the learning curve.

Allen (1919) proposed a four-step process to training: preparation, presentation, application, and inspection. Preparation provides the worker with some points to consider before the instruction begins to connect the reasons for the training to the training itself. Presentation is the execution of the lesson plan. The instructor provides the learner with the required information, emphasizing key points and the reasons for each. Application is about hands-on experience. First, the instructor demonstrates the job and then the learner must repeat the demonstration to show the information transferred effectively from the instructor to the learner. Inspection is the final step and deals with assessing the learner’s ability to do the work unaided by the instructor. Allen suggested that once a learner is at this step in the process, the instructor must change hats from a teacher to an inspector. If the learner cannot achieve the required results, then there is a failure within the training process.

Allen (1919) dealt primarily with developing a single best method for training and suggested that a standard method to perform a job is necessary to initiate training. Allen primarily dealt with training new learners and did not discuss the need for improvements to quality or efficiency through successive methods improvements. In virtually every industry, there have been advances in tools, techniques, materials, and so forth. Thus, Allen's work was written from the perspective of the trainer and does not connect well to the ongoing improvement needs of an organization. However, Allen's basic constructs of how to instruct became part of the methodology deployed within this research.

The adult learner. Knowles (1984) studied how adults learn best. Knowles's work on andragogy led to understanding the difference between child and adult learners. The principles that Knowles developed included partnering with adults when planning or evaluating the instruction; providing a way for the adult to experience the learning which bodes well for the learn-by-doing mentality of adults; ensuring the subjects learned are relevant to the immediate needs on the job or in the learner's personal life; and ensuring that training is focused on the reason for the training instead of a broad view of conceptual frameworks (Appendix D). Knowles's approach paralleled Allen (1919) in understanding the self-directed learner. An adult learner can think for himself or herself, learn what they think is most relevant to their current situation, and learn to apply it to the task at hand. What Knowles described relates to improving work practices. A person must be willing to learn something new. If individuals or groups are to improve, then there must be a willingness to learn a new way. This willingness highlights what Juran

(1978) suggested concerning quality circles. There first must be a willingness on the part of the worker to deliberately make quality work a part of daily practice. The only way to facilitate the mentality required is through training.

Another position in the work of Knowles (1984) was his approach to partner with the adult learner as a way to engage the learner on a course of improvement. According to Coetzer (2011), workplace supervisors need to improve their level of engagement in the learning process of employees. It is not simply good enough for a manager to tell an employee to go and learn something new. The better approach is to discuss specific behaviors and then develop a plan for improvement. Then a dialogue can occur based on the employee's assessment, thus leading to acceptance within the learning process.

Knowles (1984) suggested that learning must be relevant to the individual. If it does not relate to the person's interests or needs on the job, then the learning will be wasted. An additional relevant aspect is to provide an explanation of why training is required. Establishing a real reason to believe that the training is important is a prerequisite for adult learners. Knowles's insights on adult education are of significant importance when trying to improve behaviors and change work practices in the workplace.

When preparing the adult learner for change in the workplace, there are some key observations that are essential. According to Gill (2009), the interventions must be relevant, meaningful, and applicable to daily work. The interaction with employees must be respectful, positive, and the work environment must encourage the formation of new, more productive habits. The methodology must incorporate the concepts of both Knowles (1984) and Gill (2009) for successful work practice improvement in the workplace.

Training within industry. In 1943, the U.S. Bureau of Training wrote a book on training within industry (TWI) under the authority of the war manpower commission. The purpose was to train up new workers in the factories while many factory workers enlisted in the armed services (http://trainingwithinindustry.net). The U.S. Bureau of Training developed its methodology based on the ideas of Allen (1919), Gilbreth (1909), and Taylor (1911). Each researcher has had an influence on the modern concept of industrial training. More importantly, the basic concepts behind developing the best methodology for manufacturing were written in this training manual. Within the original text, there is a model of five needs for supervisors. The needs are knowledge of the work, knowledge of responsibilities, skill in instructing, skill in improving methods, and skill in leading. The instruction manual centers on the three skills of instruction, methods, and leadership. Table 2 highlights the training methodology for each of the three skills.

Job instruction is broken down into preparing the worker for the work being performed, presenting the operation, trying out the operation, and follow up. Hannon et al. (2011) suggested that effective job instruction relied on both effective training and effective assessment. Both were highlighted within this study.

Table 2

Training Within Industry Steps of Implementation

Steps	Instructions	Methods	Leadership
1	Prepare the worker	Break down the job	Get the facts
2	Present the operation	Question every detail	Weigh and decide
3	Try-out performance	Develop the new method	Take action
4	Follow-up	Apply the new method	Check results

Note. From "Job Instruction Sessions Outline and Reference Material", by U.S. Bureau of Training, 1944, p. 13-14. Washington, DC.

For job methods, the steps include breaking down the job, questioning the details, developing a new best method, and then applying the new method. Graupp and Wrona (2011) discussed job methods as the one best way or the one best method approach. The purpose of job methods was covered in both the scientific management and quality management subsections as a way to reduce variation and improve efficiency.

For job leadership, the focus is on knowing the facts, weighing and deciding the course of action, taking action, and checking results. Each of the three skills follows a scientific management approach. This is also described in Deming's (2000) plan-do-check-act cycle,

When looking at the elements of each skill in Figure 4, there are also redundancies. For example, the step of taking action under leadership is similar to applying the new method under methods. Likewise, checking results under leadership is similar to follow up under instruction. Thus, when removing the redundancies and developing an integrated model, the recommended approach to training is shown in Figure 2.

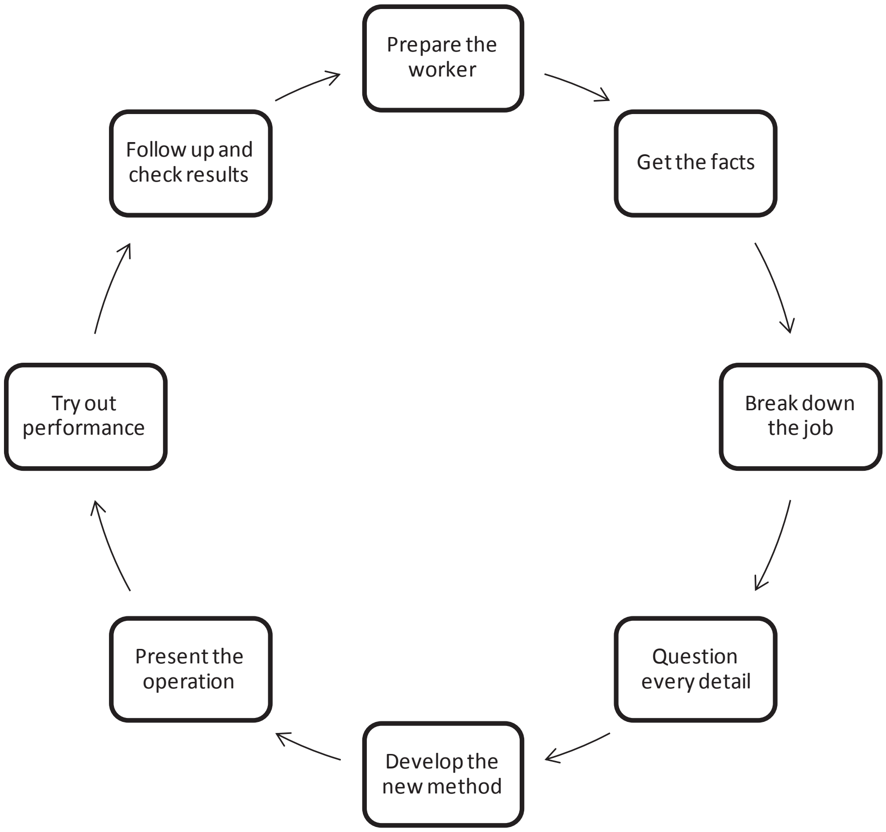


Figure 2. Depiction of training within industry methodology.

Figure 2 highlights two key points. First, according to Graupp and Wrona (2011), the training protocol must include the elements of all three skills for sustainment. Second, according to Ford (2009), the training protocol must contain a level of continuity to allow workers and managers alike to continue looking for improvements to the job. Thus, the circular representation depicted in Figure 5 is most appropriate to show both the elements required for successful sustainment and the continued quest for methods improvement.

Change Management and Workplace Behavior

When trying to achieve a change in the workplace, it becomes important to remove old habits to form new ones (Kotter, 1996). However, the history of a person and the environment a person finds himself or herself in will dictate a response (Skinner, 1953). More specifically, if the history of a person has reinforced consequences, whether positive or negative, then that person will behave according to those reinforced consequences unless acted upon by an external force (Kearney, 2008). Thus, the training protocol and the instructor must work to break old habits in order to form new ones that are more productive to the work environment by using positive reinforcement.

Positive reinforcement is a consequence applied to increase the probability of recurring behavior, and negative reinforcement is a consequence removed to extinguish the behavior (Skinner, 1953, p. 69). From this segmentation, Alberto (2006), Bailey et al. (2006), and Newman et al. (2007) suggested that each behavior or action has three basic components: antecedents, behaviors, and consequences. An antecedent is defined as an input to a single behavior. A response is an action exhibited by a person once the brain collects the antecedents and determines the best action to take. A consequence is the effect of the action taken. One of the limitations of this study was the ability to control the consequences given by either an individual worker within the study, the group of workers using peer pressure, or the manager of the employees within this experiment providing clear direction and expectations (Skinner, 1953). Studying behavior in its entirety in a practical workplace setting has its limitations. Thus, the focus of this experiment will center on the transition of the worker from the current state to an improved future state.

Transition. To ensure the participants in this experiment internalize a new way of operating, the works of Kegan's (1982) and Bridges (2003) will be used to focus on the transition of a person from one stage to the next and how this phenomenon occurs. Kegan suggested a worker will first try to hold onto the methods he or she already has, then discover a contradiction of learning a new and better way, and finally exhibit a function of continuity where the worker permits himself or herself to become part of the new method. Bridges developed a similar model. Bridges suggested that once the worker goes through all three functions of the transition, the worker has evolved its perceptions of the workplace and a new reality exists. The change transition may be quick or may take time for a worker to adjust. The purpose of the methodology chosen in this experiment is to provide a bridge for the worker to transition from the current method to the new method when doing their work.

Maslow (1954) described a theory of human motivation by focusing on a fundamental look at needs. In the workplace, the common thread found in people is they want to improve themselves on the job. However, as suggested by Thorndike (1911), workers are sometimes stopped by controlling mechanisms, such as management, economics, and educational attainment. Employee behavior may become less than positive should employee engagement or empowerment become blocked.

Maslow (1954) described how character is formed by people as needs are satisfied (p. 36). Kegan (1982) pointed to the transitional period as foundational to the change process. Thus, the question of whether or not adult workers can learn a new way to do their work is a question that must be answered to determine if the experimental treatments can be sustained. Maslow distinguished between behaviors that show purpose, such as working for pay and adverse behavior that shows no purpose, such as being disengaged in a conversation (p. 64). Maslow also believed that human behavior can be positively influenced with an end in mind. The methodology used within this study provided a way for a person to transition from the loss of the old behaviors to the accepting of new behaviors that are more productive to the workplace. The workplace is a purposive environment where workers are paid for their effort. Thus, the ability to change to a new way is possible as long as people are willing to learn.

Workplace behavior. Behavioral characteristics have been defined within the work of Park (2004) as productive and counterproductive attributes. Productive attributes are those that support the organizational mission and vision, impose a set of values, provide for robust communications, and foster collaboration amongst all members within the workplace. Counterproductive attributes are those that prove to be unfair, conflicting, limited in organizational scope, risk averse, and unsupportive of organizational goals. The training methodology used within this study will work to strengthen productive attributes while reducing counterproductive attributes within the workplace. I will provide a more detailed review within this section to link each attribute to this study.

Characteristics of a productive workplace. Characterizing the workplace will help determine those work practices that are productive. Park et al. (2004) pointed to the attributes within the workplace that are either positively or negatively related to culture change and knowledge management implementation success in the workplace**.** Park et al. hypothesized that a positive correlation exists between successful implementation of knowledge management and the behavioral attributes of trust, sharing information freely (feedback), working closely with others (interpersonal relationships), and teamwork. Figure 3 depicts the essential elements of a productive workplace.

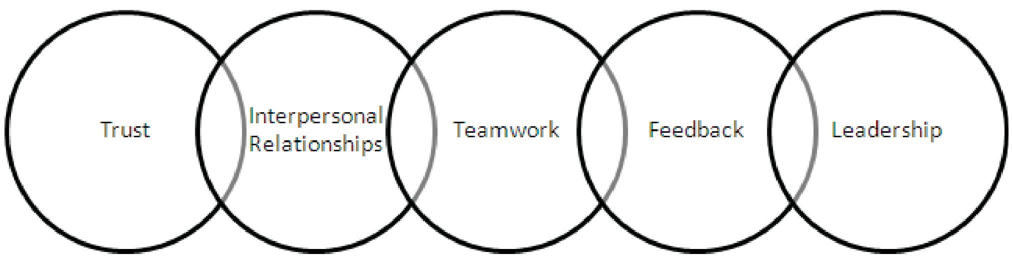


Figure 3. Characteristics of a productive workplace.

Trust in the workplace. Gibb (1978) developed his concept of trust as a foundational framework of relationship building in an organization. Gibb described trust as, “wherever people are close and intimate, loving, interdependent, and open to one another; wherever instinct or knowledge give us a sense of being able to be ourselves with others” (Gibb, 1978, p.14). Boersma (2011) conducted a recent study that validated the work of Gibb by determining the need for mutual understanding and trust within an organization as the cornerstone of change management. Within the context of change management, trust is a basic need to move towards self actualization described by Maslow (1954).

Fear is the absence of trust. From a workplace perspective, fear is generally what stops or stalls an improvement initiative within the workplace. Fear also enacts roadblocks to communication and results in poor performance (Gibb, 1978, p. 15). It seems only natural for humans to trust and to fear in different proportions. According to Gibb (1978), how much to trust and how to handle fear are dilemmas that face all people. When trying to change behavior within the workplace, the focus should be to build trust and remove fear to unlock the true potential in people.

Another component of trust is integrity and mutual respect for others. Gibb suggested that trust brings about integrity and mutual respect because the person is considered as being in the moment naturally working through the experience. When trust levels are low, a person experiences a behavioral defense mechanism that works to move a person away from being personal. A person typically does this by putting on a false front to guard against others using information against them (Gibb, 1978, p. 26). Another defense mechanism is to withdraw from the work. Thus, it became important to establish a basis of trust at the onset of this experiment.

Interpersonal relationships. Relationship building and being personal are important characteristics to building trust on the job (Gibb, 1978, p. 34). Nason (1995) discussed relationship quality as an indicator of individual performance in a group setting. Thus, the stronger the relationships within the group, the better the overall work performance. Nason's work was supported by Fiedler (1967) who discussed that work performance was tied to interpersonal relationships with others. Workers must allow themselves to be open enough where another can discover who they are. When workers play to their fears, they tend to hide and withdraw. Fiedler (1967) mentioned people use up more energy when letting fear dictate the outcomes. Thus, it is important for people to be in relationship with each other. Many of the poor behaviors can be corrected rather easily, and performance will improve, if there is an improvement in trust and relationships.

Harris-Pereles (1997) discussed the importance of interpersonal relationships. However, Harris-Pereles found that the importance of the work was what determined the behaviors seen in the workplace. If the workplace suggeseds that the work is meaningful and followed up with as much support as required, then a worker was more likely to perceive the importance and behave in a manner consistent with achieving results.

Through the work of Graupp and Wrona (2011), there was a clear need for the trainer to relate to the people being trained. The trainer in this study knew the work content and engaged with each of the workers before the training treatments take place to gain their perspective in developing the treatment. This first step ensured there is an established relationship in place. Further, the trainees know the trainer cared about how successful each employee was in performing the job.

Teamwork. When discussing group dynamics in the workplace, Gibb (1978) suggested a few key points about the work itself that will improve performance. Gibb suggested that workers need to discover the meaning of the work for themselves, the work must be meaningful to the organization, the workers must be compatible to one another, the workers must be included in decision making meetings, the workers must spend more time working than managing, and the workers help one another to build relationships based on trust. With these basic tenets of teamwork come advantages of speed and efficiency while producing a quality product.

Miller et al. (2009) studied human behavior in a nursing environment to determine the behaviors required in high stress situations. To be successful with a patient, Miller et al. concluded that nursing skills are a vital component, but are secondary to teamwork skills to ensure successful patient care. They further indicate that all of the professional licensing, training, and nursing standards will not catch the various human factor situations that arise (p. 254). Rather, a better approach discussed by Miller is to focus on how well interdisciplinary teams function together when trying to improve reliability.

Wright (2000) believed that employees will learn the appropriate methods based on the group they encounter in the workplace. Workers will behave differently when working within their own team than when working with others outside their team. Wright (2000) concluded that to ensure commitment in a variety of group settings, the focus needs to be on a positive workplace climate.

Kimura et al. (2009) discussed the ability to predict team success through characteristics of good teamwork. They found extraversion, agreeableness, conscientiousness, emotional stability, and openness to be significant when looking at teamwork effectiveness. Dayan et al. (2008) found that teamwork quality relied on interactional justice. This is synonymous with extraversion, conscientiousness, and environmental turbulence which is synonymous with agreeableness, emotional stability, and openness. Thus, Dayan (2008) supports the findings of Kimura et al. (2009) and supports the need for a foundation of trust. Dittman (2010) discussed the concept of preparing the worker to collaborate. Dittman proposed that structured training programs centered on collaboration is a key that is missing from the literature. Thus, this research will fill the gap that Dittman described.

Finally, Opengart (2005) and Weinberger (2002) found that emotional intelligence is a primary driver of understanding coworkers. When workers are not emotionally prepared to work, teamwork can be compromised and trust is disrupted. Thus emotional intelligence is a necessary part of the teamwork equation. The trainer was attentive to each trainee to determine and address any behavioral issues during the administration of the training treatments.

Feedback. Feedback is another main theme within the literature. Feedback is defined as sharing information freely. Amigo et al. (2008) discussed feedback within a franchise pizza restaurant. They found that feedback administered through visual and verbal communication must remain positive for it to be effective. Slater (2001) discussed that feedback was an essential part of the change process. Blanchard (2002) wrote quick feedback must be based on the behavioral traits seen, and must be tied to goal setting.

Several authors (Sandaker, 2009; Amigo, 2008; Hayes et al., 2009) agreed with the need for feedback to be quick, be based on behavior, and be tied to goal setting.

Feedback can be provided as soon as an action is taken, or much later on after the action is taken. Feedback can be certain with clear and concise consequences or uncertain which may provide for repeated behavior. Finally, feedback can be either positive or negative. The literature suggested feedback that is sooner, certain, and positive is preferred to encourage improved worker performance within the workplace. Feedback was a major component of this research and was administered before, during, and after the treatments of each employee.

Leadership. In addition to interpersonal relationships, Fiedler (1967) suggested that workplace performance is also tied to leadership and the surrounding work environment. Alshuk (1998) completed a study on leadership follow-up and determined follow-up had a positive effect on behavior and outcomes. Leadership can also have a negative effect on workplace behavior. Burroughs (2001) discussed that leaders who are unjust and aggressive towards their workers are perceived differently by workers and workplace performance may suffer.

According to Gostick and Elton (2007), leadership has four basic elements: goal setting, communication, trust, and accountability. Within the scope of this experiment, the workers being trained knew and understood the goals of the experiment. The trainer trusted each worker to do a quality job and to hold themselves accountable to making good product. Bossidy and Charan (2002) validated these assumptions and further suggested that in the absence of good leadership, the ability to execute improvements will prove difficult. The leader in the work area under study was progressive and possessed the leadership ability to ensure his people were accountable after the training treatments took place.

Characteristics of Counterproductive Workplaces

By synthesizing the works of Gruys et al. (2003) and Fox et.al. (2001), counterproductive work behaviors fall into three basic categories for the workplace, withdrawal from the work, anti-social behavior, and self imposed deviance. Withdrawal from the work includes not communicating effectively, high absenteeism, high turnover rates, repeated lateness, a general complacency on the job. For the purpose of my research, insufficient communication and general complacency was reviewed further.

Antisocial behavior includes workplace violence, incivility, bullying and sexual harassment (Alberto & Troutman, 2006). Self imposed deviant behavior includes pilfering, sabotage, substance abuse and ineffective job performance (Alberto & Troutman, 2006). While antisocial behavior and self imposed deviant behaviors are important aspects of behavior, this study assumed that these behaviors were addressed through the appropriate organizational discipline measures in place.

Insufficient communication. According to Kotter (1996), poor communication causes projects to fail and companies to falter. Thus, when trying to improve performance within the workplace, it was imperative to ensure the communication approach was developed to prevent backsliding. Insufficient communication can also be defined as not understanding the vision, mission, scope, goals, and current state of the workplace. Some or all of these may be missing thus causing waste within the work people do.

Harrison (2006) and Murphy (2010) provide examples of poor communication in the work environment. Harrison (2010) worked on improving quality in hospitals to reduce the number of times a patient readmits to the hospital by providing the right care the first time through. She cited communication issues as the main cause for hospital readmittance. Murphy (2010) claimed that poor communication led to most of the preventable deaths in hospitals. He further suggested that sound procedural policies are the only way to improve the outcomes. Within my experiment, a best method was determined and deployed for each treatment. Further, the approach in Chapter three will discuss how the treatments were communicated for effective dissemination of procedures.

Complacency. Complacency is defined as being satisfied with the current state without realizing there is more work to do. A complacent person does not expend extra effort to make improvements and lives in the status quo. Bielic et. al (2010) suggested that complacency leads to excessive errors and poor quality. For example, a person may not realize the scrap they are creating causes excessive costs to a business. The current performance may be acceptable for today's business needs but not acceptable to be competitive in the future marketplace. Being complacent further suggests that a worker does not have to think about what they are doing. Thus, being complacent is a withdrawal behavior from work.

One may question whether or not there is a risk of becoming complacent in different job settings. For example, is there a difference between being complacent in a manufacturing setting versus being complacent in a governmental agency pushing paper? It is the author's contention that operator error can occur in just about every workplace setting whether making products or keying information into a database. Taylor (1911) suggested that the cost of doing the work will increase over time. Thus, by not looking for more efficient ways to conduct work, there is an increased risk of higher cost to those paying for the service.

The conclusion from Fox et al. (2001) was the only true way to prevent or minimize the counterproductive behaviors within the workplace is to promote the productive behaviors which focus on communication, collaboration, and values. From the review of both productive and counterproductive characteristics, I incorporated only productive characteristics of behavior within the training protocol of this study.

MANOVA

The literature review explains MANOVA through the following items: first, it provides a definition of simple MANOVA and how it differs from simple ANOVA. Next, it explains the various purposes of MANOVA to understand how to utilize the test statistic. A review of a few key research papers provides a better understanding of MANOVA. Following the exposition on Simple MANOVA, the subsection continues with an explanation of repeated measures MANOVA and how it differs from Simple

MANOVA. Finally, a review of a few key papers helps to understand the application of repeated measures MANOVA.

MANOVA vs. ANOVA. An analysis of variance (ANOVA) provides a way to measure differences of multiple variables across multiple groups at once. ANOVA is a more complex form of the t-test and thus there was a need to develop a new F-test to handle the complex computations. The usability of ANOVA is widespread within research due to its ability to complete advanced statistical analysis. In its basic form, it compares the differences in means both between groups and within groups to provide for a complete analysis. Also, ANOVA assumes normality. However, ANOVA only allows for one dependent variable. In this research, there were multiple dependent variables. In order to determine which independent variables have the greatest impact on the dependent variables, there was a requirement for a more complex model to complete the research.

The use of a multivariate analysis of variance (MANOVA) addressed the main and interaction effects of categorical variables on multiple dependent interval variables. MANOVA uses one or more categorical independents as predictors, like ANOVA. However, there was more than one dependent variable. Where ANOVA tests the differences in means of the interval dependent for various categories of the independent variables, MANOVA tests the differences in the centroid (vector) of means of the multiple interval dependents, for various categories of the independent variables. One may also perform planned comparison or post hoc comparisons to see which values of a factor contribute most to the explanation of the dependents.

There are multiple potential purposes for MANOVA. The first purpose is to compare groups formed by categorical independent variables on group differences in a set of interval dependent variables. The second purpose is to use lack of difference for a set of dependent variables as a criterion for reducing a set of independent variables to a smaller, more easily modeled number of variables. The third purpose is to identify the independent variables which differentiate a set of dependent variables the most.

Within research, there are three basic forms of MANOVA, Hotelling's T, one-way MANOVA, and factorial MANOVA. Hotelling's T allows a researcher to review one independent variable against multiple dependent variables. For example, if a researcher wanted to study how temperature fluctuations affect safety, quality, and productivity, he could use this test statistic. One-way MANOVA takes the Hotelling's T MANOVA one step further by allowing the researcher to conduct an experiment. For example, if the researcher wanted to determine how the various dependent variables react to two or more extremes in temperature, then the utilization of a one-way MANOVA will be necessary.

Taking the concepts of the Hotelling's T and the one-way MANOVA design one step further, when wanting to account for multiple independent variables, a researcher can use a factorial MANOVA design. There are several MANOVA applications in the literature. A summary of a few MANOVA studies helped to understand of the wide applicability and power of the technique.

MANOVA in practice. A number of research studies have used the MANOVA test statistic. Shen et al. (2007) utilized MANOVA to study the significance of differences between leadership, team trust, and performance as it relates to both service and manufacturing industries. They found that there are significant differences, both between industries and within industries, when reviewing the different independent variables.

Schneider et al. (1998) conducted a MANOVA study to determine how personality factored into the employee selection process for roles within certain groups. Schneider et al. used 35 different industries as their independent variable and 16 Myers-Briggs personality types as their dependent variables. Their hypothesis suggested that differences in personalities from employee to manager exist. Following this analysis, the researcher conducted a nested MANOVA to remove the effect of the industrial sector and instead focus on organizations within selected industries. According to Schneider, the goal was to understand the multilevel relationship of personality to determine if there are differences within industrial sectors and between organizations of the same sector.

Varese et al. (1998) examined behavioral skills among 64 female prison inmates who have reported either high or low levels of depression based on a survey. They used four behavioral skills surveys as their independent variables and measured depression and response bias as their dependent variables. They utilized MANOVA to determine the significance within and between groups. After the initial analysis, they also conducted a few univariate ANOVA's to further analyze segments of their study.

Kliewer (1991) utilized MANOVA to study coping strategies of middle childhood. Her independent variables consisted of surveys that looked at competence, behavior, monitoring, blunting, and locus of control. Her dependent variables were three stress and coping interviews completed before, during, and after the study. Her results showed that coping using an avoidance mechanism was most prevalent among socially competent children.

Further review of the literature revealed a few key points about the study and use of MANOVA as a test statistic. Wilkinson (1975) suggested that when using the MANOVA approach, it is clear there is an error in the data and no measure within MANOVA can sufficiently describe the relation between treatment and response. Strahan (1982) discussed the problem with Type 1 error utilizing MANOVA. While Wilkinson (1975) suggested further analysis to understand the key relationships and explain conclusions, Strahan (1982) suggested that a more stringent Alpha should be used to show significance. Thus, a higher degree of statistical significance explains why Schneider et al. (1998) and Varese et al. (1998) conducted further analysis to develop their conclusions.

Repeated Measures MANOVA. The definition of repeated measures MANOVA is a generalized form of analysis of variance when there are two or more dependent variables (Stevens, 2000). The approach answers if changes in independent variables have an impact on the dependent variables. If so, what are the differences among dependent variables and independent variables? The repeated measures MANOVA design can be conducted by segmenting the sample into groups and determining both between-group and within-group variation. The design can also keep the sample size as one group and look for within-group variation only. A number of studies, examined below, have used repeated measures MANOVA.

Haynes (2010) and Marable (2011) provide similar between group studies in education and performance but do so using one dependent variable. Thus, their studies represent a repeated measures ANOVA design. My research focuses on two dependent variables, thus requiring an analysis using MANOVA. However, each of these studies had the same basic construct of a repeated measures time series design. Gottenberg (2006) conducted a time series study on how teacher maturity relates to leadership practice. Using a repeated measures design, she categorized years of service to determine the significance of seven leadership practices based on experience level. She utilized a single group of 360 principals within the study to determine the leadership gaps and developmental needs of principals by focusing on variation within the group.

Morgan (2006) also conducted a repeated measures MANOVA single group study. She focused on the mental skills training program of female athletes at the college level. She analyzed five dependent variables over the course of a semester to determine how the training has improved scores on four survey instruments. While the structure of these works resembles the approach used within this research, survey instruments provide for the data for analysis. Thus, these studies do not completely represent the same approach within my research.

Cohen (2007) researched the effects of developmental feedback on third graders baseball throwing performance. She split the training into four groups and conducted a factorial MANOVA repeated measures design by providing different levels of feedback to the different groups. Cohen's analysis looked for the difference between-groups and within-groups. Shanley (2008) completed a similar feedback study and looked for differences between groups providing children immediate feedback and providing no feedback on parental self efficacy. A repeated measures MANOVA study concluded that immediate feedback had a positive impact on parenting skills. Evans (2007) took a similar approach in her research. Evans split her participants into an experimental group and a control group to determine the differences between-groups. The experimental group received strength training and the control group received no training. A repeated measures MANOVA study provided time series information to determine any significant difference between the groups.

Ramey (2009) also studied the effects of a training initiative on students' performance between-groups over a three year period. However, Ramey utilized a repeated measures MANCOVA design where she looked to understand the longitudinal changes in student performance as well as looked for gaps between demographics of students noted within the study. The only significant difference before and after treatments took place in the special needs group. The other groupings showed no significant differences.

In my research, the utilization of a repeated measures MANOVA within groups design helped study the significance of differences between quality and productivity as it relates to pre and post behavioral patterns on a single group of workers. The purpose of utilizing Repeated Measures MANOVA was to study how the different levels of the independent variable effects the dependent variables over time. I will provide further information on the statistical techniques in Chapter 3.

Summary and Transition

The literature review in Chapter 2 provided a summation on the topic of improving work practices through improvements in training. The themes of scientific management and methods improvement, industrial training and adult learning, change management and behavioral characteristics, and MANOVA were discussed and demonstrate there is a method to improve work practices and behavior in the workplace. While the focus of this study was on a high-technology manufacturer, the theoretical foundation indicated the applicability of proper training protocol and change management utilized in several different industrial sectors or working situations. Thus, the literature provided further evidence of the ability to improve work practices through improved training protocol in any business setting.

Any change initiative must take into account the workplace environment and ensure honesty, integrity, and mutual respect as a set of core values. In addition to establishing the proper work environment, positive feedback and high performance teamwork are essential change management categories to address within the workplace. Thus, the inclusion of each of these important workplace characteristics was a necessary part of the research methodology.

The next chapter will highlight the research methodology used to conduct this study. An overview of the research design and methodology will define the approach. A measurement system highlights the data collection plan that includes a discussion on the variables, the population size, and how to code the data. Finally, there will be a detailed review on how to analyze the data utilizing repeated measures MANOVA.

Chapter 3: Research Method

Introduction

The purpose of this quantitative study was to see whether gains in performance were achieved by implementing standard work practices and a specialized training plan in an environment where quality is critical. The purpose of this chapter is to provide the method used for this research along with a discussion on how the data was analyzed utilizing SPSS statistical software.

The quantitative experiment in this study took place in a high-technology manufacturing plant where the work presented unique challenges. First, the work environment exhibited a high-model mix. Thus, the ability to develop consistent work practices was compromised. Second, the training protocol used to train both existing and new workers was based on repeatable work, which does not exist in this plant because each product is unique. Thus, the training method had to be adjusted to fit the low-volume, custom production runs. Third, the ability to continually improve was hampered because 50% of the products were single-order production runs. Thus, the ability to learn and incorporate best practices from one production order to the next was limited. The company selected for the experiment was Endicott Interconnect Technologies, an electronics manufacturer of printed circuit boards that was willing to improve costs associated with product quality.

As stated in Chapter 1, there is a need to study standard work practices and improve training protocols when operating in a niche market that is highly customized and exhibits low volumes. This research applied scientific management and methods improvements, industrial training, and change management to develop standard work practices in a high-model mix, low-volume environment. I used this research to challenge the paradigm that standard work practices work only with highly repeatable tasks. Further, this research showed how standard work practices and an improved training model provided for improvement in outcomes.

The purpose of this chapter was to document the method used to collect and analyze the data. I will begin with a discussion of the each research question and hypothesis. Next, I will discuss the quantitative analysis used in this experiment, the population and sampling plan, and the treatment details to ensure robustness in experimental design. In the instrumentation section, I will discuss the measurement system used to collect data, before and after each treatment. Finally, I will provide a section on both (a) reliability and validity and (b) participant protection.

Research Questions and Hypotheses

This section will explain the main research question and the four sub questions that provided a roadmap for the study. The research questions included the null and alternative hypothesis as well as an explanation of how the hypotheses were derived.

Main Research Question (RQ_1)

How are workers in a highly customized job shop manufacturing environment able to improve quality and productivity levels through improved training protocol and enhancing work practices?

Hypothesis for RQ_1

The main goal of this research was to determine if improving training protocol and implementing standard work practices improves performance. Thus, the hypothesis of this study is:

H0: There is no difference in group outcomes after administering a series of training treatments that target improved work practices.

HA: There is a difference in group outcomes before and after treatments.

The main hypothesis is broken down into two hypotheses that test for each dependent variable.

$H0_1Q$: The means of the quality metric for the 3 repeated measures the same.

$H0_1P$: The means of the performance metric for the 3 repeated measures the same.

Secondary Research Question (RQ_2)

How do the three training treatments impact on the two outcomes of quality and performance? Are workers able to improve composite process yield and productivity scores after each treatment? The hypothesis derived from this question expects that workers with proper training will improve outcomes. The rationale for this prediction is that the training methodology used is more substantial and the ability to standardize work among all workers will result in improved outcomes (Graupp & Wrona, 2006).

Hypotheses for RQ_2

$H0_{21}$: There is no difference in process yield and productivity scores related to contamination control training.

HA_{21}: There is a difference between the process yield and productivity scores related to contamination control training.

$H0_{22}$: There is no difference in process yield and productivity scores related to material handling training.

HA_{22}: There is a difference between the process yield and productivity scores related to material handling training.

$H0_{23}$: There is no difference in process yield and productivity scores related to equipment malfunction prevention training.

HA_{23}: There is a difference between the process yield and productivity scores related to equipment malfunction prevention training.

Tertiary Research Question (RQ_3)

If there is a significant impact in outcomes, which particular training treatment will have the biggest impact on the two outcomes? The hypotheses derived from this question expect that there will be different changes in outcomes from one level to the next.

Hypotheses for RQ_3

$H0_{31}$: The change in the outcomes for contamination training is less than the change in outcomes for material handling training.

HA_{31}: The change in the outcomes for contamination training is more than the change in outcomes for material handling training.

$H0_{32}$: The change in the outcomes for contamination training is less than the change in outcomes for equipment malfunction training.

HA_{32}: The change in the outcomes for contamination training is more than the change in outcomes for equipment malfunction training.

$H0_{33}$: The change in the outcomes for material handling training is less than the change in outcomes for equipment malfunction training.

HA_{33}: The change in the outcomes for material handling training is more than the change in outcomes for equipment malfunction training.

To test the third set of hypotheses, a post-hoc analysis, specifically the application of the Scheffe interval and Tukey HSD post-hoc statistical tests were used to identify which measures (which of the 3 training regiments) differs from one another in terms of quality and/or productivity. These tests are only performed after the MANOVA F-test indicates that significant differences do exist among the measures (the training regiments) and thus are only examined if both H01Q and H01P are rejected.

Quaternary Research Question (RQ_4)

Which particular outcome is affected the most by which training? Considering there is a significant impact on outcomes for each training treatment, which outcome is more significant to the training treatments, process yield or productivity? The hypotheses derived from this question expected there will be improvements in both process yield and productivity at each level of the experiment.

Hypotheses for RQ$_4$

$H0_{41}$: Process yield will not differ among the different levels of training.

HA_{41}: Process yield will differ among the different levels of training.

$H0_{42}$: Productivity will not differ among the different levels of training.

HA_{42}: Productivity will differ among the different levels of training.

To test the fourth set of hypotheses, a post-hoc analysis, specifically the application of the Scheffe interval and Tukey HSD post-hoc statistical tests, were used to identify which outcomes were most significant for the different training treatments. These tests are only performed after the MANOVA F-test indicates that significant differences do exist among the training treatments and thus are only examined if both H01Q and H01P are rejected.

Research Design and Approach

The research design was a repeated-measures experiment that involves three treatments. The research technique was MANOVA to identify the significant effects. Both are explained below. In this subsection, I outlined the research design which is the logical structure of the research data and the research technique. Together, the research design and technique define the methodology. The adopted research design was repeated measures and the adopted technique is MANOVA. Both are explained below in some detail. The methodology itself is defined through a series of steps detailed in Chapter 3.

A repeated measures MANOVA is used for two types of study design, studies that investigate either change in mean scores over three or more time points, or differences in mean scores under three or more different conditions (Retrieved from http://statistics.laerd.com). In this study, the research investigated changes in mean scores over three different conditions based on the implementation of three training treatments. The same people are being measured more than once on the same dependent variables, hence, why this research used a repeated measures design. Thus, the MANOVA test required at least one independent variable and at least two dependent variables. The dependent variables needed to be continuous, and the independent variable needed to be categorical (Retrieved from http://statistics.laerd.com). Both of these conditions were satisfied within the setup of this study.

In repeated measures MANOVA, the independent variable has categories, called *levels,* where measurements are repeated over time. However, when measurements are made under different conditions, the conditions are the levels (or related groups) of the independent variable (Retrieved from http://statistics.laerd.com). In this research, the training type was the independent variable with contamination prevention, material handling, and equipment malfunction as the three levels of the independent variable.

Figure 4 depicts a more detailed diagram of the research design. The figure shows one group of 90 people receiving all three treatments separated by time. Before the first treatment and after each treatment was administered, the measurements were taken by each subject for both quality (process yield) and performance (productivity).

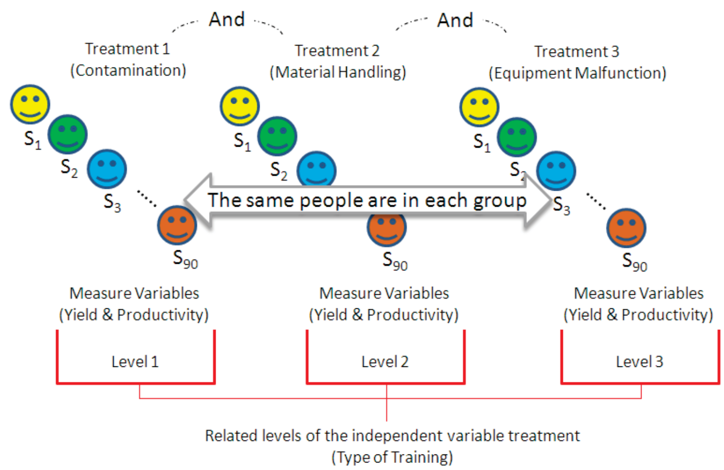


Figure 4. Visual depiction of research design developed from the website http://statistic.laerd.com.

Table 3 depicts the research study in tabular form with 90 subjects (S_1 to S_{90}), each receiving the three treatments at three time points (T_1 to T_3). A pretest and posttest is a measurement of both quality and performance for each worker within the study. A pretest measurement for both dependent variables occurs at time point T_0 and a posttest occurred after each of the three treatments were administered.

Table 3

Research Design in Tabular Form

Time	T_0		T_1		T_2		T_3	
Treatment			Contamination (X1)		Material Handling (X2)		Equipment Malfunction (X3)	
Subject	Process Yield (Y)	Productivity (P)	Process Yield (Y)	Productivity (P)	Process Yield (Y)	Productivity (P)	Process Yield (Y)	Productivity (P)
S_1	$Y_{s1,T0}$	$P_{s1,T0}$	$Y_{s1,T1}$	$P_{s1,T1}$	$Y_{s1,T2}$	$P_{s1,T2}$	$Y_{s1,T3}$	$P_{s1,T3}$
S_2	$Y_{s2,T0}$	$P_{s2,T0}$	$Y_{s2,T1}$	$P_{s2,T1}$	$Y_{s2,T2}$	$P_{s2,T2}$	$Y_{s2,T3}$	$P_{s2,T3}$
S_3	$Y_{s3,T0}$	$P_{s3,T0}$	$Y_{s3,T1}$	$P_{s3,T1}$	$Y_{s3,T2}$	$P_{s3,T2}$	$Y_{s3,T3}$	$P_{s3,T3}$
..	..	..	..	..	..	..	..	..
S_{90}	$Y_{s90,T0}$	$P_{s90,T0}$	$Y_{s90,T1}$	$P_{s90,T1}$	$Y_{s90,T2}$	$P_{s90,T2}$	$Y_{s90,T3}$	$P_{s90,T3}$

Note. Research design in tabular form.

The research was a quantitative pretest posttest experimental design that used actual data from a high-technology manufacturing environment. The data was extracted from the company's data warehouse in real time. This research involved one independent variable, training type, at three levels with two dependent variables, process yield and productivity. The quantitative pretest, posttest design was best suited for this research due to the use of successive treatments to facilitate a step function change in the outcomes. The tests were a collection of quality and performance metrics for each worker within the study. The data collection came directly from the enterprise resource planning tool that is deployed within the work environment. The research design was appropriate due to the need to implement improvements in work practices and training protocol within the organization under study.

To analyze the results, I performed a one-way MANOVA to determine the difference in response to the three treatments given. The independent variable was defined as whether or not the group received the treatments. The two dependent variables, quality and productivity, was used within the MANOVA model. The three treatments were based on the top three causes of product quality defects within the manufacturing environment under study: contamination prevention, proper material handling practices, and equipment readiness. I interviewed subject matter experts to determine and validate the top three defect causes. According to Singleton and Straits (2005), a quantitative approach measures the strength of the relationship, the direction of the relationship and the linearity of the relationship (p. 54). This study looked for causality by utilizing a within-subjects experimental design.

Appropriateness of Design

A within-subjects experimental design was chosen for a few reasons. First, the environment in which the experiment was conducted is heavily regulated. Any changes to work practices must be documented, approved by our customer, and encompass the entire work group. The company is not allowed to implement an experimental group on one shift and a control group on another. Thus, any changes in work practices must be documented and encompass the complete work group. The experiment in this study provided a single treatment within a 24-hour period to ensure that changes encompass the entire group.

Second, the measures for quality are not known until the product enters a test unit several process steps down the line. The product quality is not visible to the naked eye and testers are used to detect nonconformance. For example, hole spacing and circuit line spacing are measured in microns. Thus, with multiple processes and multiple people handling the product, and no ability to determine quality after each process step, there was a need to ensure all people within the process are given the same treatments.

Third, from my interactions and preliminary discussions with the current management team suggest they were more readily accepted a quantitative approach to the problem over a qualitative approach because they were looking for direct causality. Thus, I needed to conduct a true experimental design to ensure both reliability and validity of the research as well as provide the company with data that suggests the appropriateness of the three training treatments as pre-requisites for the job. Considering a need to protect against the random assignment of subjects to the treatments, the within-subjects approach was most applicable.

Improving work practices on a continual basis to improve quality was the premise of this study. A repeated measures design allowed the author to determine the individual affects of each treatment within the study. Further, the experiment determined the composite affect of each successive treatment and all treatments within the study. Thus, the repeated measures design was believed to be the most appropriate approach to the study.

An important consideration in repeated measures design is the sample size. To determine the sample size, I used power analysis to determine the feasibility of acquiring the required repeated measures sample size. The GPower analysis, as shown in the setting and sample section of Chapter 3, indicated a sample size of 86 when using a repeated measures approach to guarantee a 1-alpha of 95% and a power of 1-beta of 95% at an assumed medium effect size of $f = 0.25$. A repeated measures within-subjects approach guaranteed that all personnel received all treatments. Thus, since every worker within the population must participate and, as long as the population was greater than $N = 86$, then the sample is adequate to guarantee the required power. The current work environment has a population 220 people. The experiment was sanctioned by my company thus a 100% response rate was guaranteed. Thus, the population of 220 guarantees the requisite sample size of 86. Further, any worker that missed a treatment was not allowed to work on the product until they went through the same treatment as the rest of the group. Thus, the quality management controls were in place to prevent the existence of non treatment workers from creating noise within the data.

Setting and Sample

The sample of participants was drawn from production workers at a printed circuit board manufacturer where I am employed. There were 220 employees working on the production line that defined the population and qualified for this sample. Figure 5 depicts the power analysis for a repeated measures within factors MANOVA design with one group and three treatments. Figure 6 depicts the *x-y* plot for the minimum number of samples needed for a 95% confidence level. The sample size required for a 95% confidence level is at least 86. Since the regulations discussed above required that all workers receive the treatment, and since the population of 220 was greater than the minimum sample size of 86, then all 220 were used in the analysis to ensure the process yield and productivity numbers showed causality.

Further, the repeated measures approach helped to remove any potential noise in the data when looking at improvement over time. Participants were required to go through each training treatment as a condition of working within the production areas. Participants were only classified as having received the treatments or not having received the treatments. Participants in this study were not identified by name nor were there any identification of the individuals within the study.

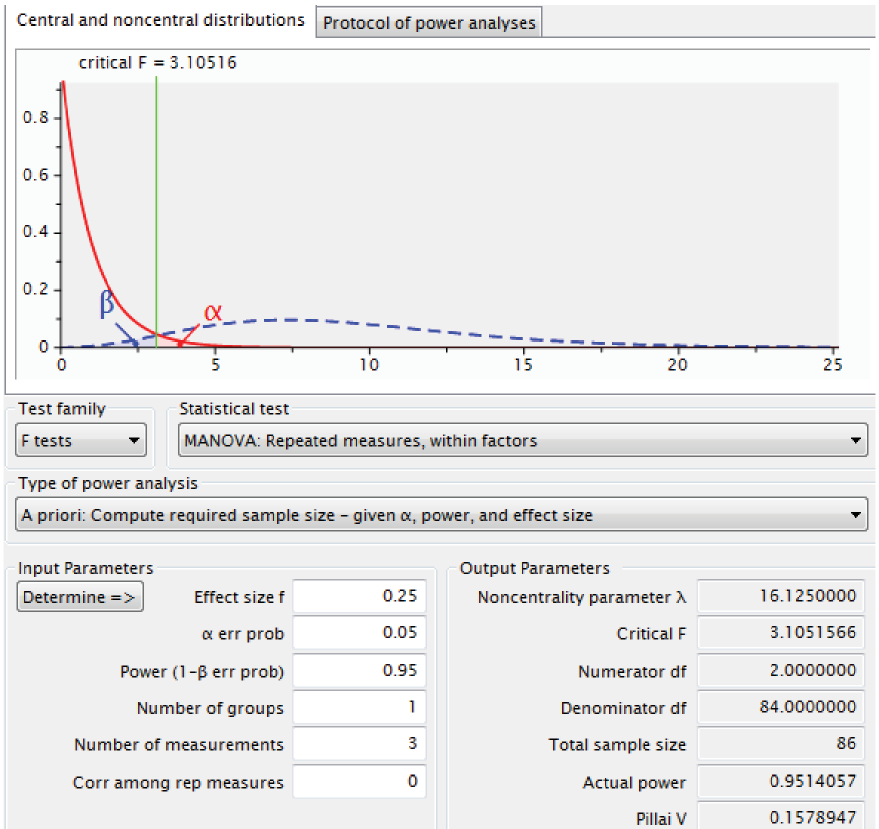


Figure 5. Sampling power analysis.

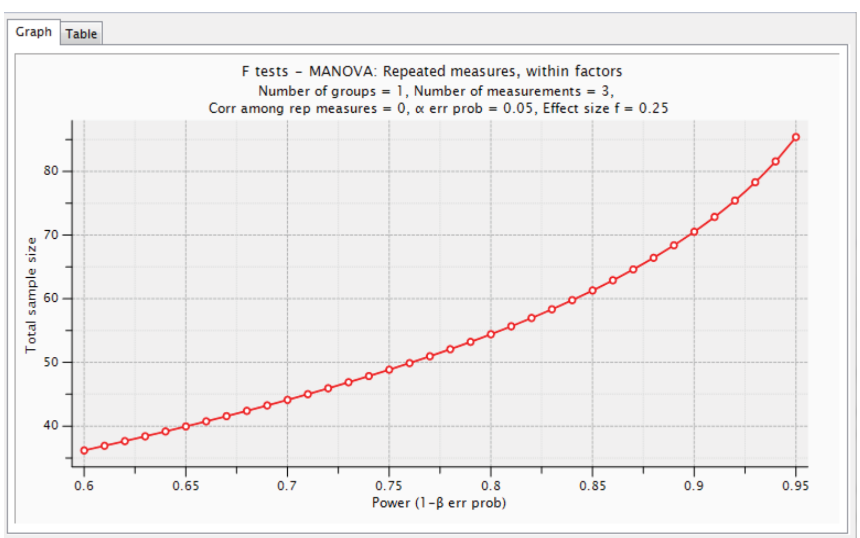


Figure 6. Sample Size.

Sampling Method

The sampling method used within this study was a purposive sample. Specifically, all 220 available workers participated in the experiment. Each worker's quality and performance was assessed before the experiment began as part of the observation at time T_0. Once the pretest was complete, the participants within the work environment received the training to prevent variation from operator to operator on the job. Thus, once the first training class ended, any preexisting certified operators in the work area were required to go through the new training protocol before being allowed to go back to work. Thus, the better approach was to keep the data collection at the participant level and have one group for the study. The researcher tracked process yield data for each participant in the study.

The metrics were collected by participant by shift and then by department. Each department focused on separate areas of the process such as, laminations, layup and press areas, drill, develop, etch and strip, copper plating, and wash and inspect. Thus, each of these areas of the process provided data to determine which treatment was more or less effective from a productivity perspective.

Treatment

The training treatments within this experiment follow the same format and approach as used in training within industry (TWI). Graupp & Wrona (2011) provide an updated version of this training that accounts for the communication and collaboration needs of the study. Thus, the TWI methodology became the basis for each treatment. The instructor within this facility possessed the appropriate training and education to administer the training treatments according to the improved training protocol as called out in the TWI methodology. To protect against variation from one instructor to the next, the same instructor was used for all groups and all treatments given in this experiment.

The first portion of each treatment provided the preparation work necessary to complete the treatment. The instructor reviewed the overall quality levels, the cost of scrap, and the types of defects seen within the process that pertain to contamination to each employee in an informal setting. From there, the instructor informally solicited feedback from the workers to determine the best method to standardize to. According to Despain and Converse (2003), there is a need to include workers in the process up front to increase the chances of successful transition during implementation. Once the feedback was collected, the instructor reviewed each step of the process and put together the best work practice for the training treatment. Before the treatment was administered, a final review with the subject matter experts provided full disclosure to the management team, the engineering team, and the quality team. The new work practices were also documented within the company's quality management system to provide an auditable reference to the training protocol and best work practice.

The second portion of the training was to administer the best work practice treatment derived from the communication and collaboration of all employees. To achieve this, a formal classroom setting was used. The instructor reviewed what was discovered within the preparation work and then proceeded to present the training in a three step approach. The first step was to verbally explain the best work practice by going through one important step at a time with an actual product for demonstration purposes. The second step was to then repeat this explanation but with more emphasis on the key points that a worker must be aware of. The third step was to then repeat this explanation for a third time highlighting the reasons why each key point is critical to the quality of the product or the efficiency of the process. The goal of these three steps was to provide a clear and understandable picture of what the job entails without overburdening them with knowledge that does not pertain to process quality or efficiency.

The third portion of this training was to provide hands on coaching with each employee. The hands-on coaching was also segmented into three steps. First, the worker must show they can do the job with the instructor acting as a coach and correcting mistakes right away. The second step was to have the worker repeat the process but with reciting a verbal explanation back to the instructor. The third step had the operator repeat the process for a third time but this time explaining to the instructor the key points and the reasons why at every step within the training. At this stage of the treatment, the instructor ensured the operator knew the job and understood the key aspects of successfully completing the job. This portion of the training continued until each worker provided confirmation to the instructor they have mastered the training and can return to the work environment.

The fourth and final portion of this treatment was to follow up within 24 hours and ensure the workers were following the new best method. Any discrepancies was dealt with immediately to ensure the data was robust to noise. Once the instructor confirmed the training treatment had been completely implemented, the documentation for each worker was submitted within the quality management system for certification. Each treatment took one day to administer and one day to follow up. There was a 2-week break between treatments to provide enough clarity on how the treatments have affected the outcomes. A posttest measurement of process yield and productivity by participant was collected during this time.

Instrumentation and Materials

The manufacturer within this study uses an enterprise resource planning tool coupled with a time collector as part of the data collection methods. The two data points of process yield and productivity were tracked by business unit, by shift and by department. Thus, the data was easily accessible and collectable from the central database for all stages of the research.

The first dependent variable, process yield, measures the percent of good panels produced over time. The process yield was tracked by the enterprise resource planning database and was segmented by defect code and group. To establish a baseline, an average of the prior 12 weeks of data was utilized. The process yield was also measured for two weeks after each successive treatment. The raw data was made available as an appendix to the study.

The second dependent variable, productivity, is an efficiency metric that provides and efficiency score to the operation. The better the score, the more cost effective the operation is. The labor hours were collected by the company's Kronos labor tracking system and was segmented by group. To establish a baseline, an average of the prior 12 weeks of data was utilized. The productivity was also measured for two weeks after each successive treatment. The raw data was made available as an appendix to the study.

Measures

The independent variable within this study was training type. The three levels of training type helped to determine the most applicable treatment for improving both process yield and productivity. The different levels of the independent variable was identified categorically as those that received training and those that did not. The dependent variables, process yield and productivity, are continuous measures.

Process yield (Y) is a quality measure represented as a percent or ratio of good units to the total number of units produced. Equation 1 below represents the mathematical formula for process yield.

$$Y_{st} = \sum g_{st} / \sum u_{st} \qquad (1)$$

In equation 1, *g* equals the number of good units produced per subject *s*, per after treatment measurement period *t*, and *u* equals the total number of units produced per subject, per after treatment measurement period.

Productivity (P) is a measure of efficiency and is represented as a ratio of units produced over the labor hours used to produce them. Equation 2 below represents the mathematical formula for productivity.

$$P_{st} = \sum u_{st} / (\sum h_{st} + (\sum O_{st} \text{ x } 1.5)) \qquad (2)$$

In equation 2, *u* equals the number of units produced per subject *s*, per after treatment measurement period *t*, and *h* equals the total number of labor hours expended per subject, per after treatment measurement period. Overtime hours (O) are more costly to the business than straight time hours. Thus, overtime hours were rolled in at 1.5 times that of regular hours.

Data Collection and Analysis

This study derived its research questions from the objective of implementing a training within industry program. The training treatment design was developed by the U.S. Bureau of Training. The design of the training for each of the three training treatments is located in Appendix A. The main focus of the research was to prove that improved training protocol better prepares a worker for the work they perform. Coupling improved training with a standard work practice or helps to reduce variation within the work and thus improves process yield and productivity.

Data Collection

The data collection aspect of this research began with understanding the capability of the current data collection system. For the labor hour tracking component, the manufacturer is a contract manufacturer and submits bills to customers for hours worked. Thus, the manufacturer has a system that captures each employee's work time on a job. I ran a labor hour report with a breakdown by operation. To determine the number of units produced at each operation, I ran a production status report in SAP and thus can determine how many units were produced at each station over the same period of time as the labor hour report. The units collected were represented in a report as the number of panels produced through each work center. Each machine is considered a work center within the work environment. Thus, it was easy to assign the number of units produced to each operator based on the shift they work.

Process yield data was coded into the system based on the defect type. For example, a defect type may be a scratch, a circuit short, a void, and so forth. A scratch is an aesthetic appearance issue on the face of the board. A short circuit is where the copper circuit is not connected. A void is where there is missing copper within the hole where components are connected to the board. The major reasons for each of these main defects are believed to be due to contamination, material handling practices, or equipment malfunction. Each defect type was traced to the shift and operator they come from thus making it easy to determine any individual quality improvements based on the three treatments.

Data Analysis

This study utilized a statistical software tool to analyze the data from the experiment. In order to compute the results of the study, a more in-depth review of how the repeated measures MANOVA statistic computes the output was required. When looking at within-group variation in a repeated measures design, the F-test statistic calculates the ratio of the mean square of each condition divided by the mean square of error. The equation for a repeated measures MANOVA design is shown in equation 3.

$$F = \mathrm{MS}_{\mathrm{conditions}} / \mathrm{MS}_{\mathrm{error}} \quad (3)$$

With a repeated measures within-group design, the same subjects are used as a single group throughout the experiment. Thus, there was no need for the between-subjects term. However, the experiment looked for differences over time. Thus, the between subjects term became the time term where there was a need to determine the outcome differences between one treatment and the next. Figure 7 depicts the total variability accounted for within the experiment.

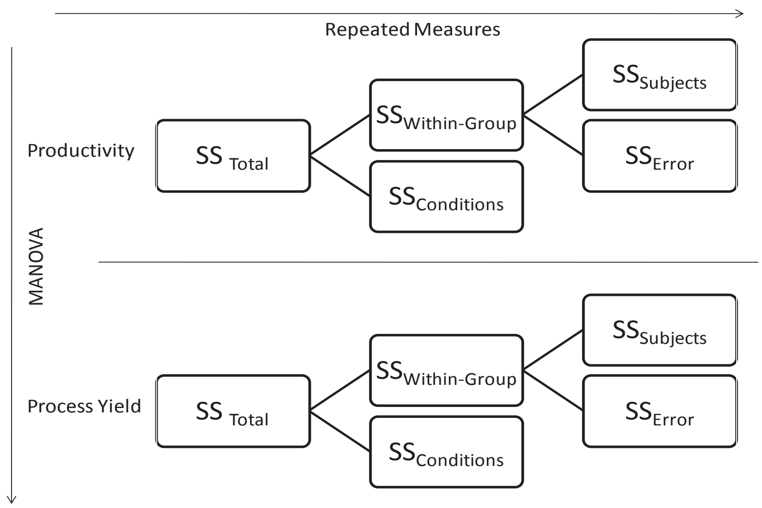


Figure 7. Total variability within a repeated measures design study.

This approach allowed the removal of between-subjects variability, thus providing insight into the variability of each condition. The data collection was based on daily productivity and quality scores for each subject before the training treatments and directly after each of the three training treatments. Table 4 provides an example of how the numbers will be represented. For each subject, the experiment should show improvement in both productivity and process yield based on the treatments given. As an example, subject 1 in Table 4 shows a baseline of 85% process yield or 85 good units out of every 100 units produced. For productivity, the baseline for subject 1 represents 2.1 or 2.1 units produced for every labor hour expended.

Table 4

Analysis Variables and Example Data

Time	T_0		T_1		T_2		T_3	
Treatment			Contamination (X1)		Material Handling (X2)		Equipment Malfunction	
Subject	Process Yield (Y)	Productivity (P)	Process Yield (Y)	Productivity (P)	Process Yield (Y)	Productivity (P)	Process Yield (Y)	Productivity (P)
S_1	85%	2.1	87%	2.5	90%	2.8	94%	3.2
S_2	83%	2.4	88%	2.6	91%	3.2	96%	3.2
S_3	82%	3.2	86%	2.5	90%	3.2	93%	3.2
..	..	..	..	..	..	..	..	..
S_{90}	84%	2.6	87%	2.5	89%	3	90%	3.2

Note. Data collection table with example data.

I used SPSS, a statistical analysis program created by IBM, to run the general linear model and calculate the F-statistic for this experiment. Using SPSS to calculate the results, the general table of results form is shown in Table 5. Within the degrees of freedom calculation, k represents the number of factors in the study and n represents the sample size.

Table 5

Table of Results from SPSS

Source	SS	df	MS	F
Conditions	$SS_{conditions}$	(k-1)	$MS_{conditions}$	$MS_{conditions}$ / MS_{error}
Subjects	$SS_{subjects}$	(n-1)	$MS_{subjects}$	$MS_{subjects}$ / MS_{error}
Error	SS_{error}	(k-1)(n-1)	MS_{error}	
Total	SS_T	(N-1)		

Note. Table of results format from SPSS.

Within SPSS, the categorization of a Repeated Measures MANOVA experiment with two outputs is known as a doubly multi-variate study of a general linear model repeated measures design. To start the analysis, the first step in SPSS was to enter the variables under study on the *variable view* tab. Figure 8 provides a snapshot of the variable input into SPSS. The variables are coded in SPSS as Y for yield and P for productivity for the baseline (T_0) and after each treatment (T_1,T_2, and T_3).

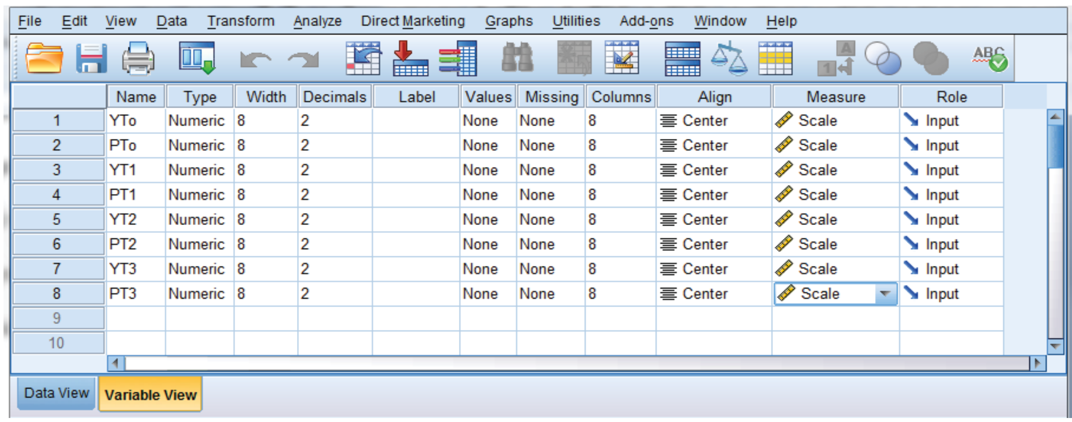
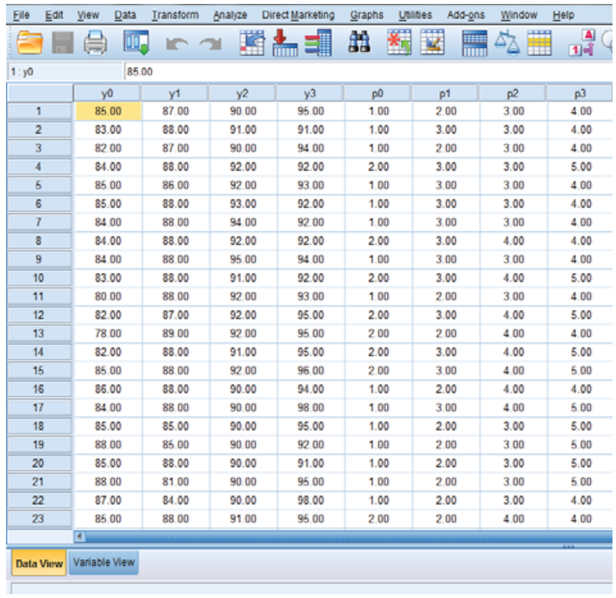


Figure 8. SPSS variable viewtab.

Once the variables are coded into SPSS, the next step was to add the data from the administered treatments into the data view tab. Figure 9 provides a data view based on the example data used in Table 4.



	y0	y1	y2	y3	p0	p1	p2	p3
1	85.00	87.00	90.00	95.00	1.00	2.00	3.00	4.00
2	83.00	88.00	91.00	91.00	1.00	3.00	3.00	4.00
3	82.00	87.00	90.00	94.00	1.00	2.00	3.00	4.00
4	84.00	88.00	92.00	92.00	2.00	3.00	3.00	5.00
5	85.00	86.00	92.00	93.00	1.00	3.00	3.00	4.00
6	85.00	88.00	93.00	92.00	1.00	3.00	3.00	4.00
7	84.00	88.00	94.00	92.00	1.00	3.00	3.00	4.00
8	84.00	88.00	92.00	92.00	2.00	3.00	4.00	4.00
9	84.00	88.00	95.00	94.00	1.00	3.00	3.00	4.00
10	83.00	88.00	91.00	92.00	2.00	3.00	4.00	5.00
11	80.00	88.00	92.00	93.00	1.00	2.00	3.00	4.00
12	82.00	87.00	92.00	95.00	2.00	3.00	4.00	5.00
13	78.00	89.00	92.00	95.00	2.00	2.00	4.00	4.00
14	82.00	88.00	91.00	95.00	2.00	3.00	4.00	5.00
15	85.00	88.00	92.00	96.00	2.00	3.00	4.00	5.00
16	86.00	88.00	90.00	94.00	1.00	2.00	4.00	4.00
17	84.00	88.00	90.00	98.00	1.00	3.00	4.00	5.00
18	85.00	85.00	90.00	95.00	1.00	2.00	3.00	5.00
19	88.00	85.00	90.00	92.00	1.00	2.00	3.00	5.00
20	85.00	88.00	90.00	91.00	1.00	2.00	3.00	5.00
21	88.00	81.00	90.00	95.00	1.00	2.00	3.00	5.00
22	87.00	84.00	90.00	98.00	1.00	2.00	3.00	4.00
23	85.00	88.00	91.00	95.00	2.00	2.00	4.00	4.00

Figure 9. SPSS data view tab with sample data.

Once the data was entered into the system, SPSS was then ready to compute the statistical tests. Before computing the statistical tests, there was a need to check two assumptions. The first assumption, normality, must be verified to ensure the data represents a normal population. The normality test via a QQ-Plot will show if the data is linear or not thus providing a quick visual of normality.

Sphericity is the second assumption that must be verified before looking at the statistics. Sphericity (see Figure 17) will test whether the variances across the three training treatments are equal as well as the covariance between the pairs of conditions are equal. I used Mauchly's test statistic in SPSS to determine if $p > 0.05$. Homogeneity of variance was not required within this experiment because I have one group or population for all three treatments. Once the assumptions were satisfied, the repeated measures analysis was computed. However, if the assumptions were only partially satisfied, the analysis still proceeded but with the assumed risk of assumptions violations.

The repeated measures analysis is located under the *analyze, general linear model, repeated measures* category in SPSS. A dialogue box will pop up as shown in Figure 10.

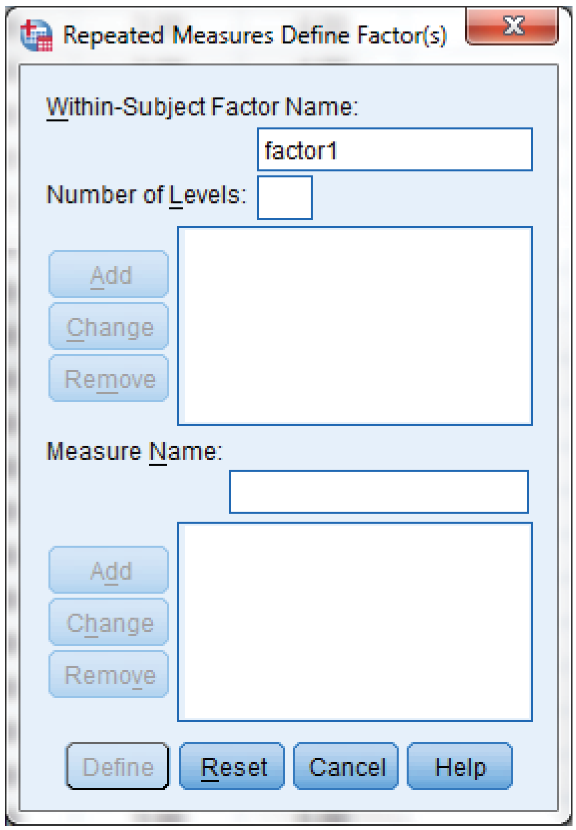


Figure 10. SPSS repeated measures dialogue box.

The first step was to fill in the number of levels for factor 1. In this experiment, there was a baseline and three levels. Thus, the input for *number of levels* is 4. Under *measure name*, the experiment had two outputs, yield and productivity. Thus, each of these outputs was added to the measure box. A screenshot with example data filled into the dialogue box is shown in Figure 11.

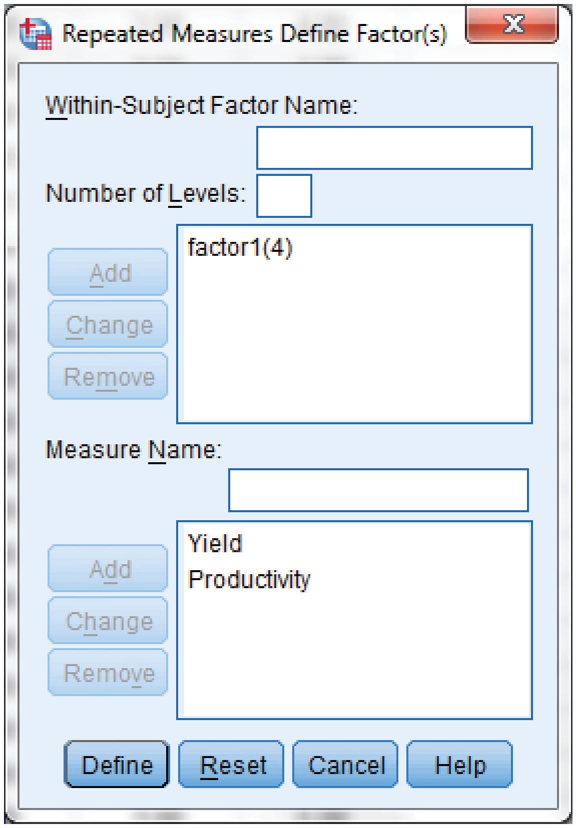


Figure 11. SPSS repeated measures factor definition screen.

Once the data was filled in the define factors screen, the next step was to click the define button. The screen shot in Figure 12 shows the dialogue box to link each within subjects variable previously defined in the variable view tab to the factor within the repeated measures study.

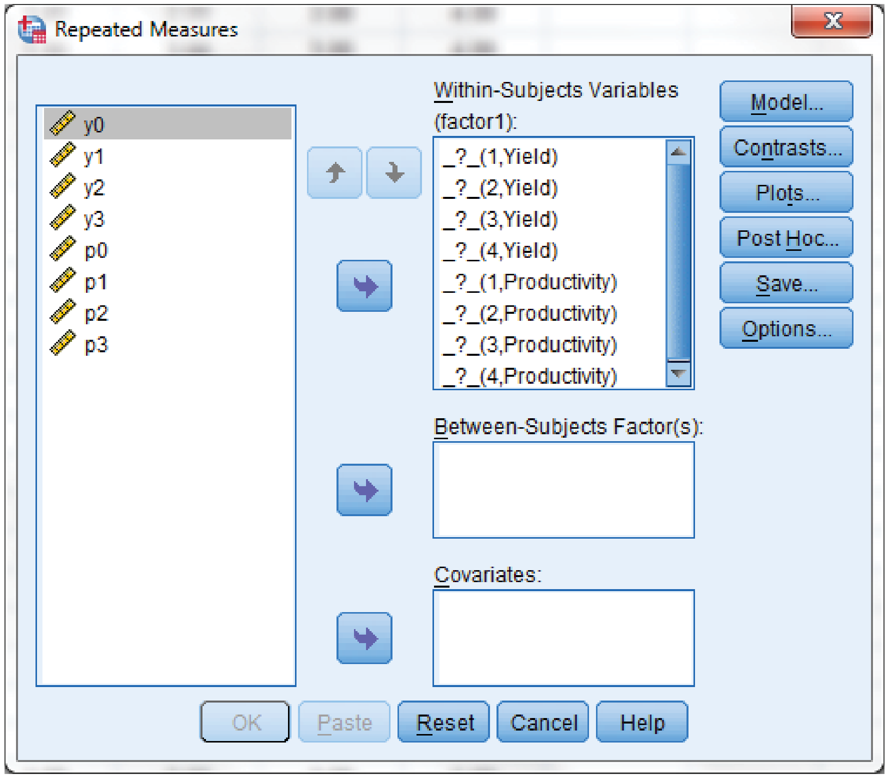


Figure 12. SPSS repeated measures variable linkage.

The next step was to link each variable to the measures within the repeated measures design. Figure 13 represents a screen shot of each defined measure.

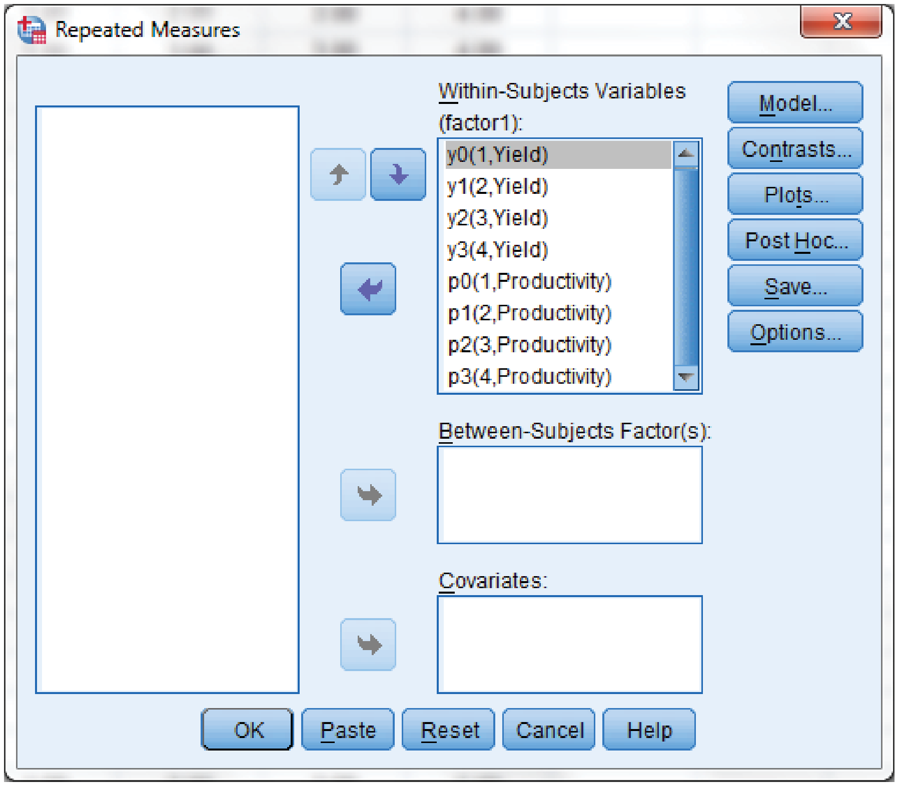


Figure 13. SPSS repeated measures variable linkage example.

Once the data was setup, the next step was to click the MODEL button to select the type of sum of squares analysis required for this experiment. The model type for this experiment will be either *type III* if there are not any missing cells or *type IV* if there are a few missing cells. SPSS utilized *type IV* to remove the data points with missing data from the computation. Figure 14 provides a screen shot of the model type selection screen.

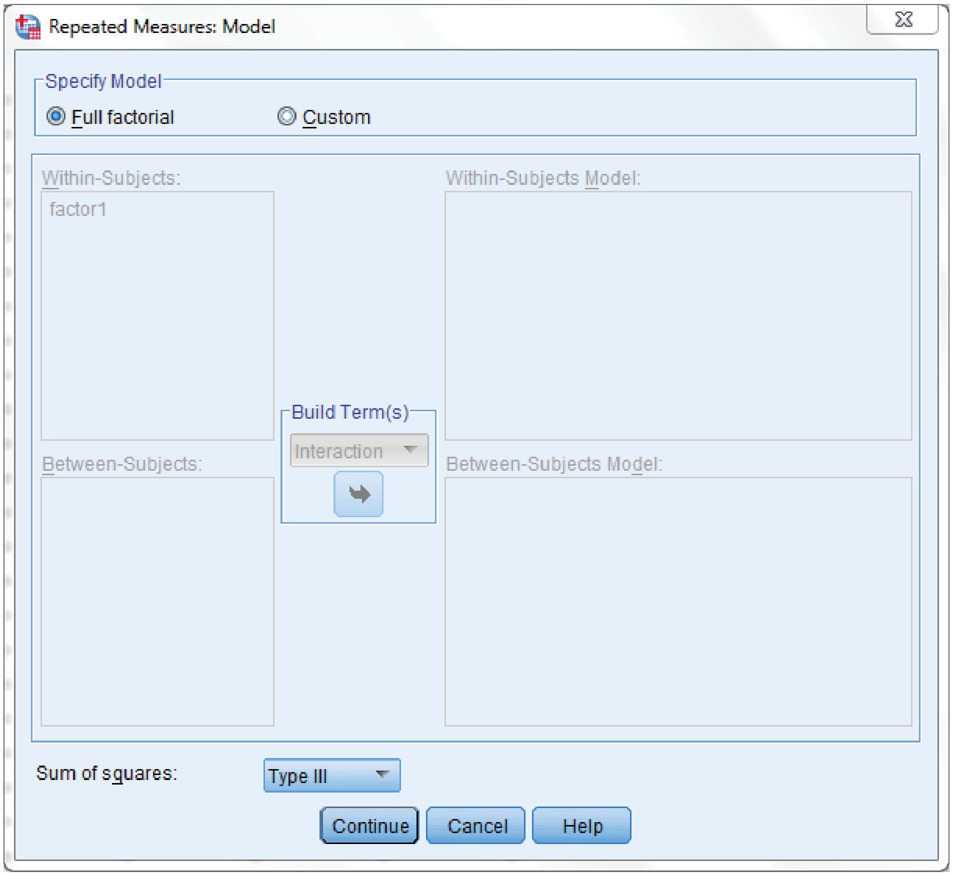


Figure 14. SPSS repeated measures model type selection screen.

Once the model was set to either type III or type IV, the next step was to click the CONTINUE button and then click on the CONTRASTS button. The contrast used for this experiment was repeated because, according to Field (2009), each category or treatment is compared against the previous category or treatment. Thus, select REPEATED from the drop down box and click the CHANGE button followed by the CONTINUE button. Figure 15 provides a screen shot of the contrast selection screen.

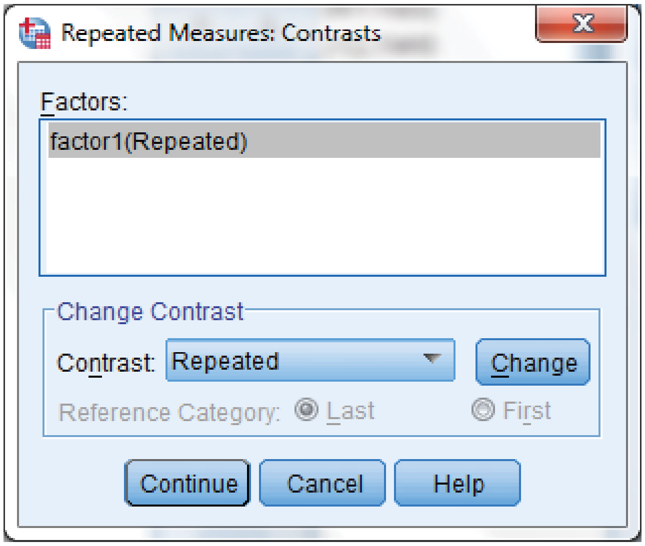


Figure 15. SPSS repeated measures contrasts selection screen.

After the contrast was selected, the next step was to determine the graphical plots to display. For this experiment, the plots showed each of the dependent variables in graphical form for each successive treatment. Figure 16 displays a screen shot of the plot dialogue box. To display a plot, select the factor and then select if the treatment category should be on the horizontal or vertical axis. Within this experiment, the treatment will be depicted on the horizontal axis to show the improvement trend over each successive treatment. Thus, to setup the correct plot, click to highlight the factor, then click the ➥ button next to the horizontal dialogue box, click the ADD button and then click the CONTINUE button.

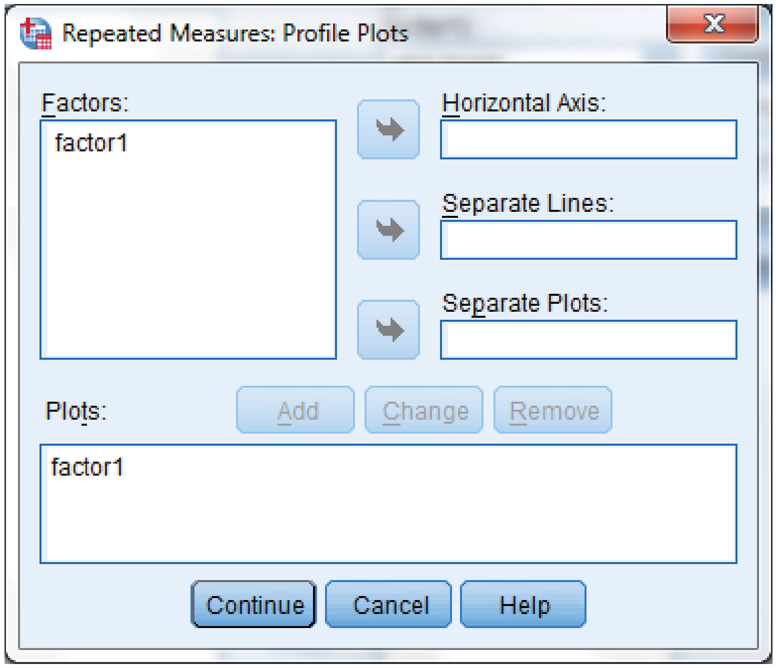


Figure 16. SPSS repeated measures profile plot selection screen.

For the post hoc dialogue box, SPSS does not provide any ability to conduct post hoc analysis while performing a multivariate study. Thus, the need for post hoc analysis was assessed once the initial analysis was completed in Chapter 4.

The final step before computing the data was to click on the OPTIONS button. The options include a series of displays to represent the data. For this experiment, the data was summarized using descriptive statistics, estimates of effect size, observed power, and sum of squares matrices. The significance level was set to 0.05 for a 95% confidence interval. Figure 17 displays the selection options in the *options* screen.

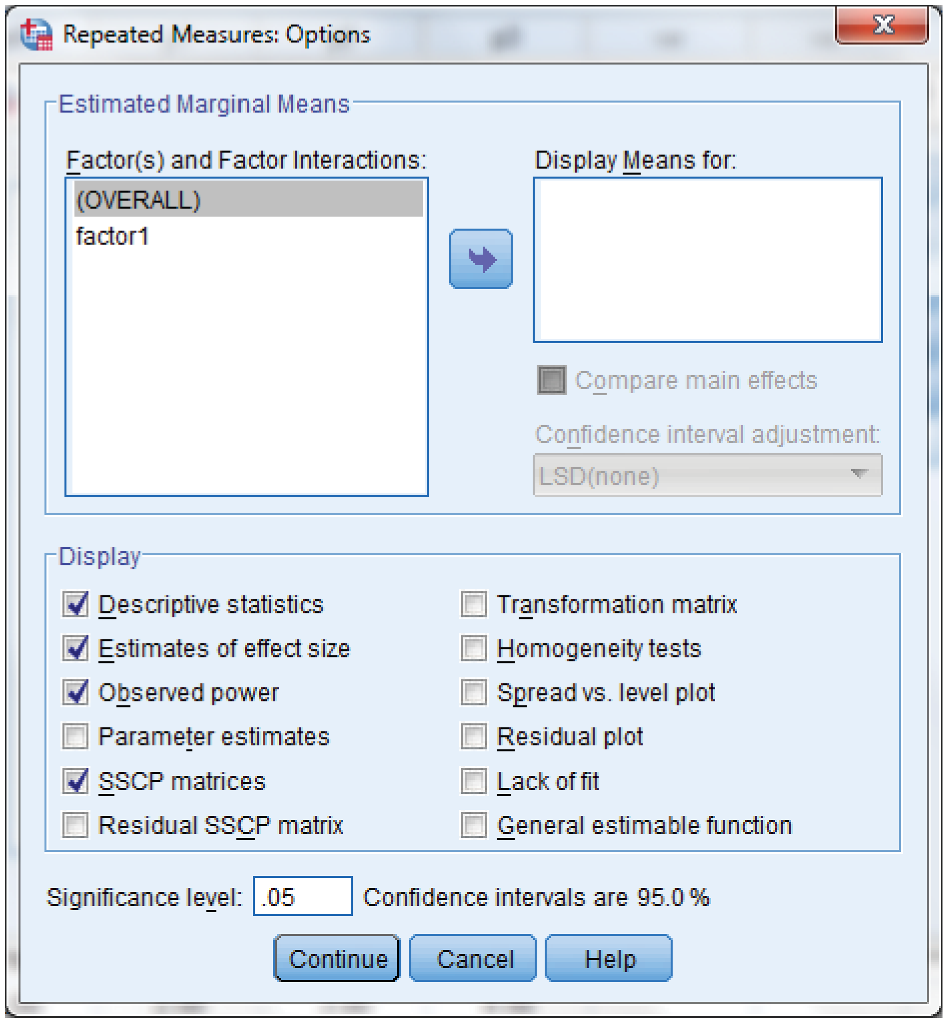


Figure 17. SPSS repeated measures options selection screen.

To display the metrics, click the OVERALL and then click the ➥ button to display the means of the overall. Next click the FACTOR, and then click the ➥ button to display the means of the factor. Finally, select the four displays as shown in Figure 23 and then click the CONTINUE button to start the analysis. Figures 18-24 represent a selection of the example output from SPSS. Figure 18 provides the factors for the within subjects design. Figure 19 provides the descriptive statistics for the example data. The basic statistics include the mean, standard deviation, and sample size for each factor and level within the experiment.

Within-Subjects Factors

Measure	factor1	Dependent Variable
Yield	1	y0
	2	y1
	3	y2
	4	y3
Productivity	1	p0
	2	p1
	3	p2
	4	p3

Figure 18. An example of SPSS output factors for the dependent variables.

Descriptive Statistics

	Mean	Std. Deviation	N
y0	84.1000	2.66922	90
y1	87.0222	1.81738	90
y2	91.1000	1.87862	90
y3	95.3111	2.11280	90
p0	1.3222	.49328	90
p1	2.4667	.60336	90
p2	3.2333	.42532	90
p3	4.2778	.45041	90

Figure 19. An example of SPSS output for descriptive statistics.

Figure 20 represents the multivariate output that includes the Pillai's trace, Wilk's Lambda, Hotellings trace, and Roy's largest root. According to Field (2009) Pillai's trace is defined as the proportion of variance in the combination of dependent variables that is explained by the independent variables. The larger the Pillai's trace value, the greater the difference among the treatments within the experiment. Wilk's lambda represents the proportion of variance in combination of dependent variables not accounted for by the independent variables. Wilk's lambda is the reciprocal of Pillai's Trace. Thus, small values of Wilk's lambda represent large differences among the treatments within the experiment. Hotelling's trace tests the mean differences between two groups. If there is not much error in the data, the Hotelling's trace is closely approximated by Pillai's trace. Roy's Largest root is the proportion of variance explained by the largest dependent variable. For more than two groups, and the assumption of homoscedasticity or the assumption that all independent variables within the experiment have the same variance, is not met, then Pillai's trace is recommended as the most robust test statistic.

Multivariate Tests

Within Subjects		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Factor 1	Pillai's Trace	.975	84.63	6.00	534	0.000	.487	507.8	1.000
	Wilks' Lambda	.070	246.47	6.00	532	0.000	.735	1478.8	1.000
	Hotelling's Trace	12.646	558.53	6.00	530	0.000	.863	3351.1	1.000
	Roy's Largest Root	12.595	1120.96	3.00	267	0.000	.928	3362.9	1.000

Figure 20. An example of multivariate test output.

Mauchly's Test of Sphericity

						Epsilon		
Within Subjects Effect	Measure	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Factor 1	Productivity	0.904	8.899	5	0.113	0.938	0.972	0.333
	Yield	0.789	20.8	5	0.001	0.859	0.887	0.333

Figure 21. An example of SPSS Mauchly's test of sphericity output

Before utilizing the F-statistic and running the model, each treatment of the independent variable needed to be approximately normally distributed. Further, the data must be tested for sphericity to determine if the variances for each treatment set of scores are equal. (Dunn and Clark, 1987) Figure 21 is an example of the sphericity output in SPSS. The SPSS program will help the researcher to determine if the data meets both normality and sphericity assumptions.

Once the data was considered normal and spherical the contrasts were tested using the F- statistic to show significance. As shown in Figure 22, the contrasts provide some detail to determine the differences between the levels or treatments. The output showed if there were any significant differences between one treatment and the next. Once complete, the final step was to conduct a post-hoc analysis to determine which of the two outcomes was most significant. For MANOVA, the F-test was repeated within SPSS to calculate the test statistic based on the different outcomes.

Tests of Within-Subjects Contrasts

Source	Measure	Factor 1	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Factor 1	Productivity	Level 1 vs. Level 2	768	1	768	62	.000	.414	62	1.000
		Level 2 vs. Level 3	1496	1	1496	211	.000	.704	211	1.000
		Level 3 vs. Level 4	1596	1	1596	170	.000	.657	170	1.000
	Yield	Level 1 vs. Level 2	117	1	117	190	.000	.681	190	1.000
		Level 2 vs. Level 3	52	1	52	111	.000	.557	111	1.000
		Level 3 vs. Level 4	98	1	98	314	.000	.779	314	1.000
	Productivity	Level 1 vs. Level 2	1086	89	12					
		Level 2 vs. Level 3	630	89	7					
		Level 3 vs. Level 4	834	89	9					
	Yield	Level 1 vs. Level 2	55	89	.619					
		Level 2 vs. Level 3	42	89	.473					
		Level 3 vs. Level 4	27	89	.313					

Figure 22. An example of SPSS tests of within-subjects contrasts output.

Reliability and Validity

The reliability of the data was guaranteed by the method of collection. Specifically, the use of an enterprise resource planning tool to extract the data does not allow for any variance in data collection. The workers are all trained to log on and log off of each job in a manner that allows the company to charge for hours worked. These procedures are set and the quality department confirms on a quarterly basis that the operators are logging appropriately. The quality of the units was reviewed in inspection and test stations after each process step within the operation. While the inspection stations require human interaction and can cause some variability, the test stations optically check all aspects of the product quality to ensure no bad units were passed on through the process. Thus, the test stations act as a check to protect against false positives at the inspection stations. The data at the test stations were checked against the findings at the inspection stations to ensure I have a complete picture of quality for the product.

The validity was maintained by employing the training to all workers within the same manufacturing environment. All areas show the same issues in terms of material handling defects, contamination defects, and equipment readiness defects. Correlating the effects of three overarching training treatments on the workers within this work environment provided the validity necessary. Thus, both reliability and validity were considered and the experimental design protected against unreliable and invalid results.

Participant Protection

Before the data collection phase, an application for conduct of the study was submitted to the Walden University Institutional Review Board (IRB). In addition, a signed company permission statement was obtained from the President of the company to gain access to the workforce. To protect participants' privacy, an observation ID number was used. The names of the subjects were neither collected nor shared. Even though there was no name association to any of the data collected, any retained information regarding this study will be kept in a locked file cabinet for up to seven years and all digital archival data will be password protected.

Summary

Chapter 3 provided the method for this study which included the treatments, measures, and data collection plan. The analytical procedure was highlighted next using MANOVA as the statistical procedure for this study. Comparison of each treatment on the dependent variables was made within this study. A statement on the participant protection was provided to note the confidentiality of all participants within the study. Although there was a need to record those trained within the quality management system, the individual names or employee ID's were not noted as part of this study.

Chapter 4: Results

Introduction

The purpose of this quantitative study was to see whether gains in performance were achieved by implementing standard work practices and a specialized training plan in an environment where quality is critical. The purpose of this chapter is to provide the results of this research, how the data was prepared for statistical analysis, and the statistical evaluation of the training treatments. I will answer the main research question: Can improvements in training practices and standardized work improve key performance outcomes in a highly customized, low volume manufacturer? The three predetermined work practices for this study are foreign material contamination, material handling, and equipment malfunction prevention. The two dependent variables are process yield and productivity. RQ_1 examined whether workers in a highly customized job shop manufacturing environment can improve quality and productivity levels through an improved training protocol and enhanced work practices. RQ_2 examined whether the three training treatments impact the two outcomes of quality and performance. RQ_3 examined which of the three training treatments will have the greatest impact on the outcomes. RQ_4 examined which of the two outcomes is more influenced by the three training treatments. A Repeated Measures MANOVA analysis was used to answer the four research questions.

Data Preparation

For a repeated measures design, the first step was to determine which of the participants went through all three company-sponsored training treatments. Removing missing data ensured that there were no inconsistencies when looking at the impact of each training treatment on the two quality outcomes of process yield and productivity. Table 6 provided a summary of the participation in *each* training treatment as well as a summary of participation in *all three* training treatments. A detailed list of participant data is provided in Appendix B.

Table 6

Summary of Training Participation

	Contamination Control (T_1)	Material Handling (T_2)	Equipment Readiness (T_3)	Full Participation ($T_1 + T_2 + T_3$)
n	232	232	232	232
Number Trained	183	185	169	126
Percent Trained	79%	80%	73%	54%

According to Table 7, there were 232 participants. Participation in the contamination control training (T_1) totaled 189 or 79% of the total population. Participation in the material handling training (T_2) totaled 185 or 80% of the total population. Participation in the equipment readiness training (T_3) totaled 169 participants or 73% of the total population. Considering that the repeated measures design can use data only from participants who went through all three training treatments, the combined participation for completing all three training treatments ($T_1 + T_2 + T_3$) totaled 126 or 54% of the total population. The quality and productivity data for those who did not participate in all three training exercises was discarded for the remainder of the analysis. If the sample size required to achieve a 95% confidence level for this study was 86, a sample size of 126 was more than adequate to proceed.

Additionally, all data entered into MANOVA must first meet the requirements of normality. If the data is not normal going into the MANOVA statistical test, then there is a greater risk of error when interpreting the results of this study. Table 7 shows the descriptive statistics for the original data set $N = 126$.

Table 7

Descriptive Statistics for Original Data Set

	Descriptive Statistics		
Training Level	Mean	Std. Dev.	N
P_0	4.8	2.17	126
P_1	3.5	1.69	126
P_2	2.4	1.01	126
P_3	3.6	1.54	126
Y_0	98.87	2.26	126
Y_1	98.92	2.09	126
Y_2	99.07	1.62	126
Y_3	99.39	1.21	126

From Table 7, the productivity mean scores degrade over the first two treatments from the baseline with an improvement in the final treatment. The process yield mean scores show improvement after each successive treatment. The standard deviation scores also show slight improvement in both productivity and process yield suggesting the variance has decreased. To determine if the productivity data represents a normal curve, a series of histograms are shown in Figures 23-26 representing the original data set in Appendix C.

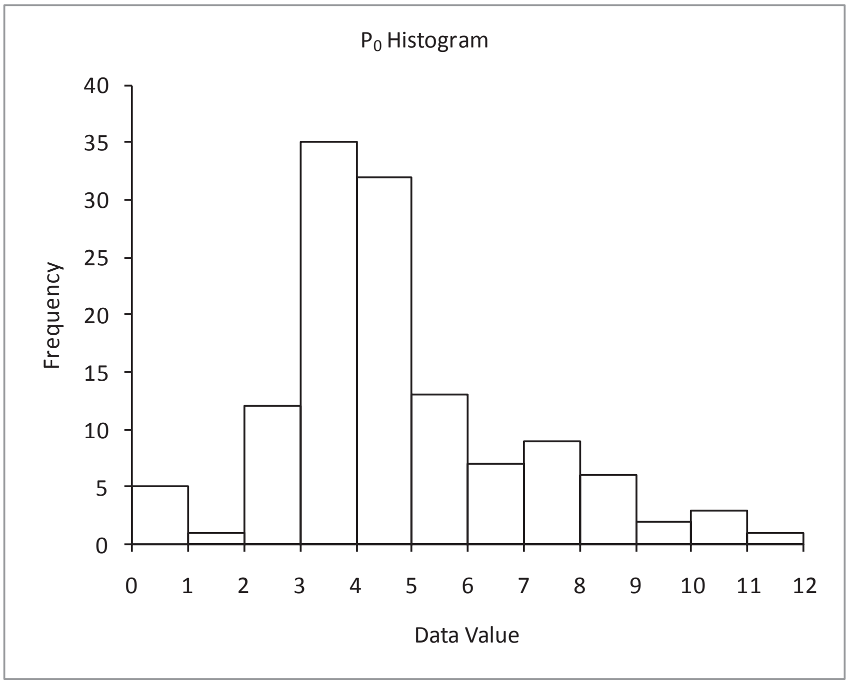


Figure 23. Histogram for the baseline productivity data (P_0).

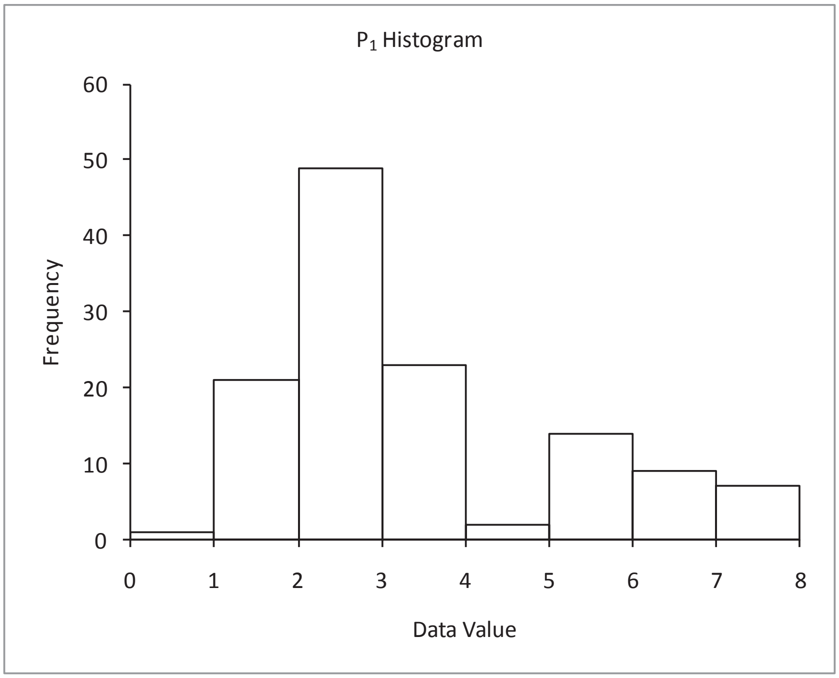


Figure 24. Histogram for the first treatment productivity data (P_1).

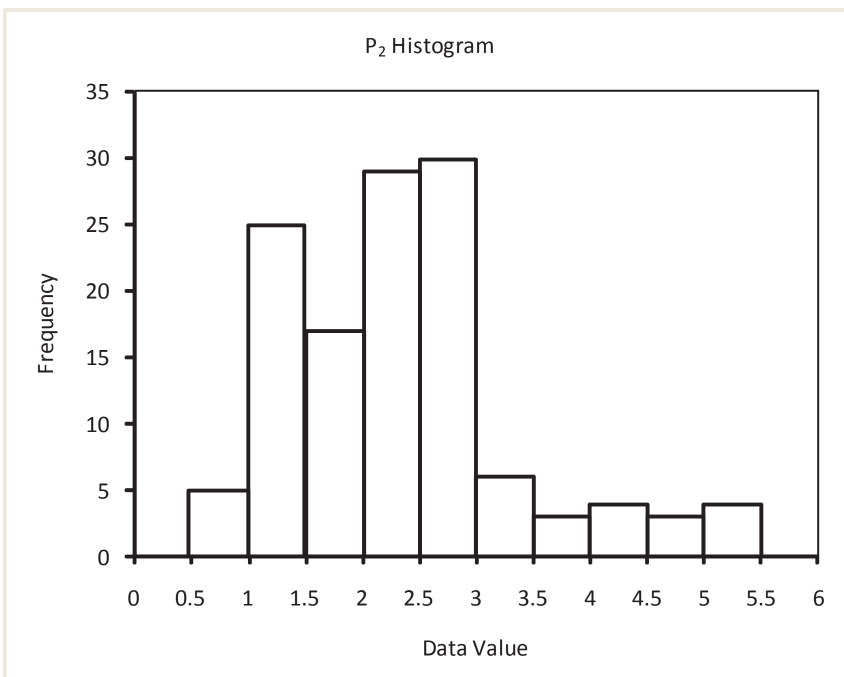


Figure 25. Histogram for the second treatment productivity data (P_2).

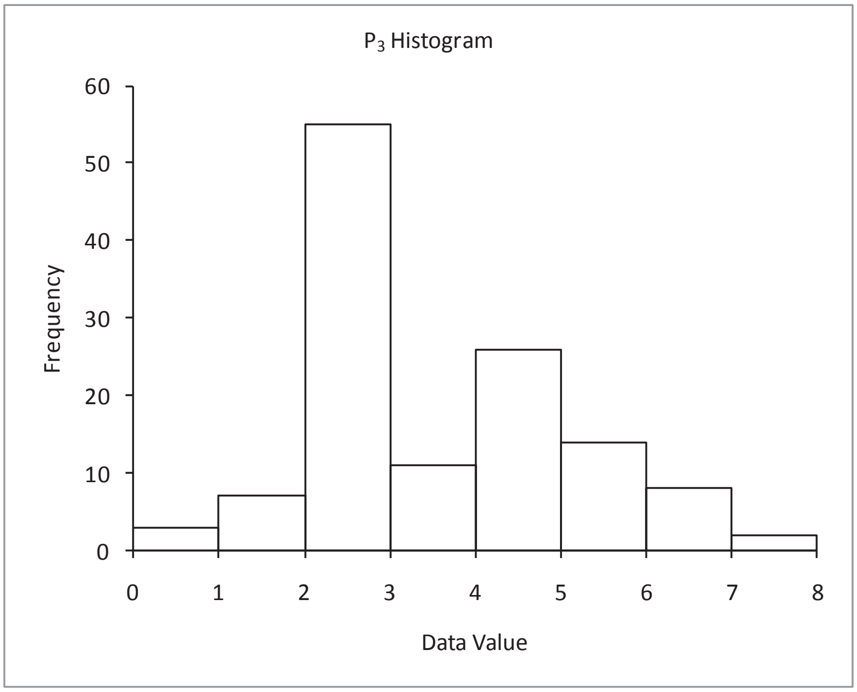


Figure 26. Histogram for the third treatment productivity data (P_3).

The histograms for the productivity data show there is some minor skewness and kurtosis in the data. The data in Table 8 provides a summary of skewness and kurtosis for the baseline productivity (P_0) and each subsequent training productivity (P_1,P_2,P_3). Skewness is a measure of symmetry to determine if the data looks symmetrical from left to right on a normal distribution plot. Kurtosis provides an understanding of how peaked or flat the curve is within the data set on a normal distribution plot.

Table 8

Summary of Skewness and Kurtosis for Productivity

Process Yield		Statistic	Standard Error	z-score
Yo	Skewness	0.876	0.216	4.056
	Kurtosis	0.834	0.428	1.949
Y1	Skewness	0.999	0.216	4.625
	Kurtosis	-0.211	0.428	-0.493
Y2	Skewness	0.911	0.216	4.218
	Kurtosis	0.788	0.428	1.841
Y3	Skewness	0.573	0.216	2.653
	Kurtosis	0.684	0.428	1.598

The productivity data shows approximate normality for the baseline T_0 with a skewness of 0.836 (*SE* = 0.216) and a kurtosis of 0.834 (*SE* = 0.428), after training treatment T_1 with a skewness of -0.999 (*SE* = 0.216) and a kurtosis of -0.211 (*SE* = 0.428), after training treatment T_2 with a skewness of 0.911 (*SE* = 0.216) and a kurtosis of 0.788 (*SE* = 0.428) and after training treatment T3, with a skewness of 0.573 (*SE* = 0.216) and a kurtosis of -0.684 (*SE* = 0.428). All four productivity data sets show a small positive skewness indicating a slight skew to the right of the data set. Further, all four productivity data sets show a close to normal kurtosis.

The following Q-Q plots in Figures 27-30 represent the productivity data and are consistent with the findings that the productivity data exhibits a close approximation to normal.

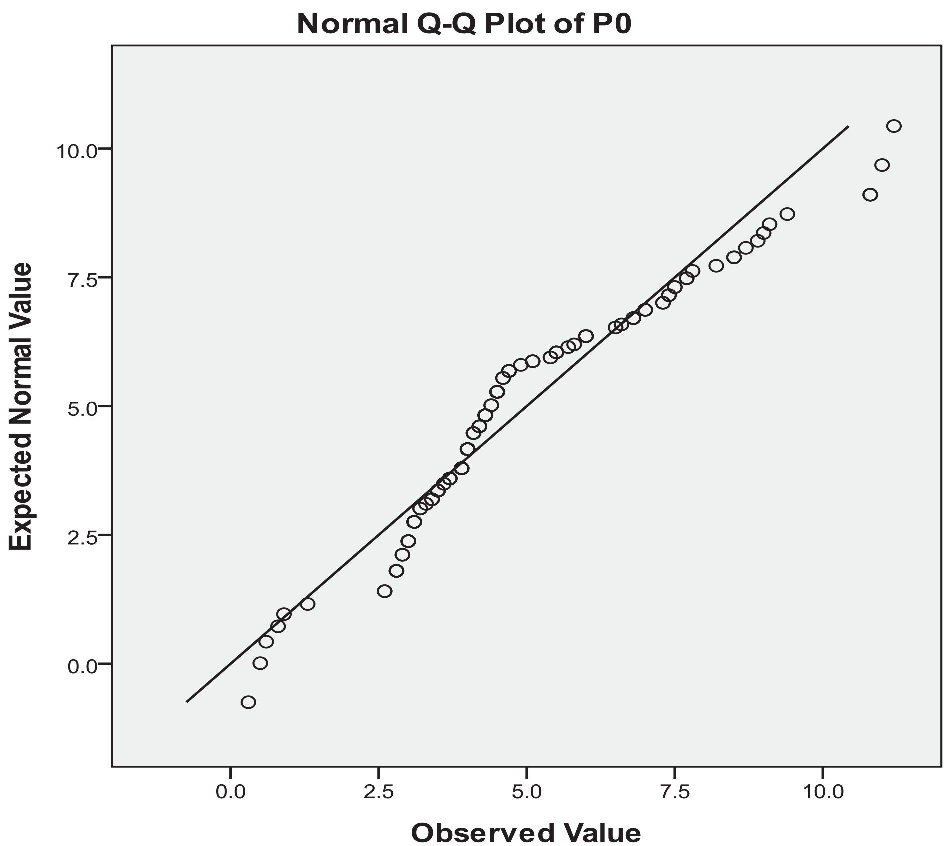


Figure 27. Q-Q Plot for the baseline productivity data (P_0).

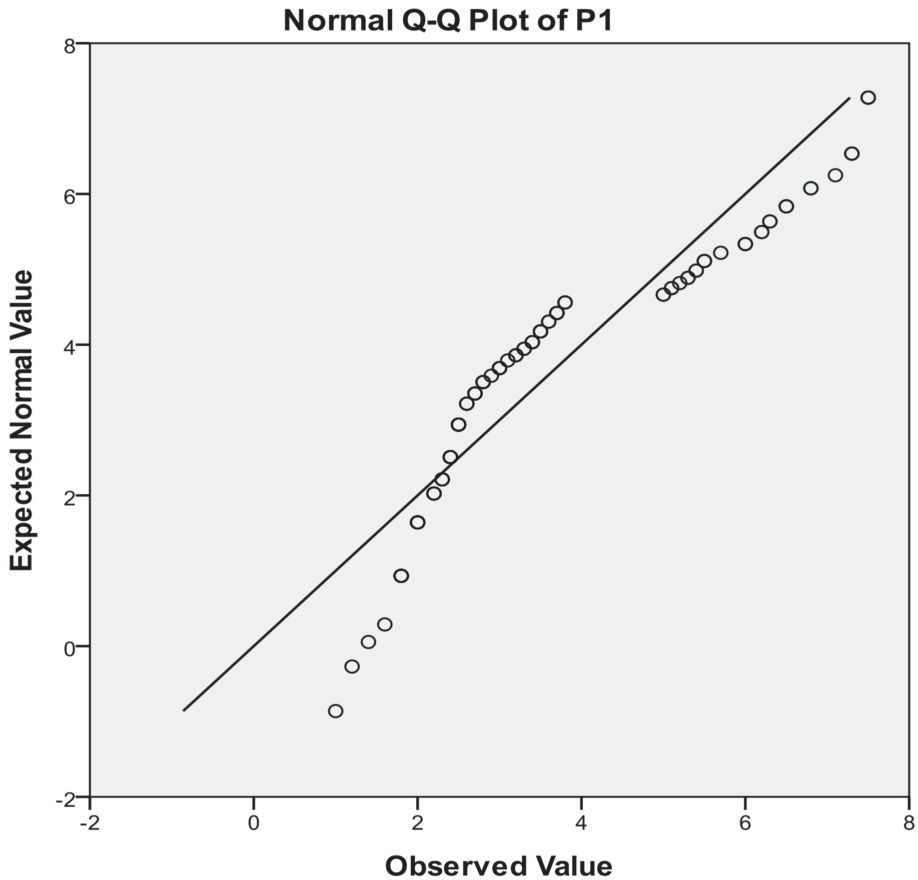


Figure 28. Q-Q Plot for the first treatment productivity data (P_1).

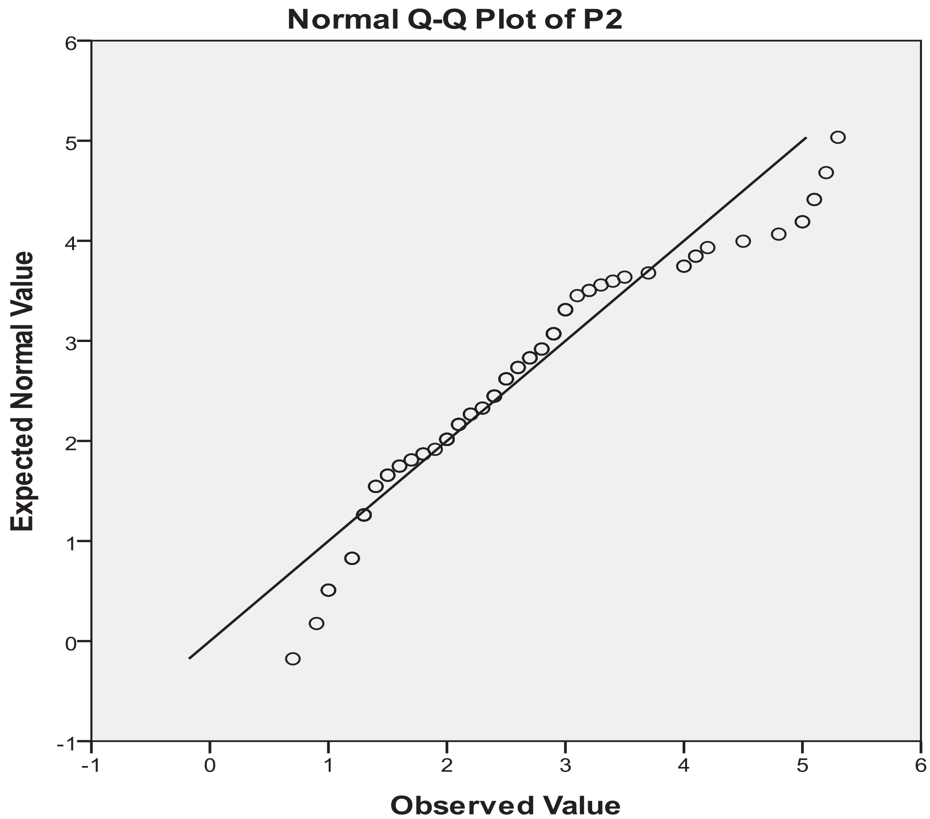


Figure 29. Q-Q Plot for the second treatment productivity data (P_2).

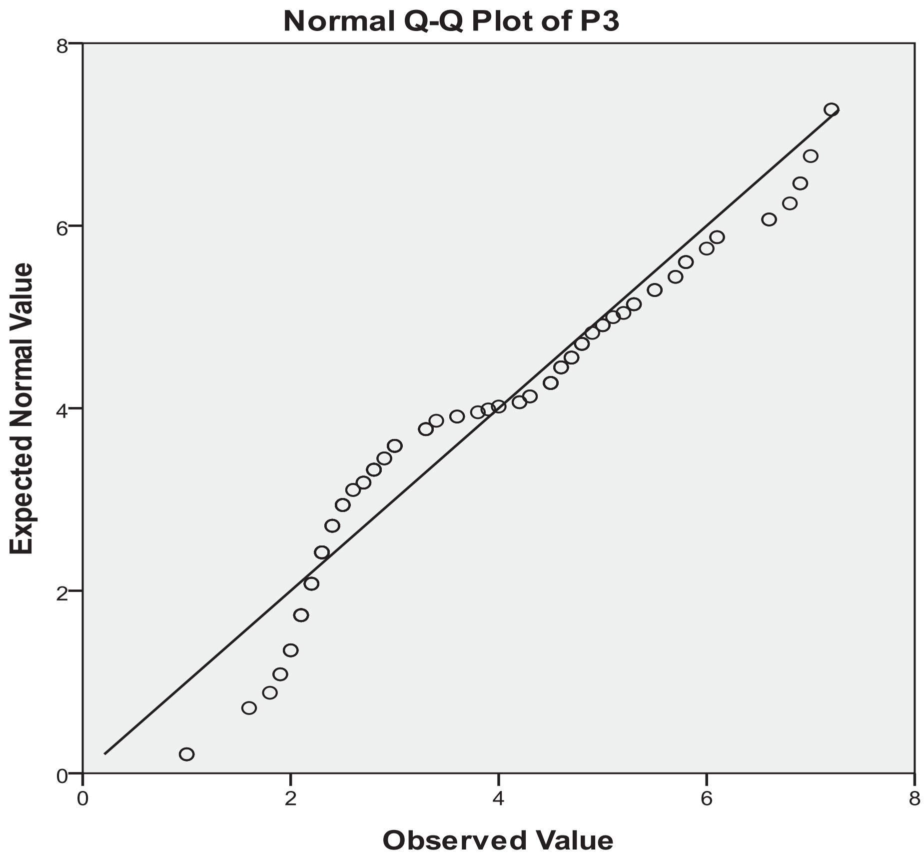


Figure 30. Q-Q Plot for the third treatment Productivity data (P_3).

To determine if the process yield data represents a normal curve, a series of histograms are shown in Figures 31-34.

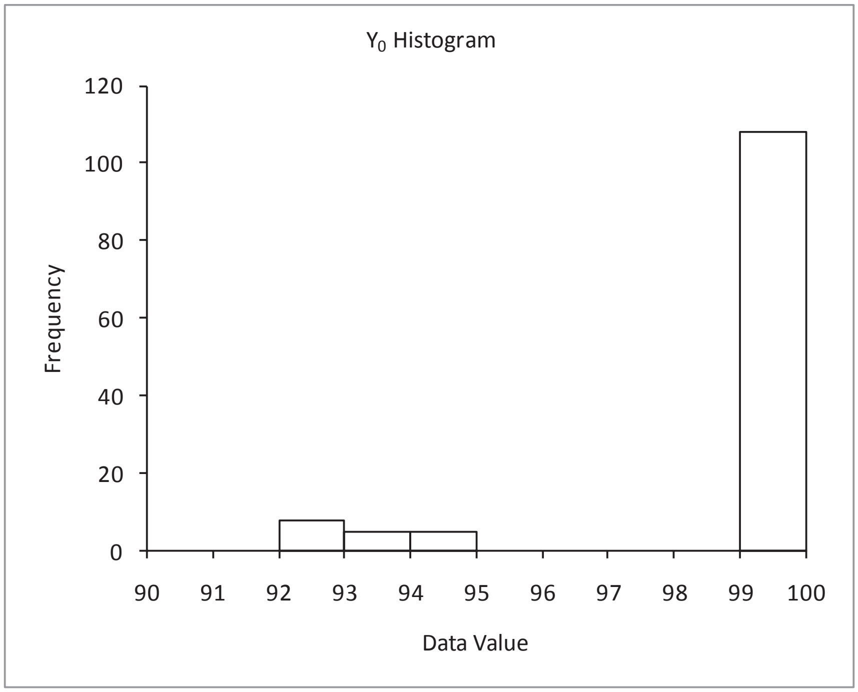


Figure 31. Histogram for the baseline process yield data (Y_0).

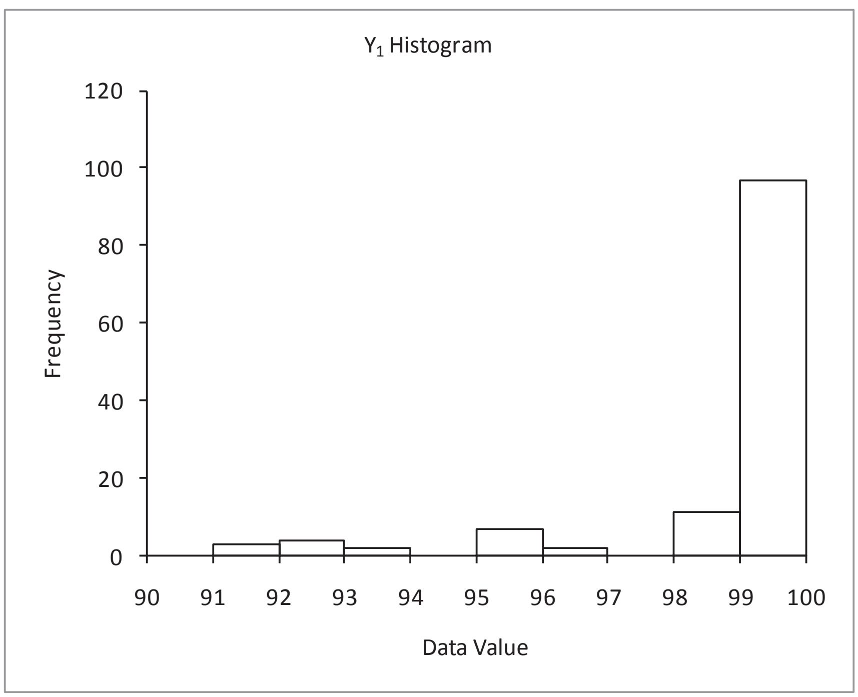


Figure 32. Histogram for the first treatment process yield data (Y_1).

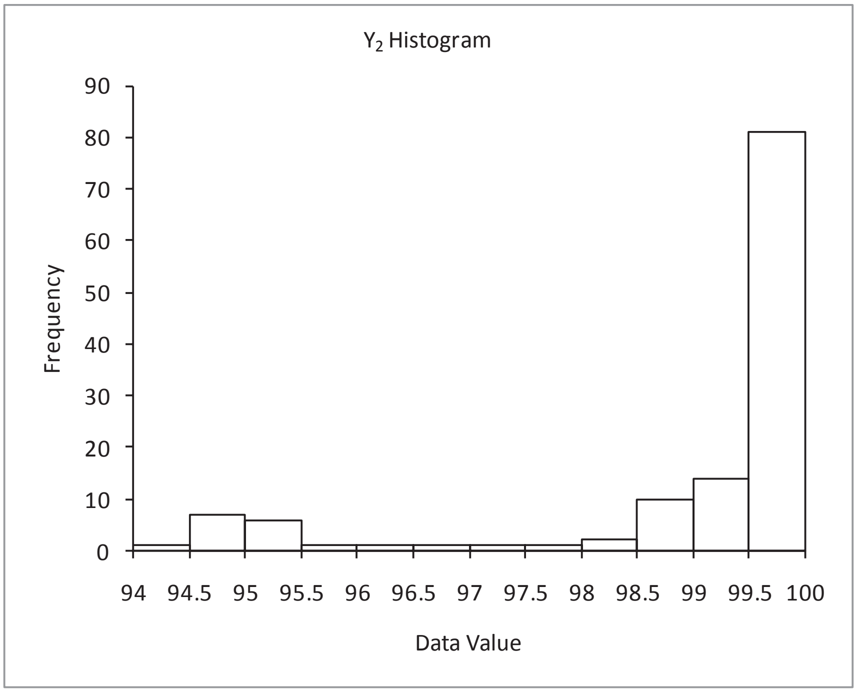


Figure 33. Histogram for the second treatment process yield data (Y_2).

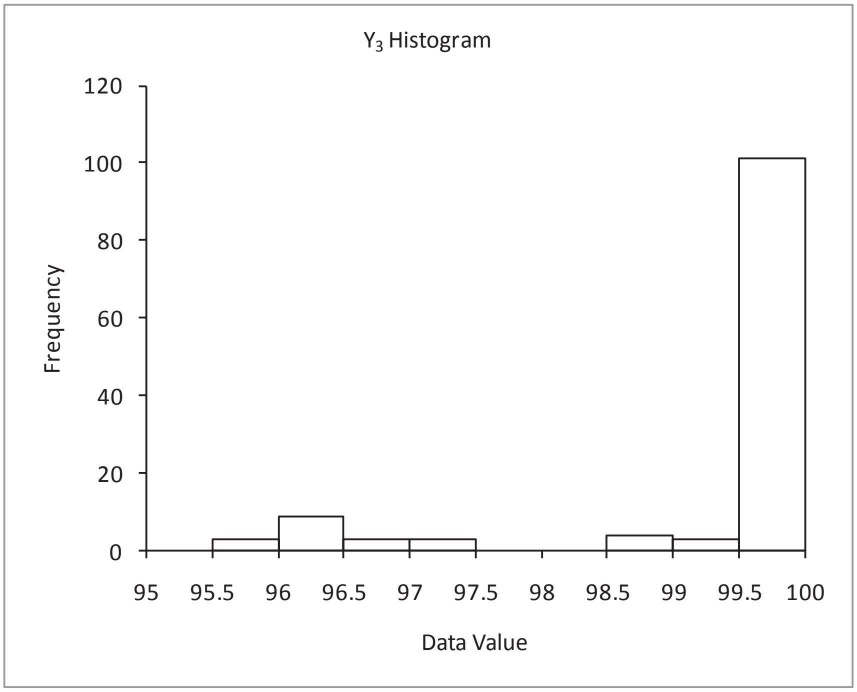


Figure 34. Histogram for the third treatment process yield data (Y_3).

The histograms for the process yield data show there was strong skewness in the data. The data in Table 9 provides a summary of skewness and kurtosis for the baseline process yield (Y_0) and each subsequent training process yield (Y_1,Y_2,Y_3).

Table 9

Summary of Skewness and Kurtosis for Process Yield

Process Yield		Statistic	Standard Error	z-score
Yo	Skewness	-2.077	0.216	-9.616
	Kurtosis	2.485	0.428	5.806
Y1	Skewness	-2.298	0.216	-10.639
	Kurtosis	4.087	0.428	9.549
Y2	Skewness	-1.955	0.216	-9.051
	Kurtosis	2.309	0.428	5.395
Y3	Skewness	-2.022	0.216	-9.361
	Kurtosis	2.43	0.428	5.678

Note. The z-scores were derived by dividing the statistic into the standard error.

The process yield data shows non normality for the baseline T_0 with a skewness of -2.077 (*SE* = 0.216) and a kurtosis of 2.485 (*SE* = 0.428), after training treatment T_1 with a skewness of -2.298 (*SE* = 0.216) and a kurtosis of 4.087 (*SE* = 0.428), after training treatment T_2 with a skewness of -1.955 (*SE* = 0.216) and a kurtosis of 2.309 (*SE* = 0.428) and after training treatment T3, with a skewness of -2.022 (*SE* = 0.216) and a kurtosis of 2.43 (*SE* = 0.428). All four process yield data sets show a significant negative skewness indicating a significant skew to the left of the data set. Further, all four process yield data sets show significant positive kurtosis. The following Q-Q plots in Figures 35-38 represent the process yield data and is consistent with the findings that the process yield data exhibits non normality and requires a closer review for outliers.

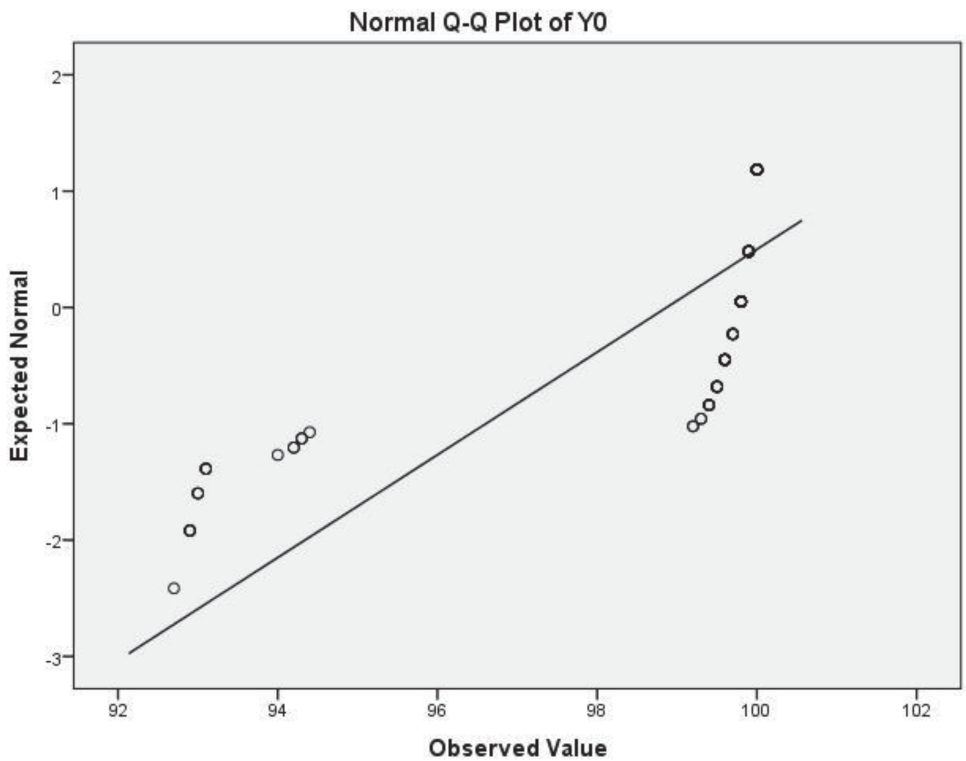


Figure 35. Q-Q Plot for the baseline process yield data (Y_0).

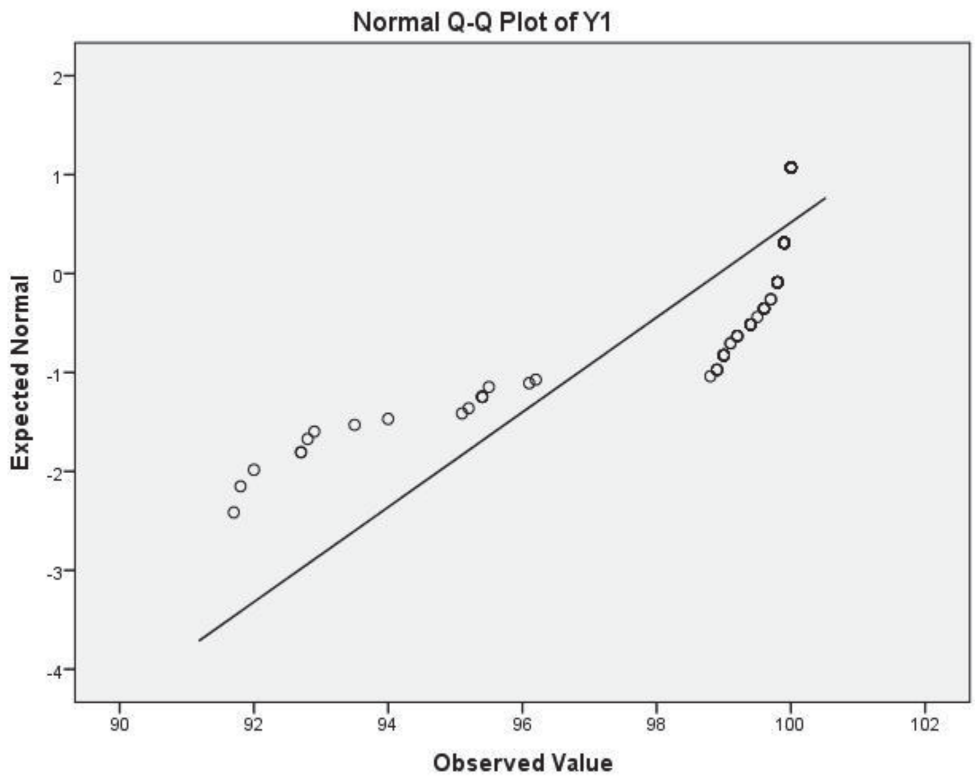


Figure 36. Q-Q Plot for the first treatment process yield data (Y_1).

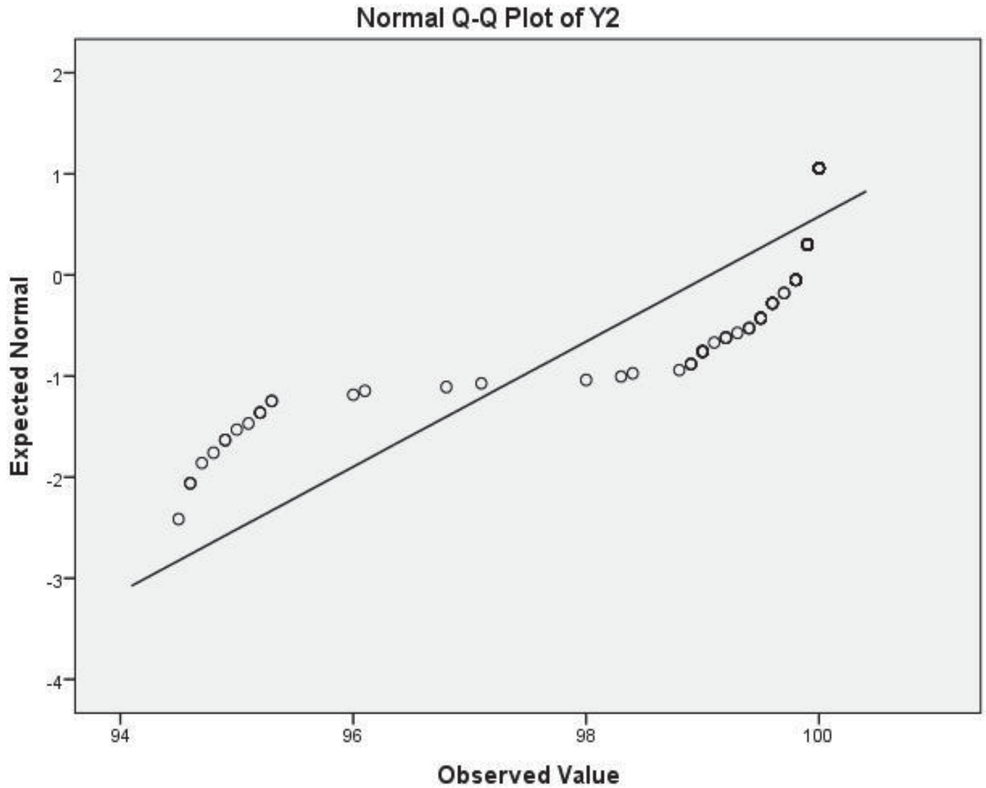


Figure 37. Q-Q Plot for the second treatment process yield data (Y_2).

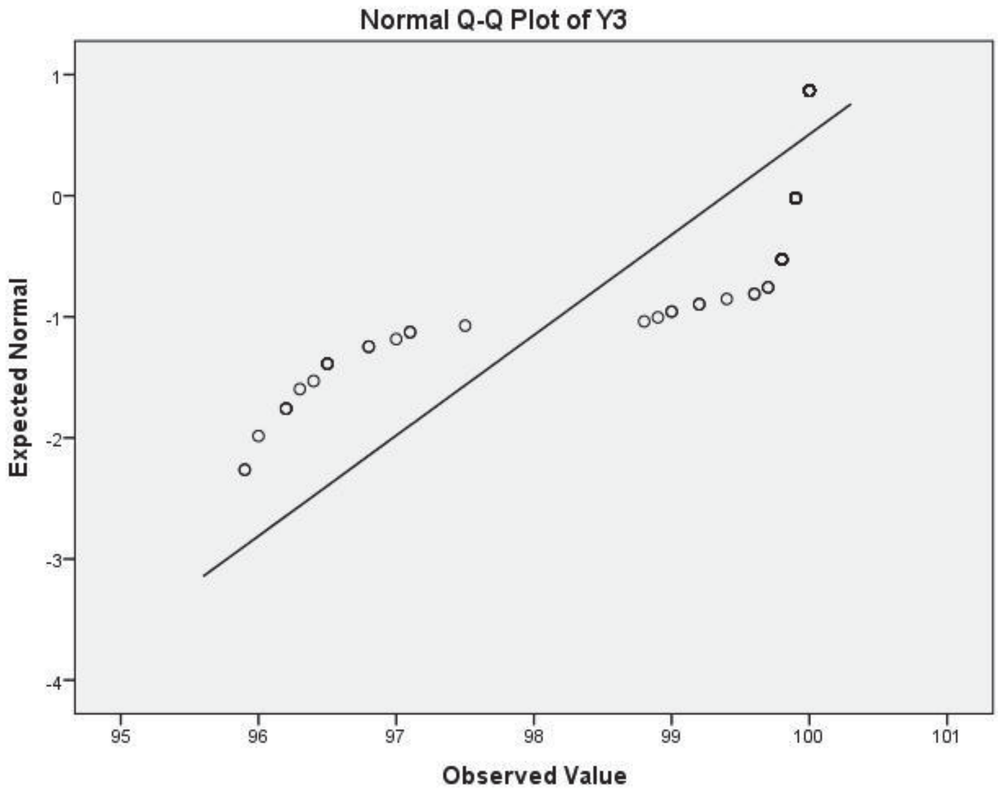


Figure 38. Q-Q Plot for the third treatment process yield data (Y_3).

When reviewing the Q-Q plot for normality, the basic outcomes for all four plots show a non-linear fit. The non-linear fit is consistent with the skewness findings that there was an issue with normality within the data set. A box plot for the process yield data set in Figure 39 was used to determine if there were outliers within the data.

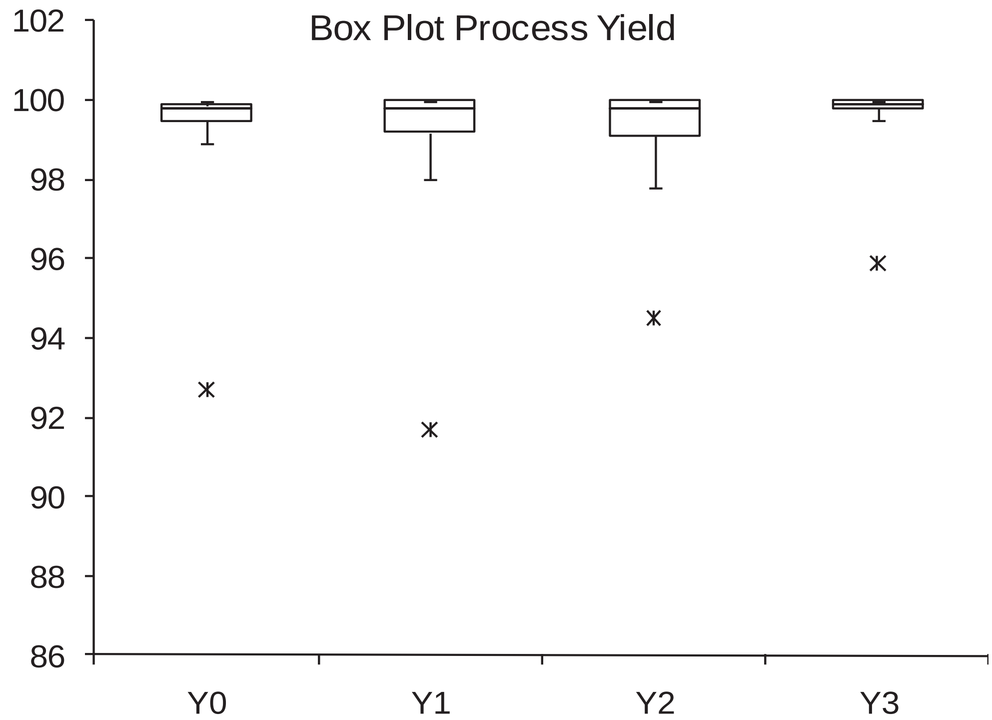


Figure 39. Box plot for the process yield data set.

The box plot indicates there were outliers in the baseline and in each subsequent training treatment. Table 10 provides the statistical detail for the box plot. Any data points that fall below $Q_1 - 1.5 * IQR$ or above $Q_3 + 1.5 * IQR$ are considered outliers. Q_1 represents the 25% %quartile, Q_3 represents the 75 percent quartile and IQR represents the interquartile range or Q_3-Q_1.

Table 10

Summary of Box Plot Process Yield Statistics

Box Plot Summary Statistics				
Labels	Y_0	Y_1	Y_2	Y_3
Min	92.7	91.7	94.5	95.9
Q_1	99.5	99.2	99.125	99.8
Median	99.8	99.8	99.8	99.9
Q_3	99.9	100	100	100
Max	100.0	100.0	100.0	100.0
IQR	0.4	0.8	0.875	0.2
Upper Outliers	0	0	0	0
Lower Outliers	18	18	18	25

Table 10 suggests there were 18 lower outliers for the baseline and the first two treatments and 25 outliers in the final treatment. When reviewing the box plots and the raw process yield data in Appendix C, the first 18 data points exhibiting lower process yield scores are from the final test at the end of the manufacturing process. After further evaluation, the first 18 process yield data points shown in table 11 are from the end-of-line test area which catches defects before the product is packed and shipped to the customer. The process yield at the end-of-line step averages 93.4% whereas the rest of the process sectors exhibit an average process yield of greater than 99%.

Table 11

Summary of First 18 Data Points

Subject	Y0	Y1	Y2	Y3
S1	93.1	95.2	94.7	96.5
S2	92.9	95.4	94.6	97.1
S3	93.0	95.5	97.1	97.5
S4	93.0	95.4	95.2	96.4
S5	92.9	95.1	94.8	96.5
S6	92.9	95.4	95.3	96.8
S7	93.1	96.1	96.1	96.5
S8	93.1	93.5	96.0	96.8
S9	92.9	94.0	94.9	95.9
S10	93.0	95.4	95.2	96.5
S11	94.3	91.8	95.0	96.2
S12	94.2	92.0	96.8	96.3
S13	94.4	92.7	95.3	96.0
S14	94.2	96.2	94.6	96.2
S15	94.3	91.7	95.2	96.2
S16	94.0	92.7	94.5	95.9
S17	93.1	92.8	95.1	97.0
S18	92.7	92.9	94.9	97.1
Average	93.39	94.10	95.29	96.52
Std. Dev.	0.62	1.58	0.74	0.45
Yield Loss	6.61	5.90	4.71	3.48

The disparity in process yield data from the first 18 data points to the rest of the data must be addressed because the yield fall out did not originate from the final test area. Thus, the first 18 data points were removed from the initial data set to allow for a revised normality test.

However, there was noticeable improvement in the end-of-line mean scores with relatively consistent variance from one treatment to the next. Thus, I returned to the first 18 data points as a supplemental analysis later on in the study. Repeating the original exercise with 108 data points, the summary of skewness is shown in Table 12. The Q-Q Plots show the productivity data set in Figures 40-43 after removing the end-of-line data. The raw productivity data detail is located in Appendix E.

Table 12

Summary of Skewness and Kurtosis of Productivity Data for N = 108

Productivity		Statistic	Standard Error	z-score
P_0	Skewness	0.71	0.233	3.047
	Kurtosis	0.989	0.461	2.145
P_1	Skewness	0.918	0.233	3.940
	Kurtosis	-0.396	0.461	-0.859
P_2	Skewness	0.91	0.233	3.906
	Kurtosis	1.001	0.461	2.171
P_3	Skewness	0.425	0.233	1.824
	Kurtosis	-0.655	0.461	-1.421

Note. The z-scores were derived from dividing the statistic into the standard error.

Productivity data are approximately normally distributed for the baseline (P_0) with a skewness of 0.71 (*SE* = 0.233) and a kurtosis of 0.989 (*SE* = 0.461), after training treatment 1 with a skewness of 0.918 (*SE* = 0.233) and a kurtosis of -0.396 (*SE* = 0.461), after training treatment 2 with a skewness of 0.91 (*SE* = 0.233) and a kurtosis of 1.001 (*SE* = 0.461), and after training treatment 3, with a skewness of 0.425 (*SE* = 0.233) and a kurtosis of -0.655 (*SE* = 0.461). The skewness was expected based on the production variability within the process. The Q-Q plots for productivity in Figures 35-38 visually represent a normal approximation.

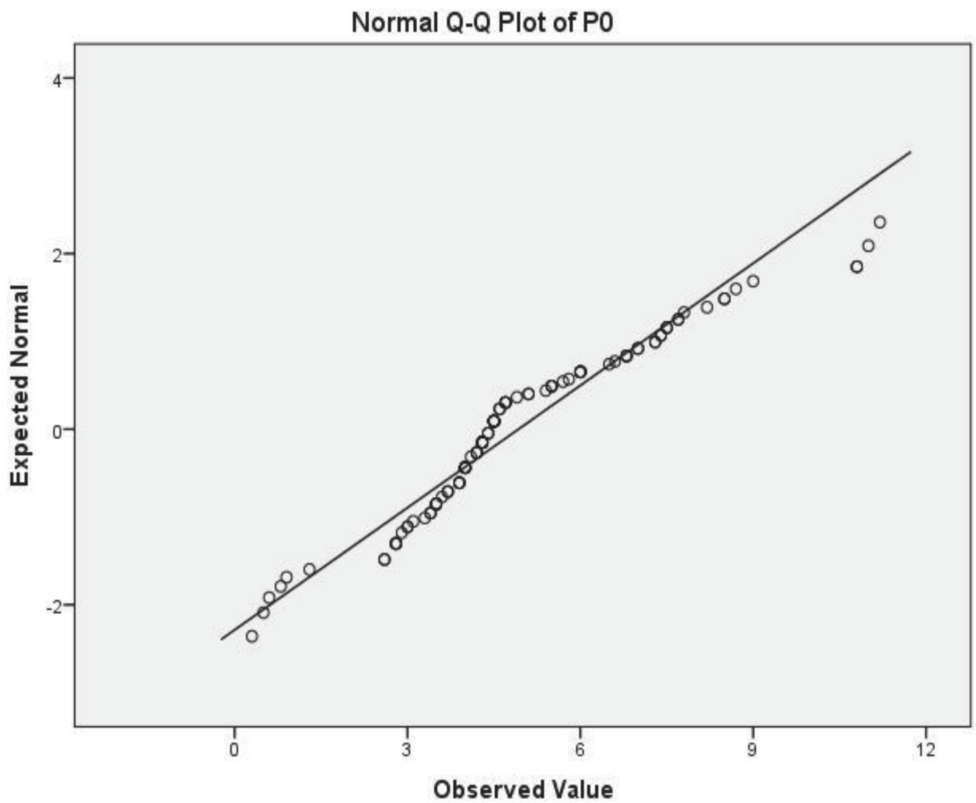


Figure 40. Q-Q Plot for the productivity baseline (P_0) data.

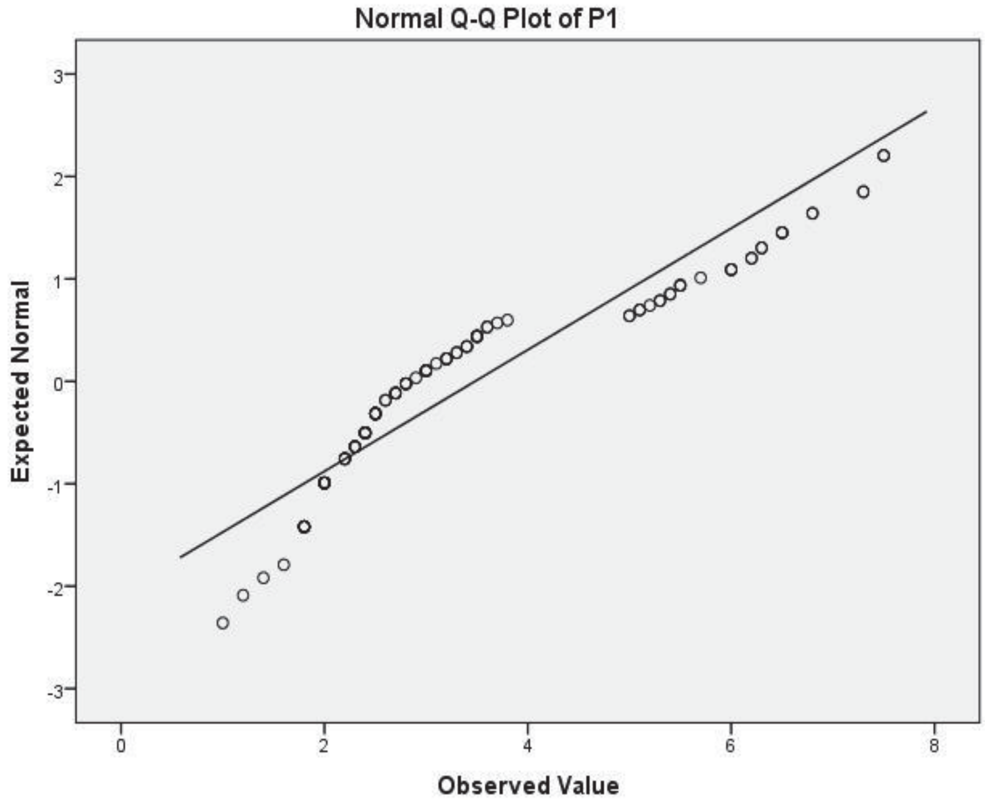


Figure 41. Q-Q Plot for the productivity treatment 1 (P_1) data.

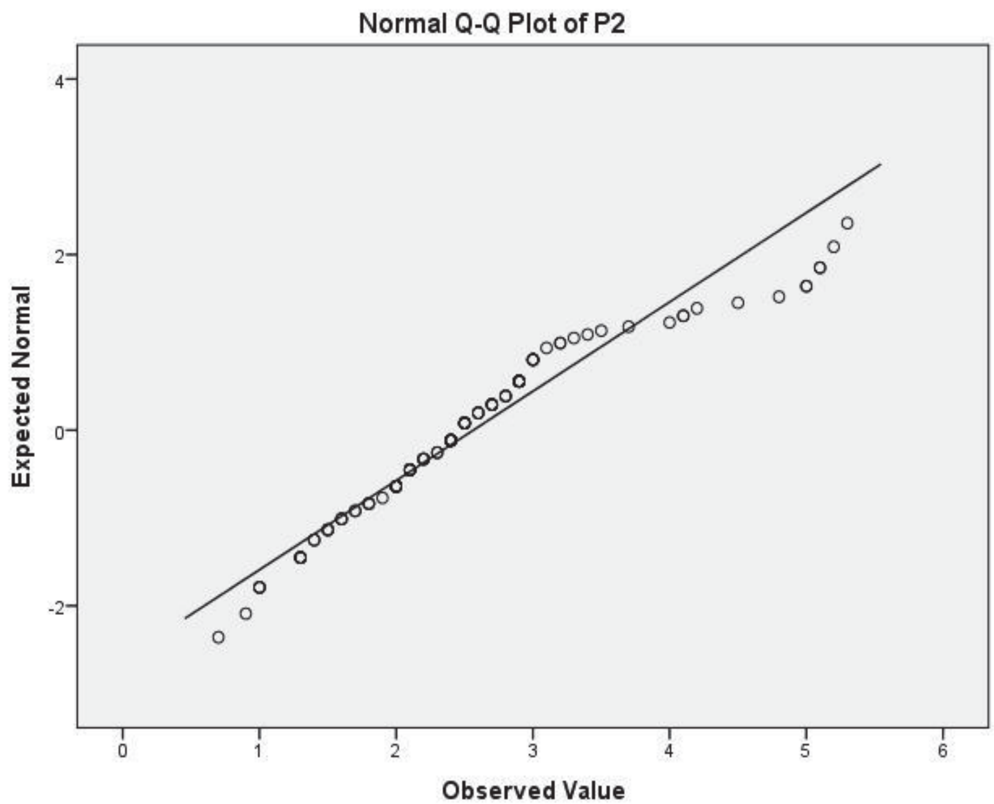


Figure 42. Q-Q Plot for the productivity treatment 2 (P_2) data.

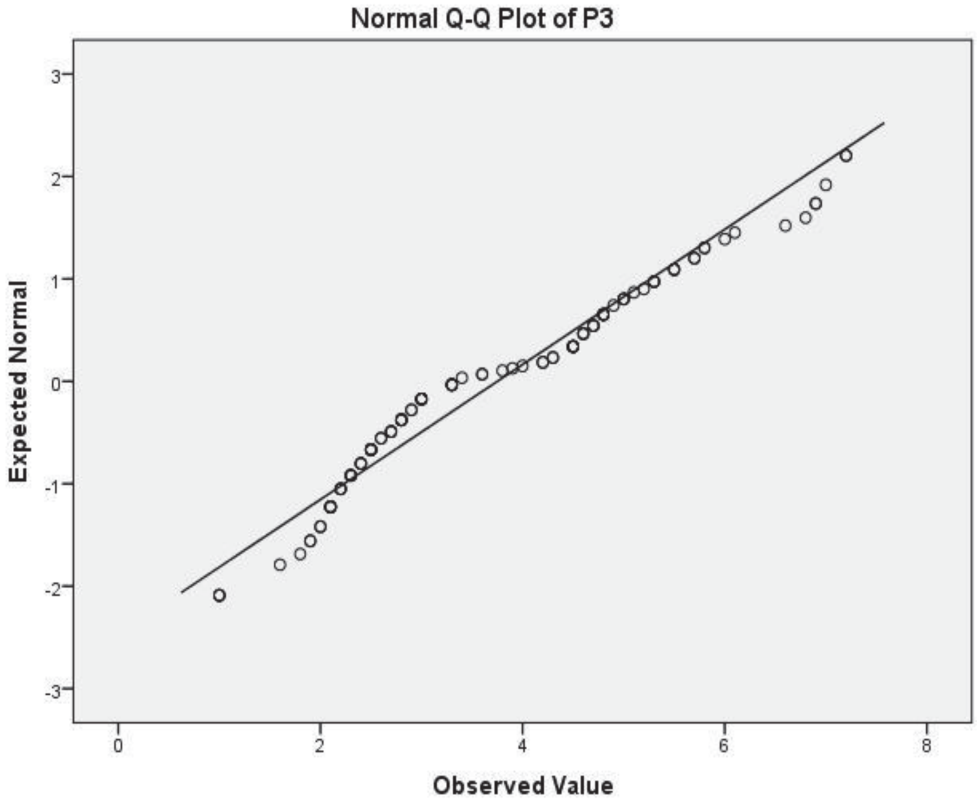


Figure 43. Q-Q Plot for the productivity treatment 3 (P_3) data.

Productivity data for the baseline and all three training treatments were approximately normally distributed as assessed by visual inspection of normal Q-Q Plots. I proceeded with caution to conduct the MANOVA analysis on the productivity data considering the interpretation of outcomes may exhibit some minor error.

The same normality exercise was repeated for the 108 data points of process yield. The charts in Figures 44-47 show the process yield Q-Q Plots for process yield data.

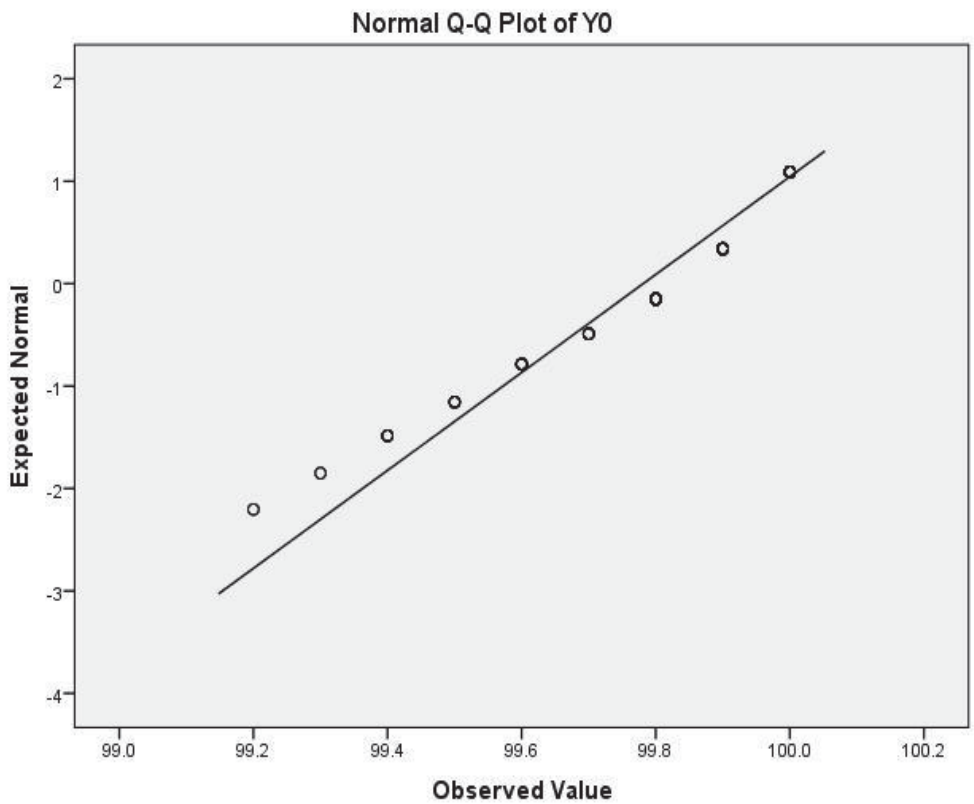


Figure 44. Q-Q Plot for the revised baseline process yield data (Y_0).

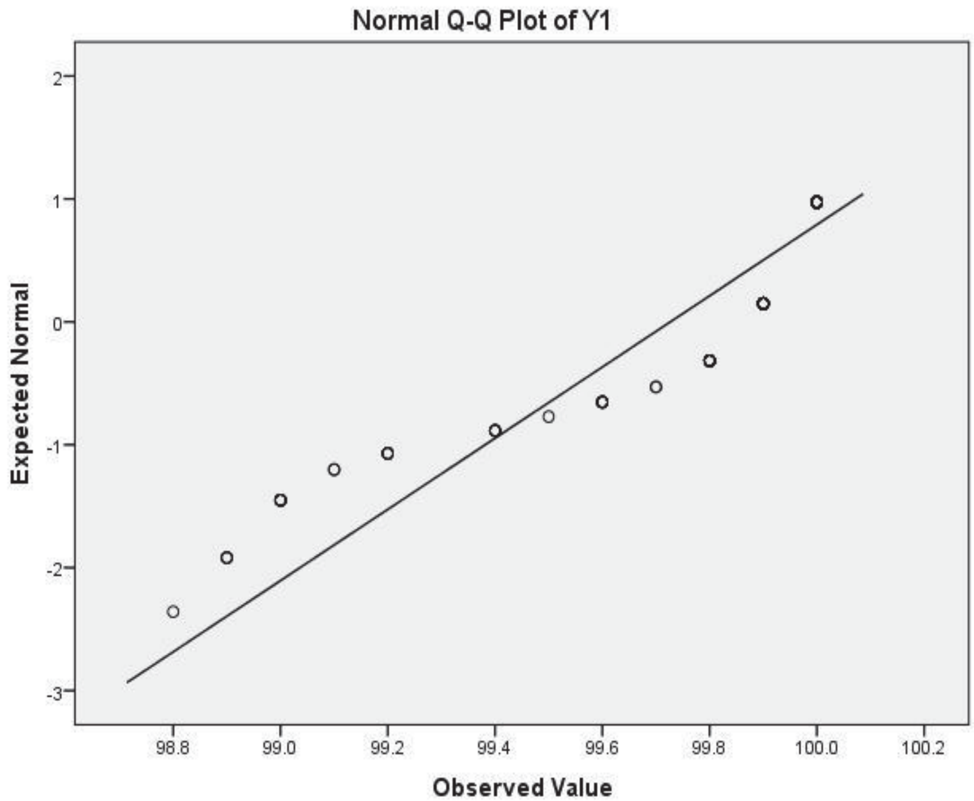


Figure 45. Q-Q Plot for the revised first treatment process yield data (Y_1).

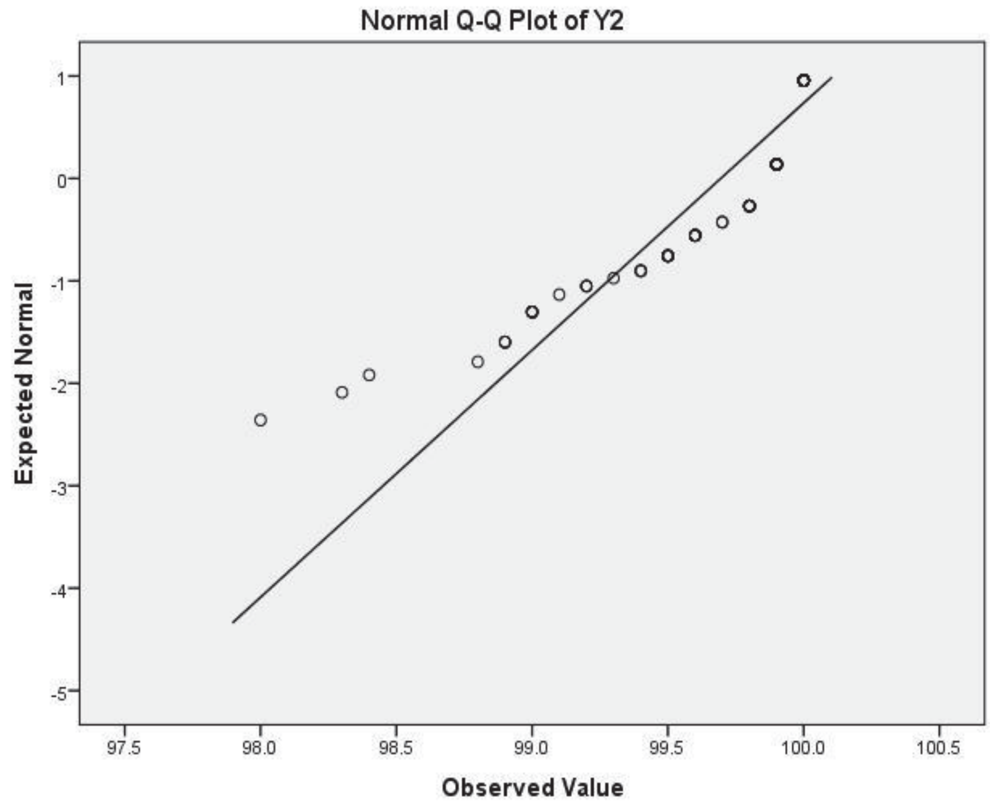


Figure 46. Q-Q Plot for the revised second treatment process yield data (Y_2).

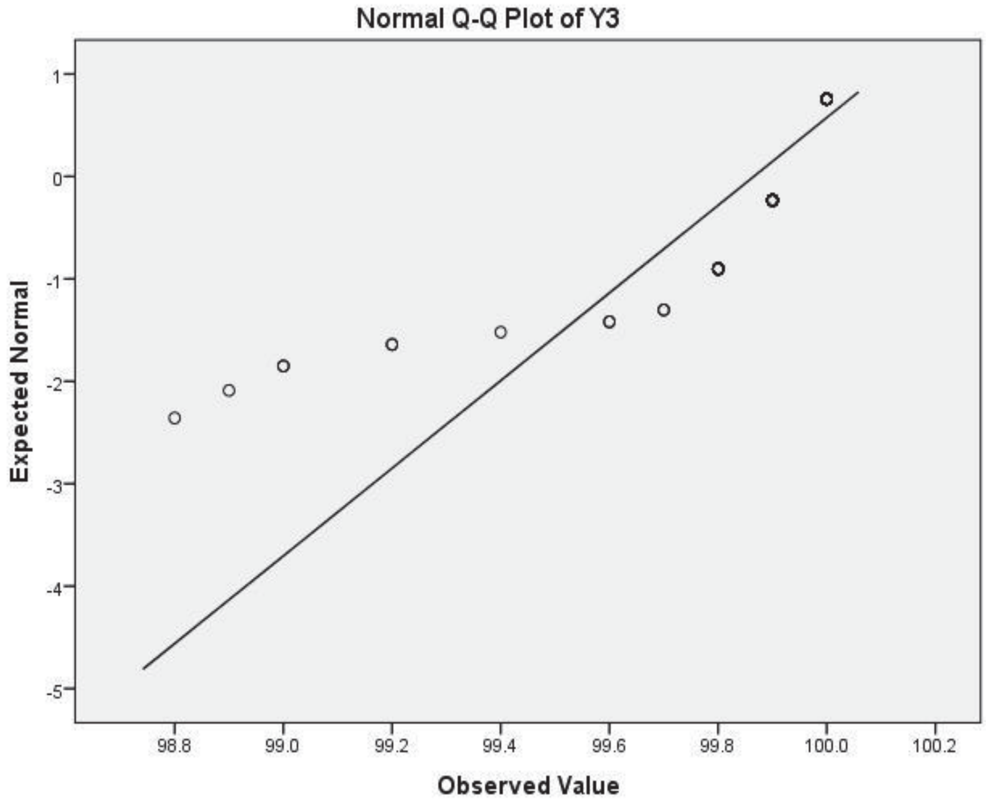


Figure 47. Q-Q Plot for the revised third treatment process yield data (Y_3).

The Q-Q plots show an improved linear trend for the first two process yield data sets. A revised skewness and kurtosis analysis in Table 13 demonstrated the data was not meeting normality requirements to proceed.

Table 13

Summary of Skewness and Kurtosis of Revised Process Yield Data.

Process Yield		Statistic	Standard Error	z-score
Yo	Skewness	-0.866	0.233	-3.717
	Kurtosis	-0.059	0.461	-0.128
Y1	Skewness	-1.306	0.233	-5.605
	Kurtosis	0.395	0.461	0.857
Y2	Skewness	-1.804	0.233	-7.742
	Kurtosis	3.208	0.461	6.959
Y3	Skewness	-3.01	0.233	-12.918
	Kurtosis	9.346	0.461	20.273

Note. The z-scores were derived from dividing the statistic into the standard error.

Process yield data were not normally distributed for the baseline T_0 with a negative skewness of -0.866 (*SE* = 0.233) and a kurtosis of -0.059 (*SE* = 0.461), after training treatment T_1 with a skewness of -1.306 (*SE* = 0.233) and a kurtosis of 0.395 (*SE* = 0.461), after training treatment T_2 with a skewness of -1.804 (*SE* = 0.233) and a kurtosis of 3.208 (*SE* = 0.461) and after training treatment T3, with a skewness of -3.01 (*SE* = 0.233) and a kurtosis of 9.346 (*SE* = 0.461). While the kurtosis was relatively flat for the first two treatments, the last two treatments show greater peakedness of the distribution. Further, the data was still skewed to the left. After reviewing the data, as the treatments progress, the skewness and kurtosis should degrade from normal as the values of process yield continue to improve towards 100%. Thus, the data must be transformed to achieve a closer approximation of normality before proceeding with the MANOVA study.

The method for proportion data transformation is arcsine root. An arcsine root transformation consists of determining the square root of each data point followed by determining the arcsine for each data point. Table 14 provides the skewness and kurtosis for the transformed process yield dataset. The transformed data detail is located in Appendix D.

Table 14

Summary of Skewness and Kurtosis of Transformed Process Yield Data

Process Yield		Statistic	Standard Error	z-score
Yo	Skewness	0.143	0.233	0.614
	Kurtosis	-1.1	0.461	-2.386
Y1	Skewness	-0.447	0.233	-1.918
	Kurtosis	-0.945	0.461	-2.050
Y2	Skewness	-0.589	0.233	-2.528
	Kurtosis	-0.56	0.461	-1.215
Y3	Skewness	-1.506	0.233	-6.464
	Kurtosis	-1.02	0.461	-2.213

Note. The z-scores were derived from dividing the statistic into the standard error.

Process yield data were approximately normally distributed for the baseline T_0 with a skewness of 0.614 (*SE* = 0.614) and a kurtosis of 2.386 (*SE* = 0.461), after training treatment T_1 with a skewness of -1.918 (*SE* = 0.233) and a kurtosis of -2.050 (*SE* = 0.461), after training treatment T_2 with a skewness of -2.528 (*SE* = 0.233) and a kurtosis of -1.215 (*SE* = 0.461) and after training treatment T3, with a skewness of -6.494 (*SE* = 0.233) and a kurtosis of -2.213 (*SE* = 0.461). I proceeded to conduct the MANOVA analysis with caution considering the interpretation of outcomes with the third treatment may result in error. The Q-Q plots in Figures 48-51 show the transformation of the process yield baseline (Y_0) data and the process yield for each of the three training treatments (Y_1, Y_2, Y_3).

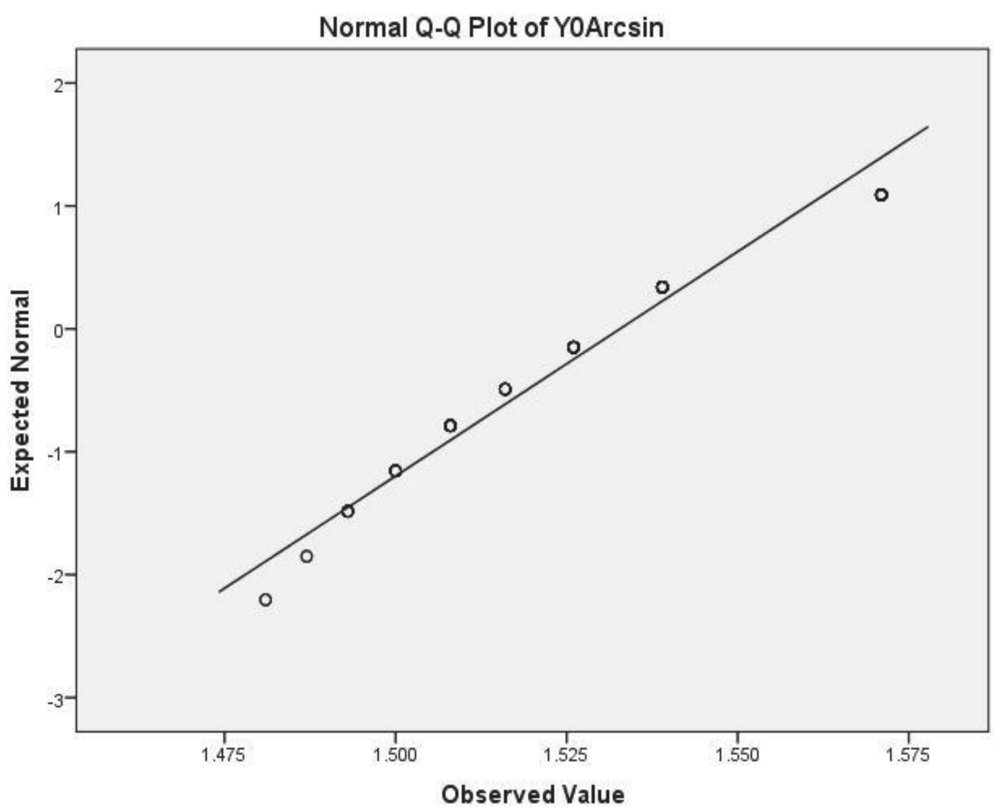


Figure 48. Q-Q Plot for the transformed process yield baseline (Y_0) data.

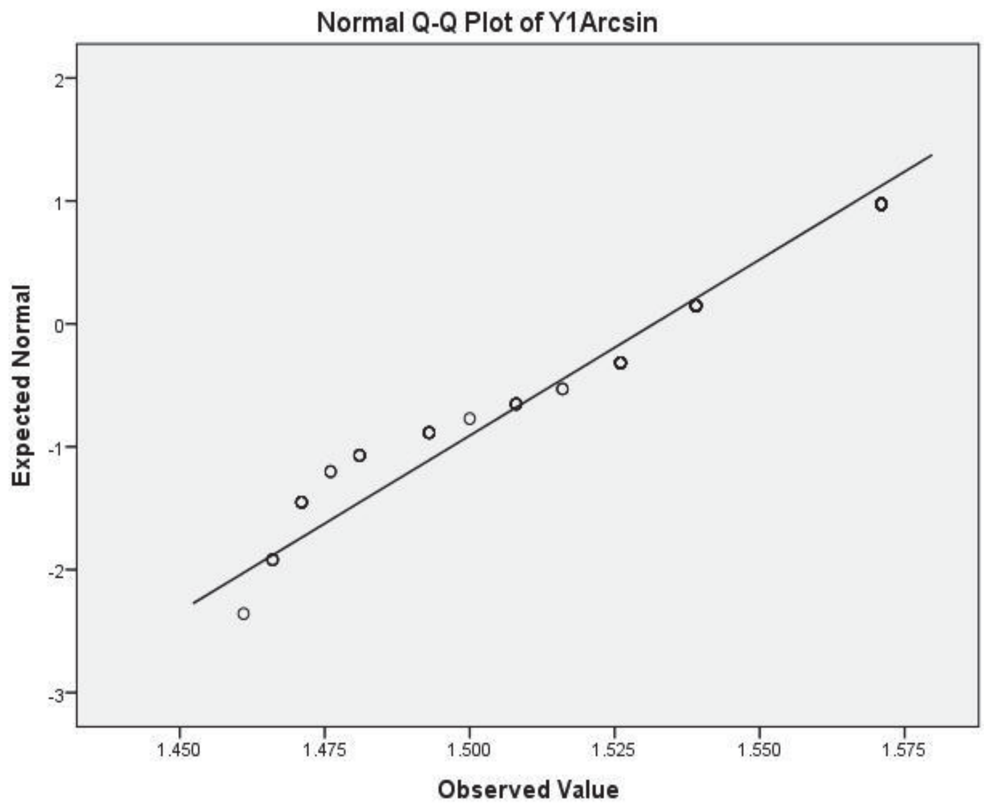


Figure 49. Q-Q Plot for the transformed process yield treatment 1 (Y_1) data.

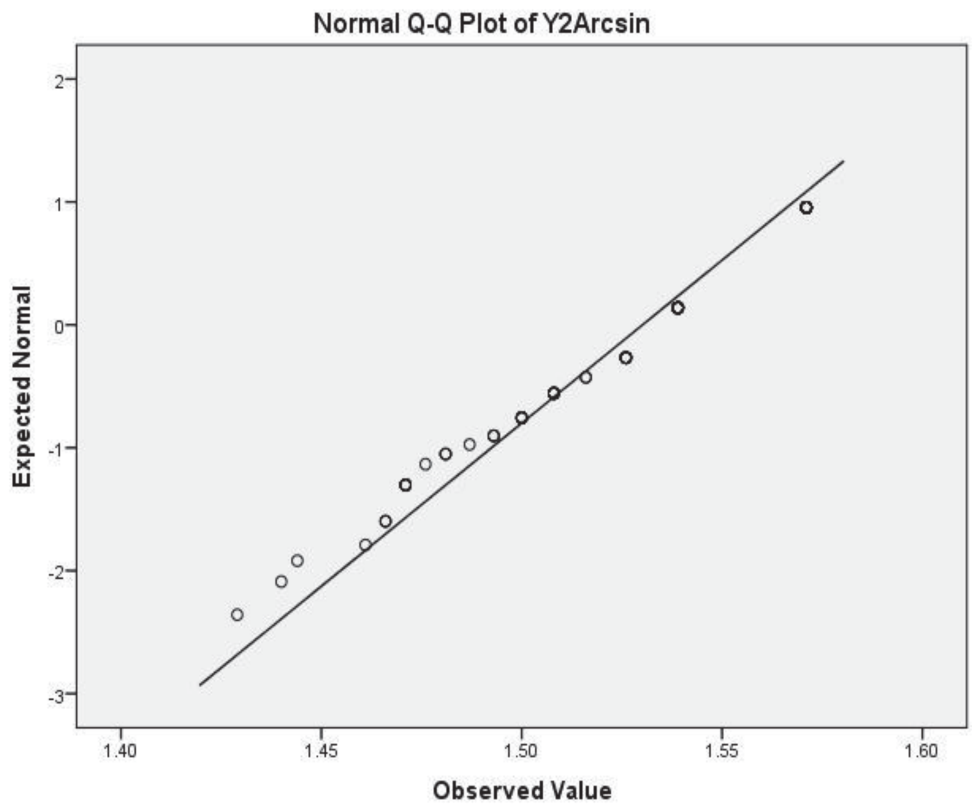


Figure 50. Q-Q Plot for the transformed process yield treatment 2 (Y_2) data.

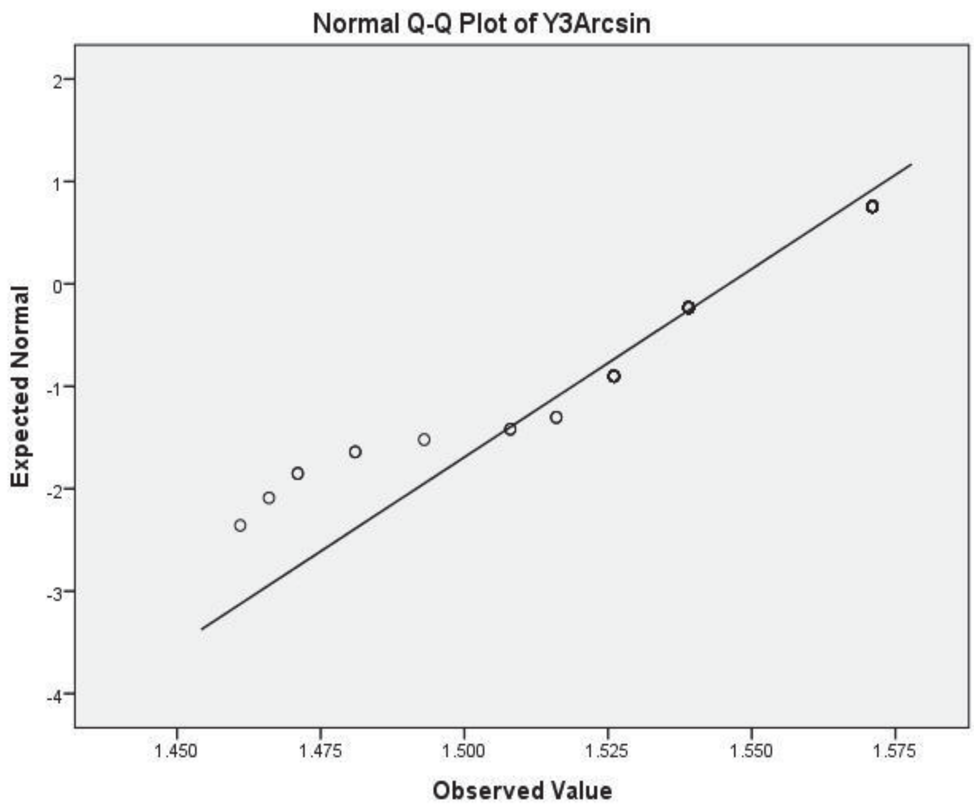


Figure 51. Q-Q Plot for the transformed process yield treatment 3 (Y_3) data.

Statistical Evaluation of Training Treatments

Now that the process yield data had been transformed and both process yield and productivity data more closely approximate normality, the MANOVA test statistic was conducted to answer the research questions within the study. Table 15 provides the descriptive statistics of both mean and standard deviation for productivity (P) and process yield (Y) at the baseline and for all three subsequent training treatments administered by the company. The final sample size for the analysis was 108 which is greater than the 86 samples required for running the test statistic and achieving a 95% confidence level.

Table 15

Summary of Descriptive Statistics

Training Level	Descriptive Statistics Mean	Std. Dev.	N
P_0	4.93	2.15	108
P_1	3.48	1.69	108
P_2	2.56	0.98	108
P_3	3.75	1.52	108
Y_0	1.53	0.03	108
Y_1	1.53	0.03	108
Y_2	1.53	0.04	108
Y_3	1.55	0.03	108

Note. P_i denotes productivity scores and Y_i denotes transformed process yield scores.

The range of mean scores for productivity vary widely from 2.56 to 4.26. Further the range of standard deviation for each subsequent training treatment ranges from 0.98 to 2.15. This range may indicate a sphericity issue within the productivity data. The process yield standard deviation is much tighter ranging from 0.27 to 0.37. Thus I expect there to be no sphericity concern for process yield. When making comparisons for means, sphericity must be reviewed because the variances from one treatment to the next could alter the interpretation of data. To further determine the effect of sphericity, I began with reviewing a multivariate test for Pillai's Trace shown in Table 16.

Table 16

Multivariate Test of Pillai's Trace

Multivariate Tests									
Within Subjects		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Factor 1	Pillai's Trace	.975	84.6	6	534	0	.487	507.8	1
	Wilks' Lambda	.070	246.5	6	532	0	.735	1478.8	1
	Hotelling's Trace	12.6	558.5	6	530	0	.863	3351.1	1
	Roy's Largest Root	12.6	1121.0	3	267	0	.928	3362.9	1

Note. Significant difference observed when p > 0.05.

As stated in Chapter 3, the larger the Pillai's Trace value, the greater the difference among the treatments within the experiment. The within subjects Pillai's Trace value equaled 0.758 and suggested that there was a difference among treatments within the experiment. However, I cannot read into this data for two reasons. First the data was bundled together and there was a difference in mean scores for each of the dependent variables. Second, there was still a sphericity concern that must be addressed. In table 17, Mauchly's test of sphericity shows that both Productivity and Process Yield violate the assumption of sphericity for productivity, $\chi^2(2) = 55.087$, $p = 0.000$ and process yield, $\chi^2(2) = 24.266$, $p = 0.000$.

Table 17

Mauchly's Test of Sphericity

Mauchly's Test of Sphericity								
						Epsilon		
Within Subjects Effect	Measure	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Factor 1	Productivity	0.594	55.087	5	0.000	0.78	0.798	0.333
	Yield	0.795	24.266	5	0.000	0.89	0.915	0.333

To gain further insight into the magnitude of the sphericity violation, I looked at the epsilon values for each dependent variable. In general, when epsilon is less than 0.75, the suggested practice is to us Greenhouse-Geiser because it tends to be a more conservative estimate of epsilon and the further removed from an epsilon of 1, the more risk of error there is. When epsilon is greater than 0.75, the recommendation is to use the Huynh-Feldt estimate because it tends to overestimate the epsilon value (http://statistics.laerd.com). Considering that both Greenhouse-Geiser and Huynh-Feldt are close to each other and both epsilons are greater than 0.75, I used Huynh-Feldt to determine the degree to which each dependent variable violates sphericity. The error for both productivity ($\varepsilon = 0.798$) and process yield ($\varepsilon = 0.915$) is relatively low.

The Huynh-Feldt correction (represented as έ), shown in Table 18, is automatically computed in SPSS when there is a need to make a correction based on violating the assumption of Sphericity. The Huynh-Feldt correction provides a shift to the degrees of freedom for the F test and resulted in a productivity correction from F (3, 321) = 109.4, p = .000 to F (2.395, 256.2) = 109.4, p = .000. Further the process yield correction went from F (3, 321) = 8.658, p = .000 to F (2.745, 293.7) = 8.658, p = .000.

The correction suggested that the repeated measures MANOVA is statistically significant ($p < .005$) and not all group means are equal. Thus, I proceeded with caution to determine where there are group differences knowing there may be some error in the data as the epsilon values for the multivariate tests are greater than 0.75

The contrasts in Table 19 helped to determine where the significant difference was between the different levels or training treatments within the study for the outputs of productivity (P) and process yield (Y). The contrasts in Table 20 suggest there was a significant difference in productivity scores from level 1 to level 2 $F(1,107) = 127.6$, $p = 0.000$, from level 2 to level 3 $F(1,107) = 54$, $p = 0.000$, and from level 3 to level 4 $F(1,107) = 179.6$, $p = 0.000$. The contrasts also suggest there was no significant difference in process yield scores from level 1 to level 2 $F(1,107) = 0.084$, $p = 0.772$ and from level 2 to level 3 $F(1,107) = 0.161$, $p = 0.689$, but there was a significant difference from level 3 to level 4 $F(1,107) = 16.963$ $p = 0.000$.

Table 18

Huynh-Feldt Correction

Univariate Tests										
Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Factor 1	Productivity	Sphericity Assumed	307.236	3	102.412	109.316	.000	.506	328.840	1.000
		Greenhouse-Geiser	307.236	2.339	131.345	109.316	.000	.506	256.402	1.000
		Huynh-Feldt	307.236	2.395	128.300	109.316	.000	.506	262.488	1.000
		Lower-Bound	307.236	1.000	307.236	109.316	.000	.506	109.613	1.000
	Yield	Sphericity Assumed	.017	3	.006	8.658	.000	.075	25.974	.994
		Greenhouse-Geiser	.017	2.670	.006	8.658	.000	.075	23.119	.990
		Huynh-Feldt	.017	2.745	.006	8.658	.000	.075	23.767	.991
		Lower-Bound	.017	1.000	.017	8.658	.000	.075	8.658	.830
Error (Factor 1)	Productivity	Sphericity Assumed	299.911	321	.934					
		Greenhouse-Geiser	299.911	250.289	1.198					
		Huynh-Feldt	299.911	256.230	1.170					
		Lower-Bound	299.911	107.000	2.803					
	Yield	Sphericity Assumed	.214	321	.001					
		Greenhouse-Geiser	.214	285.723	.001					
		Huynh-Feldt	.214	293.723	.001					
		Lower-Bound	.214	107.000	.002					

Note. The univariate tests for process yield and productivity were computed using alpha = 0.0

Table 19

Within-Subjects Contrasts

Tests of Within-Subjects Contrasts

Source	Measure	Factor 1	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Factor 1	Productivity	Level 1 vs. Level 2	225.622	1	225.622	127.634	.000	.544	127.634	1.000
		Level 2 vs. Level 3	90.933	1	90.933	54.002	.000	.335	54.002	1.000
		Level 3 vs. Level 4	152.178	1	152.178	179.602	.000	.627	179.602	1.000
	Yield	Level 1 vs. Level 2	.000	1	.000	0.084	.772	.001	.084	.060
		Level 2 vs. Level 3	.000	1	.000	0.161	.689	.002	.161	.068
		Level 3 vs. Level 4	.027	1	.027	16.963	.000	.137	16.963	.983
	Productivity	Level 1 vs. Level 2	189.148	107	1.768					
		Level 2 vs. Level 3	180.177	107	1.684					
		Level 3 vs. Level 4	90.662	107	0.847					
	Yield	Level 1 vs. Level 2	.152	107	.001					
		Level 2 vs. Level 3	.18	107	.002					
		Level 3 vs. Level 4	.171	107	.002					

Note. The within-subjects contrasts were computed using alpha = 0.05

The marginal mean plots shown in Figure 52 support the stated conclusions that the productivity marginal means were different from one treatment to the next. The magnitude of difference is shown by the slope of the connecting line from data point to data point.

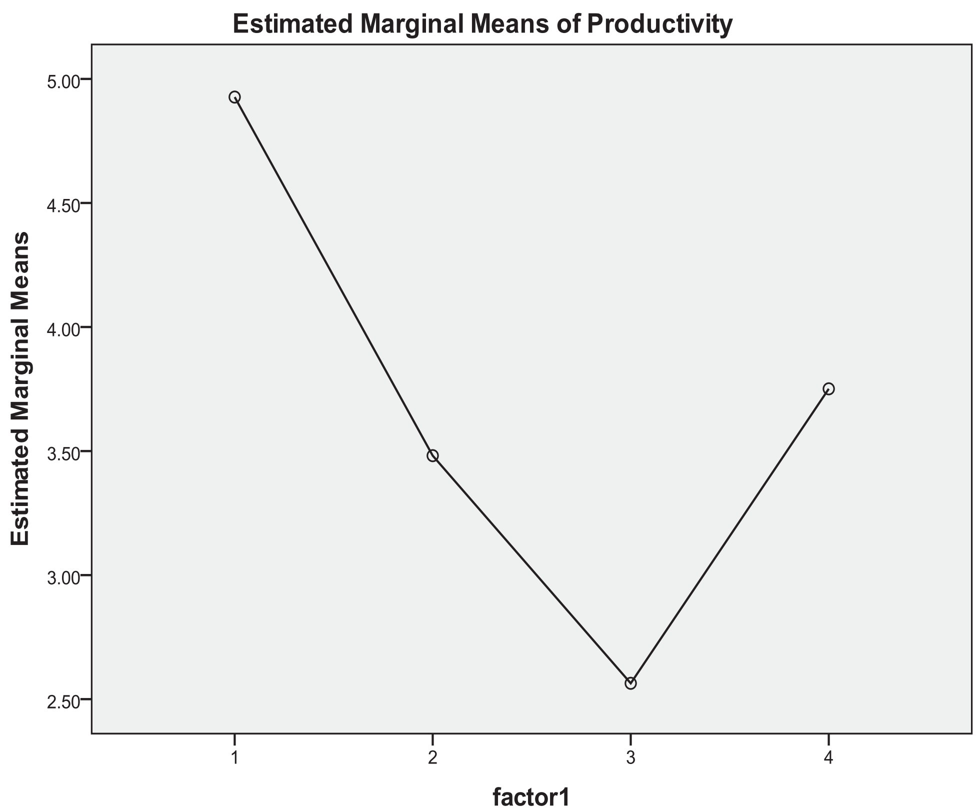


Figure 52. Estimate of marginal means for productivity.

The process yield marginal mean shown in Figure 53 suggested there was minimal difference in mean scores from level 1 to level 2 and level 2 to level 3 but there was a significant difference in mean scores from level 3 to level 4.

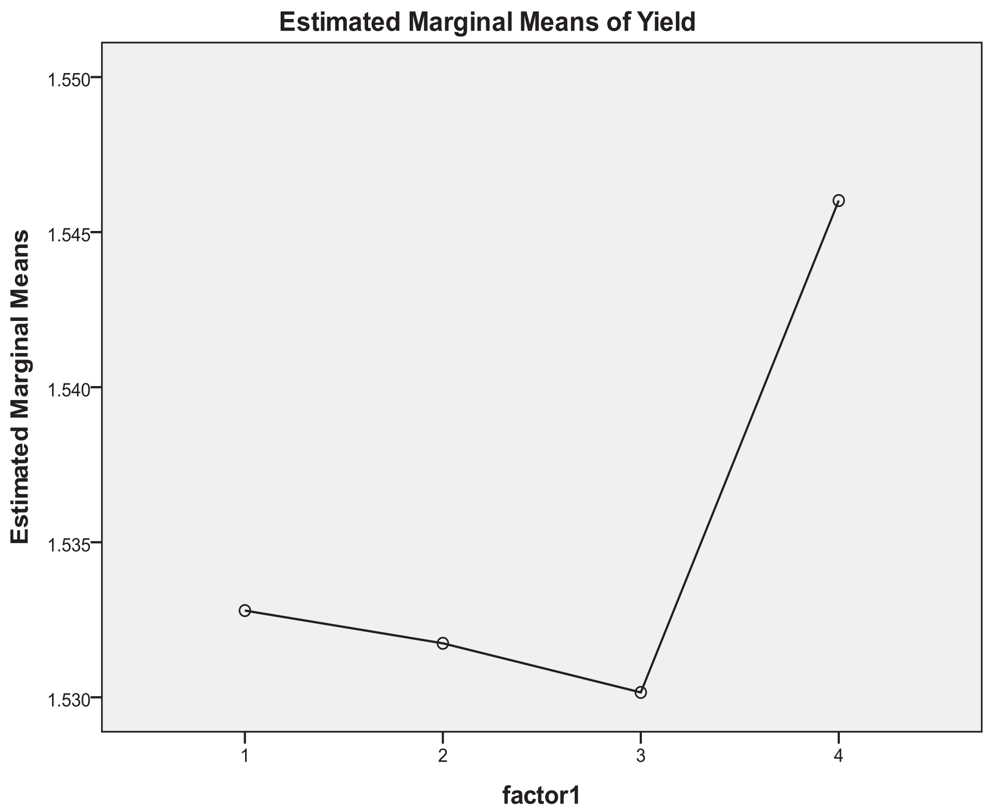


Figure 53. Estimate of marginal means for process yield.

Supplemental: End-of-Line Process Data Analysis

When reviewing the raw end of line data for process yield (Appendix B, S_1 – S_{18},) there seemed to be a pattern of improvement from one level to the next. The data in Table 21 shows the mean for Process Yield improving after each treatment was administered. Further, the means for productivity show deterioration after the first two treatments and then an improvement after the third training treatment was administered. Thus, a separate analysis on the end of line data helped provide more definitive conclusions.

Table 20

End of Line Data Descriptive Statistics

Descriptive Statistics			
Training Level	Mean	Std. Dev.	N
P_0	4.35	2.24	18
P_1	3.34	1.78	18
P_2	1.61	0.77	18
P_3	2.93	1.50	18
Y_0	93.39	0.62	18
Y_1	94.10	1.58	18
Y_2	95.29	0.74	18
Y_3	96.52	0.45	18

Note. P_i denotes productivity scores and Y_i denotes transformed process yield scores.

The range of mean scores for productivity varied from 1.61 to 4.35. Further the range of standard deviation for each subsequent training treatment varied from 0.77 to 2.24. This range may indicate a sphericity issue within the data. However, the process yield standard deviation range was from 0.44 – 1.57. Table 21 shows the Pillai's trace values for both between subjects and within subjects.

Table 21

Pillai's Trace for End of Line Data

Multivariate Tests										
Effect			Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Within Subjects	Factor 1	Pillai's Trace	.971	66.229	6.00	12	0.000	.971	397.375	1.000
		Wilks' Lambda	.029	66.229	6.00	12	0.000	.971	397.375	1.000
		Hotelling's Trace	33.115	66.229	6.00	12	0.000	.971	397.375	1.000
		Roy's Largest Root	33.115	66.229	6.00	12	0.000	.971	397.375	1.000

The within-subjects Pillai's Trace value equaled 0.971 and suggested that there was a difference among treatments within the experiment. Table 22 provided Mauchly's test of sphericity result.

Table 22

Mauchly's Test of Sphericity for End of Line Data

Mauchly's Test of Sphericity								
						Epsilon		
Within Subjects Effect	Measure	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Factor 1	Productivity	.070	41.859	5	.000	.445	.469	.333
	Yield	.234	22.847	5	.000	.532	.579	.333

Mauchly's test of sphericity showed that both Productivity and Process Yield violate the assumption of sphericity for productivity, $\chi^2(2) = 41.859$, $p = 0.000$ and for process yield, $\chi^2(2) = 22.847$, $p = 0.000$. To gain further insight into the magnitude of the sphericity violation, I used the Greenhouse-Geiser correction because it tends to be a more conservative estimate of epsilon the further removed from a value of 1. The error for both productivity ($\varepsilon = 0.445$) and process Yield ($\varepsilon = 0.532$) was relatively high.

The Greenhouse-Geiser correction (represented as έ), shown in Table 23, provided a shift to the degrees of freedom for the F test and resulted in a productivity correction from F (3,51) = 48.4, $p = .000$ to F (1.33, 22.7) = 48.4, $p = .000$. Further the process yield correction went from F (3, 51) = 34.946, $p = .000$ to F (1.33, 27.14) = 48.4, $p = .000$.

Table 23

Greenhouse-Geiser Correction

Univariate Tests

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Factor 1	Productivity	Sphericity Assumed	73.411	3	24.470	48.402	.000	.740	145.208	1.000
		Greenhouse-Geiser	73.411	1.336	54.995	48.402	.000	.740	64.657	1.000
		Huynh-Feldt	73.411	1.407	52.162	48.402	.000	.740	68.119	1.000
		Lower-Bound	73.411	1.000	73.411	48.402	.000	.740	48.402	1.000
	Yield	Sphericity Assumed	102.114	3	34.038	34.946	.000	.673	104.837	1.000
		Greenhouse-Geiser	102.114	1.597	63.952	34.946	.000	.673	55.799	1.000
		Huynh-Feldt	102.114	1.736	58.819	34.460	.000	.673	60.668	1.000
		Lower-Bound	102.114	1.000	102.114	34.946	.000	.673	34.946	1.000
Error (Factor 1)	Productivity	Sphericity Assumed	25.784	51	.506					
		Greenhouse-Geiser	25.784	22.709	1.135					
		Huynh-Feldt	25.784	23.925	1.078					
		Lower-Bound	25.784	17.000	1.517					
	Yield	Sphericity Assumed	49.676	51	.974					
		Greenhouse-Geiser	49.676	27.144	1.830					
		Huynh-Feldt	49.676	29.513	1.683					
		Lower-Bound	49.676	17.000	2.922					

Note. Computed using alpha = 0.05.

The correction suggests that the repeated measures MANOVA was statistically significant ($p < .0005$) and not all group means were equal. The contrasts in Table 24 help to determine where the significant difference is between the different levels or training treatments within the study for the outputs of productivity (P) and process yield (Y).

The contrasts suggested there was a significant difference in productivity scores from level 1 to level 2 $F(1,17) = 30.35$, $p = 0.000$, from level 2 to level 3 $F(1,17) = 55.986$, $p = 0.000$, and from level 3 to level 4 $F(1,17) = 41.889$, $p = 0.000$. The contrasts also suggested there was no significant difference in process yield scores from level 1 to level 2 $F(1,17) = 2.257$, $p = 0.151$, but there was significant difference and from level 2 to level 3 $F(1,17) = 8.33$, $p = 0.01$, and from level 3 to level 4 $F(1,17) = 52.8$, $p = 0.000$.

Table 24

Table of Within-Subjects Contrasts

Tests of Within-Subjects Contrasts

Source	Measure	Factor 1	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Factor 1	Productivity	Level 1 vs. Level 2	9.102	1	9.102	30.354	.000	.641	30.354	.999
		Level 2 vs. Level 3	73.609	1	73.609	55.986	.000	.767	55.986	1.000
		Level 3 vs. Level 4	30.942	1	30.942	41.689	.000	.710	41.689	1.000
	Yield	Level 1 vs. Level 2	8.961	1	8.961	2.257	.151	.117	2.257	.294
		Level 2 vs. Level 3	25.681	1	25.681	8.333	.010	.329	8.333	.777
		Level 3 vs. Level 4	27.134	1	27.134	52.801	.000	.756	52.801	1.000
	Productivity	Level 1 vs. Level 2	5.098	17	.300					
		Level 2 vs. Level 3	22.351	17	1.315					
		Level 3 vs. Level 4	12.618	17	.742					
	Yield	Level 1 vs. Level 2	67.489	17	3.970					
		Level 2 vs. Level 3	52.389	17	3.082					
		Level 3 vs. Level 4	8.736	17	.514					

Note. Computed using alpha = 0.05.

The marginal mean plots shown in Figures 54 and 55 supported the stated conclusions. The productivity marginal means plot in Figure 54 suggested that there were differences in mean scores from one treatment to the next. The magnitude of difference is shown by the slope of the connecting line from data point to data point. The process yield marginal mean shown in Figure 55 suggested there was significant difference in mean scores from one treatment to the next. Further, the process yield scores are all improving from one treatment to the next. Thus, the ability to improve quality performance at the end of the process was exhibited within the end of line dataset.

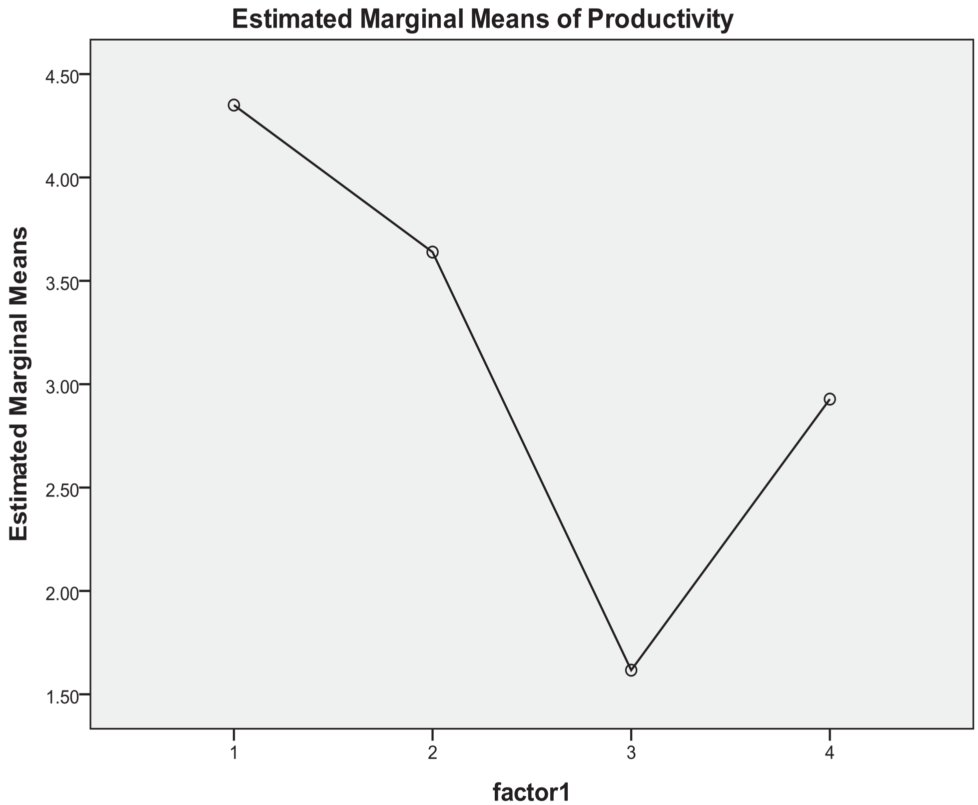


Figure 54. Estimate of marginal means for end-of-line productivity.

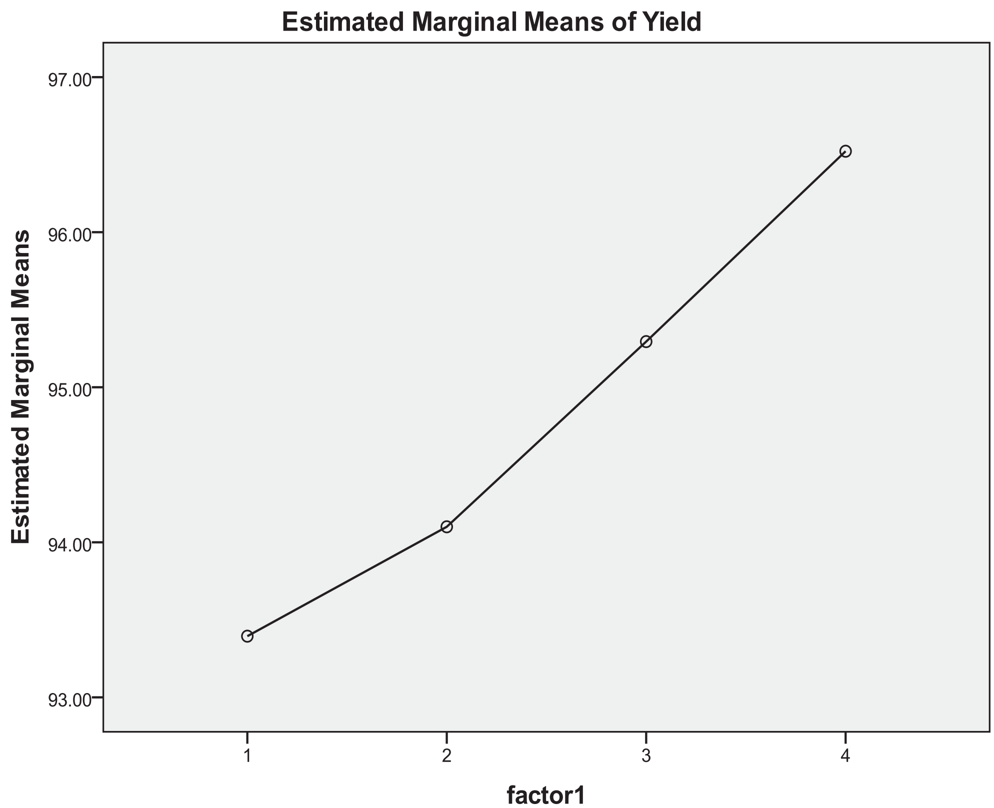


Figure 55. Estimate of marginal means for end of line process yield.

While productivity and process yield provided significant differences between treatment levels, a post-hoc analysis was required to determine the magnitude of differences between one level and the next. To conduct this analysis, I separated the process yield data from the productivity data and conduct a one-way ANOVA using Tukey HD.

Tables 25 and 26 show the difference among the various levels for productivity and process yield respectively. The Tukey HD test in Table 25 shows there was a significant difference in productivity from training treatment P_1 to training treatment P_2

($p < 0.05$) while there was no significance from training treatment P_0 to training treatment P_1 and training treatment P_2 to training treatment P_3 ($p > 0.05$)

Table 25

One-Way ANOVA for Productivity using Tukey HD Post Hoc Analysis

Multiple Comparisons						
Productivity Tukey HSD					95% Confidence Interval	
(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
0	1	.7111	.55385	.576	-.7476	2.1698
	2	2.7333	.55385	.000	1.2747	4.192
	3	1.4222	.55385	.059	-.0365	2.8809
1	0	-0.7111	.55385	.576	-2.1689	.7476
	2	2.0222	.55385	.003	.5635	3.4809
	3	.7111	.55385	.576	-.7476	2.1698
2	0	-2.7333	.55385	.000	-4.192	-1.2747
	1	-2.0222	.55385	.003	-3.48	-.5635
	3	-1.311	.55385	.093	-2.769	.1476
3	0	-1.4222	.55385	.059	-2.88	.0365
	1	-.7111	.55385	.576	-2.169	.7476
	2	1.311	.55385	.093	-.1476	2.769

Note. The Tukey HD post-hoc analysis was conducted with end of line data only.

The Tukey HD test in Table 26 shows there was a significant difference in process yield from training treatment Y_0 to training treatment Y_1 , from training treatment Y_1 to training treatment Y_2 and training treatment Y_2 to training treatment Y_3 ($p < 0.05$).

Table 26

One-Way ANOVA for Process Yield using Tukey HD Post Hoc Analysis

Multiple Comparisons						
Process Yield Tukey HSD					95% Confidence Interval	
(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
0	1	-.7371	.31290	.096	-1.561	.087
	2	-1.935	.32173	.000	-2.782	-1.088
	3	-3.127	.31710	.000	-3.963	-2.292
1	0	.737	.31290	.096	-.087	1.561
	2	-1.198	.31759	.002	-2.034	-.361
	3	-2.390	.31290	.000	-3.214	-1.566
2	0	1.935	.32173	.000	1.087	2.782
	1	1.198	.31759	.002	.361	2.034
	3	-1.193	.32173	.002	-2.040	-.345
3	0	3.128	.31710	.000	2.292	3.963
	1	2.390	.31290	.000	1.566	3.214
	2	1.192	.32173	.002	.3455	2.040

Note. The Tukey HD post-hoc analysis was conducted with end of line data only.

Further, training treatment Y_2 shows the largest mean difference (-1.1973) closely followed by training treatment Y_3 (-1.1928), and then Y_1 (-0.7371).

Summary of Research Questions

In response to the main research question, I hypothesized that there was no difference in group outcomes after administering a series of training treatments that target improved work practices. I rejected the null hypothesis and found there was a difference in group outcomes before and after treatments because the means for each level of each output variable, productivity (P) and process yield (Y) were not equal to the baseline or each other. In response to the second set of hypotheses that suggest there was no difference in productivity and process yield related scores from each of the training treatments (material handling, contamination control, and equipment malfunction), I found there was significant differences for process yield material handling and equipment malfunction. Further, for productivity scores, I found significant differences for contamination control, material handling, and equipment malfunction. While the end of line process yield data showed incremental improvement from one treatment to the next, the productivity data showed a deterioration from the baseline to the first treatment and from the first treatment to the second treatment. In response to the third set of hypotheses, I wanted to determine which training treatment had the biggest impact on either outcome. The results show that productivity had an overall negative trend with training on contamination having the largest negative impact. Further, the results show that process yield has an overall positive trend from one treatment to the next with training on contamination control having the largest impact followed by equipment readiness and then material handling. In response to the fourth set of hypotheses, I wanted to determine which outcome was affected the most by the training treatments. The data was inconclusive for productivity and while the end of line process yield data exhibited successive improvement.

Additional Factors Affecting the Outcomes

The results of the study show a negative trend for productivity which was unexpected. There is a general thought that improving quality has a direct positive effect on productivity. This could be due to a number of reasons in a real world manufacturing environment including model mix, people movement within the factory, seasonality, vendor management, and a heightened focus on quality.

The model mix during the ten week exercise could have caused a decrease in productivity. One of the hardest measures to understand in a highly customized, low volume shop is productivity. The chart in Figure 56 provides the variability within the model mix based on complexity from month to month and shows the complexity was higher during the baseline period than during the period of training during the June and July timeframe. However, the product model mix shifted in favor of products that are challenged when it comes to process yield and productivity.

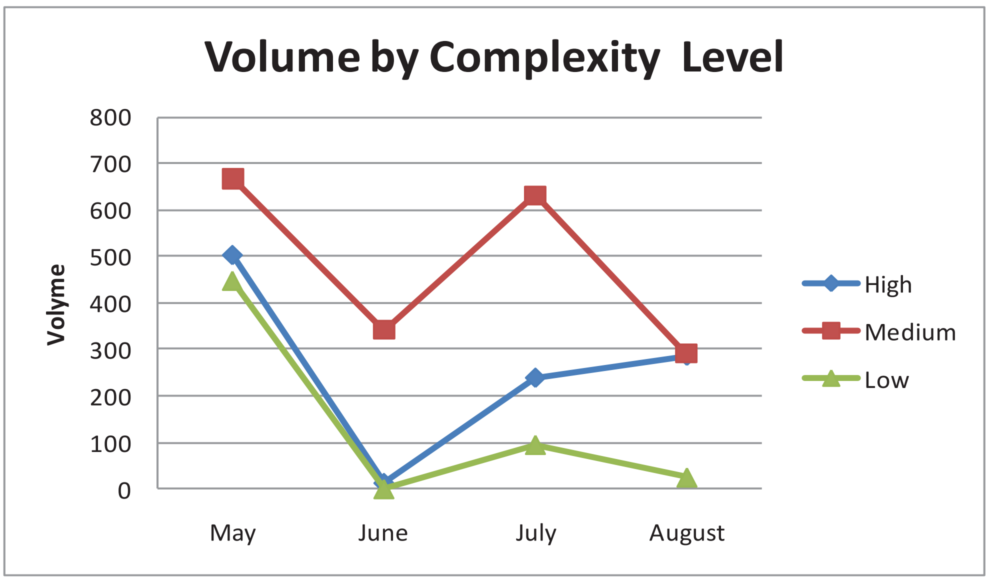


Figure 56. Monthly volumes by complexity.

During slower times, it is necessary to move the people to the work. There, has been a large shift of people moving to various departments and to and from other business units within the factory. The movement of people is not measured within the shop. However, moving people around and having to provide training or have people move along a learning curve could slow down the manufacturing process.

Seasonality is also a major issue to address. The study was conducted during the summer months within the shop. This time is usually when people take vacation and time off. Figure 57 shows the cumulative total work time spent not working by using sick time, personal time, and vacation time. The slope of the line reaches a peak in the summer months and then drops off again to smaller pitch in the January through March timeframe.

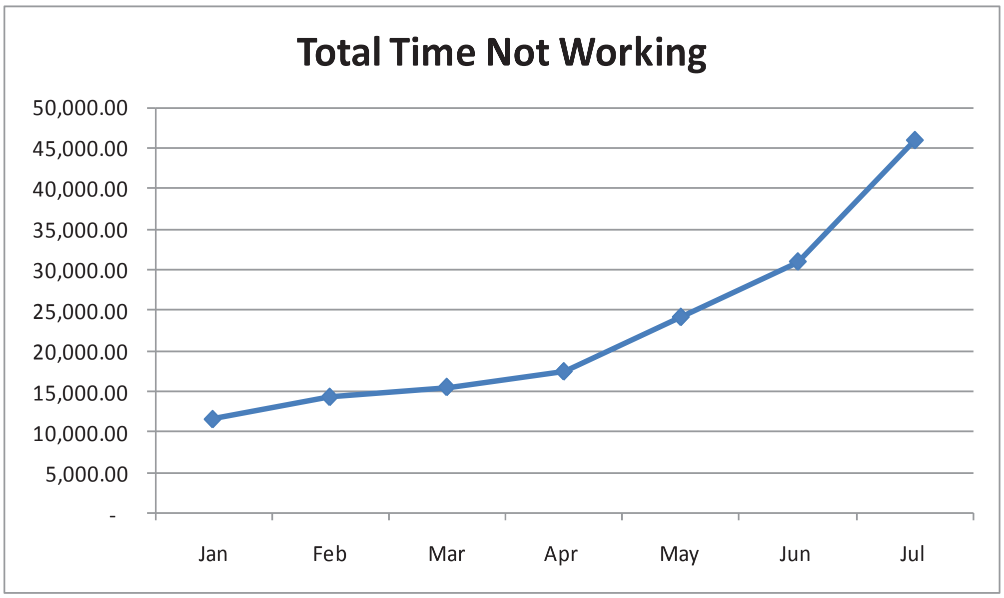


Figure 57. Total time spent not working during normal working hours by month.

The shop also conducted a week long maintenance shut down during the July 4th holiday week. While the data collection did not count this downtime week in the data, the shutdown and startup of a manufacturing site could have unfavorably altered the productivity results. The shutdown period as shown in Figure 58 occurred one week after training treatment two was administered. This corresponds to the largest difference in productivity from training treatment P_1 to training treatment P_2 and may indicate evidence of production disruption during this time frame.

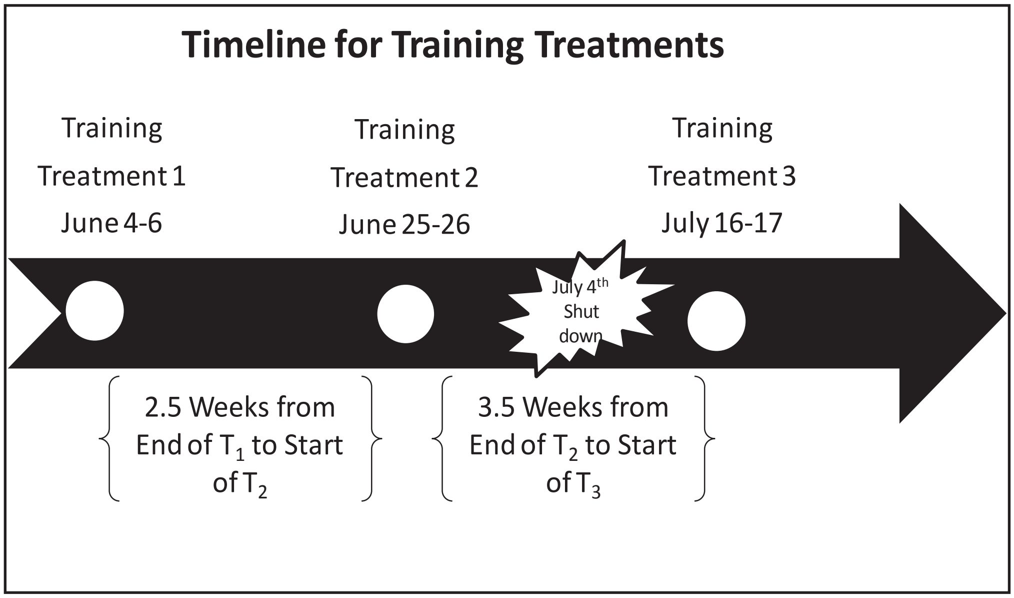


Figure 58. Timeline of training treatments corresponding to shutdown period.

An additional productivity factor affecting the business is vendor management. The ability to receive parts on time from the supply base has caused fluctuations in production requirements. Thus, a low productivity score may be indicative of vendor management issues within the facility. This factor is not measured by the company, but there have been documented cases during the training roll-out where vendor supply is short causing delays and thus missed production within manufacturing operations.

The final potential factor to affect the productivity outcome is the heightened awareness on quality during the different training treatments. As shown by the marginal means plots in figures 41 and 42, the end of line process yield data improved from one treatment to the next while the productivity exhibited a negative trend. Anecdotal evidence suggests that it takes longer to perform the job to higher quality standards and thus slows down production. However, this is not measured by the company utilized within this study.

From a process yield perspective, the only potential factors affecting successive improvement in yield is other improvement activity occurring during the time frame this training and data was collected. During this time frame, it was determined by company staff that no other significant product quality initiatives occurred except for the consolidation of equipment. There were some minor changes within departments but nothing significant that would alter the end of line quality during the period in question.

Cross-Validation of Training Approach

Within the literature review and the setup of the study, I contended that training needed to consist of an exchange of information from the trainer to the trainee and then back to the trainer in order to develop a continuous improvement mindset to the training process. Thus, during the training rollout, the company collected feedback from each one on one training session to determine where there are opportunities for improvement within the process. During the first training treatment, material handling, the feedback from each of the training participants consisted of 154 opportunities for improvement. Figure 59 shows a Pareto chart of the material handling opportunities for improvement summarized by major category.

The Pareto chart shows that process issues, packaging, and ergonomics provide for 92% of the total improvement opportunities noted during the training. A more detailed breakdown of the improvement opportunities are provided in Appendix F. Each of these opportunities must be addressed to foster an environment of engagement, empowerment, and an awareness of performance outcomes.

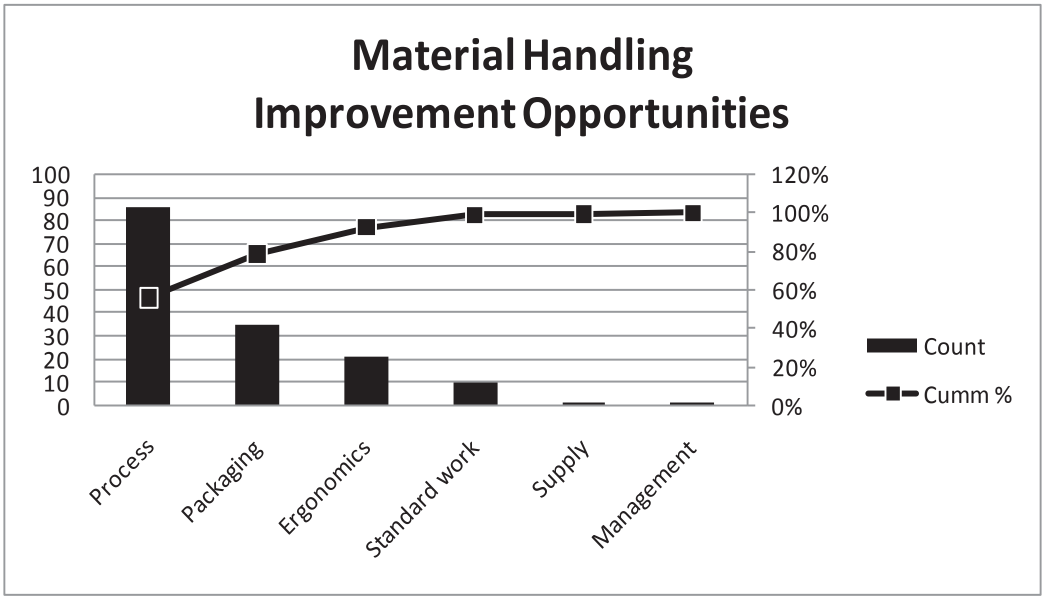


Figure 59. Pareto of material handling improvement opportunities.

Other observations or comments received include the following:

- The operators have stated that this training activity is important.
- The operators have been able to demonstrate the proper technique for material handling and provide verbal feedback that they understand the need for proper material handling.
- Operators commented that if we did not do this exercise, there would not be improvements because the focus and awareness would not be there.
- The operators appreciated the one on one interaction and thought it was a good idea instead of conducting a group training exercise.

- One operator commented that he was waiting for someone to come and ask him how the work should be done instead of telling him.
- There needs to be more detailed standard work for each individual process to handle the nuances and challenges to handling the product appropriately.
- The space between equipment causes material handling damage and must be thought through as the company moves equipment around and tries to shrink the usable floor space.
- Uneven floors can cause bouncing of product when handled by the truck drivers. The company needs to investigate uneven surfaces.
- Ergonomic issues were prevalent throughout the process and the operators made over 20 separate comments on ergonomics. There may be a need for a full blown ergonomic analysis across the shop.

During the second training treatment, contamination control, the feedback from each of the training participants consisted of 150 opportunities for improvement. Figure 60 shows a Pareto chart of the contamination control opportunities for improvement summarized by major category. The Pareto chart shows that housekeeping, process issues, and maintenance provide 80% of the total improvement opportunities noted during the training. A more detailed breakdown of the improvement opportunities are provided in Appendix G.

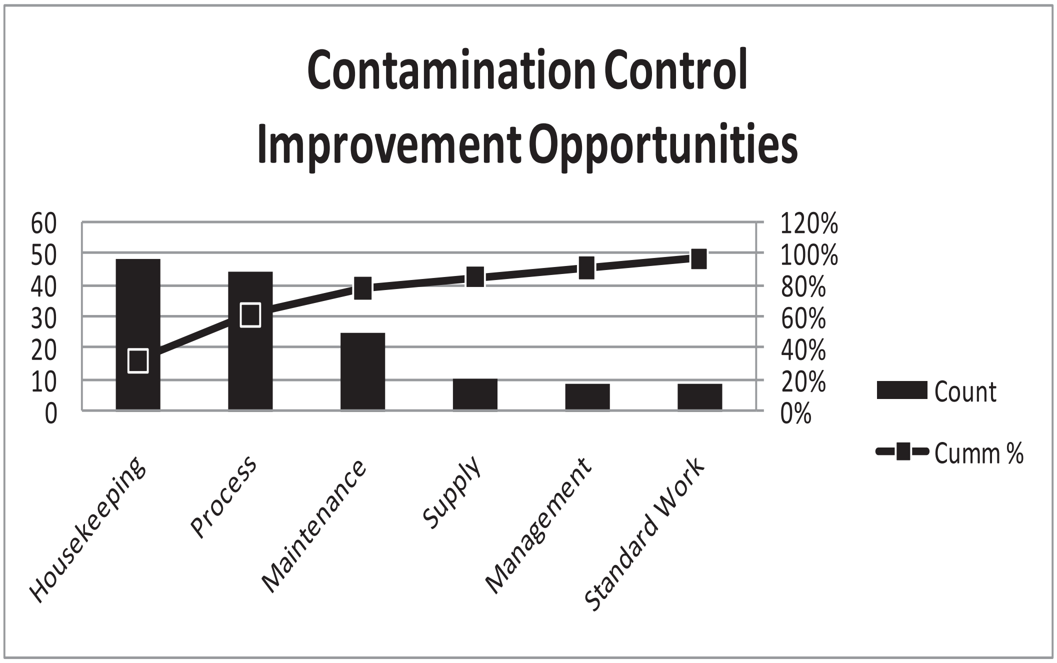


Figure 60. Pareto of contamination control improvement opportunities.

Each of these opportunities must be addressed to foster an environment of engagement, empowerment, and an awareness of performance outcomes.

Other observations or comments received include:

- Operators suggested they want to see these improvements put into place instead of being brought up with no resolution.
- Instead of sending people home during slow demand days, the operators suggested using that time to clean.
- The communications need to be better from one shift to the next and from operator to management to get the improvement necessary.

- Have professionals come in and provide what good looks like to establish a standard.
- Housekeeping represented 48 improvement opportunities or 33% of the total ideas collected. Thus, there is a generalized assessment that housekeeping is a major driver in all areas for contamination control.

During the third training treatment, equipment readiness, the feedback from each of the training participants consisted of 97 opportunities for improvement. Figure 61 shows a Pareto chart of the equipment readiness opportunities for improvement summarized by major category.

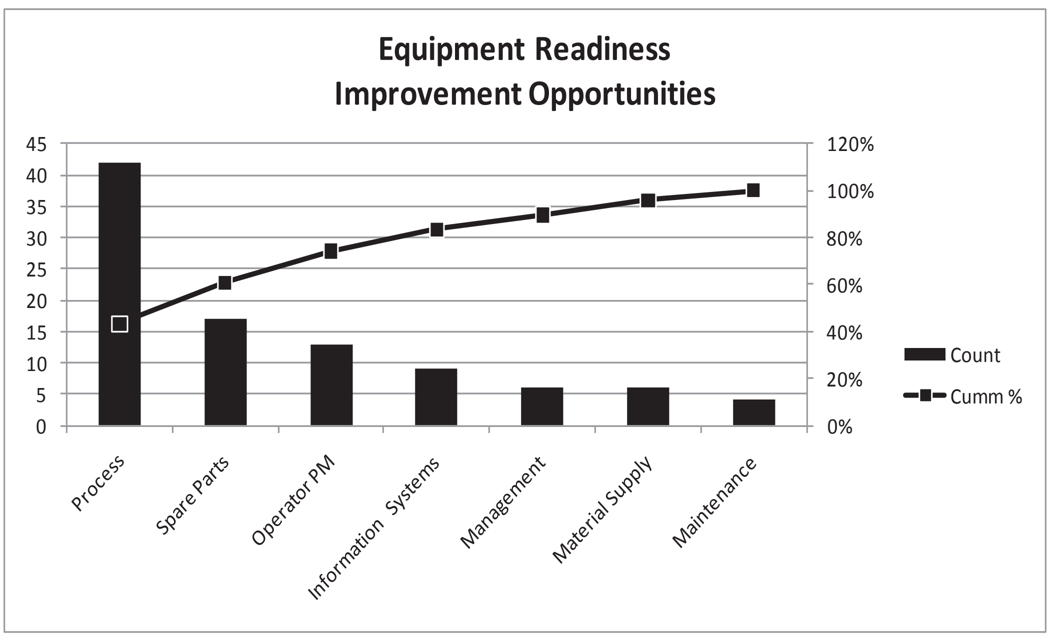


Figure 61. Pareto of equipment readiness improvement opportunities.

The Pareto chart shows that process issues, spare part availability, and operator planned maintenance practices provide for 75% of the total improvement opportunities noted during the training treatment. A more detailed breakdown of the improvement opportunities is provided in Appendix H. As with the two prior training treatments, each of these opportunities must be addressed to foster an environment of engagement, empowerment, and an awareness of performance outcomes.

Other observations or comments received include:

- It was noticed that many operators don't have an understanding about their tools, what to check for and why.
- A few comments suggested that the management team requires the operators to run no matter what condition the equipment is in.
- A few areas use a flag mechanism to alert maintenance of non-working gages but have not had success in getting the gages fixed.
- Operators liked that there was a specific dialogue about what improvements were required.
- Many of the tools were not designed for high customized, low volume work which makes it hard to utilize the equipment optimally.

The overall synthesis of these comments suggests that the majority of ideas for improvement deal with the interaction between the operator and the process. By focusing effort on the operator-process interaction point at all process steps throughout the manufacturing line, the metrics of process yield and productivity may show further improvement.

Summary

Data from the company's ERP system was collected and analyzed using SPSS statistical software to determine if there was a difference in group outcomes after administering a set of training treatments that targeted improved work practices. A second set of research questions were developed if the data showed there were differences in group outcomes from the training treatments. These secondary questions aimed to answer (a) which treatments had an effect on which outcomes, (b) which treatment had the biggest impact on each of the outcomes, and (c) which outcome benefited the most from the training treatments.

Prior to the analysis, the first step of a repeated measures MANOVA study was to ensure the data exhibited only those who went through all three training treatments provided by the company. Missing data was not allowed in a Repeated Measures MANOVA study. Further, I did not assume to use a transform of missing data values to fill in the blanks and thus this data was discarded. The second step was to determine normality of data through the use of Q-Q plots. The process yield data exhibited non normality. When looking at the data for outliers, the end of line data points were skewing the normal curve. Thus, after removing these data points the data was more normalized but the process yield data still exhibited skewness. A transformation of the data using the arcsine root method was utilized to center the dataset. Once the data more closely approximated normality for process yield, I repeated the same set of activities for productivity. The productivity data, after removing the end of line data, exhibited an approximation to normality.

The third step was to run the MANOVA analysis and answer the main research question. The data exhibited a violation of sphericity and thus the Huynh-Feldt correction was required to reduce the amount of error within the data. I proceeded with caution knowing there was some inherent risk of error in the data. The table of contrasts showed the means were different for productivity scores between all three treatments while the means were different for only one process yield score after administering the last training treatment.

After reviewing the raw data, the end of line data showed a positive process yield trend after each successive treatment. Because the end-of-line data was the final test and inspection in the manufacturing process, and there was no cost effective way to assign defects to a particular person at such a late stage in the process, a secondary analysis using the same MANOVA approach was conducted. There were 18 data points to pull from, thus I proceeded with caution knowing there is a violation to the minimum sample size considering these data points actually represent the combined work of the entire population data set. The end of line data for both productivity and process yield exhibited a close approximation to normality based on the use of Q-Q plots. The subset of data showed that productivity had an overall negative trend. Further, the results show that process yield has an overall positive trend for each of the three successive training treatments. The data suggested that the training on contamination control had the largest impact on both outcomes, positively impacting process yield and negatively impacting productivity.

As a follow up to this study, a number of real world factors that could have influenced the productivity outcome were model mix, people movement within the factory, seasonality, vendor management, and a heightened focus on quality. Each of these factors were part of the manufacturing environment during the training rollout and data collection within this study. Further, the consideration of influences on the process yield outcome was localized to incremental improvements in the shop that may have caused a positive trend within the data. However, no improvement projects were taking place during the timeframe when the training was rolled out.

A further supplemental activity from this work was the collection of the one-on-one interaction data during the company sponsored training treatments. As stated in Chapter 2, this feedback was considered a foundational aspect of the improvement process and thus warranted a summary of this data. The corporation collected and summarized the data for improvement implementation purposes. The conclusions from this effort show that focusing on the operator-process interaction point at all process steps throughout the manufacturing line may positively impact both process yield and productivity and further study is warranted.

Chapter 5: Discussion, Conclusions, and Recommendations

Overview

The purpose of this quantitative study was to see whether gains in performance were achieved by implementing standard work practices and a specialized training plan in an environment where quality is critical. The purpose of this chapter is to discuss and interpretation the results, discuss the limitations of the study and then provide a summary on the implications of social change.

The common expectations among customers are on-time delivery with good quality at a reasonable cost. When trying to improve quality in a highly customized, low-volume manufacturing environment, it is important to first examine how an employee is trained that have been associated with poor output quality. The variables in this study—foreign material contamination, product handling, and preventing equipment malfunction—were predetermined by subject matter experts; they were thought to be influenced by employees and thus controllable.

The reasons for embarking on this study were fourfold. First, the manufacturer would gain insight into how to (a) accelerate work practice improvements and (b) benefit from improved product quality, thus improving customer satisfaction and reducing business costs by reducing scrap and rework. Second, without standardized work practices, the workers would remain in a reactionary mode, constantly working to repair mistakes instead of operating in a prevention mode, where there is room to concentrate on process improvement. Third, understanding the order of significance of quality—from the most significant to the least— would help the company determine where to spend its resource dollars. Finally, by improving product quality outcomes, the manufacturer would improve on-time delivery to the customer while reducing cost.

The research literature in the fields of scientific management, industrial training, behavior modification, and quality management had paid secondary attention to combining training and methods improvement into one cohesive, continuous improvement methodology. Several companies (e.g., Toyota) have implemented standard work practices to reduce variation and improve product quality for standard products. However, as the manufacturing base for standard products continues to decline in the United States, there was little understanding of how well these techniques would work in a highly customized, low-volume manufacturing environment. This research used archival data from company-sponsored training treatments to determine whether focusing on standard work practices and improving training protocols in a high-model mix, low-volume environment had an effect on product quality. To complete the research, and adhere to the manufacturer's quality protocols, all workers received the same training treatments.

In this study, I used a within-subjects factor repeated measures MANOVA analysis to determine the effect of three training treatments on two product quality outcomes of process yield and productivity. I studied which of the training treatments had the most significant impact on which of the two quality outcomes. Finally, I evaluated the opportunities for improvement developed during the company sponsored training. All of these findings are summarized in Chapter 4. Based on these findings, recommendations for further studies are made.

Interpretation of Findings

Findings and Conclusions

Standard work practices have been broadly applied to several industries. Further, there is a common misperception that implementing standard work is enough to drive product quality. However, there is a need for standard work practices to include feedback from the employees. Further, there is a need for a more streamlined and engaging approach to training employees. Finally, there is a need to focus on a method of continuous improvement in the training process. While the company within this study has practiced the utilization of work instructions, there was limited activity on improving quality through a focused effort on combining standard work, training, feedback and continuous improvement.

This study performed a primary repeated measures MANOVA analysis on archival data of 108 employees receiving a series of three training treatments. The findings in Chapter 4 are summarized below:

- *Statistical difference of mean scores for original data set*. The MANOVA output provided that there were statistical differences in mean scores from one treatment to the next for productivity. Further, there were statistical differences in mean scores for process yield by implementing the third and final training on equipment malfunction.

- *Statistical difference of mean scores for the end of line dataset*. The MANOVA output provided that there were statistical differences in mean scores from one treatment to the next for both productivity and process yield.
- *Training treatment impact*. The largest impact on the outcomes of both productivity and process yield were determined to be foreign material contamination. While the foreign material contamination training treatment had the most significant positive impact on process yield, the same treatment had the most significant negative impact on productivity.
- *Supplemental improvement opportunities*. During the training rollout, information was received for each of the training treatments during the one-on-one training sessions. This information indicated a large amount of variation that must be continually improved upon over time.
- *Improvement recommendations*. Based on the findings within this study, it would be appropriate for the company to spend resource dollars on foreign material contamination as a first level priority. However further analysis is required to determine which sector of the process would benefit most from the implementation of foreign material contamination control. Further enhancements required in the workplace include assigning process yield end of line data to the appropriate process sector to allow for more focused analysis and improvement activity.

Limitations of the Study

Several shortcomings cropped up in the analysis of the data: violation of normality, violation of sphericity, and the effect of error on interpreting the findings. These shortcomings weaken the ability to deploy a research study and interpret outputs in a real-world manufacturing environment.

- *Data Integrity***.** There are a several areas of concern when looking at data integrity including: Model mix, people movement, seasonality, a summer shutdown period, vendor management, and a heightened awareness on quality outcomes.
  - *Model Mix.* The model mix changes from day to day and provided unique challenges to the workforce because trying to maintain a consistent output of product while also maintaining quality integrity was a very hard balance to achieve.
  - *People Movement.* During slower times, it was necessary to move the people to the work. There, had been a large shift of people moving to various departments and to and from other business units within the factory during the rollout of training. The movement of people is not measured within the shop. However, moving people around and having to provide training or have people move along a learning curve could slow down the manufacturing process.

- *Seasonality.* The study was conducted during the summer months within the shop. This time is usually when people take vacation and time off. The total time spent not working reaches a peak in the summer months and then drops off again to the level seen in January.
- *Shut-down Period.* The manufacturer conducted a week long maintenance shut down during the middle of the training rollout. While the experiment did not count this downtime week in the data, the shutdown and startup of a manufacturing site could have unfavorably altered the productivity results.
- *Vendor Management.* An additional productivity factor affecting the business was vendor management. The ability to receive parts on time from the supply base had caused fluctuations in production requirements. Thus, a low productivity score may be indicative of vendor management issues within the facility. This factor is not measured by the company but there have been documented cases where vendor supply is short causing delays and thus missed production within manufacturing operations during the training period within this study.
- *Heightened Quality Awareness***.** The final potential factor to affect the quality outcome was the heightened awareness on quality

during the different training treatments. Anecdotal evidence suggested that it took longer to perform the job to higher quality standards and thus slows down production. Further, a heightened awareness on quality may have exhibited an improvement in process yield from one treatment to the next. While the company did not have significant product quality improvement initiatives occurring during the timeframe of this study, the improvement may be indicative of awareness.

- **Transformation of data.** As described in Chapter 4, the data had to be transformed to more closely approximate normality. Once the transformation was completed, the data still exhibited some risk of error thus affecting the interpretation of outcomes. There is no way to avoid real world factors that affect outcomes of a series of training over time within a manufacturing environment that has inherent variability.

Implications for Social Change

Primary Social Impact

The ability to compete in a global economy has provided major challenges to manufacturers within the United States. To address these challenges, company leaders have tried to find lower cost manufacturing alternatives. The impact of these decisions affects a workers ability to earn a paycheck. A lack of pay has a ripple effect within a local community because an individual moves from paying into the economy to taking from the economy. By conducting this research, the primary social change application is in part to continue focusing on driving down costs, reducing the need to look at outsourcing options, and providing more sustainable jobs within the local community. I generalized the main way to provide job stability is through effectively competing on cost and quality by focusing on incremental improvement. While the ability to achieve incremental improvement is challenging, the alternatives are less appealing from a social perspective. Over the past decade, the company within this study has exhibited a trend of reduced jobs. The strategic focus is to stem the declining trend in jobs and start working towards job growth.

Other Social Impacts

When using an incremental improvement approach to improve quality, delivery, and cost, the outcomes provide the company with secondary benefits, including:

- Better vendor management relationships where customer and supplier are more responsive to each other's needs.
- Better recognition within the local community as an employer of choice thus enhancing the ability to attract top local talent.
- Improved ability to utilize the same approach in other business system processes to enhance all aspects of the business.

- Improved ability to focus on customer needs and wants thus providing an enhanced value added statement and business model to grow the business.
- Improved ability to focus on corporate citizenship by providing more programs for community outreach and support of philanthropic causes.

In summary, by providing an improved approach to incremental improvement and weaving it into daily work practices, a company can work to successfully compete, provide a sustainable and growing enterprise, and fulfill its obligation of social responsibility within the local community.

Recommendations for Action

The results of this study are applicable to all businesses that exhibit a high degree of variability in product type as well as a low level of volume and are trying to achieve incremental improvement in quality. Further, many companies making standard products have secondary process centers outside the mainstream of manufacturing that exhibit the same properties of highly customized, low volume product. Such areas include machine and tooling shops, and maintenance and repair shops. These areas are usually overlooked but they all exhibit the same properties (i.e. a customer, a product, and an expectation on quality, cost, and delivery) of highly custom, low volume production. By focusing on standard work practices and improved training, it is recommended that incremental improvements can be achieved in these secondary environments as well. In order to disseminate the results of this study, I will provide a write up for a scholarly journal. In addition, the results of this study will be presented at future conferences for Industrial Engineering, Continuous Improvement, Lean Manufacturing and Six Sigma.

Recommendations for Further Study

The recommendations for further study include:

- Localizing the study into one smaller area where the variables impacting normality are more controllable. For example, instead of studying the effects of the entire manufacturing process, a similar study could be conducted on one process center.
- Choosing more output variables to study including but not limited to employee morale, absenteeism, safety, and on time delivery.
- Providing a method of translating input variables in a transaction business process to gain further generalized results that would appeal to a larger population. For instance material handling of a physical product is understood but handling an order in a system has different characteristics and requires a translated set of output variables to measure quality.
- Coding the end of line data to the source of the discrepancy could not be completed on an individual employee or process basis. I recommend using a method of breaking the single group up into a control group and an experimental group. Although this would require three separate research projects, the two group method would help determine the significance

between groups and may provide for improved normality thus reducing error in the interpretation of results.

- Instead of eliminating blank data, use a transformation to fill in the blanks and allow for a more complete analysis. This approach may improve the normality of the data depending on where and when the bulk of the missing values were occurring.

Conclusion

This study found that when providing continual incremental standard work training to the workforce, there was a positive impact on process yield and a negative impact on productivity. While the data for productivity was inconclusive with too much variation occurring during the timeframe of the three training treatments, the end of line process yield data showed there was a direct link between implementing standard work practices and improved quality. Several explanations were offered as to why the productivity outcome did not improve and recommendations for improving the robustness of this study were provided in Chapter 5.

This study provided some insight into the many challenges of conducting research in a real world manufacturing environment, the use and limitations of Repeated Measures MANOVA using a single large group, and ensuring the measurement system within a workplace's information management system was appropriate and reliable. In addition to the challenges, this study provides an avenue for future researchers to take when looking to improve incrementally in unique and non-standard environments.

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Appendix A: A Series of Three Experimental Training Treatments

Table A1. Material Handling Training,

Operation: Product Handling PWB	Owner/Approver: Master Trainer
Tool description: PWB Product	Revision: 1
Tools & Materials: NA	Number of MFG Copies: 1
Reference Documents: END6-3105-029	Location of Copies: QSI only
Master Copy Location: QSI Training Module - Product Handling PWB	Total # of Pages: 1

#	Important Step	Key Points	Reasons
0			
1	Remove all Jewelry before entering work environment	Keep employees out of work area unless Jewelry is removed	Jewelry can cause the smallest of non conformity in a core resulting in scrap.
2	Put on approved gloves before handling product	Change gloves after touching a non clean surface (on work station or on self)	Natural oils on fingers will leave impressions on the material and potentially cause defect
3	When "GET"ting product		
	Lift corner of product one half inch from the edge of the panel with first hand	Handle on EDGES only	Impressions from fingers can cause damage when laying up multiple layers
		Be careful to not bend the material	Bends can cause poor adherence whether laminating or coating
		Be careful to not crinkle the material	Crinkles can cause poor adherence whether laminating or coating.
		Be careful to not touch top or bottom surface	Impressions on top or bottom surface could damage product during plating process
4	Trace second hand along edge to opposite side and secure panel in both hands	Follow same key points from step 3	
5	Lift product with both hands	Carry one unit at a time	Carrying multiple units could cause one panel to damage another.
		Be careful to not allow product to touch any surface during lift	Any surface scraping or touching could damage the fine lines of copper on a board.
		Lift product straight up by edges to minimize damage to surfaces – do not slide	Any surface scraping or touching could damage the fine lines of copper on a board.
6	When "PLACE"ing product	Place on approved smooth surfaces using Tyvex paper	Any surface scraping or touching could damage the fine lines of copper on a board.
		Do not stack	Stacking could lead to impressions on the bottom panel
		Do not slide	Sliding causes scratches on the board and leads to defects
		Be careful to not bend material	Bends can cause poor adherence whether laminating or coating
		Be careful to not crinkle material	Crinkles can cause poor adherence whether laminating or coating.

Table A2. Contamination Control Training,

Operation: Contamination Control PWB	Owner/Approver: Master Trainer
Tool description: PWB Product	Revision: 1
Tools & Materials: NA	Number of MFG Copies: 1
Reference Documents: END6-9025-003	Location of Copies: QSI Only
Master Copy Location: QSI Training Module - Contamination PWB	Total # of Pages: 1

#	Important Step	Key Points	Reasons
0			
1	Prepare to enter garment change room	Ensure all personal articles, coats, hats, food, etc are stored in a locker / cubby outside the garment room	Personal clothing could be contaminated
		Clean shoes using bristle cleaner prior to entering garment room	Shoes carry contamination on them
		Step on tacky mat two times per foot to remove any other loose debris	To further improve contamination removal on shoes before entering garment room
2	Enter the garment change room	Ensure no paper or cardboard enters the clean room with you	Paper and cardboard leave debris and cause contamination
		Ensure no materials enters the clean room with you	Materials and other production needs are to enter in the designated material entry door
		Ensure no clothing with excessive fibers such as Angola or mohair enters the clean room with you	Excessive fibers on clothing can make their way onto the product and cause defects
		Ensure you are wearing approves safety shoes only, no lugs or cleats.	Cleats or lugs are hard to clean and they trap contaminants.
3	Put on clean room garments	Use hair nets to fully cover all hair	Hair is a product contaminant
		Use masks to cover facial hair	Facial hair is also a product contaminant
		Ensure the garment is held by the inside of the garment during dressing	The outside of the garment must remain debris and oil free from hands
		Ensure the garment does not touch the floor during dressing	The floor in the garment room is still considered contaminated.
		Ensure the garment is zipped up and buttoned up fully	Clothing has contaminated on them and must be covered fully
		Ensure shoes do not touch the outside of the garment	Shoes still may have contaminates on them and must not touch outside of garment
		Put on gloves by holding inside of glove	Prevent oils from contaminating outside of gloves
4	Entering the clean room	Step into air shower and engage shower while rotating a few times	Remove any debris left over on garment suit or shoes
		Avoid sneezing or coughing over garment or product	Bodily fluids have been known to cause defects
		Avoid touching face or skin with gloves	Dry skin can flake off causing damage to the product
5	Leaving the clean room	Remove garment ensuring it does not touch the floor	When reusing garments, they must stay in a debris free state
		Store garment in plastic bag in garment room for reuse	When reusing garments, they must stay in a debris free state
		Only reuse garment as many as three times before acquiring a new one	When reusing garments, they must stay in a debris free state

Table A3. Equipment Readiness Training,

Operation: Equipment Readiness PWB	Owner/Approver: Master Trainer
Tool description: PWB Product	Revision: 1
Tools & Materials: NA	Number of MFG Copies: 1
Reference Documents: NA	Location of Copies: QSI Only
Master Copy Location: QSI Training Module - NA	Total # of Pages: 1

#	Important Step	Key Points	Reasons
0			
1	Conveyors	Check that all conveyor rollers are in place	Rollers missing could damage product.
		Check to ensure the rollers are working	Rollers not working could cause scraping against boards and damage product
2	Spray Pressures	Check to ensure all gauges are working	Gauges not working does not help the operator assess the operability of the equipment
		Check to ensure all gauges are within range	A gauge that is not within range could lead to defects due to uneven spray pressures
3	Plumbing	Check to ensure there are no leaks on equipment	Equipment leaks are symptoms of bigger problems and could cause major down time thus losing production Further, leaks could also damage the product.
4	Motors	Check to ensure fans are clean	Fans blowing dirty air could cause debris to land on product thus creating defects
		Check to ensure no abnormal noise is coming from machine	Excessive noise could mean a worn bearing in the motor and result in excessive downtime thus losing production
5	Spray Nozzles	Ensure all are working	Nozzles that are plugged or not working can cause the process to create defects.
6	Oscillation	Smooth Operation	Rough oscillation could cause excessive machine vibration thus damaging product
7	Temperatures	Ensure gauges work	Gauges not working does not help the operator assess the operability of the equipment
		Ensure gauges are within range	A gauge that is not within range could lead to defects due to uneven spray pressures
8	Water flow	Ensure operating within range	Water flow that is not within range could lead to equipment heat up and premature down time issues.
9	Filters	Ensure filters are clean	Filters that are unclean or clogged can cause debris and or poor air exchange thus resulting in premature down time issues.
10	Program	Ensure program is correct for job	Programs are unique to each job within a high technology, low volume environment. Thus we must protect the product to ensure the process has the right program loaded.

Appendix B: A Detailed List of Training Participation

Participant	Treatment 1 Contamination Control Training Received	Treatment 2 Material Handling Training Received	Treatment 3 Equipment Readiness Training Received	All Yes	No's
P1	YES	YES	NO		1
P2	YES	YES	YES	1	
P3	YES	NO	YES		1
P4	NO	YES	NO		1
P5	YES	YES	YES	1	
P6	YES	YES	YES	1	
P7	YES	YES	YES	1	
P8	YES	YES	YES	1	
P9	NO	YES	NO		1
P10	YES	YES	YES	1	
P11	YES	YES	YES	1	
P12	YES	YES	YES	1	
P13	YES	NO	NO		1
P14	YES	NO	YES		1
P15	YES	NO	YES		1
P16	YES	YES	YES	1	
P17	YES	YES	YES	1	
P18	YES	YES	YES	1	
P19	YES	YES	YES	1	
P20	YES	YES	YES	1	
P21	NO	YES	YES		1
P22	YES	YES	YES	1	
P23	YES	YES	YES	1	
P24	YES	NO	YES		1
P25	YES	YES	NO		1
P26	YES	YES	NO		1
P27	YES	YES	YES	1	
P28	YES	YES	NO		1
P29	YES	YES	NO		1
P30	NO	NO	YES		1

Note. A 'Yes' indicates the participant went through the training treatment while a 'No' indicates the treatments.

(table continues)

Participant	Treatment 1 Contamination Control Training Received	Treatment 2 Material Handling Training Received	Treatment 3 Equipment Readiness Training Received	All Yes	No's
P31	YES	YES	YES	1	
P32	YES	YES	YES	1	
P33	YES	YES	NO		1
P34	YES	YES	YES	1	
P35	YES	YES	YES	1	
P36	NO	YES	YES		1
P37	NO	NO	NO		1
P38	YES	YES	YES	1	
P39	YES	YES	YES	1	
P40	YES	YES	YES	1	
P41	YES	YES	NO		1
P42	YES	NO	YES		1
P43	YES	YES	YES	1	
P44	NO	YES	YES		1
P45	NO	YES	NO		1
P46	NO	YES	YES		1
P47	YES	YES	YES	1	
P48	YES	YES	NO		1
P49	YES	YES	NO		1
P50	YES	YES	YES	1	
P51	YES	YES	YES	1	
P52	YES	YES	YES	1	
P53	YES	YES	NO		1
P54	YES	YES	YES	1	
P55	YES	YES	YES	1	
P56	YES	NO	YES		1
P57	YES	YES	YES	1	
P58	YES	YES	YES	1	
P59	YES	YES	YES	1	
P60	YES	NO	YES		1

(table continues)

Participant	Treatment 1 Contamination Control Training Received	Treatment 2 Material Handling Training Received	Treatment 3 Equipment Readiness Training Received	All Yes	No's
P61	NO	YES	YES		1
P62	YES	YES	YES	1	
P63	YES	YES	YES	1	
P64	NO	YES	YES		1
P65	YES	YES	YES	1	
P66	YES	NO	YES		1
P67	NO	NO	NO		1
P68	YES	YES	YES	1	
P69	NO	YES	YES		1
P70	YES	NO	NO		1
P71	YES	YES	YES	1	
P72	YES	YES	YES	1	
P73	YES	YES	NO		1
P74	YES	YES	NO		1
P75	NO	YES	NO		1
P76	YES	YES	YES	1	
P77	YES	YES	YES	1	
P78	YES	YES	YES	1	
P79	YES	YES	YES	1	
P80	NO	YES	YES		1
P81	YES	YES	YES	1	
P82	YES	NO	YES		1
P83	YES	YES	YES	1	
P84	YES	YES	NO		1
P85	NO	NO	NO		1
P86	YES	YES	YES	1	
P87	YES	NO	YES		1
P88	YES	YES	YES	1	
P89	YES	YES	YES	1	
P90	YES	YES	YES	1	

(table continues)

Participant	Treatment 1 Contamination Control Training Received	Treatment 2 Material Handling Training Received	Treatment 3 Equipment Readiness Training Received	All Yes	No's
P91	YES	NO	YES		1
P92	NO	NO	NO		1
P93	YES	YES	YES	1	
P94	YES	YES	YES	1	
P95	NO	YES	NO		1
P96	NO	YES	NO		1
P97	YES	YES	YES	1	
P98	YES	YES	YES	1	
P99	YES	YES	YES	1	
P100	YES	YES	YES	1	
P101	YES	YES	YES	1	
P102	YES	YES	NO		1
P103	YES	YES	YES	1	
P104	NO	NO	NO		1
P105	YES	YES	NO		1
P106	YES	YES	YES	1	
P107	YES	YES	YES	1	
P108	YES	YES	YES	1	
P109	YES	YES	NO		1
P110	YES	YES	YES	1	
P111	YES	YES	YES	1	
P112	YES	YES	YES	1	
P113	NO	YES	YES		1
P114	NO	NO	NO		1
P115	YES	YES	YES	1	
P116	YES	NO	YES		1
P117	YES	YES	YES	1	
P118	NO	NO	NO		1
P119	NO	YES	NO		1
P120	YES	YES	YES	1	

(table continues)

Participant	Treatment 1 Contamination Control Training Received	Treatment 2 Material Handling Training Received	Treatment 3 Equipment Readiness Training Received	All Yes	No's
P121	YES	YES	YES	1	
P122	YES	YES	YES	1	
P123	YES	YES	YES	1	
P124	YES	YES	YES	1	
P125	YES	NO	NO		1
P126	NO	YES	YES		1
P127	YES	NO	YES		1
P128	NO	YES	YES		1
P129	YES	NO	NO		1
P130	YES	YES	YES	1	
P131	YES	YES	YES	1	
P132	NO	YES	NO		1
P133	YES	YES	NO		1
P134	YES	YES	YES	1	
P135	NO	YES	YES		1
P136	YES	YES	YES	1	
P137	YES	YES	YES	1	
P138	YES	YES	YES	1	
P139	YES	YES	YES	1	
P140	YES	YES	YES	1	
P141	YES	YES	NO		1
P142	NO	YES	NO		1
P143	NO	YES	YES		1
P144	NO	NO	YES		1
P145	YES	NO	NO		1
P146	NO	YES	NO		1
P147	YES	YES	YES	1	
P148	YES	YES	YES	1	
P149	YES	YES	YES	1	
P150	YES	NO	YES		1

(table continues)

Participant	Treatment 1 Contamination Control Training Received	Treatment 2 Material Handling Training Received	Treatment 3 Equipment Readiness Training Received	All Yes	No's
P151	YES	YES	YES	1	
P152	YES	YES	NO		1
P153	YES	NO	NO		1
P154	YES	YES	YES	1	
P155	YES	YES	YES	1	
P156	YES	YES	YES	1	
P157	YES	YES	YES	1	
P158	YES	YES	YES	1	
P159	YES	YES	YES	1	
P160	YES	YES	NO		1
P161	YES	YES	YES	1	
P162	YES	YES	YES	1	
P163	YES	YES	YES	1	
P164	YES	YES	YES	1	
P165	NO	NO	YES		1
P166	YES	YES	YES	1	
P167	YES	YES	YES	1	
P168	NO	YES	YES		1
P169	YES	YES	NO		1
P170	NO	NO	NO		1
P171	YES	YES	YES	1	
P172	NO	NO	NO		1
P173	YES	YES	YES	1	
P174	YES	NO	YES		1
P175	YES	NO	YES		1
P176	YES	YES	YES	1	
P177	YES	YES	YES	1	
P178	YES	YES	YES	1	
P179	NO	YES	YES		1
P180	YES	YES	YES	1	

(table continues)

Participant	Treatment 1 Contamination Control Training Received	Treatment 2 Material Handling Training Received	Treatment 3 Equipment Readiness Training Received	All Yes	No's
P181	NO	NO	YES		1
P182	YES	YES	YES	1	
P183	YES	YES	YES	1	
P184	NO	YES	NO		1
P185	YES	YES	NO		1
P186	NO	YES	YES		1
P187	YES	YES	YES	1	
P188	NO	NO	YES		1
P189	YES	YES	YES	1	
P190	YES	YES	NO		1
P191	YES	NO	YES		1
P192	YES	YES	YES	1	
P193	NO	NO	NO		1
P194	YES	YES	YES	1	
P195	YES	YES	YES	1	
P196	YES	YES	YES	1	
P197	YES	YES	NO		1
P198	YES	NO	YES		1
P199	NO	YES	NO		1
P200	YES	NO	YES		1
P201	YES	YES	YES	1	
P202	YES	YES	YES	1	
P203	YES	YES	YES	1	
P204	YES	YES	YES	1	
P205	YES	YES	YES	1	
P206	YES	YES	YES	1	
P207	YES	NO	NO		1
P208	YES	YES	YES	1	
P209	YES	YES	YES	1	
P210	YES	YES	YES	1	

(table continues)

Participant	Treatment 1 Contamination Control Training Received	Treatment 2 Material Handling Training Received	Treatment 3 Equipment Readiness Training Received	All Yes	No's
P211	YES	YES	NO		1
P212	NO	NO	NO		1
P213	YES	YES	NO		1
P214	YES	YES	NO		1
P215	YES	YES	YES	1	
P216	NO	NO	YES		1
P217	YES	YES	YES	1	
P218	NO	YES	NO		1
P219	YES	YES	NO		1
P220	YES	YES	YES	1	
P221	NO	YES	NO		1
P222	NO	NO	NO		1
P223	NO	YES	YES		1
P224	YES	YES	YES	1	
P225	YES	YES	YES	1	
P226	YES	YES	YES	1	
P227	YES	NO	YES		1
P228	YES	NO	NO		1
P229	YES	NO	YES		1
P230	YES	YES	YES	1	
P231	YES	YES	YES	1	
P232	YES	YES	YES	1	

Note. A 'Yes' indicates the participant went through the training treatment while a 'No' indicates the participant did not receive the training treatment. The 'All Yes' category tallies the participants who went through all three training treatments.

Appendix C: Process Yield Raw Data Set

	Process Yield			
Subject	Y0	Y1	Y2	Y3
S1	93.1	95.2	94.7	96.5
S2	92.9	95.4	94.6	97.1
S3	93.0	95.5	97.1	97.5
S4	93.0	95.4	95.2	96.4
S5	92.9	95.1	94.8	96.5
S6	92.9	95.4	95.3	96.8
S7	93.1	96.1	96.1	96.5
S8	93.1	93.5	96.0	96.8
S9	92.9	94.0	94.9	95.9
S10	93.0	95.4	95.2	96.5
S11	94.3	91.8	95.0	96.2
S12	94.2	92.0	96.8	96.3
S13	94.4	92.7	95.3	96.0
S14	94.2	96.2	94.6	96.2
S15	94.3	91.7	95.2	96.2
S16	94.0	92.7	94.5	95.9
S17	93.1	92.8	95.1	97.0
S18	92.7	92.9	94.9	97.1
S19	99.9	99.9	99.9	99.9
S20	99.8	99.8	99.9	99.9
S21	99.9	99.8	99.8	99.9
S22	100.0	99.9	99.9	100.0
S23	99.8	99.8	99.9	99.8
S24	99.9	99.7	99.8	99.9
S25	99.8	99.8	99.9	99.8
S26	99.9	99.9	99.9	99.9
S27	100.0	99.6	100.0	99.9
S28	99.8	100.0	99.9	100.0
S29	99.9	99.9	99.8	99.9
S30	99.8	99.9	99.9	99.8

Note. The baseline process yield (Y_0) is based on a twelve week average while the process yield after each treatment is based on a two week average.

(table continues)

	Process Yield			
Subject	Y0	Y1	Y2	Y3
S31	100.0	99.9	99.8	99.9
S32	100.0	100.0	99.9	100.0
S33	100.0	100.0	100.0	100.0
S34	99.8	99.9	99.8	99.9
S35	100.0	100.0	100.0	100.0
S36	99.9	100.0	99.9	100.0
S37	100.0	100.0	100.0	100.0
S38	99.9	100.0	99.8	99.9
S39	99.8	100.0	100.0	99.9
S40	99.7	99.9	99.5	100.0
S41	99.5	100.0	99.5	99.9
S42	99.7	100.0	100.0	99.9
S43	99.6	99.9	99.6	99.8
S44	99.7	100.0	100.0	99.9
S45	99.3	100.0	99.9	99.9
S46	99.5	99.9	99.9	99.9
S47	99.6	99.8	99.8	99.8
S48	99.4	99.9	99.9	99.8
S49	99.6	100.0	100.0	100.0
S50	99.7	99.9	99.9	99.9
S51	99.6	99.7	99.8	99.9
S52	99.8	98.9	99.0	100.0
S53	99.6	99.0	99.2	100.0
S54	99.5	99.4	99.0	100.0
S55	99.2	99.0	99.1	99.9
S56	99.6	99.1	98.9	100.0
S57	99.6	99.0	99.4	100.0
S58	99.4	98.9	99.2	99.9
S59	99.6	99.1	99.2	100.0
S60	99.8	99.8	99.6	99.8

(table continues)

	Process Yield			
Subject	Y0	Y1	Y2	Y3
S61	99.7	99.9	98.9	99.8
S62	99.5	99.8	99.0	99.2
S63	99.6	99.8	99.3	100.0
S64	99.4	98.9	99.0	99.9
S65	100.0	99.6	99.5	100.0
S66	99.8	100.0	99.9	100.0
S67	100.0	100.0	99.6	99.8
S68	99.8	99.9	99.9	99.7
S69	99.8	99.9	99.7	99.9
S70	99.6	100.0	99.6	99.9
S71	99.8	100.0	99.9	99.8
S72	99.6	99.9	99.6	99.9
S73	99.6	99.9	99.5	100.0
S74	99.8	99.9	99.6	100.0
S75	99.8	99.9	99.6	99.8
S76	99.6	99.6	99.5	99.9
S77	99.8	99.6	99.7	100.0
S78	99.9	99.8	99.8	99.8
S79	99.9	99.9	99.6	100.0
S80	99.4	99.9	98.3	99.8
S81	99.2	99.9	98.8	99.4
S82	99.6	99.9	98.0	99.9
S83	99.3	99.8	99.0	99.8
S84	99.5	99.8	99.4	100.0
S85	99.8	99.9	99.0	99.7
S86	99.9	100.0	99.5	100.0
S87	99.4	99.8	100.0	100.0
S88	99.9	99.9	99.4	99.6
S89	99.8	99.4	99.9	99.0
S90	99.8	99.2	99.9	98.8

(table continues)

	Process Yield			
Subject	Y0	Y1	Y2	Y3
S91	99.5	99.0	99.8	98.9
S92	99.7	99.6	99.9	99.2
S93	100.0	100.0	100.0	100.0
S94	99.9	99.2	99.9	99.8
S95	100.0	99.0	100.0	100.0
S96	99.9	99.8	100.0	99.9
S97	100.0	99.4	100.0	100.0
S98	100.0	99.2	100.0	99.8
S99	99.9	99.2	100.0	99.6
S100	99.7	99.0	98.4	99.8
S101	99.8	98.8	99.8	99.0
S102	99.9	99.8	100.0	99.9
S103	100.0	99.8	99.9	99.9
S104	99.4	99.6	100.0	100.0
S105	99.9	99.0	98.9	99.9
S106	100.0	100.0	100.0	100.0
S107	100.0	100.0	100.0	100.0
S108	100.0	100.0	100.0	100.0
S109	100.0	100.0	100.0	100.0
S110	100.0	100.0	100.0	100.0
S111	99.9	99.4	100.0	100.0
S112	100.0	99.4	100.0	100.0
S113	100.0	99.5	100.0	100.0
S114	99.9	99.6	100.0	100.0
S115	100.0	99.4	100.0	100.0
S116	99.9	100.0	100.0	100.0
S117	99.8	100.0	100.0	100.0
S118	100.0	100.0	100.0	100.0
S119	99.9	100.0	99.9	99.9
S120	99.9	100.0	99.9	99.9

(table continues)

	Process Yield			
Subject	Y0	Y1	Y2	Y3
S121	100.0	100.0	100.0	100.0
S122	100.0	100.0	100.0	100.0
S123	100.0	100.0	100.0	100.0
S124	100.0	100.0	100.0	100.0
S125	100.0	100.0	100.0	100.0
S126	100.0	100.0	100.0	100.0

Note. The baseline process yield (Y_0) is based on a twelve week average while the process yield after each treatment is based on a two week average.

Appendix D: Transformed Process Yield Data Set

	Process Yield Dataset			
	Y0 Arcsin	Y1 Arcsin	Y2 Arcsin	Y3 Arcsin
S19	1.539	1.539	1.539	1.539
S20	1.526	1.526	1.539	1.539
S21	1.539	1.526	1.526	1.539
S22	1.571	1.539	1.539	1.571
S23	1.526	1.526	1.539	1.526
S24	1.539	1.516	1.526	1.539
S25	1.526	1.526	1.539	1.526
S26	1.539	1.539	1.539	1.539
S27	1.571	1.508	1.571	1.539
S28	1.526	1.571	1.539	1.571
S29	1.539	1.539	1.526	1.539
S30	1.526	1.539	1.539	1.526
S31	1.571	1.539	1.526	1.539
S32	1.571	1.571	1.539	1.571
S33	1.571	1.571	1.571	1.571
S34	1.526	1.539	1.526	1.539
S35	1.571	1.571	1.571	1.571
S36	1.539	1.571	1.539	1.571
S37	1.571	1.571	1.571	1.571
S38	1.539	1.571	1.526	1.539
S39	1.526	1.571	1.571	1.539
S40	1.516	1.539	1.500	1.571
S41	1.500	1.571	1.500	1.539
S42	1.516	1.571	1.571	1.539
S43	1.508	1.539	1.508	1.526
S44	1.516	1.571	1.571	1.539
S45	1.487	1.571	1.539	1.539
S46	1.500	1.539	1.539	1.539
S47	1.508	1.526	1.526	1.526
S48	1.493	1.539	1.539	1.526

Note. The process yield dataset was transformed using the Arcsin-root method

(table continues)

Process Yield Dataset				
	Y0 Arcsin	Y1 Arcsin	Y2 Arcsin	Y3 Arcsin
S49	1.508	1.571	1.571	1.571
S50	1.516	1.539	1.539	1.539
S51	1.508	1.516	1.526	1.539
S52	1.526	1.466	1.471	1.571
S53	1.508	1.471	1.481	1.571
S54	1.500	1.493	1.471	1.571
S55	1.481	1.471	1.476	1.539
S56	1.508	1.476	1.466	1.571
S57	1.508	1.471	1.493	1.571
S58	1.493	1.466	1.481	1.539
S59	1.508	1.476	1.481	1.571
S60	1.526	1.526	1.508	1.526
S61	1.516	1.539	1.466	1.526
S62	1.500	1.526	1.471	1.481
S63	1.508	1.526	1.487	1.571
S64	1.493	1.466	1.471	1.539
S65	1.571	1.508	1.500	1.571
S66	1.526	1.571	1.539	1.571
S67	1.571	1.571	1.508	1.526
S68	1.526	1.539	1.539	1.516
S69	1.526	1.539	1.516	1.539
S70	1.508	1.571	1.508	1.539
S71	1.526	1.571	1.539	1.526
S72	1.508	1.539	1.508	1.539
S73	1.508	1.539	1.500	1.571
S74	1.526	1.539	1.508	1.571
S75	1.526	1.539	1.508	1.526
S76	1.508	1.508	1.500	1.539
S77	1.526	1.508	1.516	1.571
S78	1.539	1.526	1.526	1.526

(table continues)

Process Yield Dataset				
	Y0 Arcsin	Y1 Arcsin	Y2 Arcsin	Y3 Arcsin
S79	1.539	1.539	1.508	1.571
S80	1.493	1.539	1.440	1.526
S81	1.481	1.539	1.461	1.493
S82	1.508	1.539	1.429	1.539
S83	1.487	1.526	1.471	1.526
S84	1.500	1.526	1.493	1.571
S85	1.526	1.539	1.471	1.516
S86	1.539	1.571	1.500	1.571
S87	1.493	1.526	1.571	1.571
S88	1.539	1.539	1.493	1.508
S89	1.526	1.493	1.539	1.471
S90	1.526	1.481	1.539	1.461
S91	1.500	1.471	1.526	1.466
S92	1.516	1.508	1.539	1.481
S93	1.571	1.571	1.571	1.571
S94	1.539	1.481	1.539	1.526
S95	1.571	1.471	1.571	1.571
S96	1.539	1.526	1.571	1.539
S97	1.571	1.493	1.571	1.571
S98	1.571	1.481	1.571	1.526
S99	1.539	1.481	1.571	1.508
S100	1.516	1.471	1.444	1.526
S101	1.526	1.461	1.526	1.471
S102	1.539	1.526	1.571	1.539
S103	1.571	1.526	1.539	1.539
S104	1.493	1.508	1.571	1.571
S105	1.539	1.471	1.466	1.539
S106	1.571	1.571	1.571	1.571
S107	1.571	1.571	1.571	1.571
S108	1.571	1.571	1.571	1.571

(table continues)

Process Yield Dataset				
	Y0 Arcsin	Y1 Arcsin	Y2 Arcsin	Y3 Arcsin
S109	1.571	1.571	1.571	1.571
S110	1.571	1.571	1.571	1.571
S111	1.539	1.493	1.571	1.571
S112	1.571	1.493	1.571	1.571
S113	1.571	1.500	1.571	1.571
S114	1.539	1.508	1.571	1.571
S115	1.571	1.493	1.571	1.571
S116	1.539	1.571	1.571	1.571
S117	1.526	1.571	1.571	1.571
S118	1.571	1.571	1.571	1.571
S119	1.539	1.571	1.539	1.539
S120	1.539	1.571	1.539	1.539
S121	1.571	1.571	1.571	1.571
S122	1.571	1.571	1.571	1.571
S123	1.571	1.571	1.571	1.571
S124	1.571	1.571	1.571	1.571
S125	1.571	1.571	1.571	1.571
S126	1.571	1.571	1.571	1.571

Note. The process yield dataset was transformed using the Arcsin-root method.

Appendix E: Productivity Raw Data Set

	Productivity			
Subject	P_0	P_1	P_2	P_3
S_1	3.1	2.4	1.4	2.3
S_2	3.0	2.5	1.3	2.3
S_3	3.1	2.5	1.4	2.3
S_4	3.1	2.6	1.3	2.3
S_5	3.0	2.4	1.3	2.2
S_6	3.2	2.7	1.5	2.4
S_7	2.9	2.5	1.3	2.3
S_8	3.1	2.4	1.3	2.3
S_9	3.2	2.4	1.2	2.5
S_{10}	3.1	2.5	1.3	2.5
S_{11}	4.1	3.8	1.2	2.0
S_{12}	3.9	3.7	1.3	2.1
S_{13}	4.0	3.7	1.3	2.2
S_{14}	4.0	3.8	1.2	2.4
S_{15}	4.1	3.7	1.2	2.1
S_{16}	9.1	7.1	3.0	6.1
S_{17}	8.9	7.3	2.6	6.6
S_{18}	9.4	7.5	4.0	5.8
S_{19}	4.3	3.3	2.9	3.3
S_{20}	4.0	3.5	3.2	3.3
S_{21}	4.3	3.5	2.9	3.3
S_{22}	4.2	3.3	2.8	3.0
S_{23}	4.5	3.5	2.9	3.0
S_{24}	4.5	3.7	2.8	3.6
S_{25}	4.3	3.5	2.7	3.0
S_{26}	4.3	3.4	2.5	3.3
S_{27}	4.4	3.5	2.9	3.6
S_{28}	3.5	3.0	2.1	4.5
S_{29}	3.3	2.7	2.4	4.2
S_{30}	3.4	2.4	2.7	4.5

Note. The baseline productivity (P_0) is based on a twelve week average while the productivity after each treatment is based on a two week average.

(table continues)

Subject	Productivity P_0	P_1	P_2	P_3
S_{31}	3.1	2.7	2.4	4.2
S_{32}	4.5	6.0	3.0	4.3
S_{33}	4.7	6.0	3.5	4.6
S_{34}	4.3	6.2	3.4	4.3
S_{35}	4.5	6.3	3.0	4.8
S_{36}	4.4	6.3	3.2	4.6
S_{37}	4.6	6.2	3.0	4.8
S_{38}	4.0	2.5	2.0	2.2
S_{39}	3.5	2.3	2.1	2.3
S_{40}	4.2	2.4	2.5	2.5
S_{41}	4.1	2.5	2.1	2.3
S_{42}	4.3	2.5	2.3	2.3
S_{43}	3.9	2.7	2.4	2.3
S_{44}	4.0	2.6	2.1	2.2
S_{45}	3.7	2.4	2.5	2.8
S_{46}	3.9	2.0	2.2	2.7
S_{47}	3.7	2.2	2.0	2.6
S_{48}	3.4	2.6	2.2	2.8
S_{49}	3.6	2.0	2.1	2.8
S_{50}	3.7	1.8	2.3	2.9
S_{51}	3.5	2.0	2.2	3.0
S_{52}	4.7	2.5	3.0	4.7
S_{53}	4.7	2.9	2.9	4.5
S_{54}	4.5	2.3	2.9	4.5
S_{55}	4.9	2.3	3.0	4.9
S_{56}	4.0	2.5	3.3	4.8
S_{57}	5.1	2.5	2.7	4.7
S_{58}	4.7	2.5	2.9	4.8
S_{59}	4.6	2.5	2.9	4.7
S_{60}	2.8	2.0	1.3	2.1

(table continues)

Subject	Productivity			
	P_0	P_1	P_2	P_3
S_{61}	3.0	1.8	1.3	2.5
S_{62}	2.8	1.8	1.6	2.1
S_{63}	2.8	2.2	1.6	2.4
S_{64}	3.0	1.8	1.3	2.1
S_{65}	2.8	2.2	1.4	2.0
S_{66}	2.6	1.8	1.0	2.0
S_{67}	2.9	2.0	1.0	1.8
S_{68}	2.6	2.0	1.3	1.6
S_{69}	3.9	2.4	1.8	2.5
S_{70}	3.9	2.0	3.0	2.4
S_{71}	4.0	2.8	2.5	2.5
S_{72}	4.2	2.0	2.0	2.1
S_{73}	4.5	3.0	2.4	2.5
S_{74}	4.5	2.5	1.8	2.2
S_{75}	4.0	2.0	2.7	2.9
S_{76}	4.0	1.8	2.6	2.8
S_{77}	3.5	2.2	2.4	3.0
S_{78}	4.5	2.4	2.6	2.8
S_{79}	4.0	1.8	2.5	2.8
S_{80}	6.8	6.5	2.4	4.6
S_{81}	6.5	6.5	2.9	4.5
S_{82}	6.8	6.8	2.7	4.8
S_{83}	6.8	6.8	2.6	4.5
S_{84}	6.6	6.5	3.1	4.5
S_{85}	11.0	7.3	3.7	5.8
S_{86}	10.8	7.5	4.8	5.5
S_{87}	11.2	7.3	4.2	6.0
S_{88}	10.8	7.5	4.0	5.7
S_{89}	7.3	5.0	2.0	2.4
S_{90}	7.0	5.5	2.4	2.7

(table continues)

Subject	P_0	Productivity P_1	P_2	P_3
S_{91}	7.5	6.0	1.8	2.6
S_{92}	7.4	5.7	2.2	2.5
S_{93}	7.3	5.3	2.0	2.7
S_{94}	6.0	3.0	2.4	5.3
S_{95}	6.0	3.4	3.0	5.0
S_{96}	6.0	3.4	2.0	5.5
S_{97}	5.5	3.0	2.4	5.3
S_{98}	5.5	3.2	2.5	5.1
S_{99}	6.0	3.6	2.8	5.0
S_{100}	6.0	3.8	2.9	5.2
S_{101}	5.8	3.6	2.1	5.3
S_{102}	7.7	5.3	5.0	7.2
S_{103}	7.5	5.2	5.1	7.2
S_{104}	7.7	5.4	5.3	7.0
S_{105}	7.0	5.0	5.1	6.8
S_{106}	8.5	5.1	4.1	6.9
S_{107}	8.5	5.5	4.5	6.6
S_{108}	9.0	5.5	5.2	6.9
S_{109}	8.7	5.4	5.0	6.1
S_{110}	8.2	5.1	4.1	5.8
S_{111}	4.5	2.4	1.7	3.0
S_{112}	4.0	2.8	1.5	3.3
S_{113}	4.3	3.1	1.6	3.9
S_{114}	5.5	2.8	1.4	3.4
S_{115}	4.5	2.8	1.5	3.0
S_{116}	5.4	2.7	2.5	5.5
S_{117}	5.7	3.2	2.0	5.0
S_{118}	5.1	2.3	2.4	5.7
S_{119}	7.4	3.0	2.0	4.0
S_{120}	7.8	3.2	1.9	3.8

(table continues)

Subject	Productivity P_0	P_1	P_2	P_3
S_{121}	0.9	1.8	1.5	1.9
S_{122}	1.3	2.0	1.7	1.9
S_{123}	0.8	1.6	1.3	2.1
S_{124}	0.5	1.2	0.7	1.0
S_{125}	0.6	1.4	0.9	1.0
S_{126}	0.3	1.0	1.0	1.0

Note. The baseline productivity (P_0) is based on a twelve week average while the productivity after each treatment is based on a two week average.

Appendix F: Material Handling Improvement Opportunities

	Area	Material Handling Opportunity for Improvement	Category
1	Circ	Develop a way to load product without reaching over the side rail on machine.	Ergonomics
2	Circ	Use a right sized adjustable cart instead of using backer supply to hold top upright.	Ergonomics
3	Circ	Add adjustable feeder tables to the clean room.	Ergonomics
4	Circ	Eliminate two person jobs being handled by one person.	Ergonomics
5	Circ	Add a lift assist for heavy panels. Panels must be slightly adjusted after once placement due to weight.	Ergonomics
6	Circ	Use racks for product.	Packaging
7	Circ	Procure new tubs and carts.	Packaging
8	Circ	Label tubs based on size.	Packaging
9	Circ	Find a new glove for panel cleaner that does not leave fingerprints.	Process
10	Circ	Move machine away from wall to allow loading from the end instead of from the side.	Process
11	Circ	Re-layout LDI machine to create more space for carts thus allowing corner to corner handling.	Process
12	Circ	Investigate warped panels because they have to be pushed down to run through machine.	Process
13	Circ	Boards with leader boards require to grab in middle of leader board. Find a better way.	Process
14	Circ	Adjust the guideline of holding panel corner to corner due to a more likely chance to crack laminate.	Process
15	Circ	Need better solution than leader boards.	Process

(table continues)

	Area	Material Handling Opportunity for Improvement	Category
16	Circ	Develop material handling spec. per station instead of a generalized spec. for all processes to follow.	Standard Work / Training
17	Circ	Update video to include all products.	Standard Work / Training
18	Coat	Implement lift assist because its difficult to not touch the middle active areas of heavier product.	Ergonomics
19	Coat	Operators cannot reach corner to corner on panels larger than 24x28. Implement a lift assist.	Ergonomics
20	Coat	Redesign carts to allow for better handling practices. Currently, the operator has to use the slots to pull out panel because reaching corner to corner is not practical.	Ergonomics
21	Coat	Re-evaluate use of pink foam and implement better design for different sized boards.	Packaging
22	Coat	Procure more pink foam.	Packaging
23	Coat	Keep product out of tubs and into slotted racks with wide grooves.	Packaging
24	Coat	White ID being scraped when board is laid flat and damaged. Develop an alternative method.	Packaging
25	Coat	Replace old racks.	Packaging
26	Coat	Enforce one panel per tub rule.	Packaging
27	Coat	Edge damage occurs when multiple smaller product is put into tubs and product bang against each other. Enforce one panel per tub rule unless using foam inserts to protect panels.	Packaging
28	Coat	Procure more gloves.	Process
29	Coat	Develop a new handling method for heavy panels at develop line.	Process
30	Coat	Use interleaf paper when stacking product.	Process

(table continues)

	Area	Material Handling Opportunity for Improvement	Category
31	Coat	Right size adjustable racks to prevent handling damage during movement.	Process
32	Coat	Specify proper gloves at expose machine.	Process
33	Coat	Develop a designated work station for mass hole fill machine.	process
34	Coat	Ensure all operators wear gloves.	Process
35	Coat	Hold the sides of the panels at vertical coat machine to prevent dropping product.	Process
36	Coat	Develop a better way to remove jammed product. Currently, the operator has to grab the active area to remove a jammed board.	Process
37	Coat	Develop carts to accommodate the oddball sized product.	Process
38	Coat	Develop a rule to not use slots for material movement. If the panel is too thick, the operator will use the slots causing shavings to fall.	Process
39	Coat	Develop a universal cart instead of jamming product in the wrong sized carts.	Process
40	Coat	Organize workplace to allow operators to find proper carts.	Process
41	Coat	Determine why core panels warp in MOSS tool.	Process
42	Coat	Moss Tool can catch and rip into circuit area if panels have rough edges. Develop an alternative.	Process
43	Coat	Need an approved surface to place panels on. Current station does not have an approved surface.	Process
44	Coat	Frame on Argon table prevents corner to corner handling. Develop a better table.	Process
45	Coat	More likely to drop a panel if held corner to corner due to profiled panels. Develop a better practice.	Process

(table continues)

	Area	Material Handling Opportunity for Improvement	Category
46	Coat	Develop specialized handling specs per station.	Standard Work
47	Drills	Implement a lift assist for heavier panels that are hard to manage.	Ergonomics
48	Drills	Implement maximum weight rule for a tub. When there are too many panels in a tub, the tub is hard to pick up.	Ergonomics
49	Drills	Procure more carts to reduce bending at the waist.	Ergonomics
50	Drills	Re-design carts. Current carts design is too low, damaged, falling apart, and there are teeth at the bottom that can cause edge delamination, also panels move and shimmy in carts.	Ergonomics
51	Drills	Implement a lift assist for heavy panels. Operator can't flip heavy panel to check for damage.	Ergonomics
52	Drills	Develop an alternative method for drill machine product handling. Operator can't reach back corner of machine to hold corner to corner.	Ergonomics
53	Drills	Use correct tubs, metal pieces break and cause damage to product.	Packaging
54	Drills	Implement rule of one panel per tub.	Packaging
55	Drills	Reduce stack height rules for tubs now that panels are heavier.	Packaging
56	Drills	Procure smaller tubs for open slot panels.	Packaging
57	Drills	Use one panel per tub and right size to reduce defects.	Packaging
58	Drills	Replace tubs that are falling apart and have metal sticking out of the sides.	Packaging
59	Drills	Procure thicker, clean interleaf paper.	Packaging
60	Drills	Ensure slots are clean from profile to make it easier to get onto pins instead of needing to pound the board down the slot area.	Process

(table continues)

	Area	Material Handling Opportunity for Improvement	Category
61	Drills	Provide interleaf paper for all processes.	Process
62	Drills	Remove practice of placing backers in tubs with thicker panels, hard to get out and may slip on active areas, holds debris against panels instead of falling in depressions.	Process
63	Drills	Ensure Drill team wears gloves.	Process
64	Drills	Repair / replace carts that are damaged and failing.	Process
65	Drills	Get cart to transport to view tool.	Process
66	Drills	Follow standard work by first handling backer then handling panel instead of holding panel with one hand and placing backer	Process
67	Drills	Develop better method to load/ unload tool. The right adjustable bar on the optical laser is too close to the board and can hit the board when loading.	Process
68	Drills	Clean out tubs.	Process
69	Drills	Get smaller hand held vacuums to clean machines each shift.	Process
70	Drills	Keep aisles clear and conduct more 5S.	Process
71	Drills	Make gloves mandatory across all product groups.	Process
72	Drills	Improve the Slot interface. Currently there is a need to pound down to fit over pins.	Process
73	Drills	Fix the scrubber to only run one pass on product.	Process
74	Drills	Ensure tub stack height is never violated during high production runs.	Process
75	Drills	Improve workplace organization.	Process

(table continues)

	Area	Material Handling Opportunity for Improvement	Category
76	Drills	Develop standard practice when hand carrying a panel.	Process
77	Drills	Re-layout space to improve product handling and flow.	Process
78	Drills	Develop a better method than sliding panels at Laser and x-ray.	Process
79	Drills	Re-establish the guidelines to account for holding the boards too tight. The board could crack slots if holding tight enough.	Process
80	Drills	Improve consistency of training in all areas.	training
81	Lam	Lower layup station #1 because it is too high for the operator.	Ergonomics
82	Lam	Reduce stacking height because bottom tubs absorb all the weight potentially damaging the product when too many tubs are stacked.	Packaging
83	Lam	Open up the slot size on the rolling baskets.	Packaging
84	Lam	Recoat rolling baskets.	Packaging
85	Lam	Put all product on racks to remove tubs and warpage issues.	Packaging
86	Lam	Eliminate coated baskets.	Packaging
87	Lam	Make a standard for one panel per tub.	Packaging
88	Lam	Procure new tubs or racks.	Packaging
89	Lam	Repackage prepreg because using bags are too hard to handle and creating damaged prepreg.	Packaging
90	Lam	Develop a better process because panels can get caught loading and unloading in rolling baskets at bondfilm.	Process

(table continues)

	Area	Material Handling Opportunity for Improvement	Category
91	Lam	Reduce sliding of Panels against backers in bond film process.	Process
92	Lam	Check product for warpage before product gets caught in rollers of core cleaner.	Process
93	Lam	Add a stop on the core cleaner to prevent panels from hitting the floor before and operator can reach corner to corner.	Process
94	Lam	Level and extend press crane because it does not allow for full range of motion.	Process
95	Lam	Rewrite guidelines about sliding fingers along edges because an operator could get cut on sharp edges.	Standard Work
96	Lam	Add a stop on the core cleaner to prevent panels from hitting the floor before and operator can reach corner to corner.	Process
97	Lam	Procure more tables at the correct height.	Process
98	Lam	Make shelf heights on racks larger for better maneuverability.	Process
99	Lam	Implement standard work where we don't bond film more than we can layup because it results in excess handling.	Standard Work
100	Lam	Develop specialized handling specs for the process.	Standard Work
101	Plate	Provide lift assists for larger, heavier panels. Sometimes operator has to touch active areas due t size and weight.	Ergonomics
102	Plate	Develop a shop rule to handle one panel at a time. Being pushed to handle two panels at once.	Standard Work
103	Plate	Put all product in racks instead of tubs.	Process
104	Plate	Add more vertical racks.	Process
105	Plate	Educate employees on how sliding the panel will affect middle active area.	Training

(table continues)

	Area	Material Handling Opportunity for Improvement	Category
106	Plate	Prevent the need to touch panel to realign on conveyor at TPP plate process.	Process
107	Plate	Rewrite guidelines about sliding fingers along edges because an operator could get cut on sharp edges.	Standard Work
108	Plate	Revise guideline specifically for vertical plate. No flat surfaces and cannot catch corner to corner.	Standard Work
109	Profile	Add a lift assist at profile. Heavy boards are unsafe to hold corner to corner.	Ergonomics
110	Profile	Develop standard work so we don't run in batches and placing whole jobs loose in tubs and moving them from machine to machine causes damage.	Standard Work
111	Profile	Develop correct tub size for panels after profile.	Packaging
112	Profile	Put product into racks.	Packaging
113	Profile	Use the yellow tubs for 18X24 product.	Packaging
114	Profile	Procure more slotted carts.	Packaging
115	Profile	Procure new black boxes and frames.	Packaging
116	Profile	Procure gloves.	Process
117	Profile	Ensure product does not come in with damage from other processes.	Process
118	Profile	Load product on fixture at each station, do not place loosely in tubs.	Process
119	Profile	Develop handling specs specific to each workstation.	Process
120	Profile	Use only one type of glove.	Process

(table continues)

	Area	Material Handling Opportunity for Improvement	Category
121	Profile	Use 5s and develop clear path for travel with product.	Process
122	Profile	Add extra carts instead of carrying panels around by hand.	Process
123	Profile	Reduce setups and teardowns causing extra product handling.	Process
124	Profile	Develop better guidelines. Following guidelines is an extra 6 steps and is inefficient.	Standard Work
125	Profile	Implement more automation for hands off product.	Process
126	Profile	Procure more interleaf paper.	Process
127	Profile	Add more space at Mark VII. It can hit spindle holder at back of tool, only 2 - 3 inches of space.	Process
128	Profile	Develop a standard practice at drills to not let green tape out of their area.	Standard Work
129	Profile	Change gloves more often.	Standard Work
130	Profile	Stop operators from sliding panels out of frames vs. removing frames from tubs and opening as proper.	Standard Work
131	Profile	Fix loaders to handle product less by hand.	Process
132	Profile	Develop a better alternative than using skids for blank cores.	Process
133	Profile	Develop specialized handling specs per station.	Standard Work
134	Profile	Limit number of panels in tubs.	Standard Work
135	Profile	Provide more show and tell training.	training

(table continues)

	Area	Material Handling Opportunity for Improvement	Category
136	Spec Plt	Redevelop guidelines for the process. Cannot handle corner to corner due to size and weight.	Ergonomics
137	Spec Plt	Develop a work area to place panels.	Process
138	Spec Plt	Fix the guidelines. The current guide does not work for basket / rack loading.	Process
139	Spec Plt	Add a cart to move from unload to rinse/dry.	Process
140	Test	Add a lift assist because weight of boards is an issue for women.	Ergonomics
141	Test	Update Guidelines and develop a new practice. The Operators can't reach corner to corner when feeding short side first.	Ergonomics
142	Test	Update guidelines and develop a new practice. Its hard to flip composite for proper orientation if holding corner to corner.	Ergonomics
143	Test	Develop a better tub because its hard to retrieve product out of tubs when not using edges near slots.	Packaging
144	Test	Put product in racks.	Packaging
145	Test	Use the correct size tubs and paper for product.	Packaging
146	Test	Develop a standard that all composites should be one per tub across plant.	Packaging
147	Test	Develop a better practice for gloves. Its hard to get gloves on due to moist hands.	Process
148	Test	Replace frames for running product through wash. They are falling apart.	Process
149	Test	Replace lock washers to keep screws in place on wash.	Process
150	Test	Prevent the tapped holes being stripped.	Process

(table continues)

	Area	Material Handling Opportunity for Improvement	Category
151	Test	Get new rails on A6, panels can fall off into machine.	Process
152	Test	Develop specialized handling specs per station.	Standard Work
153	Test	Focus and improve on truckers drop off and pick up work practices.	Standard Work
154	Test	Procure more comfortable gloves.	Supply

Appendix G: Contamination Control Improvement Opportunities

	Area	Contamination Control Opportunity for Improvement	Category
1	Test	Use Tackey Rollers for all product instead of just when product wont test correctly.	Process
2	Test	Procure wipes for clean station.	Supply
3	Test	The tubs that come into the room are dirty, need cleaning.	Housekeeping
4	Test	Develop a 5S Station.	Housekeeping
5	Test	Procure a smaller dust mop to get under benches and between legs of tables.	Housekeeping
6	Test	Clean the large grey carts as part of daily housekeeping.	Housekeeping
7	Test	Have floor professionally cleaned due to a prior leak.	Housekeeping
8	Test	Implement an in house vacuum system.	Housekeeping
9	Test	Clean dazor base near joint.	Housekeeping
10	Test	Implement a practice of not reusing gloves.	Process
11	Test	Paint the ceilings and floors at the aquastorm process.	Housekeeping
12	Test	Clean around the wash and drip panes.	Housekeeping
13	Test	Add keyboard cleaning to daily housekeeping. Using a dirty keyboard while wearing gloves does not help.	Process
14	Test	Procure a separate punch machine for black prepreg to reduce cross contamination issues.	Process
15	Test	Remove the basket from the floor that catches leaks, and repair leaks.	Process

(table continues)

	Area	Contamination Control Opportunity for Improvement	Category
16	Test	Procure new racks to remove rusty racks from floor.	Packaging
17	Test	Need to practice more clean room standards in non clean room areas such as hair nets.	Process
18	Test	Add tacky mats to more areas.	Process
19	Test	Enforce 100% participation for cleaning.	Housekeeping
20	Test	Remove profile dust coming in on product.	Housekeeping
21	Circ	Clean third floor.	Housekeeping
22	Circ	Get a new etcher that does not leak.	Process
23	Circ	Super clean needs to be split up over three shifts.	Housekeeping
24	Circ	Replace carts that are in bad shape.	Packaging
25	Circ	Clean windows in etch area.	Housekeeping
26	Circ	Replace the PVC in the slotted carts.	Maintenance
27	Circ	Remove rust and ceiling debris to prevent from falling on table.	Housekeeping
28	Circ	Stop reusing gloves. Grey gloves being used for more than one operation possibly spreading contaminants.	Process
29	Circ	Replace seals on windows of etcher doors.	Maintenance
30	Circ	Clean pumice laminator. Currently not being cleaned.	Housekeeping

(table continues)

	Area	Contamination Control Opportunity for Improvement	Category
31	Circ	Fix cupric leaks	Maintenance
32	Circ	Look for different glove. Grey gloves break down over time	Process
33	Circ	Enforce the cleanliness rules.	Management
34	Circ	Add visual aids at station.	Standard work
35	Circ	Review Process because maintech heat rollers can pick up debris and deposit on product.	Process
36	Circ	Procure better carts with wider slots.	Packaging
37	Circ	Shorten hose for cleaning LDI.	Housekeeping
38	Circ	Procure more alcohol wipes to clean tacky rollers.	Supply
39	Circ	Replace bands holding up pipes because they are rusting, breaking, and falling to the floor.	Maintenance
40	Circ	Replace photohelic.	Maintenance
41	Circ	Adjust air flow to prevent contaminate.	Maintenance
42	Circ	Develop 5S schedule by day and by shift.	Standard work
43	Circ	Check filters on equipment daily product waiting in hallway, need to change the route of the product into the cleanroom.	Maintenance
44	Circ	Provide more feedback and support from management.	Management
45	Circ	Purchase cleaning supplies (lucky 7 and garbage bags) so cleaning can be done.	Supply

(table continues)

	Area	Contamination Control Opportunity for Improvement	Category
46	Circ	Hold repeat offenders accountable for workplace cleanliness.	Management
47	Circ	Provide an alternative glove. The red gloves at ICT are not good and fingers poke through after a while.	Process
48	Circ	Ensure PM's are done on equipment.	Maintenance
49	Circ	Ensure feedback to techs on cleanliness is received and acted upon	Management
50	Circ	Watch for copper flakes on edges because that could get onto panel.	Process
51	Circ	Provide better awareness of the entire process so operators can understand the ramifications of not cleaning.	Standard work
52	Lam	Give employees a second red stripe do they don't have to unzip their suits to kronos on/off jobs.	Process
53	Lam	Provide retractable vacuum hoses at the layup station instead of dragging on the floor.	Process
54	Lam	Clean racks during super clean.	Housekeeping
55	Lam	Provide stronger air hoses to clean pins.	Process
56	Lam	Control the amount of spray in pins (too much leaves residue).	Process
57	Lam	Use PACO pads for all high performance product (3 ply press pads have frayed edges).	Process
58	Lam	Add a storage cabinet to clean room paco pads and tedlar supplies for ease of use and contamination concerns.	Housekeeping
59	Lam	Develop a practice were operators don't put backers into tubs which introduces debris on purpose.	Process
60	Lam	Fix the gears in the dummy elevator out of bondfilm.	Maintenance

(table continues)

	Area	Contamination Control Opportunity for Improvement	Category
61	Lam	Improve teardown cleaning tool for slots.	Process
62	Lam	Clean rollers on conveyor connected to press.	Housekeeping
63	Lam	Clean tubs.	Housekeeping
64	Lam	Redo clean room air flow.	Maintenance
65	Lam	Procure clean room paper.	Supply
66	Lam	Procure new and more vacuum nozzles in bake.	Housekeeping
67	Lam	Seal the doors that lead from the bake room to the press to prevent clean room issues.	Maintenance
68	Lam	Develop better storage for copper punch fixtures to prevent storing against wall and causing debris.	Housekeeping
69	Lam	Ensure prepreg punches are by type and not by size to prevent cross contamination.	Standard work
70	Lam	Get rid of cardboard in the room.	Process
71	Lam	Remove excess epoxy dust at press.	Process
72	Lam	Replace missing brushes in the plate cleaner.	Maintenance
73	Lam	Clean ceiling tiles in laminations area.	Housekeeping
74	Lam	Clean punches more frequently than once a week.	Housekeeping

(table continues)

	Area	Contamination Control Opportunity for Improvement	Category
75	Lam	Develop a standard practice to not reuse prepreg bags.	Process
76	Lam	Procure new cleanroom suits, the current model hits the floor and they are hard to get in and out of.	Process
77	Lam	Develop standard practice for cleaning tubs. Crib operator was told by a technician to not bother cleaning out tubs.	Management
78	Lam	Implement a tub washer, modified dishwasher.	Process
79	Lam	Procure suitcases and black boxes.	Packaging
80	Lam	Isolate layup from bake and prep to control contaminates.	Process
81	Drills	Procure clean paper to replace dirty / wrong sized paper.	Supply
82	Drills	Procure clean rags and Windex bottles and develop a housekeeping cart for area.	Supply
83	Drills	Procure a long enough vacuum cord.	Housekeeping
84	Drills	Require gloves for all products.	Process
85	Drills	Improve clogged filters on shop vacs.	Process
86	Drills	Procure new tables in middle row because edges are flaking and crumbling.	Process
87	Drills	Enforce 5S on all machines.	Housekeeping
88	Drills	Order clean paper and more cleaning supplies.	Supply
89	Drills	Procure new equipment (skids are rusty, hand trucks are leaking oil, and flaking paint, carts are rusty).	Process
90	Drills	Stop dirty tubs coming in from building 258.	Housekeeping

(table continues)

	Area	Contamination Control Opportunity for Improvement	Category
91	Drills	Ensure operators wash hands.	Housekeeping
92	Drills	Use alcohol wipes to wipe down tables.	Housekeeping
93	Drills	Stop carrying panels under arms.	Standard work
94	Drills	Clean out debris on SLP tubs.	Housekeeping
95	Drills	Develop standard work to not put backers in tubs with clean product.	Standard work
96	Drills	Change profile machine drill bits more often to reduce copper shavings.	Process
97	Drills	Enforce vacuuming of trays before they leave storage.	Housekeeping
98	Drills	Replace air showers in laminations.	Maintenance
99	Drills	Vacuum machines at Profile.	Housekeeping
100	Drills	Remove broken drill bits and tape at drill machines.	Housekeeping
101	Coat	Tacky roll panels once cured.	Housekeeping
102	Coat	Require gloves in area.	Standard work
103	Coat	Ensure all shifts follow practices.	Management
104	Coat	Check HEPA filters more often.	Maintenance
105	Coat	Clean carts more often.	Housekeeping

(table continues)

	Area	Contamination Control Opportunity for Improvement	Category
106	Coat	Have manager audit super clean for follow-up.	Management
107	Coat	Slow down roller at the end of entek.	Process
108	Coat	Fix leak causing corrosion on the entek line.	Maintenance
109	Coat	Put filters on all vents to capture contaminates.	Maintenance
110	Coat	Ensure regular PM and cleaning of machines.	Housekeeping
111	Coat	Managers must be more present on the floor to ensure 5S is taken seriously.	Management
112	Coat	clean tubs before they leave storage.	Housekeeping
113	Coat	Ensure no dirty tubs coming from 18 with copper pieces in them.	Housekeeping
114	Coat	Prevent I&R black fibers from 18.	Housekeeping
115	Coat	Blow back out process effects expose and film developer.	Process
116	Plate	Check airs controls because front of room gets very humid.	Maintenance
117	Plate	Procure new interleaf paper that may be dirty.	Housekeeping
118	Plate	Provide better gloves for each operation.	Process
119	Plate	Ensure new people learn all the nuances of an area causing contamination.	Standard work
120	Plate	Remove paint falling and oil dripping from ceiling pipes at Chem Polish machine.	Maintenance

(table continues)

	Area	Contamination Control Opportunity for Improvement	Category
121	Plate	Change gloves more frequently.	Process
122	Plate	Wrap pipes to contain and prevent falling debris.	Maintenance
123	Plate	Clean black boxes.	Housekeeping
124	Plate	Increase the exhaust.	Process
125	Plate	Strip and repaint main areas in rooms.	main
126	Plate	Put covers on carts to protect panels.	Process
127	Plate	Clean the vents.	Housekeeping
128	Plate	Provide better filtration on PLB line to reduce contamination.	Maintenance
129	Plate	Enforce gloves as necessary for process.	Process
130	Plate	Change gloves for different areas.	Process
131	Plate	Improve maintenance of all equipment.	Maintenance
132	Plate	Remove grease and grime from deburr tool.	Housekeeping
133	Plate	Use slotted carts.	Packaging
134	Profile	Procure soap to mop with instead of reusing dirty water.	Supply
135	Profile	Replace glove damages	Supply

(table continues)

	Area	Contamination Control Opportunity for Improvement	Category
136	Profile	Procure new tools and clamps because operators have to tape panels down leaving residue.	Process
137	Profile	Clean dirty tubs.	Housekeeping
138	Profile	Prevent orders coming in with old and dirty paper.	Supply
139	Profile	Remove source of dust on Phenolic backers in storage room.	Process
140	Profile	Clean templates before and after use.	Housekeeping
141	Profile	Add holding racks for vacuum plates for each machine.	Process
142	Profile	Simplify FOD/FOE spec - many parts do not pertain to us.	Standard work
143	Profile	Clean tubs more regularly.	Housekeeping
144	Profile	Wear gloves for all products and all areas.	Process
145		Enforce the guidelines.	Management
146	Spec Plt	Adjust the humidity to reduce condensation on parts.	Process
147	Spec Plt	Clean ceiling tiles and vents near baker line.	Maintenance
148	Spec Plt	Replace rusted pipes on machinery.	Maintenance
149	Spec Plt	Repair rolling baskets.	Maintenance
150	Spec Plt	Clean and repaint emergency shower.	Housekeeping

Appendix H: Equipment Readiness Improvement Opportunities

	Area	Equipment Readiness Opportunity for Improvement	Category
1	Test	Add a computer for SAP use at Manufacturing inspect area.	Information Systems
2	Test	Use less pass codes at wash area.	Information Systems
3	Test	Use different paper sizes at Wash area so they don't have to cut their own.	Material Supply
4	Test	Procure more Pink / gray foam sheets in wash area, current ones are old and breaking down.	Material Supply
5	Test	Develop better process. Titration sometimes runs out at wash- causes machine to be out of spec.	Material Supply
6	Test	Procure supply to prevent wash Machine from shutting down.	Material Supply
7	Test	Fix bent Probes.	Operator PM
8	Test	Fix light receptacles that become unattached if someone hits the inspection scope between products.	Operator PM
9	Test	Make sure hi pot probes and springs are working prior to using on panel.	Operator PM
10	Test	Check calibration.	Operator PM
11	Test	Perform PM's more often.	Operator PM
12	Test	Procure new fixture because everett EOL tools are sometimes hard to setup.	Process
13	Test	Install tacky mat outside of wash room.	Process
14	Test	Procure more frames at wash to replace broken ones.	Process
15	Test	Replace racks at wash area that are old and worn out.	Process

(table continues)

	Area	Equipment Readiness Opportunity for Improvement	Category
16	Test	Store backup dazer lights for when they go out.	Spare Parts
17	Circ	Procure filters for DES Etch.	Material Supply
18	Circ	Replace 4 missing parts at Pumice machine.	Spare Parts
19	Circ	Level Conveyor at EQ#13892.	Process
20	Circ	Replace black roller discs that are worn down at EQ# 13892.	Spare Parts
21	Circ	Align loader head at Eq#13892.	Process
22	Circ	Fix cupric leaks instead of making us rinse the machine every hour.	Process
23	Circ	Properly Debug LDI programs.	Information Systems
24	Circ	Procure new tool EQ 13403.	Process
25	Circ	Make it easier to adjust brushed on pre-clean / pumice scrubber.	Process
26	Circ	Replace rusty section of equipment.	Process
27	Circ	Perform proper PM's.	Operator PM
28	Circ	Rebuild sections of equipment that are broken down.	Process
29	Circ	Create program backups for tools.	Information Systems
30	Circ	Improve shift communication status on tools.	Information Systems

(table continues)

	Area	Equipment Readiness Opportunity for Improvement	Category
31	Circ	Keep parts and supplies for tools on hand.	Spare Parts
32	Circ	Procure a new machine or frame process because machine is not capable for thinner product.	Process
33	Circ	Improve spare parts availability.	Spare Parts
34	Circ	Increase maintenance staff because they are down to one person.	Management
35	Circ	Consistently conduct PM's.	Operator PM
36	Lam	Procure spare parts for machines.	Spare Parts
37	Lam	Order parts so we can use equipment at EQ #21469 and 19399.	Spare Parts
38	Lam	Improve layup station software - press cycle changes after you make your selection (3 operators repeated this issue).	Information Systems
39	Lam	Develop process to prevent thin product from jamming at Bondfilm Line #24301.	Process
40	Lam	Sharpen dull Pre-preg punch more frequently if we plan to continue punching many sheets at one time.	Process
41	Lam	Provide enough space to store tooling plates.	Process
42	Lam	Improve ergonomics issues with lifting heavy plates.	Process
43	Lam	Keep the equipment clean for use.	Operator PM
44	Drills	Remount Hitachi pressure gages that are under tool and hard to see.	Process
45	Drills	Ensure people follow OPM.	Operator PM

(table continues)

	Area	Equipment Readiness Opportunity for Improvement	Category
46	Drills	Procure more vacuums.	Process
47	Drills	Provide OPM on Laser.	Operator PM
48	Drills	Air blocker slide plate should be lower so operators don't have to jump and hit it. (EQ#E0097	Process
49	Drills	Add an operator or a better drill bit at Schmolls to prevent fails due to thin drill bits.	Process
50	Drills	Improve frequency converter at Schmolls.	Process
51	Drills	Clean Machine #18 keyboard to prevent sticking - E0492.	Process
52	Drills	Keep machines clean.	Operator PM
53	Drills	PM more often.	Operator PM
54	Drills	Develop alternative plan for schmoll capacity.	Process
55	Coat	Procure Entek chemicals to prevent out of stock conditions.	Material Supply
56	Coat	Improve program - self dosing program on EQ#54391 - doesn't always register command, slow pump.	Process
57	Coat	Replace hinges on auto coater panel holder.	Spare Parts
58	Coat	Replace Dog Bone pins at beginning of shift.	Spare Parts
59	Coat	Ensure racks at Entek fit all panel sizes.	Process
60	Coat	Procure spare parts for Argon 4 machine that has broken part.	Spare Parts

(table continues)

	Area	Equipment Readiness Opportunity for Improvement	Category
76	Profile	Provide interface with prior shift.	Information systems
77	Profile	Clean out machines at end of shift.	Operator PM
78	Profile	Procure monitor needed at EQ#24350.	Information systems
79	Profile	Repair EQ22575 where only 1 of 4 stations work.	Process
80	Profile	Repair EQ23638 station 1 which does not work.	Process
81	Profile	Procure vacuum for XLP stations 2&4.	Process
82	Profile	Improve reliability at EQ23790. Bulls eye to optically align is taped.	Process
83	Profile	Service EQ23911 - servo kicks off when running larger product.	Process
84	Profile	Procure new hoses and connectors at EQ20929 & 21960.	Spare Parts
85	Profile	Replace Mark VII 5-4 spindles.	Spare Parts
86	Profile	Provide more cross training on machines.	Management
87	Profile	Procure a skilled supertech to support quicker down time response.	Management
88	Profile	Replace torn mats in area.	Process
89	Profile	Replace Posalux machine lights that are out.	Process
90	Profile	Repair Posalux machine backup memory problems.	Process

(table continues)

	Area	Equipment Readiness Opportunity for Improvement	Category
91	Profile	Service MarkVII machine - requires 7-8 resets per shift due to servo motor errors.	Process
92	Profile	Procure spare parts.	Spare Parts
93	Profile	Provide meetings with maintenance, engineering and operators on a frequent basis would help communication.	Management
94	Spec Plt	Repair crack in floor pan at EQ23715 - leaks from nickel holding tank.	Process
95	Spec Plt	Repair baskets that are worn recoat protective coating which is chipping and creating sharp edges that could damage product.	Process
96	Spec Plt	Repair humidity dryer that is broken in the line.	Process
97	Spec Plt	PM Hoist because it will slip and stick.	Maintenance

Curriculum Vitae

Name and Rank Information

Antonio DePaolo, Vice President Business Excellence

Endicott Interconnect Technologies Inc.

2010 – Present

Teaching / Training Experience

Corporate Seminars

- Principles of Lean Manufacturing
- Six Sigma Greenbelt and Blackbelt
- Problem Solving
- Kaizen
- Value Stream Mapping

Education Background

Ph. D. in Applied Management and Decision Sciences, Leadership and Organizational Change

Walden University

2012

Master of Engineering, Industrial Engineering

University at Buffalo

1998

Bachelor of Science in Industrial Engineering

University at Buffalo

1997

Prior Experience

Global Director of Operational Excellence, 2009 - 2010

Taconic Corporation

Hudson, NY

Corporate Director of Continuous Improvement 2002 - 2009

Wabash National Corporation

Lafayette, IN

Manager of Industrial Engineering 2000 – 2002

The Stanley Works

East Greenwich, RI

Industrial Engineer 1998 – 2000

Delphi Automotive

Lockport, NY

Supervisor 1997 – 1998

TAD Technical on assignment at General Motors Powertrain

Tonawanda NY

Professional Growth Activities

- Training Seminars Completed
    - Kepner Tregoe Problem Solving
    - Six Sigma Greenbelt
    - Six Sigma Blackbelt
    - Six Sigma Master Blackbelt
    - Toyota Production Systems
    - Kaizen
    - Leadership training
    - Lean enterprise
    - Manufacturing Systems Design
    - Lean equipment design
    - Shainin
    - TQM
    - Flow Manufacturing
    - Workplace Organization
    - Overall Equipment Effectiveness
    - Resource Planning

- Simulation
- Systematic Layout planning
- Error Proofing
- QS 9000 / ISO 16949
- Ergonomics
- Cellular Manufacturing
- Training within Industry

- Courses and Knowledge Area Modules (KAM) completed at Walden University
    - SBSF 7100 Research Forum, 2007 – ongoing
    - SBSF 8005 Foundations for Doctoral Studies, 2007
    - AMDS 8417 Foundation Research Seminar I: Human Inquiry and Science
    - AMDS 8427 Foundation Research Seminar II: Research Methods
    - AMDS 8437 Foundation Research Seminar III: Data Analysis in AMDS
    - KAM I Principles of Societal Development – Improving the hourly employee development process, 2008
    - KAM II Principles of Human Development – Improving the employee performance appraisal process, 2008
    - KAM III General Systems Theory – Improving the new product commercialization Process, 2009
    - KAM V Leadership – Leadership factors that affect performance, 2010

- KAM VI Organizational Change – Developing factors that predict organizational change success, 2010
- KAM VII Research Methods – Mixed Methods approach to studying organizational change, 2011

- Seminars / Meetings Attended
    - Multi Variate Analysis of Variance Webinar, 2011
    - Walden University Residency Milestone 1, Lansdowne, Virginia, 2008
    - Walden University Residency Milestone 2, St Charles, Illinois, 2009
    - Walden University Residency Milestone 3, Minneapolis, Minnesota, 2010
    - Walden University Residency Milestone 4, Miami, Florida, 2011