THE EFFECTS OF BEHAVIOR-BASED SAFETY TECHNIQUES ON BEHAVIOR VARIATION, TARGETED AND NON-TARGETED SAFE BEHAVIORS, AND PRODUCTIVITY AND QUALITY IN MANUFACTURING FACILITIES

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THE EFFECTS OF BEHAVIOR-BASED SAFETY TECHNIQUES ON BEHAVIOR VARIATION, TARGETED AND NON-TARGETED SAFE BEHAVIORS, AND PRODUCTIVITY AND QUALITY IN MANUFACTURING FACILITIES

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VITA

Jessie Franklin Godbey II, son of Jessie Franklin Godbey and Etta Lou (Kempf) Godbey, was born October 26, 1960, in Ypsilanti, Michigan. He graduated from Ypsilanti High School in 1978. After high school he joined the U.S. Army and served in the 1st Battalion, 75th Infantry Regiment, Airborne Ranger achieving the rank of sergeant. Upon honorable discharge from the U.S. Army he attended The University of Michigan and graduated cum laude with a Bachelor of Science degree in Industrial and Operations Engineering, 1989. While working as an industrial engineer for General Motors Corporation and Braun Brumfield, Inc., he completed his Master of Science in Industrial and Operations Engineering (Engineering Management) from The University of Michigan in 1992. After completing his Master's degree he worked for Ford Motor Company until entering the Doctor of Philosophy program in Industrial and Systems Engineering (Occupational Safety and Ergonomics) at Auburn University in 1996. Besides working in industry, he has taught as instructor and assistant professor at Georgia Southern University and Montana Tech of The University of Montana. He currently is Program Coordinator of the Occupational Safety and Health Technology program at Jacksonville State University, Jacksonville, Alabama. He married Caroline Baker Kinzie Godbey, on October 11, 1980. They have three wonderful and intelligent children; Jesse Franklin Godbey III born December 1, 1989, Eleanor Kinzie Godbey born March 25, 1992, and Mitchel Kempf Godbey born April 30, 1994.

DISSERTATION ABSTRACT

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In the field of occupational safety and health, worker behavior is often associated with the immediate cause of workplace accidents and injuries. As a result an understanding of worker behavior is a major area of concern and is necessary to reduce the cost of workplace accidents. Recent efforts to improve workplace safety have included programs based on applied behavioral research. These efforts are often referred to as behavior-based safety programs. There are a wide variety of behavior-based safety programs using different methods and techniques. Researchers have identified four fundamental behavior-based safety requirements essential to improving the specific behaviors targeted by the program. Questions however, remain concerning the impact of these fundamental techniques on other non-targeted behaviors and their effect on other organizational variables such as productivity and quality.

A multiple-baseline study across four groups was conducted at two manufacturing facilities in the southeast United States. The four groups consisted of 40, 26, 71, and 47 hourly workers in two different production departments at each of the two manufacturing facilities. The fundamental techniques of behavior-based safety were implemented across a staggered timeline within the four groups. Direct observation was used to measure targeted behaviors, those directly included in the intervention. At the same time direct observation was used to measure critical behaviors not included in the intervention or non-targeted behaviors. Concurrent data were collected on the organizational variables of productivity and quality.

The application of fundamental behavior-based safety techniques resulted in significant improvement of targeted behaviors. The effects of this targeted behavior variation on non-targeted behaviors and productivity and quality data were investigated using statistical process control techniques. The performance of non-targeted behaviors increased substantially suggesting that behaviors may belong to conceptual classes resulting in positive covariation as a result of the implementation of behavior-based safety techniques. There was no apparent change in productivity and quality, suggesting that improved performance of targeted behaviors has no adverse effect on these organizational measures. This study provides additional information and aids in the understanding of the effects of behavior variation that may assist in reducing workplace accidents and injuries.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The rate of occupational fatalities and injuries in the United States has declined slightly in recent years; however workers' compensation cases and cost have steadily increased indicating a continual need to focus on workplace safety (National Safety Council, 2004). Despite continued focus on occupational safety and health, American industry, as a whole, has experienced little to no significant increases in safety performance as measured by a decrease in injury rates. More than 5000 American workers die and nearly 5 million are injured on the job each year (National Safety Council, 2004). At the same time many individual organizations have experienced a decrease in injury rates by implementing various safety techniques and programs.

Research Objectives

There were three main objectives of the present research. The purpose of this research was to first validate underlying behavior-based safety program techniques. Secondly, this research investigated the relationship between targeted safe behavior variation and other non-targeted safe behaviors. The third objective of this research was to examine the association between targeted safe behavior variation and production and quality measures in manufacturing facilities.

The first objective of this research was to conduct an evaluative study reaffirming and demonstrating the effects of behavior-based safety techniques. Traditional occupational safety and health control measures such as machine safeguarding, personal protective equipment, and safety training focusing on unsafe conditions and unsafe acts are essential components of any effort to improve workplace safety. Over the past 20 years American industry has begun to implement safety and health programs based on applied behavioral research. Collectively, these types of safety and health programs are often referred to as behavior-based safety programs. Behavior-based safety programs are a systematic approach to promoting behavior supportive of injury prevention (Sulzer-Azaroff and Austin, 2000). There are numerous examples of effective behavior-based safety programs employing nonmonetary consequences such as feedback to increase safe behavior (Krause, Seymour, and Sloat, 1999; Sulzer-Azaroff and Austin, 2000). There are many methods and variations of behavior-based safety programs and as a result behavior-based safety means different things to different people. For that reason, among others, it is practically important to continue exploring the usefulness of behavior-based safety programs.

Other questions remain regarding the impact on behaviors that are not specifically included in the behavior-based safety program. The second objective of this research was to investigate the effects of behavior-based safety techniques on these "non-targeted" behaviors. Behavior-based safety programs typically identify and define specific "target" behaviors with the objective of increasing the frequency of these target behaviors. As a behavior-based safety program increases these target safe behaviors, what happens to other behaviors that are related to safety but not specifically included in the behavior-based safety program? For instance, if the behavior-based safety program targets and measures the use of eye protection, and as a result an increase in this behavior is observed, what effect does this have on the use of hearing protection that was not targeted by the behavior-based safety program?

The final objective of this research was to examine the impact of behavior-based safety techniques on organizational variables such as production and quality measures in manufacturing facilities. This increase in the number of behavior-based safety programs has piqued the interest of occupational safety and health professionals and management. Consequently, this increased exposure has raised concerns as well. Many of these concerns center on organizational measurements, such as productivity and quality. The axiom that "the safe establishment is efficient productively and the unsafe establishment is inefficient" is not universally endorsed (Heinrich, Petersen, and Roos, 1980). It is often argued that safety improvements increase productivity but examples of safety controls adversely affecting productivity, at least in the short-term, are common as well. There are many examples of safety improvements such as properly designed workstations and tools that increase productivity and quality. On the other hand, it may be argued that safety controls, such as machine safeguarding and personal protective equipment (PPE), interfere with the normal course of work and therefore decrease productivity and quality measures (Heinrich et al., 1980). The effect of a behavior-based safety program on organizational variables such as productivity and quality is not clear. Does an overall increase in safe behavior have no effect on productivity or is a generalized increase in safe behavior accompanied by an increase in productivity or a decrease? What about the effect of increased safe behavior on quality? Productivity, for example, has been "observed" to increase during a period of increasing safe behavior resulting from an effective behavior-based safety program (Sulzer-Azaroff and Santamaria, 1980). This impact, however, has not been carefully measured.

Research Significance

This age-old question of workplace safety vs. workplace efficiency seems to depend on the individual circumstances. Therefore, additional information regarding the relationship between workplace safety and related variables may improve various aspects of workplace decisions. The significance of this research was to determine the effect of changes in safe behavior on these other variables and therefore provide information to improve overall workplace safety. This research applied the fundamental principles of behavior-based safety programs in order to change behavior. The intention of this research was not to permanently implement a behavior-based safety program at the cooperating manufacturing facilities but only to initiate changes in behavior in order to examine the effect of behavior variation.

Research and Dissertation Organization

This study developed and implemented observation and feedback techniques commonly used in behavior-based safety programs at two medium-sized manufacturing facilities. Each of the facilities gave written permission for access to their facilities and production information. The behavior-based safety program techniques included pinpointing critical safe behaviors at each facility. After a baseline measurement, graphical feedback was provided to initiate changes in the pinpointed behaviors.

Measurement of pinpointed behaviors continued throughout this intervention period. The effect of these changes in targeted safe behaviors was compared with simultaneous measurements of productivity and quality. The facilities had productivity and quality data collection procedures in place prior to the study. Productivity and quality data were consolidated throughout the baseline and intervention period and examined for any impact associated with variation in targeted safe behaviors.

At the same time behaviors were pinpointed for inclusion as a “targeted” safe behavior, a separate set of critical behaviors were identified. These “non-targeted” safe behaviors were measured throughout the baseline and intervention periods in the same manner as the targeted safe behaviors. These non-targeted behaviors, however, were not included in the intervention training and no feedback pertaining to these non-targeted behaviors was provided to employees. As with the dependent productivity and quality data these dependent non-targeted safe behavior data were examined for any relationship with the variation in the targeted safe behaviors.

This dissertation is organized following the manuscript format. The manuscripts constitute the body of the dissertation. Chapters 1 and 2 are the traditional dissertation introduction and literature review. Chapter 3, 4, 5 and 6 are stand-alone manuscripts reporting the results and conclusions of this study. Chapter 3 discusses the use of statistical process control (SPC) charts for measuring behavior variation. Chapters 4, 5 and 6 present the effect of fundamental behavior-based safety techniques on targeted safe behaviors, non-targeted safe behavior, organizational productivity and quality measures.

CHAPTER 2

LITERATURE REVIEW

There are more than 5,000 occupational fatalities and nearly 5 million workers injured annually in the United States (National Safety Council, 2004). Examining this data more closely shows that, on average, in the United States approximately one worker dies, and 800 are injured, every 90 minutes. The associated cost of these occupational fatalities and injuries is estimated to be more than $150 billion each year (National Safety Council, 2004). This estimate includes medical costs and productivity losses. This is an indication of the seriousness of occupational safety and health and the issues associated impact on American industry. The reasons for improving workplace safety involve moral and ethical issues, as well as, legal motives and economic motives. Industry is in business to make money, not injure valued employees. It is obvious that as incidents involving injury and damage decline related organizational costs decline. Yet questions remain concerning the actual impact increasing workplace safety has on the bottom line of an organization. Large amounts of resources are expended each day to increase the safety of American workers. Controls range from providing personal protective equipment such as eye protection to full implementation of a comprehensive safety and health program. To implement effective workplace safety controls it is necessary to identify the cause of these injuries and fatalities. In other words, the first step to preventing occupational injuries is the identification of occupational hazards. Hazards are conditions or activities that have the potential to produce harm.

Often these “causes” of incidents are grouped into two categories. The first category consolidates “unsafe conditions” while the second category includes “unsafe acts”. Research has attempted to determine the portion of accidents caused by unsafe acts compared to unsafe conditions (Heinrich, 1931). Other research has found that both unsafe conditions and unsafe acts are contributing factors in the majority of industrial incidents (Brauer, 2006). Regardless of the proportion of incidents caused by each of these two categories, there may always be room for improvements in behaviors and conditions and emphases should include both “unsafe acts” and “unsafe conditions”.

Effective prevention of industrial incidents must include controlling both unsafe conditions as well as unsafe acts (DeJoy, 2005). Since the beginning of the modern industrial safety movement in the early 1900’s, unsafe conditions have been a target of engineering controls. Workplace safety has been improved by the use of inspection procedures, job safety analysis, workplace and tool design improvements, and machine safeguarding. Heinrich (1931) suggested the development and enforcement of safety rules to control unsafe acts by workers. Fitch (1976) describes engineering controls as focusing on reducing or eliminating physical hazards in the workplace and behavioral interventions as an attempt to change the behavior of the worker so that the interaction with the environment occurs in a safe fashion. Over the last two decades there has been an increased effort to control unsafe acts, in part, based on evolving incident causation models. Zohar and Luria (2003) state that careless behavior still prevails during many routine jobs, making safe behavior an ongoing managerial challenge. Peterson (1988) emphasizes the failure of management systems and human error in workplace incident causation. Peterson (1988) also suggests that unsafe acts or human error is often increased because of management system failures. A type of effort to control unsafe acts includes a classification of safety and health programs referred to as behavior-based safety programs. Behavior-based safety programs are a systematic approach used to promote behavior that minimizes potential harm (Sulzer-Azaroff and Austin, 2000).

Behavior-Based Safety

Research efforts have focused on determining the impact of various conditions on workers' safe behavior. A review of the literature indicates two classifications of research concerning workplace safe behavior. The first classification of research involves workplace safe behavior as the dependent variable. Research has attempted to show the relationship between various levels of organizational "safety culture" and its effect on safe behavior (Glendon and Litherland, 2001; DeJoy, 2005). Other research has determined the relationship between different levels of workplace thermal conditions and its effect on safe behavior (Ramsey, Burford, Beshir, and Jensen, 1983).

The second classification of research involves modification of workplace safe behavior (independent variable) and the measurement of the effects of this behavior variation. This research represents one of the practical applications of behavior analysis. It is largely based on the concepts and principles of operant conditioning and reinforcement theory outlined by B.F. Skinner (1938). This applied behavior analysis approach utilizes the antecedent-behavior-consequence (ABC) model (Daniels, 1989). Antecedents prompt particular behaviors. Training may be an example of an antecedent as it prompts the worker to behave safely (i.e., wear proper PPE). Consequences are what come after the behavior. Avoiding an injury may be an example of a consequence associated with the behavior of wearing proper PPE. Having a coworker tell a colleague that he was just observed to perform a task in a safe way might be another consequence. Some consequences will change the probability that the associated behavior will reoccur in the future. Consequences are generally more basic in affecting behavior than antecedents (Geller 2001). Safe behaviors are thought to typically have more frequent and certain punishing consequences (increased task effort and discomfort) and infrequent and uncertain reinforcing consequences (low probability of avoiding an injury) (Daniels, 1989; Geller, 2001). For example, workers often experience discomfort and task difficulty when properly wearing personal protective equipment but the consequence of avoiding injury is less frequent and less certain. Behavioral techniques often assume that employee behavior is a function of its consequences. Behavior that is positively reinforced tends to increase in frequency. This positive reinforcement has several advantages over disciplinary measures in the workplace (McAfee and Winn, 1989). Much of this research is based on previous applied behavioral research and is typically referred to as behavior-based safety, which has been defined earlier.

Behavior-based safety programs vary in form and complexity but there are several essential elements found in effective programs. Sulzer-Azaroff and Austin (2000) identify the following fundamental requirements:

1. Identification of target behaviors (pinpointing)
2. Development of precise definitions of these critical behaviors to ensure reliable measurement
3. Development and implementation of a behavior measuring system (observations)

4. Development and implementation of a reinforcement system for target behavior improvement (intervention) to include feedback

The collective purpose of these four stages is behavior modification in support of injury prevention.

Identification and Measurement of Behaviors

Critical behaviors are identified through various methods (Geller, 2001). Analysis of data such as injury records, accident reports, near-miss reports, and job safety analysis can be used to identify critical behaviors. Other methods include input from knowledgeable personnel such as supervisors, safety managers, and workers. The identified critical behaviors are then precisely defined. This is an important step to ensure accurate measurement. An example of a precise behavior definition follows, "when cutting wire bands from stacked boxes, employee cuts with one hand and holds the metal strap above the cut with the other hand" (Komaki, Barwick, and Scott, 1978). It is important to note that certain identified critical behaviors are difficult to actively observe and, therefore, difficult to define and precisely measure. For example, housekeeping may be identified as a critical behavior. Rather than focusing on the observable behavior (cleaning the workstation) it is necessary to focus on the product of the behavior. Again this product of behavior must be precisely defined to be accurately measured. An example of precise product of behavior definition would be "any oil/grease spill larger than 3 X 3 inches in a walking area" (Komaki, Heinzmann, and Lawson, 1980).

An observational code or checklist is developed from the identified critical behaviors. The observer proceeds through the area and observes every employee. The observer instantaneously records a safe or an unsafe observation for each behavior. Each employee is only observed long enough to make a determination. The data from these observations are used to calculate a percentage of safe behavior.

Percentage of Safe Behavior = (Total Number of Safe Behaviors Observed ÷ Total Number of Behaviors Observed)

If there are two or more observers involved in the measurement process, observation reliability can be assessed. Observation reliability is measured by having two independent observers simultaneously record the critical behaviors. These independent scores can then be compared for reliability.

Behavior Reinforcement Techniques

After baseline measurements are collected a method of increasing these critical behaviors is implemented. These intervention techniques are varied but typically involve one or more positive reinforcement methods. Researchers have examined the effect of tangible rewards and intangible reinforcements as intervention tools. Geller, Rudd, Kalsher, Streff, and Lehman (1987) examined the short-term and long-term effects of several intervention strategies and concluded that behavior methods using intangible reinforcement typically maintain over a longer period of time than behaviors modified using tangible reward strategies. A common method of intervention employed to increase critical behaviors is feedback; that is, feedback to employees regarding the level of behavior as measured by the observations. This feedback typically takes the form of verbal and/or graphic feedback. Research demonstrates that feedback can be effective at increasing critical behavior (Komaki et al., 1978; Sulzer-Azaroff and Austin, 1980). Research has also determined that social comparison feedback is more effective than only providing individual feedback (Williams and Geller, 2000).

Another intervention method is the use of training. Employees are trained in how to correctly perform the critical behaviors. Often training is used in combination with feedback. Research has shown that a combination of verbal feedback (praise) and training can be effective (Hopkins, Conrad, Dangel, Fitch, Smith, and Anger, 1986).

Goal setting in combination with feedback is another effective intervention technique. Setting goals for the improvement of the critical behaviors has been shown to be effective (Laitinen and Ruohomaki, 1996; Cooper, Phillips, Sutherland, and Makin, 1994). Locke and Latham (1990) examined both assigned and participative goal setting and found no significant differences in the associated performance. Other research has shown that a combination of all three intervention techniques, feedback, training, and goal setting can be effective in increasing critical workplace safe behaviors (Reber, Wallin, and Chhokar, 1990).

Success of Behavior-Based Safety

Research has established that the application of behavior analysis principles through the implementation of the fundamental requirements of a behavior-based safety program can be effective at increasing critical safe behaviors. Grindle, Dickinson, and Boettcher (2000) reviewed eighteen behavior-based safety programs implemented in manufacturing organizations all showing an increase in safe behaviors after consequent intervention. Does an increase of safe behavior, however, have a direct impact on workplace safety? In other words, does an increase in safe behavior decrease incidents and the resulting injuries? Answering this question is difficult without long-term evaluation of injury rates in the presence of a behavior-based safety program. The few long-term behavioral studies conducted have shown a significant decrease in the injury rate (Fox, Hopkins, and Anger, 1987). Other research has shown a significant correlation between safe behavior and injury rates (Laitinen, Marjamaki, and Paivarinta, 1999). Krause et al., (1999) examined the effect of behavior-based safety methods in 73 organizations revealing a significant decrease in incidents with an average reduction of 26% in the first year and an average reduction of 69% by the end of the fifth year.

Behavior-Based Safety and Other Organizational Variables

Even though there has been a significant amount of research in the field of behavior-based safety there are, however, many unanswered questions. In particular, questions pertaining to the effect on other organizational variables such as productivity and quality remain unanswered (Krause et al., 1999; McAfee and Winn, 1989). Krause et al., (1999) explains the similarities between the behavior-based safety approach and the quality improvement approach outlined by Deming (1986). Rightly or wrongly, industrial management is often primarily concerned with production. Therefore, safety programs such as behavior-based programs must either enhance, or at the very least, not adversely impact productivity or quality. There have been numerous studies showing an increase in production performance when the target was production performance behaviors, however, the effect on production is not clear when safety behaviors are targeted. Eikenhout and Austin (2005) demonstrated an increase in targeted customer service performance behaviors with the implementation of several interventions including goal setting and feedback. The production performance of a roofing crew was improved when crews received both feedback and tangible rewards based on previous production activity (Austin, Kessler, Riccobono, and Bailey, 1996). Zohar and Luria (2003) described a study at a milk-products plant where supervisory safety and quality criteria were improved using weekly feedback.

Researchers report an "observed" increase in productivity associated with increases in safe behavior (Sulzer-Azaroff and Santamaria, 1980) or at least no indications that productivity changed as safe behaviors varied (Komaki et al., 1980). Krause (2002) described a study showing 30% of surveyed managers perceived that quality and productivity benefited from the implementation of a behavior-based safety program. Sarkus (1997) suggests that behavioral approaches targeting safe behaviors increase employee involvement and collaboration that result in improved production. Accordingly, numerous researchers suggest that it would be beneficial to demonstrate that relationship between increases in safe behavior, as initiated by a behavior-based safety program, and productivity (McAfee and Winn, 1989; Austin, Kessler, Riccobono, and Bailey, 1996; Sulzer-Azaroff and Austin, 2000; Zohar and Luria, 2003).

Behavior-Based Safety and Other Non-Target Behaviors

Other unanswered questions remain concerning any behavior covariation. For example, many researchers report an increase in target behaviors such as the use of eye protection or safety belts (Komaki et al., 1980; Laitinen et al., 1999; Geller et al., 1987);

however, it is not clear how this increased safe behavior with eye protection affected other PPE use. Researchers have reported that there "appears" to be a positive effect on other safety measures as a result of increasing safe behaviors (McAfee and Winn, 1989). For instance, it was "informally observed" that the frequency of safety meetings increased as safe behaviors increased (Sulzer-Azaroff and Santamaria, 1980). More recent researchers have investigated the affect on non-target behaviors. Streff, Kalsher, and Geller (1993) observed an increase in a single non-target behavior (safety belt use) after implementation of interventions targeting another single behavior (wearing of safety glasses). In a non-manufacturing environment, Ludwig and Geller (1997) noticed increases in targeted behaviors (complete intersection stopping) and non-targeted behaviors (safety belt and turn signal use) after participative goal setting and feedback intervention. Both Streff et al., (1993) and Ludwig and Geller (1997) suggest that this "response generalization" may be a result of behaviors organized into functional response classes and consequently participative interventions facilitate the activation of implicit rules that influence these other "related" behaviors.

These functional response classes could be understood as conceptual classes. Based on these studies and others, Austin and Wilson (2001) point out that not all behavioral covariation is "response generalization". Austin and Wilson (2001) describe five types of response-response relationships and suggest that proper classification of behavior covariation is helpful in understanding and therefore influencing behaviors. Houchins and Boyce (2001) suggest that these functional response classes are developed through previous training and a common history and as a result this observed "generalization-like" effect is not true response generalization but response induction.

These studies did not examine several behaviors simultaneously within multiple manufacturing sites.

Research Needs

Based on the literature reviewed continued opportunities exist for demonstrating and clarifying the effects of behavior-based safety techniques in order to improve workplace safety. This research utilized the fundamental requirements of a behavior-based safety program as outlined by Sulzer-Azaroff and Austin (2000) to explore the effects of behavior variation. The first purpose of this research is to conduct an evaluative study reaffirming and demonstrating the effects of behavior-based safety techniques on targeted safe behaviors. The second purpose of this research is to examine the impact of behavior-based safety techniques on productivity and quality measures in manufacturing facilities. It would be beneficial to demonstrate that increases in safe behavior, as initiated by behavior-based safety techniques, have no adverse effect on production or quality measures. The final purpose of this research is to investigate the effects of behavior-based safety techniques on non-targeted behaviors. Specifically, it is hypothesized that:

1. The initiation of behavior-based safety techniques will have no effect on targeted safe behaviors.
2. The initiation of behavior-based safety techniques will have no effect on non-targeted safe behaviors.
3. The initiation of behavior-based safety techniques will have no effect on group productivity.

4. The initiation of behavior-based safety techniques will have no effect on group production quality.

CHAPTER 3

USING STATISTICAL PROCESS CONTROL CHARTS AS A PROBLEM-SOLVING TOOL TO ANALYZE BEHAVIOR VARIATION

Introduction

"What gets measured gets done" (author unknown). Measurement of critical variables is an essential component of a successful organization. Proper measurement is necessary to determine how well an organization is performing. This guiding principle applies to safety performance just as it does to productivity and quality performance. Manufacturing has historically used methods of statistical process control (SPC) as an effective process improvement tool in production and quality. With the ever-increasing cost of accidents and injuries, using effective methods for measuring and analyzing safety performance is crucial. As a result, many organizations have adapted the statistical process control method (control charts) as a problem-solving tool to analyze and improve the safety process.

Safety can be treated as a characteristic of the process just as quality characteristics of the process are measured. Manufacturing organizations measure the "quality" of the product they produce by taking a representative sample of critical characteristics and apply statistical process control techniques to analyze the process. In a similar manner, manufacturing organizations can measure and analyze the "safety" characteristics of their process by utilizing the same statistical process control techniques.

In other words, safety may be considered a characteristic of the process, just like quality, that allows the manufacturing process to function within limits and produce a product. The application of statistical process control techniques, and in particular control charts of behavioral observations, however, has been limited. This paper will outline the practical aspects of statistical process control techniques on behavioral observations for identifying and establishing a stable process before applying an intervention package and the effectiveness of statistical process control techniques for identifying beneficial intervention tools.

Commonly used safety performance measures include the Occupational Safety and Health Administration's (OSHA) Total Recordable Case Incident Rate (TCIR), Days Away from Work/Restricted/Transfer Rate (DART), and Days Away From Work Injury/Illness (DAFWII). These are examples of reactive or trailing measures of safety performance. In other words, these types of measures tell us what has happened, such as three recordable injuries per 100 employees per year, so management can make the appropriate adjustments based on this level of performance. Many argue that organizations are preoccupied with this type of trailing safety performance measure and that the focus should be on proactive or leading safety performance measures. Both Geller (2001) and Petersen (2005) discuss the drawbacks of using trailing measures including the pressure to not report incidents. As a result of this under-reporting, hazards are not analyzed and problems are not solved. The event frequency presents another difficulty when using injury measures. Injuries (hopefully) occur relatively infrequently requiring larger sample sizes for determining significance. Injury measures, therefore, require data collection over a longer period of time in order to capture enough data.

These trailing safety performance measures, however, may provide useful long-term information (Petersen, 2005). Prevette (2006) describes a method of using statistical process control techniques to examine monthly injury rates. He also discusses how many organizations incorrectly use monthly injury rates and as a result the "numbers are driving the actions, rather than the actions driving the numbers". Wheeler (1999) describes this as "numerical illiteracy".

Proactive or leading safety performance measures include safety audits, safety meetings/training, and safety perception surveys. These leading measures of safety performance provide an opportunity to proactively adjust performance to potentially avoid or reduce the number of incidents. In contrast to trailing measures, leading measures can occur relatively frequently. This reasonable frequency allows these safety measures to be used to determine significant process variation. Petersen (2005) suggests, "Perhaps our inability to create these needed (forward-looking) measures is one reason for our lack of excellent safety performance".

Behavioral observations are another example of leading safety performance measures that allow organizations to proactively identify problems before an incident or injury occurs. Typically, behavioral observations are presented graphically by the use of run charts. This graphical presentation of behavioral data allow for quick and accurate interpretation. Little training is necessary for the user to analyze the represented data. Graphing behavioral observations enables the identification of changes in data and estimating trends. Statistical process control techniques are specifically designed for just such graphical analysis of data. "The driving mechanism for continuous improvement in safety is the proper use of behavioral and statistical science coupled with employee involvement" (Krause, 1997). The coupling of statistical process control techniques with the run chart also provides information on the stability of the behavioral process before changes are implemented. This paper discusses the use of statistical process control techniques to analyze behavior variation and use this information as a problem-solving tool to improve the safety process.

Behavioral Observation

Behavioral observation is a measurement commonly used in behavior-based safety programs. Behavior-based safety programs are derived from applied behavioral research. Komaki et al., (1978) project in a food manufacturing plant provided one of the earliest applied behavioral research studies based in the workplace. Behavior-based safety programs are a systematic approach to promoting behavior supportive of injury prevention (Sulzer-Azaroff and Austin, 2000). There are numerous examples of effective behavior-based safety programs employing nonmonetary consequences such as feedback to increase safe behavior (Krause et al., 1999; Sulzer-Azaroff and Austin, 2000). Behavior-based safety programs vary in form and complexity but one essential element found in effective programs is the identification of target behaviors (pinpointing). Critical behaviors are identified through various methods (Geller, 2001) such as analysis of documentation data including injury records, accident reports, near-miss reports, and job safety analysis. Other methods include input from knowledgeable personnel such as supervisors, safety managers, and workers. An important aspect of identifying critical behaviors is their relationship to the performance of the safety process. Care must be taken to pinpoint behaviors that impact safety performance. It would be a waste of effort and resources to measure, analyze, and improve behaviors that have little impact on preventing incidents and injuries.

The data from these behavioral observations are typically used to calculate a percentage of safe behavior.

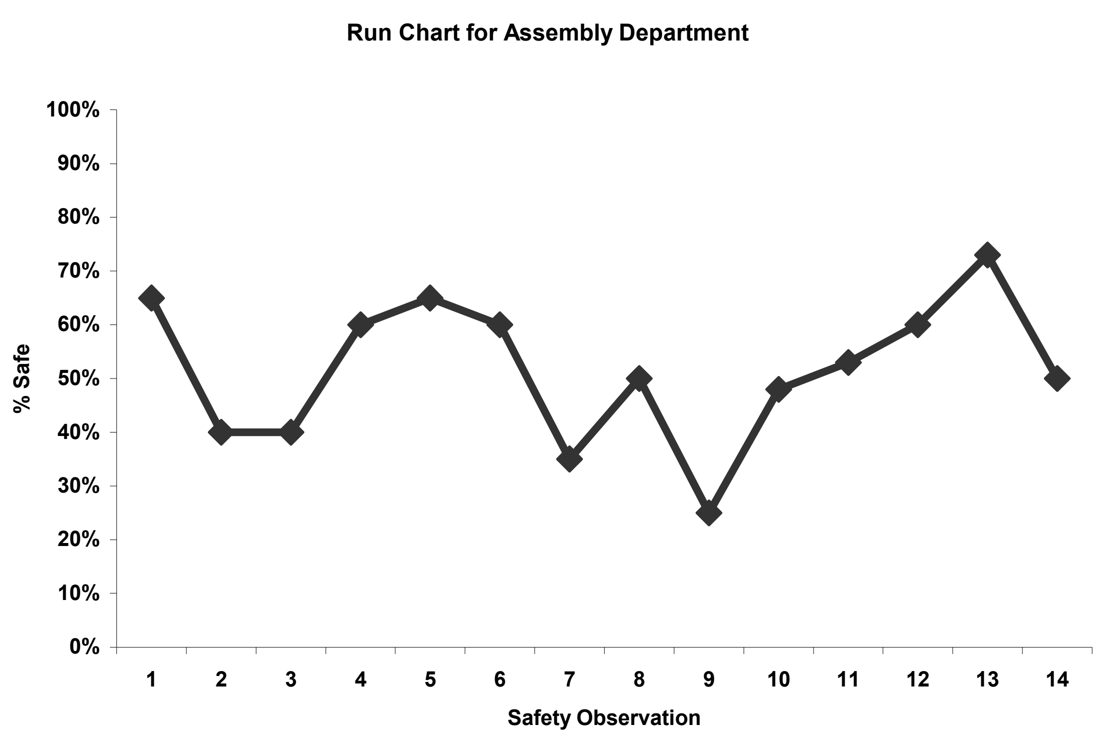
Percentage of Safe Behavior = (Total Number of Safe Behaviors Observed ÷ Total Number of Behaviors Observed)

This percent safe measure is typically presented in the form of a run chart that is posted to provide feedback to employees. Figure 1 provides an example of a run chart displaying percent safe (dependent variable) along the y-vertical axis and observation group or time (independent variable) along the x-horizontal axis. Behavior-based safety programs encourage visual review and discussion of this chart by both management and employees. Care must be taken when using this percent safe measure. Geller (2001) points out several problems with percentages. Percentages are not symmetrical and require reference to a starting number. For example, an increase in safe behavior in Department 1 from 50% to 70% is not equivalent to an increase in safe behavior in Department 2 from 70% to 90%. Department 1 experienced a 40% increase (20 ÷ 50), whereas, Department 2 had a 28.6% increase (20 ÷ 70) in safe behavior. Geller (2001) suggests the use of the term “percentage points”. In this example the change in safe behavior of both departments may be reported as an increase of 20 percentage points. One method for identifying useful information from this percent safe measure is by utilizing statistical process control techniques.

Statistical Process Control

Statistical Process Control (SPC) was developed by Walter A. Shewhart at Bell Laboratories in the 1920's and presented in his classic *Economic Control of the Quality of Manufactured Product* (1931). Shewhart's fundamental concept is the understanding of process variation in order to improve the process. Statistical process control utilizes graphical techniques to identify and understand process variation. All processes have natural variation that result in changing outcomes. Process variation is always present because of random fluctuations and inconsistencies in the process. Deming (1986) described this random process variation as "common cause" variation. Common cause

FIGURE 1. Example of Run Chart.



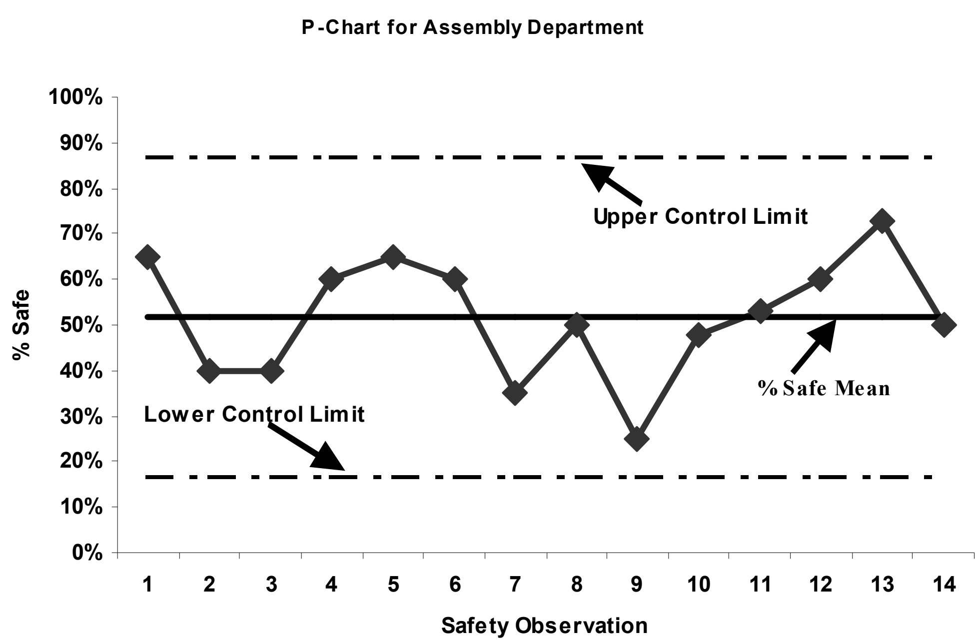
variation is random but predictable and stable within a range of distinct distribution limits. In other words, this common cause variation is caused by conditions that are inherent to the process. Other process variation is a result of non-random or unusual events. “Special cause” variation (Deming, 1986) is intermittent and not part of the natural process variation. This special cause variation is typically a result of changes in manpower, material, machinery, and/or methods (Ishikawa, 1976).

Statistical process control uses control charts to graphically present variation within the parameters of the process. This visual representation of process variation may then be used to intervene to improve the process. The process is “in control” when all variation is random and the data points fall between the statistical limits and therefore, are a result of common causes. The measured data can be interpreted as “in control” when all variation is random and is between the statistical control limits and therefore, is a result of common causes. The measured data can be interpreted as “in control” when all variation is random and is between the statistical control limits and therefore, is a result of common causes. The process is “out of control” when variation is a result of special causes or not random. An example indicating special cause variation may be when a single data point falls outside the set statistical limits or 7 consecutive data points fall above or below the mean. Statistical process control is a statistical technique that allows unnatural process variation to be identified and the special cause of this variation to be acted upon. Statistical process control is a process improvement or problem-solving tool.

A run chart (Figure 1) is the starting point for the control chart (Figure 2). A centerline is added representing the statistical mean of the data. Next an “upper” and “lower” control limit is placed on the run chart located at values that approximate three standard deviations from the mean. These control limits represent the limits within which a stable process operates and are used to distinguish common cause variation from special cause variation. There are different types of control charts for different statistical distributions of data.

There are two categories of data for control charts: variables and attributes. Variables are continuous data. Typical variables are based on measurements such as length or time. Attributes data, on the other hand, are data that can be counted or classified into one or two categories – good or bad, go or no-go, safe or at-risk. The distinction between variables and attributes data is necessary to determine the appropriate type of control chart. Behavioral observations fall into this attributes category of data. In

FIGURE 2. Example of P-Chart.



the context of behavior-based safety programs, behavioral observations are typically recorded as safe behavior or at-risk behavior. There are different types of attribute charts (p, np, c, and u) depending on whether the data are number of defects or defectives; nonconformities or nonconformance. For behavioral observations and percent safe measurements, the p-chart is most appropriate because the data are represented by the "proportion of nonconforming units in a sample". Behavioral observation data with two possible outcomes (safe, at-risk) best fits a binomial distribution. When the sample size is sufficient ($n\overline{p} \geq 5$) this binomial distribution can be approximated by a normal distribution. In this case the control limits for the p-chart are based on the standard deviation using the following formula:

$$CL_p = \overline{p} \pm 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$$

where:

$\overline{p}$ = is the mean proportion safe

n = is the sample size

Figure 2 shows a p-chart with the centerline representing the mean, and the upper and lower control limit lines. The lower control limit line is placed at zero if it is a negative number. This is an example of control limits based on equal sample size. Often it is not possible to have an equal sample size of behavioral observations over time. There are two options for constructing a p-chart with varying sample size. First, individual control limits may be calculated for each of the observation periods with different sample sizes. This will result in irregular shaped control limit lines that may be confusing. When the differences between sample sizes are small (within 25% of the mean sample size), the recommended procedure is to calculate the control limits using the average sample size (Stapenhurst, 2005). This will result in smooth or straight control limit lines. If a value falls near one of these "average" control limit lines, however, it may be necessary to calculate the actual control limit to analyze the corresponding variation in the process. Practically speaking, 12-15 data points provide a good test for stability (Wheeler, 1999).

Evaluating Behavioral Observations

The control chart may now be used as a problem-solving tool by evaluating the variation of the behavioral observations. If the behavioral observations are randomly distributed around the mean with no predictable patterns and no points outside the control limits then the process may be considered stable and in a state of statistical control. Any observed variation is a result of common causes. When the process is in statistical control, management must decide if this percent safe behavior is satisfactory. If not, action should be taken to improve the average pinpointed safe behavior. For example, suppose one of the critical pinpointed behaviors was proper wearing of safety glasses. Assume the P-chart showing this behavior is in statistical control with a mean of 60%. Management, however, is not satisfied with this performance and approves the purchase of new adjustable, more comfortable safety glasses in hopes of increasing this safe behavior. It is important to note that when the process is stable interventions must be "process" changes. Intervening without process knowledge weakens the process. Deming (1986) referred to this tendency as "tampering".

A process may be "out of control" if the observed variation is non-random. This non-random variation is a result of a special cause acting on the process. There are numerous rules for identifying this non-random variation (Stapenhurst, 2005). Three of the most commonly used rules for identifying an out of control process according to Stapenhurst (2005) are the following:

- Any one point falling above the upper control limit or below the lower control limit (Figure 3);
- A "run" of seven or more consecutive points all above or below the mean (centerline) (Figure 4); and
- A "trend" of seven or more consecutive points increasing or decreasing in value (Figure 5).

A process that is not in control indicates that the special cause acting on the process should be identified and, if necessary, action should be taken to eliminate the cause. For

FIGURE 3. P-Chart showing one point out of control.

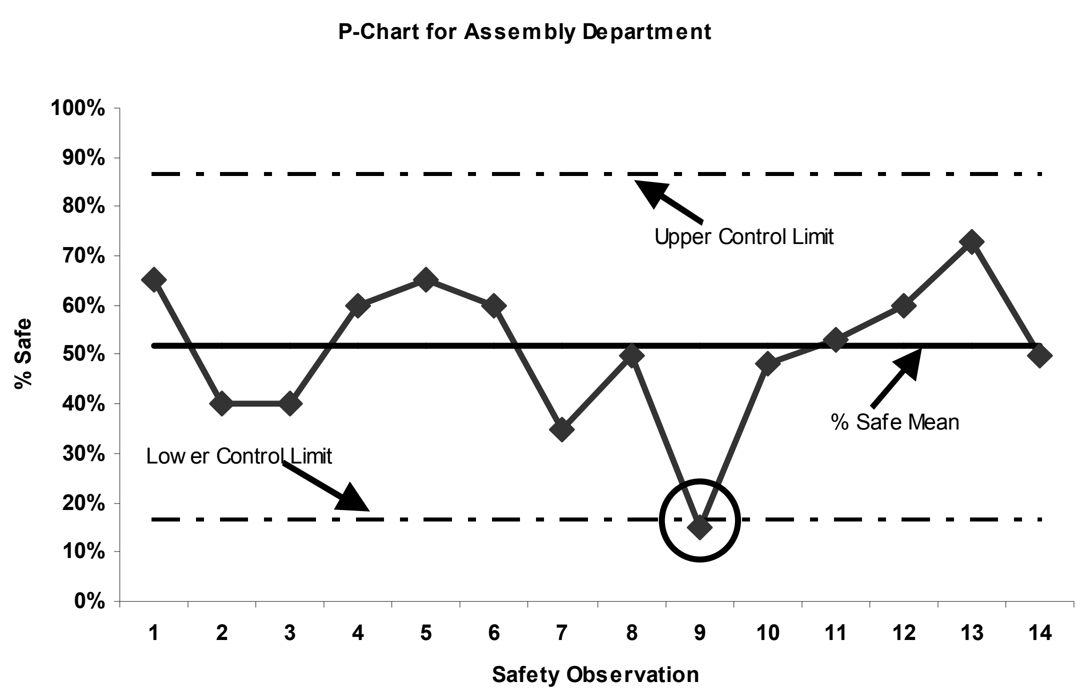
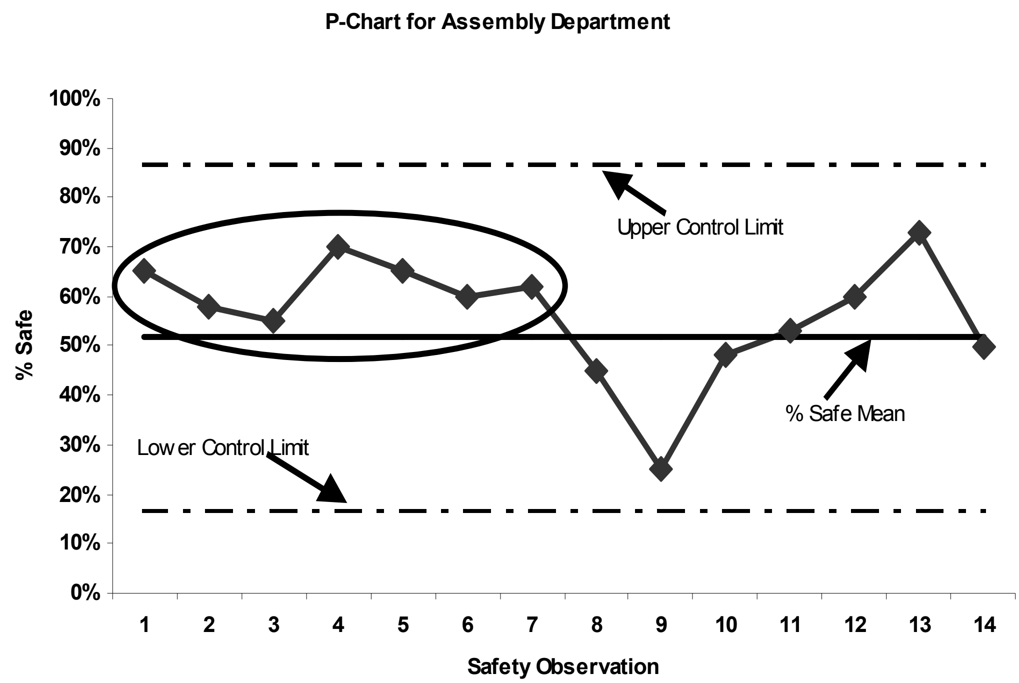


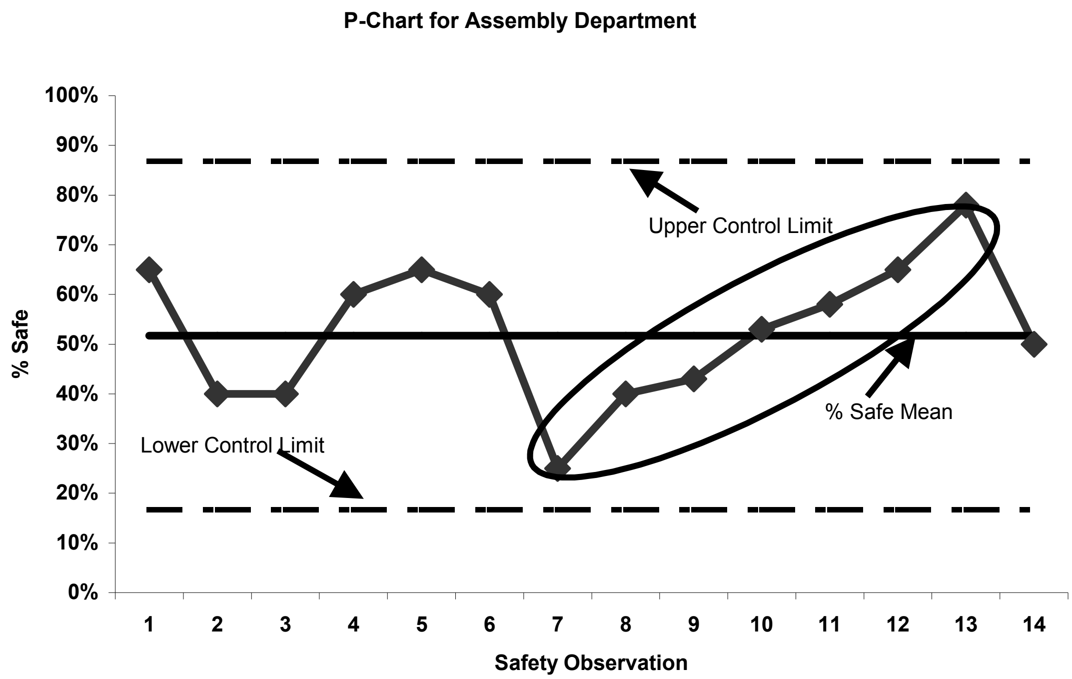
FIGURE 4. P-Chart showing out of control run.



behavioral observations, a point outside the lower control limit indicates a special cause lowering pinpointed safe behavior. For example, perhaps a P-Chart associated with the proper placement of pallets (i.e., no part of a pallet extending over the aisle marking) shows one point below the lower control limit indicating the presence of special cause variation. Upon investigation it is discovered that the employee regularly assigned to forklift duty has been out sick and a less experienced employee has been driving the forklift. Further inquiry revealed the replacement driver had not been fully trained.

A point outside the upper control limit indicates the presence of a favorable condition increasing the frequency of pinpointed safe behavior. All cases of special cause variation should be investigated fully to identify and eliminate the special cause or, in the case of increasing safe behavior, identify and incorporate as a permanent change.

FIGURE 5. P-Chart showing out of control trend.



Returning to the example of wearing safety glasses, after a period of time the P-Chart may show a run of seven or more points above the mean indicating variation from a special cause (new safety glasses). If after a period of time there is no indication of special cause variation, management may decide to try another course of action to improve the performance of wearing safety glasses.

The use of statistical process control provides an opportunity for continuous improvement of the leading measures like pinpointed safe behaviors. Krause (1997) describes four objectives of safety performance measurement; identifying problem areas, stimulating preventive action, documenting safety efforts, and reinforcing improvements in performance. Behavioral observations and statistical process control techniques provide an organization the opportunity to meet all four of these objectives. As described above, the main purpose of control charts is to identify problem areas (special cause variation) and prompt analysis (stimulate action) to implement corrective actions. Behavior-based safety programs are often successful at increasing safe behavior by utilizing feedback, positive reinforcement, and goal setting. Incorporating control chart features onto safe behavior run charts provides an opportunity to show (document) statistical validation of safe behavior improvement techniques. Behavior-based safety programs often establish baseline measures before implementing improvement techniques. Using control charts will provide strong statistical evidence of safe behavior improvement after implementing positive reinforcements. This graphical technique is a simple and effective method of publicizing and communicating results to workers and management. Control charts also provide an additional opportunity to provide reinforcement (feedback) of critical behaviors by directly involving workers in the safety process. This direct involvement may foster buy-in and improve the culture of safety within the organization.

Finally, the use of control charts with behavioral observations allows important decisions to be made by key stakeholders based on data, not hunches. Behavioral observations provide a leading measure that allows the safety process to be improved before incidents occur. Statistical process control charts offer a reliable, statistically valid, and practical way to gain control of the behavioral observation process so that the organization may more effectively and efficiently improve safety.

CHAPTER 4

REAFFIRMATION OF THE EFFECTS OF BEHAVIOR-BASED SAFETY TECHNIQUES ON TARGETED BEHAVIORS: AN EVALUATIVE STUDY

Introduction

The economic and moral cost of workplace injuries may provide motivation for employers to try new and different techniques for improving workplace safety. Over the last couple of decades implementation of "Behavior-Based Safety Programs" has become widespread among industry with varying degrees of success. There are numerous examples of effective behavior-based safety programs employing various strategies (Krause, Seymour, and Sloat, 1999; Sulzer-Azaroff and Austin, 2000). Others are more critical of behavior-based safety programs and identify several limitations (Hopkins, 2006). Behavior-based safety means different things to different people. For that reason, among others, it is practically important to continue examining the usefulness of behavior-based safety techniques. Additional studies help industry management understand the benefits of implementing behavior-based safety techniques. In other words, actions speak louder than words. The purpose of this project was, in part, to conduct an evaluative study reaffirming and demonstrating the effects of behavior-based safety techniques on targeted safe behaviors.

In general, behavior-based safety programs are a systematic approach to promoting behavior supportive of injury prevention (Sulzer-Azaroff and Austin, 2000).

Although behavior-based safety programs may be relatively recent, the underlying principles are not. Behavior-based safety programs vary in structure and design but all are based on the fundamental principles of applied behavioral research. This applied behavioral research includes the concepts of operant conditioning and reinforcement theory (Skinner, 1938) and utilizes the antecedent-behavior-consequence (ABC) model (Daniels, 1989). Antecedents prompt particular behaviors. Consequences come after the behavior and increase or decrease the future occurrence of behavior they follow. Consequences can be either reinforcing or punishing and are more fundamental in motivating the behavior than are antecedents.

Komaki, Barwick, and Scott (1978) provided one of the first examples of the application of applied behavioral research to workplace safety. Komaki et al., (1978) identified and defined critical safety behaviors for two departments in a food manufacturing facility. These targeted behaviors were observed over a 25-week period. The study included an intervention consisting of training with participatory goal setting and graphical and verbal feedback. The performance of targeted behaviors in two different departments increased from 70% and 78% to 96% and 99%, respectively. During the reversal phase, feedback was discontinued and the performance of the targeted behaviors returned to baseline levels indicating the effectiveness of feedback in this particular case.

Numerous other studies support the basic process used by Komaki et al., (1978) showing an increase in targeted behaviors after identifying critical behaviors and providing feedback based on worker performance. Sulzer-Azaroff and Santamaria (1980) analyzed a “feedback package” system over a 12-week period resulting in a significant reduction of 60% on average in the frequency rate of hazards. Zohar (1980) used feedback to increase the utilization of personal protective equipment significantly (85% -90%). Ray, Bishop, and Wang (1997) analyzed the individual effect of training, feedback, and goal setting on safe behavior. In this study training had no effect on safe behavior performance while feedback and goal setting significantly improved safe behavior performance.

Sulzer-Azaroff and Austin (2000) identified four elements, 1) pinpointing critical target behaviors, 2) development of precise definitions of these critical behaviors to ensure reliable measurement, 3) development and implementation of an observation or behavior measuring system, and 4) development and implementation of a reinforcement system for targeted behavior improvement to include feedback, as the main requirements of effective behavior-based safety programs. The collective purpose of these four elements is behavior variation in support of injury prevention.

Critical behaviors are identified or pinpointed by various methods to include analysis of safety/injury records and interviews with knowledgeable personnel (Geller, 2001). Next, the identified critical behaviors must be precisely defined to ensure accurate measurement. Precise definitions are necessary to accurately measure the occurrence of a behavior or the absence of a behavior. An observational code or checklist is developed and baseline measurements are collected. Lastly, a method of increasing the targeted behaviors is implemented. These intervention techniques vary but typically involve one or more positive reinforcement methods including feedback.

This study systematically applied the fundamental behavior-based safety techniques described above. Specifically, the techniques of pinpointing critical behaviors, developing precise definitions, collecting and measuring observable data using an observational checklist, and implementation of training, participatory goal setting, and both graphical and verbal feedback as an intervention package to increase targeted behaviors, was be evaluated. The reaffirmation and demonstrated generality of these fundamental techniques is important to provide continued evidence of the value of focused effort on improving worker safe behavior.

Method

The experimental design for this evaluative study was a multiple-baseline design across four groups. This multiple-baseline design demonstrates the effect of an intervention by showing behavior variation with the introduction of the intervention at different points in time for each group. The purpose of this staggered implementation is to introduce a level of experimental control (Robson, Shannon, Goldenhar, and Hale, 2001). After baseline behavior has stabilized, the intervention is applied to the first group while the baseline measurement is continued for the remaining groups. Using this overlapping approach, the intervention is extended to all groups. The objective is to demonstrate similar behavior variation following each introduction of the intervention.

The staggered intervention of the multiple-baseline study reduces several experimental design threats. A “history threat”, is an event that is not part of the intervention that affects the outcome of the data. The multiple-baseline across groups reduces this threat of history effect. History effects are unlikely to occur in four different groups, at four different times, each corresponding to the implementation of the study’s intervention. In other words, it is unlikely that other events may impact the group data at the same time as the initial intervention and it is even more unlikely that these coincidences will happen more than once.

There is also a threat of the effect of outside observers on the measured data. To avoid this potential “hawthorne effect”, this study included a period of baseline observations. These baseline observations continued until there was evidence of stability representing the absence of a reaction to the observer’s presence. Statistical process control charting techniques were used to demonstrate the stability of the behavior or process variation.

The multiple-baseline study in combination with statistical process control charting techniques also reduces the maturation threat. This threat is characterized by changes in measured outcomes as a result of naturally occurring events over time such as experience. The multiple-baseline design study identifies the absence of this maturation threat because the measured outcome data between the baseline period and the intervention period is typically abrupt, as opposed to the gradual change produced by maturation. In addition the use of statistical process control charting techniques allow the distinct identification of sudden or “special cause” variation in the data and gradual trend changes in the data.

In this study a combination of run charts and statistical process control charts were used to present and analyze the data. The independent variables consist of the behavior-based safety techniques of training, participatory goal setting, and graphical and verbal feedback. The dependent variables consist of the targeted behaviors. These targeted behaviors are plotted over time (weekly) using a run chart for each of the four groups. Each run chart includes two distinct phases, baseline and intervention. Graphing behavioral observations on a run chart enables the identification of changes in data and provides estimates of trends. Statistical process control techniques are specifically designed for just such graphical analysis of data. Statistical process control charting techniques were used to analyze the data to determine whether or not significant changes in the targeted behaviors occurred following the intervention as evident by special cause variation. Two specific criteria were of interest, changes in level between phases and the identification of special cause variation within each phase.

Observation sample sizes varied based on the number of employees per department. The smaller the sample size the slower the control chart will be to identify “special cause” variation. Stapenhurst (2005) suggests a minimum average sample size of 50 associated with attribute-based statistical control charts. Montgomery and Runger (1994) report a worst-case scenario requiring 58 observations. The smallest weekly observation sample size for this study was 90.

Statistical Process Control

Statistical Process Control (SPC) was developed by Walter A. Shewhart at Bell Laboratories in the 1920’s and presented in his classic *Economic Control of the Quality of Manufactured Product* (1931). Shewhart’s fundamental concept is the understanding of process variation in order to improve the process. Statistical process control utilizes graphic techniques to identify and understand process variation. All processes have natural variation that results in changing outcomes. Process variation is always present because of random fluctuations and inconsistencies in the process. Deming (1986) described this random process variation as “common cause” variation. Common cause variation is random but predictable and stable within a range of distinct distribution limits. In other words, common cause variation is caused by conditions that are inherent to the process. Other process variation is a result of non-random or unusual events. “Special cause” variation (Deming, 1986) is intermittent and not part of the natural process variation. This special cause variation is a result of an outside event acting on the process.

Statistical process control charts can be used to analyze and interpret behavioral observations and to determine whether a perceived change in data is a result of natural process variation or a special cause from outside the process. This visual representation of process variation may then be used to intervene to improve the process. The behavioral observations can be interpreted as “in control” when all variation is random and is between the statistical limits and therefore, is a result of common causes. The behavioral observations may be determined to be “out of control” when variation is a result of special causes. An example indicating special cause variation may be when a single behavior observation point falls outside the set statistical limits or 7 consecutive points fall above or below the mean.

A run chart is the starting point for the control chart. A centerline is added representing the statistical mean of the data. Next an “upper” and “lower” control limit is placed on the run chart located at values that approximate three standard deviations from the mean. These control limits represent the boundaries of a stable process and are used to distinguish common cause variation from special cause variation.

For behavioral observations and percent safe measurements, the p-chart is most appropriate because the data are represented by the “proportion of nonconforming units in a sample". Behavioral observation data with two possible outcomes (safe, at-risk) best fits a binomial distribution. When the sample size of is sufficient (n $\overline{p}$ ≥ 5) this binomial distribution can be approximated by a normal distribution. In this case the control limits for the p-chart are based on the standard deviation using the following formula:

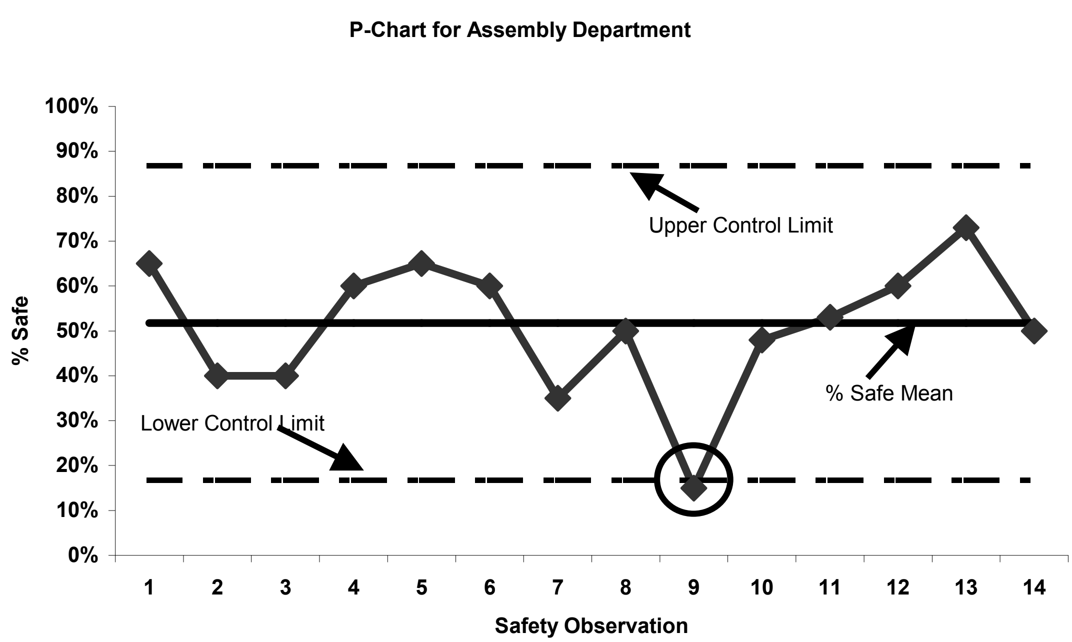
$$CL_p = \overline{p} \pm 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$$

where: $\overline{p}$ = is the mean proportion safe

n = is the sample size

Figure 6 shows a p-chart with the centerline representing the mean, and the upper and lower control limit lines. The lower control limit line is placed at zero if it is a negative number.

FIGURE 6. Example of P-Chart showing one point out of control.



Evaluating Behavioral Observations

The statistical process control chart may be used as a problem-solving tool for evaluating the variation of the behavioral observations. If the behavioral observations are randomly distributed around the mean with no predictable patterns and no points outside the control limits then the process may be considered stable and in a state of statistical control. Any observed variation is a result of common causes. It is important to note that when the process is stable interventions must be "process" changes. Intervening without process knowledge weakens the process. Deming (1986) referred to this tendency as "tampering".

A process may be "out of control" if the observed variation is non-random. This non-random variation is a result of a special cause acting on the process. There are numerous rules for identifying this non-random variation (Stapenhurst, 2005). Three of the most commonly used rules for identifying an out of control process according to Stapenhurst (2005) are the following:

- Any one point falling above the upper control limit or below the lower control limit (Figure 6);
- A "run" of seven or more consecutive points all above or below the mean (centerline); and
- A "trend" of seven or more consecutive points increasing or decreasing in value.

The present study used these three rules because of their widespread use. A process that is not in control indicates that the special cause acting on the process should be identified and, if necessary, action should be taken to eliminate the cause.

For behavioral observations, a point outside the lower control limit indicates a special cause lowering pinpointed safe behavior. A point outside the upper control limit indicates the presence of a favorable condition increasing the frequency of pinpointed safe behavior. All cases of special cause variation should be investigated fully to identify and eliminate the special cause or, in the case of increasing safe behavior, identify and incorporate as a permanent change.

Setting and Participants

The setting for this study involved two different manufacturing facilities in the southeast United States. Two different departments were selected from each of the manufacturing facilities providing four different groups. The first facility is a light manufacturing and assembly operation. The facility typically has only a day shift production operation with a skeleton maintenance crew on a second shift. The two departments selected from this facility have similar processes. Both departments utilize basic machining and assembly operations. Differences between the departments pertain only to product configuration. The participants included all 40 fulltime employees of Department R and all 26 fulltime employees of Department TW. Both departments operate a nine-hour day shift Monday through Thursday and a four-hour day shift on Friday. The facility had a compliance-based safety program focused on meeting workplace safety and environmental regulations. The facility has developed and implemented programs and training required by regulation. At the beginning of the study the facility's OSHA Total Case Incident Rate (TCIR) was 22.2, with a total workers' compensation claim cost of $94,065 for the preceding 12 months. In addition, the facility maintained a first-aid logbook recording minor “non-recordable” injuries such as small lacerations and foreign objects in eye. In the 12 months prior to this study there were 86 first-aid cases recorded.

The second facility is also a light manufacturing and assembly operation producing a different product than the first facility. Facility Two operates three 8-hour shifts over a five-day workweek, with the third shift consisting largely of maintenance activities. Approximately 85% of employees work on the day shift. The two departments selected from this facility again have similar processes centered around slightly different product lines. The participants included all 71 fulltime employees of Department 1 and all 47 fulltime employees of Department 3 for the day shift only. Like facility one this second facility’s safety efforts were entirely focused on meeting workplace safety and environmental regulations. All employees had received required regulatory safety training. In addition to this required safety training all employees had received new-hire training that included the organization’s safety rules. The organizations safety rules were basic rule such as no horseplay, running, smoking or drinking in the work areas. At the beginning of the study the second facility’s OSHA Total Case Incident Rate (TCIR) was 18.4. This TCIR includes all three shifts. Unfortunately, the second facility did not record first-aid injuries. Their injury recordkeeping only involved the required OSHA 300 log of recordable injuries. Facility Two management was unwilling to provide workers’ compensation information, stating privacy concerns.

Identification and Definitions of Critical Behaviors

The study began with pinpointing behaviors that would have the greatest impact on overall workplace safety. These targeted behaviors were identified by examining past injury and accident records and interviewing management and departmental supervisors. Targeted behaviors consisted of either the direct behavior such as properly wearing hearing protection or the outcome of a behavior such as no material protruding into marked pedestrian aisles. Twelve unique target behaviors were identified for Department R and nine for Department TW in facility one. Eight unique target behaviors were pinpointed for each of the remaining two groups, Departments 1 and 3 from the second facility. Examples of targeted behaviors include the proper use of eye and hearing protection, proper use of box cutters, work aisle housekeeping, and team lifting heavy objects.

After determining the critical behaviors, precise definitions were developed. For example, eye protection was required throughout all four departments. The definition used for eye protection was "Employee is wearing approved safety glasses with approved sideshields. Safety glasses are clean and free of scratches. Safety glasses are fitted on the bridge of nose close to eyes and sideshields are fitted flush to the frame of glasses". These precise definitions aided in the collection (observation) of data (Appendix A). A unique critical behavior checklist was developed for each of the departments (Appendix C). This checklist consisted of an abbreviated definition of each target behavior and included two additional columns labeled "Safe" and "At Risk".

Data Collection Procedures

The study involved the collection of a total of 50 weeks of observational data. Baseline observations using the developed critical behavior checklists were collected at random starting times on a daily basis in all four departments. Observers alternated routes each day when collecting observations. Observers changed starting points in each of the departments and followed different routes through the departments as they collected data. Each data collection tour took less than 30 minutes for each of the two facilities. Observations were collected 4 to 5 days per week (Monday through Friday) with only one observation session per day. Baseline observations started in Departments R and TW in Facility One and six weeks later started in Departments 1 and 3 of Facility Two. Baseline observations were collected over 11 weeks in Department R, 27 weeks in Department TW, 31 weeks in Department 3, and 36 weeks in Department 1.

Prior to the start of data collection a short meeting was held informing departmental supervisors that safety observations would be collected. The departmental supervisors were asked to inform their employees that safety data would be collected over a period of time with the intention of improving workplace safety. This explanation included the fact that individual data would not be collected; that the data collected is reported solely on the department as a whole. No other information pertaining to the study was provided to employees.

The observers visited each workstation and instantaneously recorded the workers' behavior. Each employee was observed only long enough to make a determination of whether one or more of the targeted behaviors were present and if the performance of the behaviors were "Safe" or "At Risk". Collected data were used to calculate a weekly "percent of activities performed safely" score.

Percentage of Activities Performed Safely = (Total Number of Safe Behaviors Observed ÷ Total Number of Behaviors Observed)

There were a total of three observers collecting data at any one time throughout the study. The observers included the first author and undergraduate students enrolled in a local occupational safety and health program. Inter-observer reliability was assessed approximately every four weeks. Two observers would conduct a data collection tour together without discussing their observations or findings. Reliability was calculated by dividing the number of observation agreements between the observers by the total number of observations. Reliability remained high throughout the study ranging from a low of 89% to a high of 98% with a mean reliability score of 94%.

Intervention

After establishing stable and substantial baseline data an intervention package of training, participatory goal setting, and graphical and verbal feedback was implemented in an effort to increase targeted behaviors. The one-time training session lasted approximately one hour for each of the four departments. The first author conducted each of the four on-site training sessions. The training session consisted of an explanation and a combination of pictures depicting the "safe" and "at-risk" performance of each targeted behavior. The training pictures were taken at each of the facilities using actual workers demonstrating each of targeted safe behaviors. The pictures showing "at-risk" or unsafe behaviors were carefully "staged" using actual workers from the corresponding facility. Immediately after the training session a list of the targeted behaviors was posted on each department's bulletin board. During the training session employees were shown a graph with their department's baseline performance and were encouraged to increase their performance. The layout and components of the graph were explained in detail and employee questions were answered.

The training session concluded with discussing a goal for increased performance. Collectively and with guidance, the employees of each department agreed upon a performance goal. These goals remained constant throughout the study. The employees of Department R and Department TW both agreed on 85% as a reasonable and attainable goal. The employees of Department 1 agreed on 70% for their goal and Department 3 decided on a 75% goal.

After the intervention training, observations continued with the addition of weekly feedback to the employees. Each week a short session was held explaining the preceding week's performance and encouraging improvement. The first several feedback sessions were conducted by the observers, thereafter the departmental supervisors conducted the feedback sessions. The weekly graph was placed on the department's bulletin board. Following the multiple-baseline design, the intervention was staggered for each of the four groups. The intervention was introduced at the beginning of week 11 in Department R. After establishing a stable intervention period in Department R the same intervention procedure was conducted in Department TW at the beginning of week 27. This same process was repeated in the second facility with the intervention procedure conducted at the beginning of week 31 in Department 3, and week 36 in Department 1.

Results

The results of the observational data collected on the targeted behaviors over the 50-week period are shown in four graphs, one per group (Figures 7 – 10). Each of the graphs consists of a run chart and the associated control limits for each individual department. Baseline "percent of activities performed safely" of targeted behaviors averaged 69.8% in Department R, 70.2% for Department TW, 63.5% for Department 3, and 57.1% for Department 1. The vertical line in each graph indicates the implementation of the intervention package.

The intervention was first conducted in Department R of Facility One resulting in a substantial increase in the performance of the targeted behaviors. Within the first week of the intervention phase, Department R had surpassed their goal of 85%. The average

FIGURE 7. Percent of target behaviors performed safely for Dept R–Facility One.

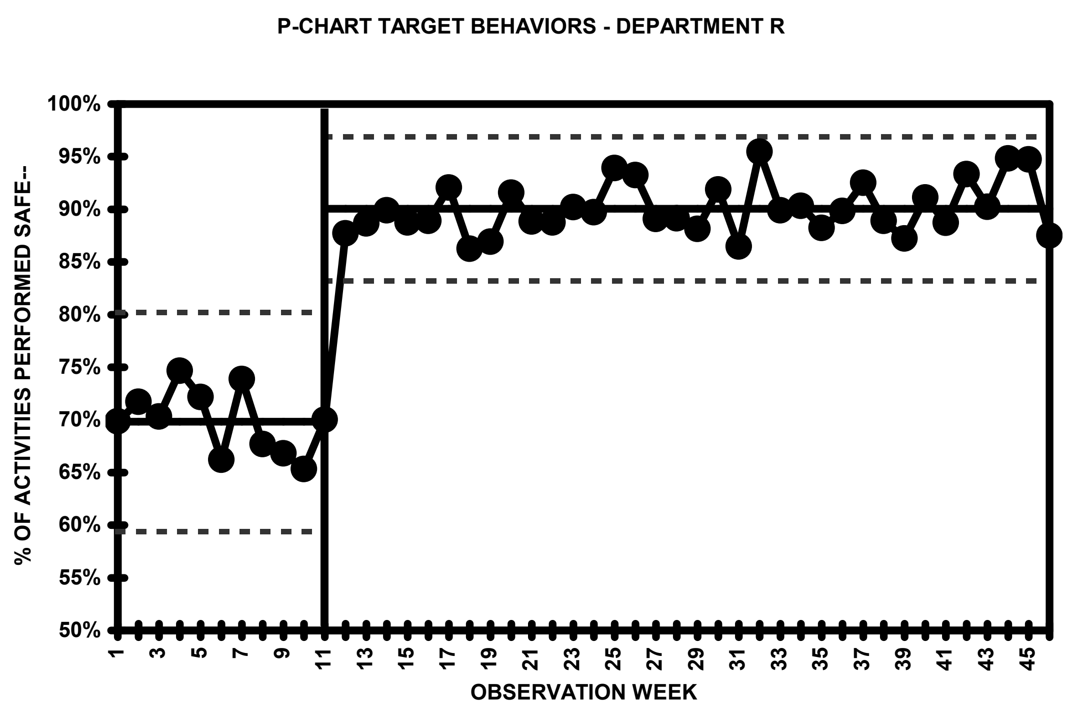
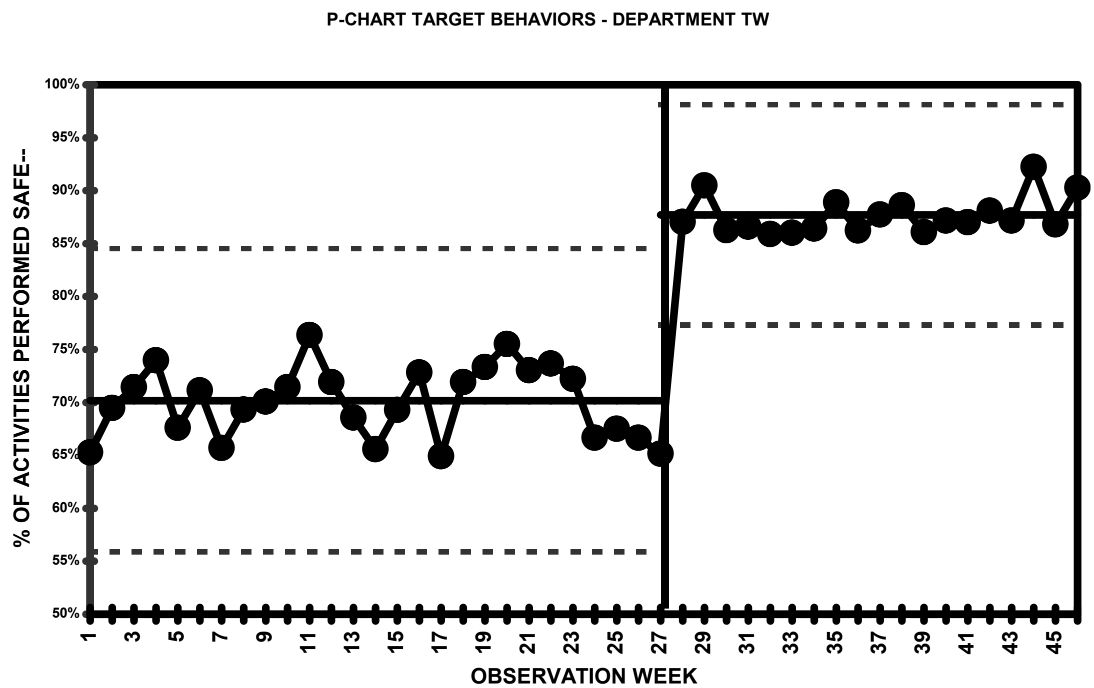


FIGURE 8. Percent of target behaviors performed safely for Dept TW – Facility One.



"percent of activities performed safely" of targeted behaviors during the intervention phase for Department R was 90.0%, an increase of 20.2 percentage points over the baseline average. The lowest weekly score during the intervention phase was considerably higher than the highest baseline weekly score for Department R. All other groups maintained baseline levels during the introduction of the intervention package to Department R including Department TW, which is in Facility One. Similar increases in average "percent of activities performed safety" were noted in the other three groups after the introduction of the intervention. Department TW's average weekly score during the intervention phase was 87.7%, a 17.5 percentage point increase over their average baseline score. The two groups from Facility Two average intervention phase scores were 77.6% for Department 3 and 75.0% for Department 1, an increase over average baseline performance of 14.1 and 17.9 percentage points respectively.

FIGURE 9. Percent of target behaviors performed safely for Dept 3 – Facility Two.

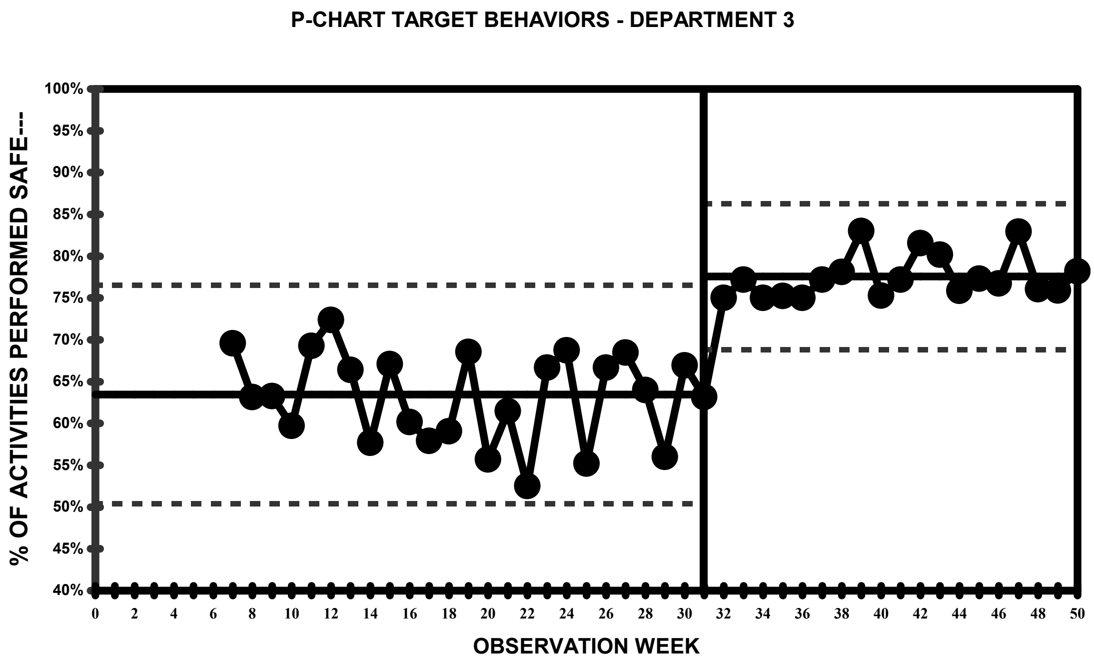


FIGURE 10. Percent of target behaviors performed safely for Dept 1 – Facility Two.

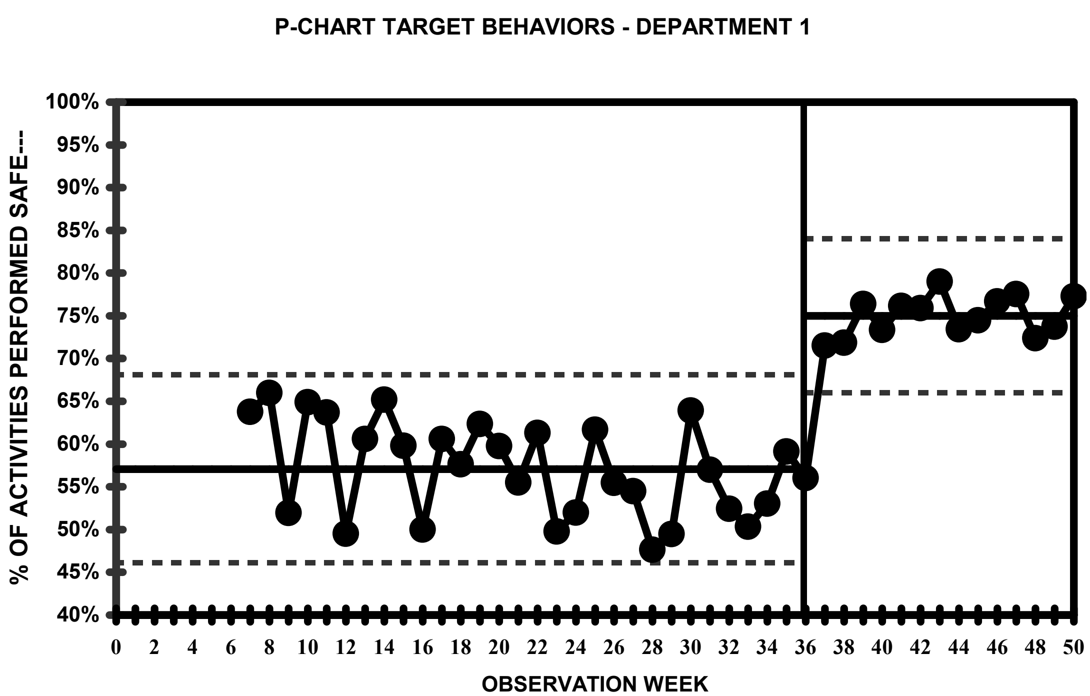


TABLE 1. Statistical Process Control Limits by Phase.

	Baseline Phase		**Intervention Phase**	
Department	**LCL**	**UCL**	**LCL**	**UCL**
R	**59.4%**	**80.2%**	**83.2%**	**96.9%**
TW	**55.9%**	**84.5%**	**77.3%**	**98.1%**
3	**50.4%**	**76.5%**	**68.8%**	**86.3%**
1	**46.1%**	**68.1%**	**66.0%**	**84.0%**

Table 1 provides the lower and upper statistical process control limits for each group by phase. Based on these control limits all four groups were in statistical process control during the baseline phase indicating a stable process. Immediately after the intervention, in all four groups, the “percent of activities performed safely” score was above the upper control limit indicating the occurrence of a “special cause” variation. As a result of this non-random variation within the process, the control limits were adjusted. This increased level of targeted safe behavior performance continued throughout the duration of the study.

Discussion

The results of this evaluative study reaffirm the benefits of behavior-based safety techniques on targeted behaviors. Targeted behaviors increased significantly and were maintained throughout the intervention phase in all four groups. This study confirms the effects of positive reinforcement in the form of feedback on targeted behavior performance and the use of training and participatory goal setting as intervention procedures. The use of statistical process control techniques indicate that the process was "in control" during both the baseline and intervention phases of all four groups. The observed variation of targeted behaviors within each phase is random and naturally occurring indicating the process is working as well as it possibly can without process changes.

This study and the corresponding increased performance of targeted safe behaviors also had an impact on incidents and injuries at the two facilities. The Total Case Incident Rate (TCIR) of "recordable" injuries for Facility One was 22.2 at the beginning of the study. At the end of the study the annualized TCIR for Facility One was cut by more than 50% to 10.6. The annualized workers' compensation cost for Facility One was reduced to a total of $22,030, a cost savings of $72,035 over the year prior to the study. The number of first-aid cases were reduced as well. In the year prior to this study there were 86 reported first-aid cases at Facility One. During the year of this study there were 25 reported cases of first-aid treatment, a 70% reduction. In fact, during the study the human resource clerk maintaining the first-aid case logbook reported a problem to the plant manager. She told the plant manager that there must be "something going on" because of the noticeable drop in employees requiring treatment. The management of Facility One maintained this program of behavior-based safety techniques and has started making plans for expansion to other corporate facilities.

Facility Two experienced a similar impact on incidents and injuries. Facility Two had a TCIR of 18.4 at the beginning of the study. This measure of "recordable" injuries was reduced to 12.8 for the year. Again, this TCIR covered the entire facility. During the study employees informally expressed a noticeable increase in general safety at the facility and, in particular, an increase in management involvement with safety concerns. Regrettably, Facility Two management was unwilling to provide information on workers' compensation cost citing privacy concerns. Likewise, it is unfortunate that Facility Two did not collect and maintain information on first-aid level injuries. It is likely that had this additional information been available a similar improvement would have been observed providing management with additional evidence of success.

Conclusion

The purpose of this study was to systematically apply the fundamental behavior-based safety techniques of pinpointing critical behaviors, developing precise definitions, collecting and measuring observational data using an observational checklist, and implementation of training, participatory goal setting, and both graphical and verbal feedback as an intervention package to increase targeted behaviors. The results reaffirm the effectiveness and demonstrate the generality of these fundamental techniques. This study provides continued evidence of the value of focused effort on improving worker safe behavior.

CHAPTER 5

INVESTIGATING THE EFFECTS OF BEHAVIOR-BASED SAFETY TECHNIQUES ON NON-TARGETED BEHAVIORS

Introduction

Workplace safety continues to be an area of concern for many manufacturing facilities. More than 5000 American workers die and nearly 5 million are injured on the job each year (National Safety Council, 2004). In recent years, organizations have taken a multi-faceted approach to improve safety. Efforts have continued in traditional areas of occupational safety and health such as machine safeguarding, personal protective equipment, and safety training. In addition, efforts aimed specifically at workers' safe behavior have emerged. Behavior-based safety programs are based on applied behavioral research and are focused on identifying and reinforcing worker behavior to improve safety performance. An increase in the number of behavior-based safety programs has raised questions concerning the effects of behavior variation techniques; in particular, questions pertaining to behavior covariation. The purpose of this research was to investigate the relationship between "targeted" safe behavior variation and other "non-targeted" behaviors.

Research efforts have focused on modification of workplace safe behavior as an independent variable and the measurement of the effects of this behavior variation.

Research has established that the application of behavior analysis principles through the implementation of the fundamental requirements of a behavior-based safety program can be effective at increasing targeted safe behaviors. Grindle, Dickinson, and Boettcher (2000) reviewed eighteen behavior-based safety programs implemented in manufacturing organizations all showing an increase in safe behaviors after consequent intervention. Krause, Seymour, and Sloat (1999) examined the effects of behavior-based safety methods in 73 organizations revealing a significant decrease in incidents with an average reduction of 26% in the first year and an average reduction of 69% by the end of the fifth year.

One specific concern centers around the impact of behavior-based safety techniques on behaviors that are not specifically included in the behavior-based safety program. Established behavior-based safety programs typically identify and define specific “target” behaviors with the objective of increasing the frequency of these target behaviors. As behavior-based safety techniques increase these targeted safe behaviors, what happens to other behaviors that are related to safety but not specifically included in the behavior-based safety program? For instance, if the behavior-based safety program targets and measures the use of eye protection, and as a result an increase in this behavior is measured, what effect does this have on the use of hearing protection or safe hand tool use or other safe work behaviors that were not targeted by the behavior-based safety program? There is a risk that while the frequency of certain safe behaviors increase; the frequency of other safe behaviors may decrease.

Several researchers report that there “appears” to be a positive effect on other safety measures as a result of increasing safe behaviors (McAfee and Winn, 1989).

Sulzer-Azaroff and Santamaria (1980) informally observed that the facility had a “neater appearance” and that the number of safety meetings increased after the implementation of a “feedback package” designed to reduce the frequency of hazardous or unsafe conditions. More recent research has investigated the affects of behavior-based safety techniques on non-targeted behaviors leading to a discourse on response generalization.

Streff, Kalsher, and Geller (1993) examined the principle of functional response class in relationship to workplace safety. Streff et al., (1993) observed an increase in a single non-target behavior (safety belt use) after implementation of a “promise card” intervention targeting the use of safety glasses. The targeted behavior of properly wearing safety glasses increased from 84.7% during baseline to 93.0% following the promise card intervention. The “non-targeted” use of safety belts increased from 12.8% during baseline to 35.1% following the intervention. Streff et al., (1993) suggest that behaviors may be organized into clusters, or functional response classes, that covary as a result of similar reinforcement histories. Another explanation presented for the observed response covariation was the transfer of training. The intervention covered on-the-job personal protective equipment (PPE) training including the use of gloves, earplugs, and safety glasses (targeted behavior). The promise card stated, “use available PPE”. The authors suggest that some employees may have transferred this pledge from on-the-job PPE use to include the use of vehicle PPE (safety belts) as part of a response class.

In a non-manufacturing environment, Ludwig and Geller (1997) reported an increase in the targeted behavior (complete intersection stopping) and non-targeted behaviors (safety belt and turn signal use) after participative goal setting and feedback intervention. Ludwig and Geller (1997) suggested that response generalization had occurred as defined by a change in a non-targeted behavior during the intervention that targeted another behavior. Response generalization refers to the spread of effect to other topographically-distinct behaviors not directly reinforced (Ludwig and Geller, 1999). This response generalization was, in part, a result of the participative goal setting process that facilitated the activation of implicit rules influencing behaviors beyond the consequences of the intervention.

Both Streff et al., (1993) and Ludwig and Geller (1997) suggest that this "response generalization" or the effects of the intervention spreading to related behaviors may be a result of behaviors organized into functional response classes. Consequently, participative interventions facilitate the activation of implicit rules that influence these other "related" behaviors. These functional response classes could be understood as conceptual classes of behaviors.

Based on these studies and others, Austin and Wilson (2001) point out that not all behavior covariation is "response generalization". Austin and Wilson (2001) describe five types of response-response relationships and suggest that proper classification of behavior covariation is helpful in understanding and therefore influencing behaviors. In particular, Austin and Wilson (2001) question the distinction between an operant class, behaviors maintained by the same reinforcing stimuli, and a conceptual class, behaviors without a shared history of direct reinforcement. Austin and Wilson (2001) argue that verbal processes involved in forming these conceptual classes may explain how some responses come to covary. Houchins and Boyce (2001) suggest that these functional response classes are developed through previous training and a common history and as a result this observed “generalization-like” effect is not true response generalization but response induction.

The present study systematically applied the fundamental behavior-based safety techniques of pinpointing critical behaviors, developing precise definitions, collecting and measuring observational data using an observational checklist, and implementation of training, participatory goal setting, and both graphical and verbal feedback as an intervention package to increase “targeted” behaviors. At the same time behaviors were pinpointed for inclusion as a “targeted” safe behavior, a separate set of critical behaviors were identified. These “non-targeted” safe behaviors were measured throughout the baseline and intervention periods in the same manner as the targeted safe behaviors. These “non-targeted” behaviors, however, were not included in the intervention training and no feedback pertaining to these non-targeted behaviors was provided to employees. The dependent non-targeted safe behavior data were examined for any relationship with variation in the targeted safe behaviors.

Method

The experimental design for this research study was a multiple-baseline design across four groups. This multiple-baseline design demonstrates the effect of an intervention by showing behavior variation with the introduction of the intervention at different points in time for each group. The purpose of this staggered implementation is to introduce a level of experimental control (Robson, Shannon, Goldenhar, and Hale, 2001). After baseline behavior has stabilized, the intervention is applied to the first group while the baseline measurement is continued for the remaining groups. Using this overlapping approach, the intervention is successively extended to all groups. The objective is to demonstrate similar behavior variation following each introduction of the intervention.

Statistical process control charting techniques were used to demonstrate the stability of the behavior or process variation and allow the distinct identification of sudden and gradual trend changes or “special cause” variation in the data. Statistical Process Control (SPC) was developed by Walter A. Shewhart at Bell Laboratories in the 1920’s and presented in his classic *Economic Control of the Quality of Manufactured Product* (1931). Shewhart’s fundamental concept is the understanding of process variation in order to improve the process. All processes have natural variation that result in changing outcomes. Deming (1986) described this random process variation as “common cause” variation. Common cause variation is random but predictable and stable within a range of distinct distribution limits. In other words, common cause variation is caused by conditions that are inherent to the process. Other process variation is a result of non-random or unusual events. “Special cause” variation (Deming, 1986) is intermittent and not part of the natural process variation. This special cause variation is a result of an outside event acting on the process. It is important to note that direct changes in the process will result identifiable variation also. Direct “process changes” should only occur when the process is stable. “Tampering” or intervening without a stable process weakens the overall process (Deming, 1986).

Statistical process control charts can be used to analyze and interpret behavioral observations and to determine whether a perceived change in data is a result of natural process variation or a special cause from outside the process. This visual representation of process variation may then be used to intervene to improve the process. The behavioral observations can be interpreted as "in control" when all variation is random and is between the statistical control limits and therefore, is a result of common causes. These control limits are set at values that approximate three standard deviations from the mean. The behavioral observations may be determined to be "out of control" when variation is a result of special causes or not random. An example indicating special cause variation may be when behavioral observations fall outside the set statistical limits or 7 consecutive observations fall above or below the mean. For behavioral observations and percent safe measurements, the p-chart is most appropriate because the data are represented by the "proportion of nonconforming units in a sample". Behavioral observation data with two possible outcomes (safe, at-risk) best fits a binomial distribution.

In the present study a combination of run charts and statistical process control charts were used to present and analyze the data. The independent variables consist of the behavior-based safety techniques of training, participatory goal setting, and graphical and verbal feedback. There are two sets of dependent variables, one set consisting of the targeted behaviors and a second set of non-targeted behaviors. Both the targeted and non-targeted behaviors are plotted over time (weekly) using a run chart for each of the four groups. Each run chart includes two distinct phases: baseline and intervention. Statistical process control charting techniques were used to analyze the data to determine whether or not significant changes in the targeted or the non-targeted behaviors occurred following the intervention as evidenced by special cause variation. Two specific criteria were of interest, changes in level between phases and the identification of special cause variation within each phase. A process may be "out of control" if the observed variation is non-random. There are numerous rules for identifying this non-random variation (Stapenhurst, 2005). In this study three of the most commonly used rules according to Stapenhurst (2005) were used for identifying an out of control process because of their widespread acceptance:

- Any one point falling above the upper control limit or below the lower control limit;
- A "run" of seven or more consecutive points all above or below the mean (centerline); and
- A "trend" of seven or more consecutive points increasing or decreasing in value.

A process that is not in control indicates that the special cause acting on the process should be identified and, if necessary, action should be taken to eliminate the cause. In this particular study, an out of control condition indicates that the fundamental behavior-based safety techniques had a significant impact on the dependant variable, either the targeted or non-targeted behaviors or both.

Observation sample sizes varied based on the number of employees per department. The smaller the sample size the slower the control chart will be to identify "special cause" variation. Stapenhurst (2005) suggests a minimum average sample size of 50 associated with attribute-based statistical control charts. Montgomery and Runger (1994) report a worst-case scenario requiring 58 observations. The smallest weekly observation sample size for this study was 90.

Setting and Participants

The setting for this study involved two different manufacturing facilities in the southeast United States. Two different departments were selected from each of the manufacturing facilities providing four different groups. The first facility is a light manufacturing and assembly operation. The facility typically has only a day shift production operation with a skeleton maintenance crew on a second shift. The two departments selected from this facility have similar processes. Both departments utilize basic machining and assembly operations. Differences between the departments pertain only to product configuration. The participants included all 40 fulltime employees of Department R and all 26 fulltime employees of Department TW. Both departments operate a nine-hour day shift Monday through Thursday and a four-hour day shift on Friday. The facility had a compliance-based safety program focused on meeting workplace safety and environmental regulations. The facility has developed and implemented programs and training required by regulation. At the beginning of the study the facility's OSHA Total Case Incident Rate (TCIR) was 22.2.

The second facility is also a light manufacturing and assembly operation producing a different product than the first facility. Facility Two operates three 8-hour shifts over a five-day workweek, with the third shift consisting largely of maintenance activities. Approximately 85% of the employees work on the day shift. The two departments selected from this facility again have similar processes centered around slightly different product lines. The participants included all 71 fulltime employees of Department 1 and all 47 fulltime employees of Department 3 for the day shift only. Like

Facility One, this second facility's safety efforts were entirely focused on meeting workplace safety and environmental regulations. All employees had received required regulatory safety training. In addition to this required safety training all employees had received new-hire training that included the organization's safety rules. The organization's safety rules were basic rules such as no horseplay, running, smoking or drinking in the work areas. At the beginning of the study the OSHA Total Case Incident Rate (TCIR) of Facility Two was 18.4. This TCIR covers the entire facility.

Identification of Target and Non-Target Behaviors

The study began with pinpointing behaviors that would have the greatest impact on overall workplace safety. These behaviors were identified by examining past injury and accident records and interviewing management and departmental supervisors. Identified behaviors consisted of either the direct behavior such as properly wearing hearing protection or the outcome of a behavior such as no material protruding into marked pedestrian aisles. The resulting list of critical behaviors were reviewed and approved for study by the management of each facility. Management of the two facilities were particularly interested in several behaviors that they considered immediate causes of safety-related incidents. These behaviors singled out by management were chosen as the set of targeted behaviors. The design of this study required progress reports and feedback only on targeted behaviors. Given the direct concern of these specific (targeted) behaviors by the host facilities, incorporating these behaviors as targeted behaviors provided opportunity for regular progress reports and feedback to management. Twelve target behaviors and twelve unique non-target behaviors were identified for

Department R. Nine target behaviors and 10 different non-target behaviors were determined for Department TW in Facility One. Eight unique target behaviors and ten non-target behaviors were pinpointed for each of the remaining two groups, Departments 1 and 3 from Facility Two. Examples of behaviors include the proper use of eye and hearing protection, proper use of box cutters, work aisle housekeeping, and team lifting heavy objects. Table 2 provides a listing of the targeted and non-targeted behaviors by department.

Table 2. Listing of Target and Non-Target Behaviors.

Department	Target Behaviors	Non-Target Behaviors
R	1. Eye Protection 2. Hearing Protection 3. Box Cutter Use 4. Proper Lifting 5. Debris in Aisle 6. Protruding Objects in Aisle 7. Team Lift Heavy Objects 8. Proper Pallet Height 9. Hands Clear – Saw 10. Housekeeping – Packing 11. Housekeeping – Rack Area 12. Housekeeping – Teflon	1. Hand Protection 2. Compressed Air Use 3. Forklift Driving 4. Proper Rack Storage 5. Hands Clear - Mill 6. Hands Clear - Countersink 7. Hands Clear - Stapling 8. Housekeeping - Mill 9. Housekeeping – Saw 10. Housekeeping – Countersink 11. Housekeeping – Bearing 12. Glue Gun Placement
TW	1. Eye Protection 2. Proper Lifting 3. Cart Use 4. Debris in Aisle 5. Protruding Objects in Aisle 6. Proper Pallet Height 7. Hands Clear – Saw 8. Housekeeping – Gasket 9. Housekeeping – Rack Area	1. Hearing Protection 2. Hand Protection 3. Box Cutter Use 4. Compressed Air Use 5. Forklift Driving 6. Proper Rack Storage 7. Hands Clear – Punch 8. Positioning - Gasket 9. Housekeeping – Saw 10. Housekeeping – Packing
1 & 3	1. Eye Protection 2. Face Protection 3. Proper Lifting 4. Power Tool Use 5. Jack Stands 6. Ladder/Stool Use 7. Debris in Aisle 8. Spills	1. Welding PPE 2. Hand Tool Use 3. Forklift Driving 4. Protruding Objects in Aisle 5. Box Cutter Use 6. Housekeeping – Work Area 7. Compressed Air Use 8. Horseplay/Smoking 9. Open Containers 10. Rolling Line

After determining the critical behaviors, precise definitions were developed. For example, eye protection was required throughout all four departments. The definition used for eye protection was; "Employee is wearing approved safety glasses with approved sideshields. Safety glasses are clean and free of scratches. Safety glasses are fitted on the bridge of nose close to eyes and sideshields are fitted flush to the frame of glasses". These precise definitions aided in the collection (observation) of data (Appendix A and Appendix B). A unique critical behavior checklist was developed for each of the departments (Appendix C). This checklist consisted of an abbreviated definition of each target behavior and included two additional columns labeled "Safe" and "At Risk". Behaviors listed on the checklist were not designated as targeted or non-targeted.

Data Collection Procedures

The study involved the collection of a total of 50 weeks of observational data. Baseline observations of both targeted and non-targeted behaviors using the developed critical behavior checklists were collected at random starting times on a daily basis in all four departments. Observers alternated routes each day when collecting observations. Observers changed starting points in each of the departments and followed different routes through the departments as they collected data. Each data collection tour took less than 30 minutes for each of the two facilities. Observations were collected 4 to 5 days per week (Monday through Friday) with only one observation session per day. Baseline observations started in Departments R and TW in Facility One and six weeks later started in Departments 1 and 3 of Facility Two. Baseline observations of both targeted and non-targeted behaviors were collected over 11 weeks for Department R, 27 weeks for Department TW, 31 weeks for Department 3, and 36 weeks for Department 1.

Prior to the start of data collection a short meeting was held informing departmental supervisors that safety observations would be collected. The departmental supervisors were asked to inform their employees that safety data would be collected over a period of time with the intention of improving workplace safety. This explanation included the fact that individual data would not be collected; that the data collected is reported solely on the department as a whole. No other information pertaining to the study was provided to employees.

The observers visited each workstation and instantaneously recorded the workers' behavior. Each employee was observed only long enough to make a determination of whether one or more of the targeted or non-targeted behaviors were present and if the performance of the behaviors were "Safe" or "At Risk". Collected data were used to calculate a weekly "percent of activities performed safely" score for targeted behaviors and a separate weekly score was calculated for the non-targeted behaviors.

Percentage of Activities Performed Safely = (Total Number of Safe Behaviors Observed ÷ Total Number of Behaviors Observed)

There were a total of three observers collecting data at any one time throughout the study. The observers included the author and undergraduate students enrolled in a local occupational safety and health program. Inter-observer reliability was assessed approximately every four weeks. Two observers would conduct a data collection tour together without discussing their observations or findings. Reliability was calculated by dividing the number of observation agreements between the observers by the total number of observations. Reliability remained high throughout the study ranging from a low of 89% to a high of 98% with a mean reliability score of 94%.

Intervention

After establishing stable and substantial baseline data an intervention package of training, participatory goal setting, and graphical and verbal feedback was implemented in an effort to increase targeted behaviors only. The one-time training session lasted approximately one hour for each of the four departments. The author conducted each of the four on-site training sessions. The training sessions consisted of an explanation and a combination of pictures depicting the "safe" and "at-risk" performance of each targeted behavior. The training pictures were taken at each of the facilities using actual workers demonstrating each of the targeted safe behaviors. The pictures showing "at-risk" or unsafe behaviors were carefully "staged" using actual workers from the corresponding facility. The existence of non-targeted behaviors was not mentioned and the non-targeted behaviors were not discussed during this training session. Immediately after the training session a list of the targeted behaviors was posted on each department's bulletin board. During the training session employees were shown a graph with their department's targeted behavior baseline performance and were encouraged to increase their performance. The layout and components of the graph were explained in detail and employee questions were answered.

The training session concluded with discussing a goal for increased targeted behavior performance. Collectively and with guidance, the employees of each department agreed upon a performance goal. These goals remained constant throughout the study. The employees of Department R and Department TW both agreed on 85% as a reasonable and attainable goal. The employees of Department 1 agreed on 70% for their goal and Department 3 decided on a 75% goal.

After the intervention training, observations of both targeted and non-targeted behaviors continued with the addition of weekly feedback on targeted behaviors only to the employees. Each week a short session was held explaining the preceding week's performance on the targeted behaviors and encouraging improvement. The first several feedback sessions were conducted by the observers, thereafter the departmental supervisors conducted the feedback sessions. The weekly graph showing percent of targeted behaviors performed safely was placed on the department's bulletin board. Following the multiple-baseline design, the intervention was staggered for each of the four groups. The intervention was introduced at the beginning of week 11 in Department R. After establishing a stable intervention period in Department R the same intervention procedure was conducted in Department TW at the beginning of week 27. This same process was repeated in the second facility with the intervention procedure conducted at the beginning of week 31 in Department 3, and week 36 in Department 1. Again, non-targeted data were collected throughout the baseline and intervention periods for all four groups.

Results

The results of the observational data collected on the targeted and non-targeted behaviors over the 50-week period are shown in eight graphs. The first four graphs present data on the targeted behaviors, one per group (Figures 11 – 14). The second set of four graphs (Figures 15 – 18) provides data on the non-targeted behaviors for each of the four groups. Each of the graphs consists of a run chart and the associated control limits for each individual department. The vertical line in each graph indicates the implementation of the intervention package.

Target Behaviors

Baseline "percent of activities performed safely" of targeted behaviors averaged 69.8% in Department R (Figure 11), 70.2% for Department TW (Figure 12), 63.5% for Department 3 (Figure 13), and 57.1% for Department 1 (Figure 14).

FIGURE 11. Percent of target behaviors performed safely for Dept R – Facility One.

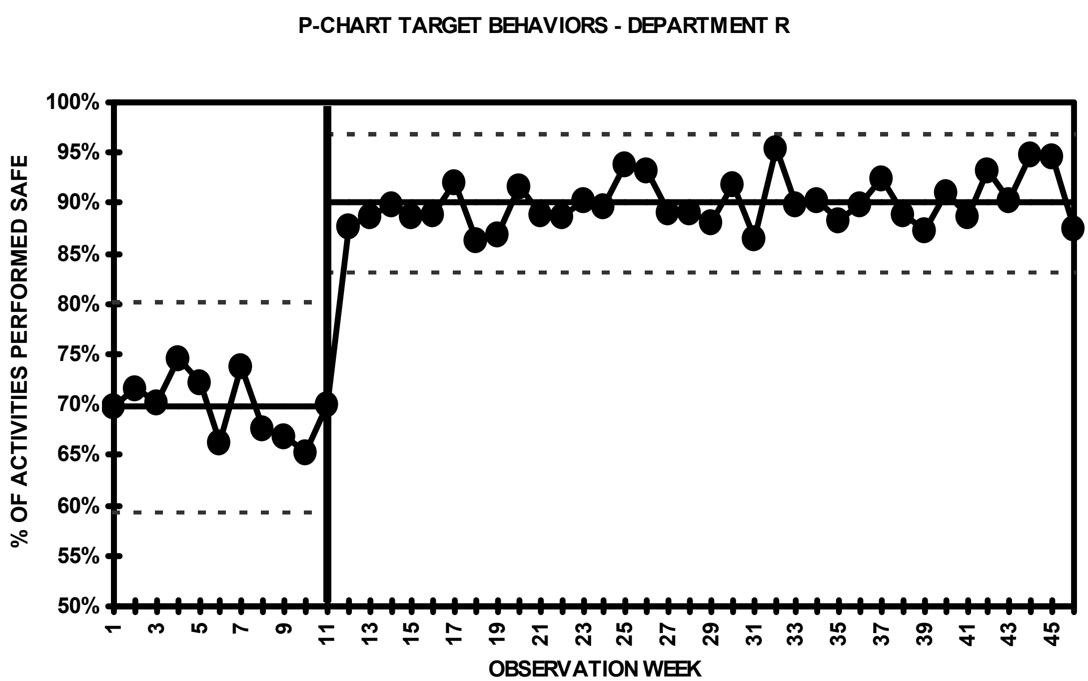
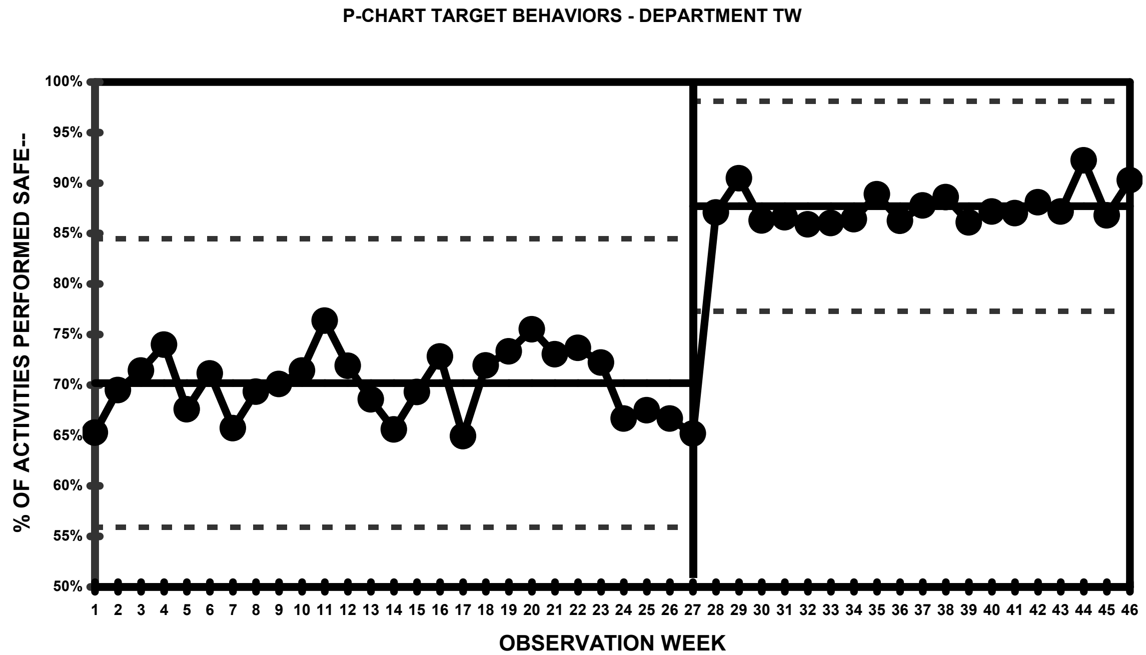
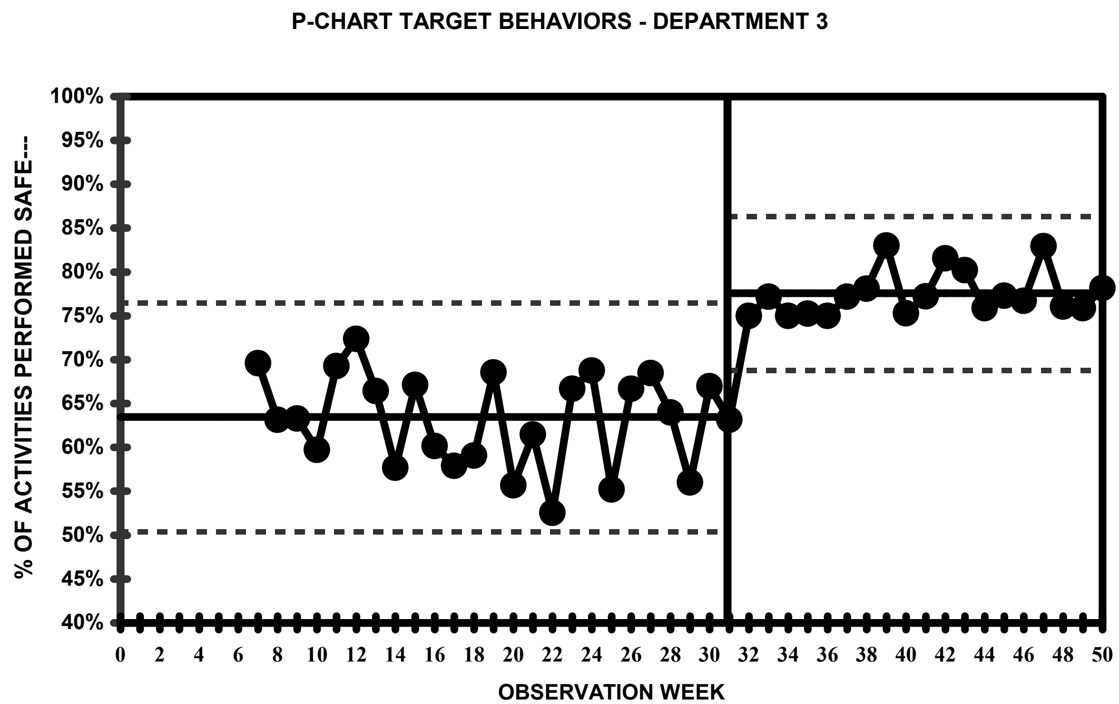


FIGURE 12. Percent of target behaviors performed safely for Dept TW–Facility One.



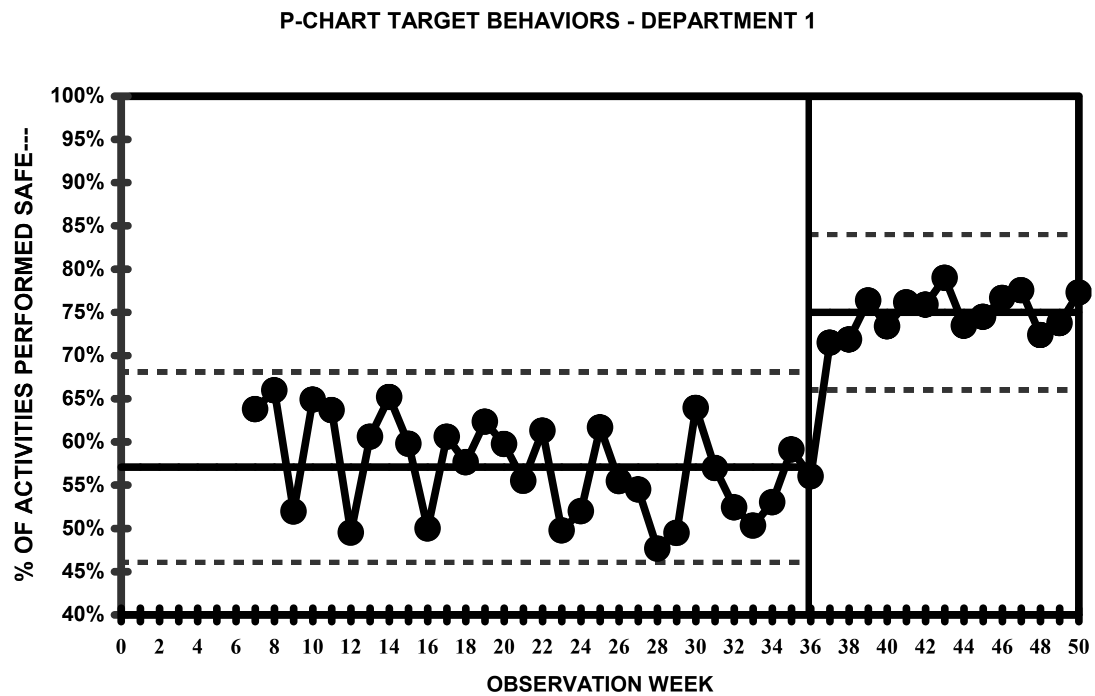
The intervention was first conducted in Department R of Facility One resulting in a substantial increase in the performance of the targeted behaviors. Within the first week of the intervention phase, Department R had surpassed their goal of 85%. The average "percent of activities performed safely" of targeted behaviors during the intervention phase for Department R was 90.0%, an increase of 20.2 percentage points over the baseline average. The lowest weekly score during the intervention phase was considerably higher than the highest baseline weekly score for Department R. All other groups maintained baseline levels during the introduction of the intervention package to Department R including Department TW, which is in Facility One. Similar increases in targeted behavior average "percent of activities performed safely" were noted in the other three groups after the introduction of the intervention.

FIGURE 13. Percent of target behaviors performed safely for Dept 3–Facility Two.



Department TW's average weekly score of targeted behaviors during the intervention phase was 87.7%, a 17.5 percentage point increase over their average baseline score. The two groups from Facility Two average intervention phase scores of targeted behaviors were 77.6% for Department 3 and 75.0% for Department 1, an increase over average baseline performance of 14.1 and 17.9 percentage points respectively.

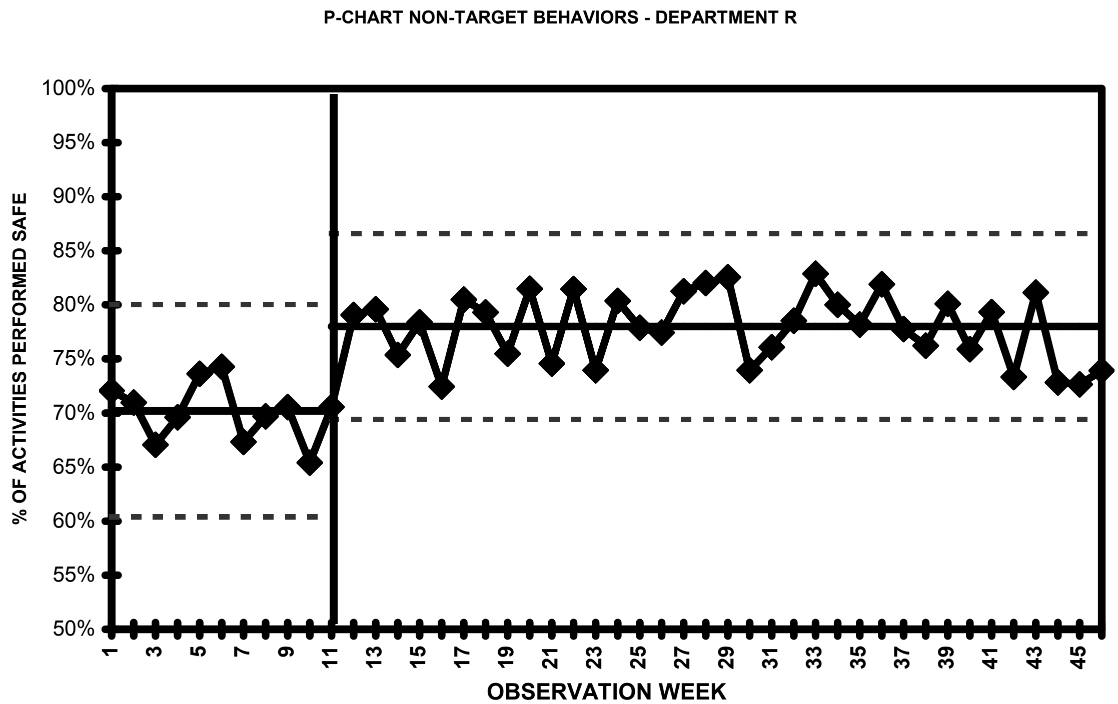
FIGURE 14. Percent of target behaviors performed safely for Dept 1–Facility Two.



Non-Target Behaviors

Figures 15 – 18 show the observed "percent of activities performed safely" of non-targeted behaviors for each of the four groups. Department R's weekly score of non-targeted behaviors averaged 70.2% during the baseline period and 78.0% during the intervention period. All of Department R's non-target weekly scores during the intervention period were above the baseline mean with an overall increase of 7.8 percentage points over the baseline average. Similar increases in average "percent of activities performed safely" of non-target behaviors were reported in the other three groups after the introduction of the intervention. Department TW's average baseline non-target score was 70.9%. This increased 7.0 percentage points to an average of 77.9%

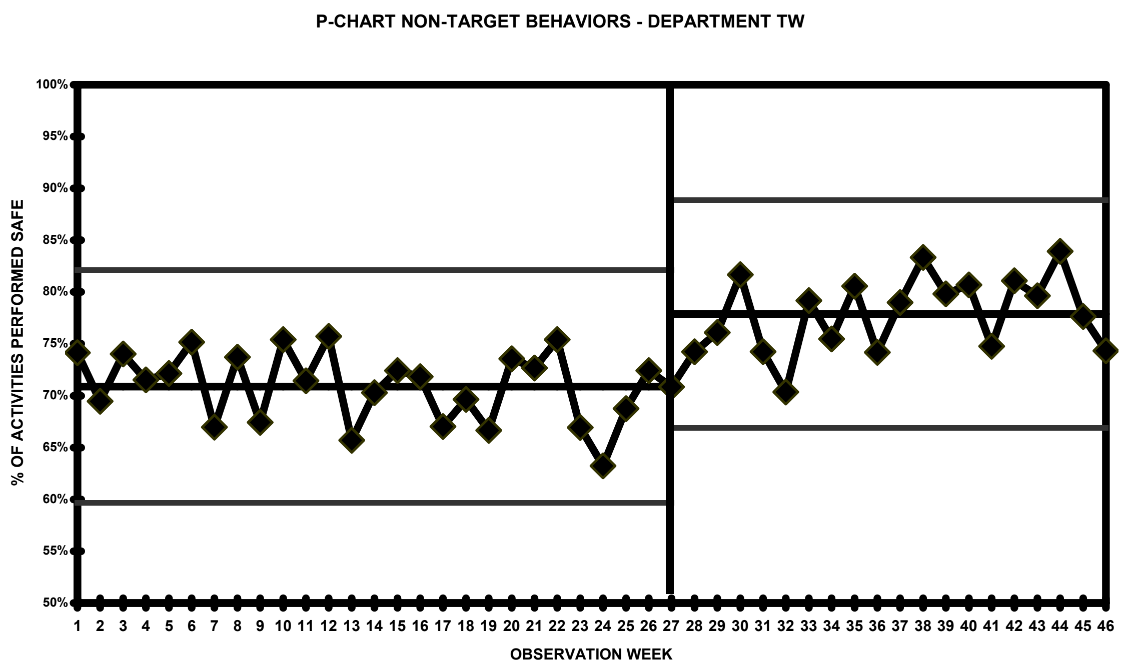
FIGURE 15. Percent of non-target behaviors performed safely for Dept. R – Facility One.



during the intervention phase. All but one of Department TW's weekly non-target scores during the intervention phase were above the baseline mean. The score during week 32 for non-targeted behaviors was 70.4%, slightly under the baseline mean of 70.9%.

The average intervention phase scores for the two groups from Facility Two were 81.8% for Department 3 and 75.6% for Department 1. Department 3 had an increase of 4.8 percentage points over their average weekly baseline non-target score of 77.0%. Department 1 reported an increase of 5.8 percentage points over a baseline non-target average performance of 69.8%. Department 3 had only two weekly scores during the intervention phase that fell below the baseline mean. The non-target score for week 34 was 76.5% and for week 38 the non-target score was 76.8%, slightly below the non-target

FIGURE 16. Percent of non-target behaviors performed safely for Dept. TW–Facility One.



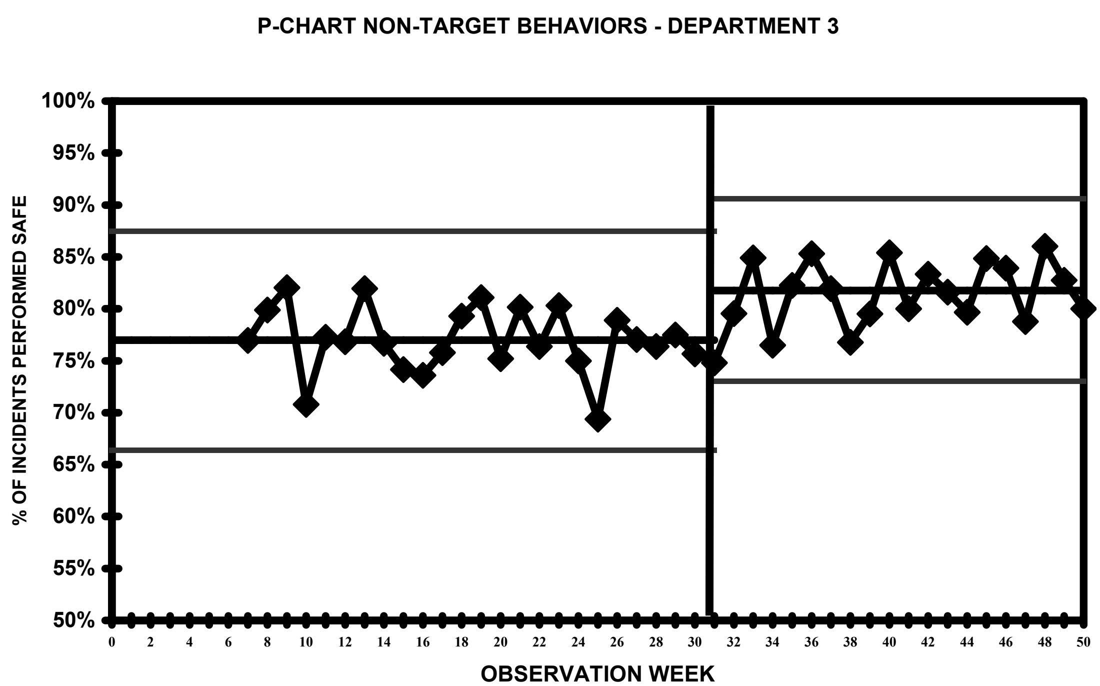
baseline weekly average of 77.0%. All of Department 1 non-target intervention phase scores were above the average weekly baseline score of 69.8%.

Based on the statistical process control limits all four groups were "in control" during the baseline phase for both target and non-target behaviors indicating a stable process. Immediately after the intervention, in all four groups, the "percent of activities performed safely" score was above the upper control limit for the targeted behaviors indicating the occurrence of a "special cause" variation. Consequently, the increase in "percent of activities performed safely" score designates a non-random event that had a significant impact on the process. This increased level of targeted behavior performance continued throughout the duration of the study.

Special cause variation was not immediately apparent for the non-targeted behaviors. None of the non-target performance scores for Department 1 and Department

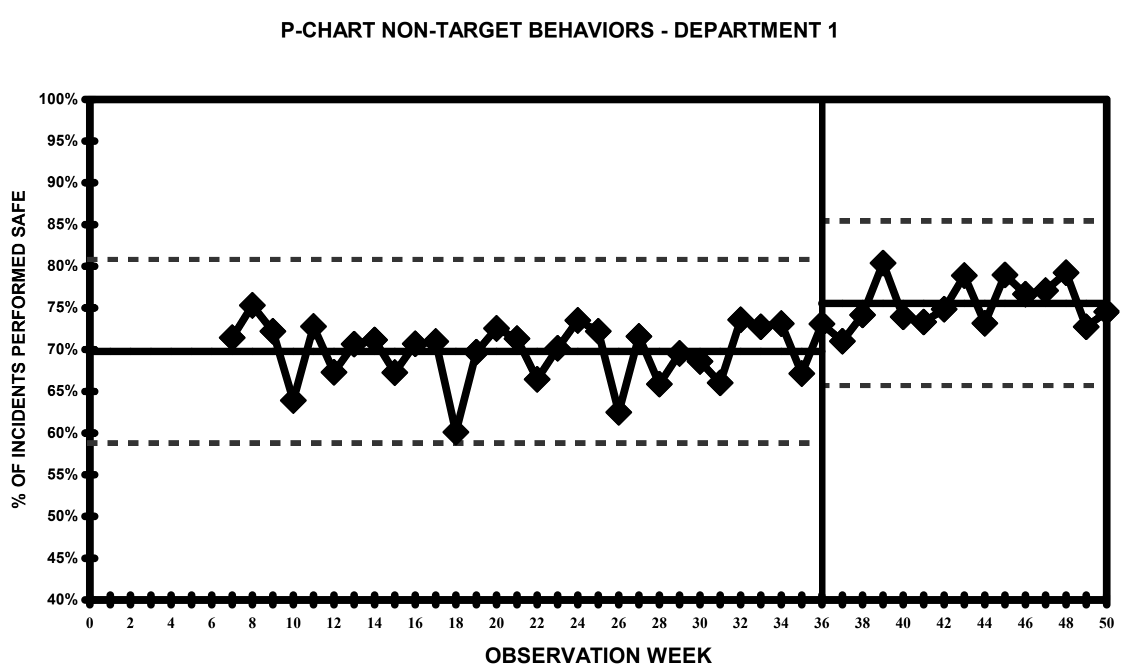
3 for Facility 2 exceeded the baseline upper control limits. Only several weeks after the intervention had taken place did the non-target performance scores of Department R and Department TW of Facility 1 exceed the baseline upper control limits. The non-target performance scores of all four groups did, however, eventually indicate the presence of a "run". A "run" of seven or more consecutive points all above (or below) the mean indicates the presence of a non-random variation on the process. In other words, the increase in non-targeted behavior performance was significant. With the exception of the three points previously mentioned the weekly non-target performance scores remained above the baseline mean throughout the duration of the study.

FIGURE 17. Percent of non-target behaviors performed safely for Dept. 3 – Facility Two.



Both the targeted and non-targeted behaviors were examined as aggregated data. The intervention phase mean for each of the individual targeted behaviors was higher than the individual baseline mean. Four out of forty-two of the non-targeted behaviors had an intervention phase mean higher than the individual non-targeted behavior baseline mean. The intervention mean for the non-target behavior of "properly using compressed air" for Department TW in Facility One was 42.3%, slightly lower than the baseline phase mean of 43.6%. "Properly using compressed air" for Department 1 in Facility Two also had a slight decrease in the mean during the intervention phase from a baseline mean of 58.0% to 56.7%. Both Department 1 and 3 from Facility Two showed a decrease in the intervention phase mean of the non-targeted behavior of "forklift driving" from the baseline mean. "Forklift driving" baseline mean for Department 1 was 44.4% with an intervention mean of 42.6%, while Department 3 decreased from 54.2% to 52.8%.

FIGURE 18. Percent of non-target behaviors performed safely for Dept. 1–Facility Two.



Discussion

The results of this study reaffirm the benefits of behavior-based safety techniques on targeted behaviors. Targeted behaviors increased significantly and were maintained throughout the intervention phase in all four groups as shown in a number of previous research studies. This study provides another example confirming the effects of positive reinforcement in the form of feedback on targeted behavior performance and the use of training and participatory goal setting as intervention procedures.

The results of this study also indicate that the fundamental behavior-based safety techniques used on targeted behaviors had a concurrent significant impact on non-targeted behaviors. The performance of both targeted and non-targeted behaviors covaried throughout the study, both sets of behaviors significantly increasing after the introduction of the intervention. This suggests that the targeted behaviors and the non-targeted behaviors belong to the same conceptual class as Austin and Wilson (2001) discussed. Previous studies only examined the relationship between conceptual classes or "response generalization" (Ludwig and Geller, 1997, 1999) between one or two targeted and non-targeted behaviors. This study, by observing a larger number of targeted and non-targeted behaviors, indicates that workplace safe behaviors may be part of a much larger than expected conceptual class of behaviors. The results suggest that the collateral effects of the fundamental behavior-based safety techniques are quite broad. This extended effect may be a product of verbal relations and the impact of a participative intervention on the relational class of "safety" as pointed out by Austin and Wilson (2001) and Ludwig and Geller (1999).

In addition to the intervention increasing targeted and non-targeted behavior performance, the results of this study also indicate that the statistical control limits of all four groups were in statistical control during both the baseline and intervention phases. The observed variation in weekly performance scores was random and naturally occurring requiring a process change for improvement. The results show that the intervention package provided this process change.

The results of this study and the corresponding increased performance of targeted and non-targeted safe behaviors also had an impact on incidents and injuries at the two facilities. The Total Case Incident Rate (TCIR) of “recordable” injuries for Facility One was 22.2 at the beginning of the study. At the end of the study the annualized TCIR for Facility One was cut by more than 50% to 10.6. Facility Two experienced a similar impact on incidents and injuries. Facility Two had a TCIR of 18.4 at the beginning of the study. This measure of “recordable” injuries was reduced to 12.8 for the year. Again this TCIR covered the entire facility. During the study employees informally expressed a noticeable increase in general safety at the two facilities and, in particular, an increase in management involvement with safety concerns.

Conclusion

The purpose of this research was to investigate the relationship between “targeted” safe behavior variation and other “non-targeted” behaviors. This investigation included the systematic application of the fundamental behavior-based safety techniques of pinpointing critical behaviors, developing precise definitions, collecting and measuring observational data using an observational checklist, and implementation of training, participatory goal setting, and both graphical and verbal feedback as an intervention package to increase target behaviors and examine the resulting affect on non-targeted behaviors. The results reaffirm the effectiveness of these fundamental techniques. This study also provides a glimpse of covariation between targeted and non-targeted behaviors. The performance of non-targeted behaviors increased significantly even though they were not specifically included as part of the intervention package. This leads to the conclusion that at least there were no adverse effects on the majority of the observed non-targeted behaviors as a result of changes in targeted behaviors. As noted in the discussion four of the non-targeted behaviors demonstrated slightly lower means after the intervention. This suggests that the benefits of implementing behavior-based safety techniques are broad in scope and that there are positive side effects beyond the immediate improvement of targeted behavior performance.

CHAPTER 6

EXAMINING THE EFFECTS OF BEHAVIOR-BASED SAFETY TECHNIQUES ON PRODUCTION AND QUALITY MEASURES IN MANUFACTURING

Introduction

The rate of occupational fatalities and injuries in the United States has declined slightly in recent years; however workers' compensation cases and costs have steadily increased indicating a continual need to focus on workplace safety (National Safety Council, 2004). In an effort to stay competitive in a global marketplace, manufacturing organizations may examine workplace injuries and illnesses and pursue activities to reduce the associated costs. Manufacturing facilities often concentrate their efforts in traditional areas of occupational safety and health such as machine safeguarding, personal protective equipment, and safety training. Endeavors focusing on unsafe conditions and unsafe acts are essential to successful improvement of workplace safety. In recent years, organizations have taken a multi-faceted approach to improve workplace safety. Traditional safety programs have been complimented with programs directed at improving workers' safe behavior. These programs are based on applied behavioral research and are collectively referred to as behavior-based safety programs. The methods used in behavior-based safety programs vary widely, however they typically focus on identifying and reinforcing worker behavior to improve safety performance.

This increase in the number of behavior-based safety programs has piqued the interest of occupational safety and health professionals and manufacturing management. Consequently, this increased exposure has raised concerns as well. Many of these concerns center on organizational measurements, such as productivity and quality. One purpose of this research was to examine the association between targeted safe behavior variation and productivity and quality measures in manufacturing facilities.

The axiom that "the safe establishment is efficient productively and the unsafe establishment is inefficient" is not universally endorsed (Heinrich, Petersen, and Roos, 1980). It is often argued that safety improvements increase productivity but examples of safety controls adversely affecting productivity, at least in the short-term, are common as well. There are many examples of safety improvements, such as properly designed workstations and tools, which increase productivity and quality. On the other hand, it may be argued that safety controls, such as machine safeguarding and personal protective equipment (PPE), interfere with the normal course of work and therefore decrease productivity and quality measures (Heinrich et al., 1980).

Over the last two decades there has been an increased effort to control unsafe acts by implementing behavior-based safety programs. Zohar and Luria (2003) state that careless behavior still prevails during many routine jobs, making safe behavior an ongoing managerial challenge. Peterson (1988) emphasizes the failure of management systems and human error in workplace accident causation. Peterson (1988) also suggests that unsafe acts or human error is often increased because of management system failures. For manufacturing facilities to be economically successful they must control the cost associated with these unsafe acts and human error.

Research has established that the application of behavior analysis principles through the implementation of the fundamental requirements of a behavior-based safety program can be effective at increasing targeted safe behaviors. Grindle, Dickinson, and Boettcher (2000) reviewed eighteen behavior-based safety programs implemented in manufacturing organizations all showing an increase in safe behaviors after consequent intervention. Krause, Seymour, and Sloat (1999) examined the effects of behavior-based safety methods in 73 organizations revealing a significant decrease in incidents with an average reduction of 26% in the first year and an average reduction of 69% by the end of the fifth year.

Even though there has been a significant amount of research in the field of behavior-based safety, there are many unanswered questions. In particular, questions pertaining to the effect on other organizational variables such as productivity and quality remain unanswered (Krause, Seymour, and Sloat, 1999; McAfee and Winn, 1989). Krause et al., (1999) explain the similarities between the behavior-based safety approach and the quality improvement approach outlined by Deming (1986). To maintain a competitive edge, management is often primarily concerned with production and quality. Therefore, safety programs such as behavior-based programs must either enhance, or at the very least, not adversely impact productivity or quality. There have been numerous studies showing an increase in production-related performance when the target was production performance behaviors, however, the effect on production is not clear when safety behaviors are targeted.

Eikenhout and Austin (2005) demonstrated an increase in targeted customer service performance behaviors with the implementation of several interventions including goal setting and feedback. The study involved a total of 115 employees in three different departments of a large department store over a 15-week period. A set of criteria identifying "good customer service" was used to develop targeted behaviors for improvement. Feedback intervention and a package intervention consisting of feedback, reinforcement, goal-setting, and celebration substantially increase "good customer service" behaviors.

The production performance of a roofing crew was improved when crews received both feedback and tangible rewards based on previous production activity (Austin, Kessler, Riccobono, and Bailey, 1996). The crew of a roofing company received graphic and verbal feedback and a monetary reinforcer based on daily calculations of labor cost savings. The labor cost savings were calculated based on the performance of the "tearing off" task associated with removing an old roof. As a result, labor cost decreased 64% from pre-intervention conditions.

Zohar and Luria (2003) described a study at a milk-products plant where supervisory safety and quality criteria were improved using weekly feedback. Thirteen shop-floor supervisors received weekly feedback based on the frequency of interaction with subordinates. The interaction included behaviors involving both safety and quality criteria. Supervisory interaction with subordinates increased significantly during the intervention phase. Based on this increased frequency of supervisory interaction worker safety behaviors and quality-related behaviors improved.

Researchers report an "observed" increase in productivity associated with increases in safe behavior (Sulzer-Azaroff and Santamaria, 1980) or at least no indications that productivity changed as safe behaviors varied (Komaki, Barwick, and

Scott, 1980). Krause (2002) described a study showing 30% of surveyed managers perceived that quality and productivity benefited from the implementation of a behavior-based safety program. Sarkus (1997) suggests that behavioral approaches targeting safe behaviors increase employee involvement and collaboration that result in improved production. Accordingly, numerous researchers suggest that it would be beneficial to demonstrate that there is a positive relationship between increases in safe behavior, as initiated by a behavior-based safety program, and other organizational variables (McAfee and Winn, 1989; Austin et al., 1996; Sulzer-Azaroff and Austin, 2000; Zohar and Luria, 2003).

The effect of a behavior-based safety program on organizational variables such as productivity and quality is not clear. Does an overall increase in safe behavior have any effect on productivity? Is a generalized increase in safe behavior accompanied by an increase or a decrease in productivity? What about the effect of increased safe behavior on quality? This impact, however, has not been carefully measured.

The present study systematically applied the fundamental behavior-based safety techniques of pinpointing critical behaviors, developing precise definitions, collecting and measuring observational data using an observational checklist, and implementation of training, participatory goal setting, and both graphical and verbal feedback as an intervention package to increase worker safe behaviors. At the same time critical worker safe behaviors were pinpointed for inclusion as a "targeted" safe behavior, productivity and quality measures were identified. These productivity and quality data were measured throughout the baseline and intervention periods at the same time behavioral observations were measuring the targeted safe behaviors. Productivity and quality data were not included in the intervention training and no feedback pertaining to these organizational measures was provided to employees. The dependent productivity and quality data were examined for any relationship with variation in the targeted safe behaviors.

Method

The experimental design for this research study was a multiple-baseline design across four groups. This multiple-baseline design demonstrates the effect of an intervention by showing behavior variation with the introduction of the intervention at different points in time for each group. The purpose of this staggered implementation is to introduce a level of experimental control (Robson, Shannon, Goldenhar, and Hale, 2001). After baseline behavior has stabilized, the intervention is applied to the first group while the baseline measurement is continued for the remaining groups. Using this overlapping approach, the intervention is successively extended to all groups. The objective is to demonstrate similar behavior variation following each introduction of the intervention.

Statistical process control charting techniques were used to demonstrate the stability of the behavior and the production and quality data. These statistical process control techniques also allow the distinct identification of sudden and gradual trend changes or "special cause" variation in the data. Statistical Process Control (SPC) was developed by Walter A. Shewhart at Bell Laboratories in the 1920's and presented in his classic *Economic Control of the Quality of Manufactured Product* (1931). Shewhart's fundamental concept is the understanding of process variation in order to improve the process. All processes have natural variation that result in changing outcomes. Deming

(1986) described this random process variation as "common cause" variation. Common cause variation is random but predictable and stable within a range of distinct distribution limits. In other words, common cause variation is caused by conditions that are inherent to the process. Other process variation is a result of non-random or unusual events. "Special cause" variation (Deming, 1986) is intermittent and not part of the natural process variation. This special cause variation is a result of an outside event acting on the process. It is important to note that direct changes in the process may result in identifiable variation also. Direct "process changes" should only occur when the process is stable. "Tampering" or intervening without a stable process weakens the overall process (Deming, 1986).

There are two categories of data for control charts: variables and attributes. Variables are continuous data, where the user chooses the precision. Typical variables can be measured and expressed by a numerical value such as length, volume, or time. Attribute data, on the other hand, are ordinal data, such as rank or counted data, and nominal data that can be classified into one or two categories – good or bad, go or no-go, safe or at-risk. The distinction between variables and attributes data is necessary to determine the appropriate type of control chart.

Manufacturing organizations have historically used methods of statistical process control as an effective analysis and process improvement tool in the areas of production and quality. Typical measures of productivity rates and scrap rates are analyzed using statistical process control techniques. Often the production and quality data are variable-type data that can be approximated by a normal distribution after testing for normality. The X/R chart is frequently used when monitoring the mean and range of this type of production and quality data. Occasionally, the number of nonconformities per product is used as a measure of quality. In the case of measuring attribute data that varies from observation to observation the U chart is most appropriate. These various types of statistical control charts can be used to monitor the variation of the process. Analysis of the plotted results on the control chart can be used to determine if the process is operating in a stable manner (in a state of statistical control), or if the pattern has been disturbed by an event that drives the process out of control. The measured data can be interpreted as "in control" when all variation is random and is between the statistical control limits and therefore, is a result of common causes. These control limits are set at values that approximate three standard deviations from the mean. The measured data may be determined to be "out of control" when variation is a result of special causes or not random. An example indicating special cause variation may be when a single data point falls outside the set statistical limits or 7 consecutive observations fall above or below the mean. In other words, these various statistical process control charts can indicate when to take action and when to leave the process alone.

Statistical process control charts can also be used to analyze and interpret behavioral observations and to determine whether a perceived change in data is a result of natural process variation or a special cause from outside the process. Just as with production and quality measures this visual representation of behavioral process variation may then be used to intervene to improve the process. For behavioral observations and percent safe measurements, the p-chart is most appropriate because the data are represented by the "proportion of nonconforming units in a sample". Behavioral observation data with two possible outcomes (safe, at-risk) best fit a binomial distribution.

In the present study a combination of run charts and statistical process control charts were used to present and analyze the data. The independent variables consist of the behavior-based safety techniques of training, participatory goal setting, and graphical and verbal feedback. There are three sets of dependent variables, one set consisting of the targeted safe behaviors, a second set of productivity measures, and a third set of quality measures. All three sets of the dependent variables are plotted over time (weekly) using a run chart for each of the four groups. Each run chart includes two distinct phases: baseline and intervention. Statistical process control charting techniques were used to analyze the data to determine whether or not significant changes in the targeted safe behaviors, the productivity, or the quality data occurred following the intervention as evidenced by special cause variation. Two specific criteria were of interest, changes in level between phases and the identification of special cause variation within each phase. A process may be "out of control" if the observed variation is non-random. There are numerous rules for identifying this non-random variation (Stapenhurst, 2005). In this study three of the most commonly used rules according to Stapenhurst (2005) were used for identifying an out of control process because of their widespread acceptance:

- Any one point falling above the upper control limit or below the lower control limit;
- A "run" of seven or more consecutive points all above or below the mean (centerline); and
- A "trend" of seven or more consecutive points increasing or decreasing in value.

A process that is not in control indicates that the special cause acting on the process should be identified and, if necessary, action should be taken to eliminate the cause. In this particular study, an out of control condition indicates that the fundamental behavior-based safety techniques had a significant impact on the dependant variable, either the targeted safe behaviors, production productivity, product quality or any combination of the three.

Productivity and quality data were based on 100% inspection and measurement. Behavioral observation sample sizes varied based on the number of employees per department. The smaller the sample size the slower the control chart will be to identify "special cause" variation. Stapenhurst (2005) suggests a minimum average sample size of 50 associated with attribute-based statistical control charts. Montgomery and Runger (1994) report a worst-case scenario requiring 58 observations. The smallest observation sample size for this study was 90.

Setting and Participants

The setting for this study involved two different manufacturing facilities in the southeast United States. Two different departments were selected from each of the manufacturing facilities providing four different groups. The first facility is a light manufacturing and assembly operation. The facility typically has only a day shift production operation with a skeleton maintenance crew on a second shift. The two departments selected from this facility have similar processes. Both departments utilize basic machining and assembly operations. Differences between the departments pertain only to product configuration. The participants included all 40 fulltime employees of

Department R and all 26 fulltime employees of Department TW. Both departments operate a nine-hour day shift Monday through Thursday and a four-hour day shift on Friday. The workers were paid an hourly rate with no production or product quality-based bonuses. Production data were collected and reported weekly to management and supervisors. The facility's quality measurement consisted of a loss material (scrap) rate. Hourly workers received no regular information on productivity or product quality and statistical process control techniques were not used at this facility. The facility had a compliance-based safety program focused on meeting workplace safety and environmental regulations. The facility has developed and implemented programs and training required by regulation. At the beginning of the study the facility's OSHA Total Case Incident Rate (TCIR) was 22.2.

The second facility is also a light manufacturing and assembly operation producing a different product than the first facility. Facility Two operates three 8-hour shifts over a five-day workweek, with the third shift consisting largely of maintenance activities. Approximately 85% of the employees work on the day shift. The two departments selected from this facility have similar processes centered around slightly different product lines. The participants included all 71 fulltime employees of Department 1 and all 47 fulltime employees of Department 3 for the day shift only. As in Facility One, the workers were paid an hourly rate with no production or product quality-based bonuses. Production data were collected and reported weekly to management only. Floor supervisors and hourly workers received no regular information productivity measures. The facility's quality measurement consisted of a 100% inspection of the final product. The number of "write-ups" for each individual product produced was posted in the department area. Statistical process control techniques were not used to present or evaluate the data. Like Facility One, this second facility's safety efforts were entirely focused on meeting workplace safety and environmental regulations. All employees had received required regulatory safety training. In addition to this required safety training all employees had received new-hire training that included the organization's safety rules. The organization's safety rules were basic rules such as no horseplay, running, smoking or drinking in the work areas. At the beginning of the study the OSHA Total Case Incident Rate (TCIR) of Facility Two was 18.4. This TCIR covers the entire facility.

Identification and Definition of Critical Safe Behaviors

The study began with pinpointing behaviors that would have the greatest impact on overall workplace safety. These targeted safe behaviors were identified by examining past injury and accident records and interviewing management and departmental supervisors. Targeted safe behaviors consisted of either the direct behavior such as properly wearing hearing protection or the outcome of a behavior such as no material protruding into marked pedestrian aisles. The resulting list of critical safe behaviors were reviewed and approved for study by the management of each facility. Twelve unique target safe behaviors were identified for Department R and nine for Department TW in Facility One. Eight unique target safe behaviors were pinpointed for each of the remaining two groups, Departments 1 and 3 from the second facility. Examples of targeted safe behaviors include the proper use of eye and hearing protection, proper use of box cutters, work aisle housekeeping, and team lifting heavy objects.

After determining the critical safe behaviors, precise definitions were developed. For example, eye protection was required throughout all four departments. The definition used for eye protection was “Employee is wearing approved safety glasses with approved sideshields. Safety glasses are clean and free of scratches. Safety glasses are fitted on the bridge of nose close to eyes and sideshields are fitted flush to the frame of glasses”. These precise definitions aided in the collection (observation) of data (Appendix A). A unique critical behavior checklist was developed for each of the departments (Appendix C). This checklist consisted of an abbreviated definition of each target behavior and included two additional columns labeled “Safe” and “At Risk”.

Data Collection Procedures for Targeted Safe Behaviors

The study involved the collection of a total of 50 weeks of observational data. Baseline observations of targeted safe behaviors using the developed critical behavior checklists were collected at random starting times on a daily basis in all four departments. Observers alternated routes each day when collecting observations. Observers changed starting points in each of the departments and followed different routes through the departments as they collected data. Each data collection tour took less than 30 minutes for each of the two facilities. Observations were collected 4 to 5 days per week (Monday through Friday) with only one observation session per day. Baseline observations started in Departments R and TW in Facility One and six weeks later started in Departments 1 and 3 of Facility Two. Baseline observations of targeted safe behaviors were collected over 11 weeks for Department R, 27 weeks for Department TW, 31 weeks for Department 3, and 36 weeks for Department 1.

Prior to the start of data collection a short meeting was held informing departmental supervisors that safety observations would be collected. The departmental supervisors were asked to inform their employees that safety data would be collected over a period of time with the intention of improving workplace safety. This explanation included the fact that individual data would not be collected; that the data collected is reported solely on the department as a whole. No other information pertaining to the study was provided to employees.

The observers visited each workstation and instantaneously recorded the workers' behavior. Each employee was observed only long enough to make a determination of whether one or more of the targeted safe behaviors were present and if the performance of the behaviors were "Safe" or "At Risk". Collected data were used to calculate a weekly "percent of activities performed safely" score for targeted safe behaviors.

Percentage of Activities Performed Safely = (Total Number of Safe Behaviors Observed ÷ Total Number of Behaviors Observed)

There were a total of three observers collecting data at any one time throughout the study. The observers included the author and undergraduate students enrolled in a local occupational safety and health program. Inter-observer reliability was assessed approximately every four weeks. Two observers would conduct a data collection tour together without discussing their observations or findings. Reliability was calculated by dividing the number of observation agreements between the observers by the total number of observations. Reliability remained high throughout the study ranging from a low of 89% to a high of 98% with a mean reliability score of 94%.

Identification and Collection of Production and Quality Data

Both facilities employed a full-time salaried industrial engineer responsible for maintaining work measurement systems. Both facilities maintained a computerized database of standard (labor) times for each routine work task. These standard labor times were developed by the use of time study techniques. In general, this standard time is the amount of time a qualified, trained operator, working at a normal pace with certain time allowances would take to produce a part, or complete the assigned task. This standard time can be compared to actual labor time to determine a productivity rate as shown in the following equation:

Productivity Rate = (Standard Labor Time ÷ Actual Labor Time)

For example, if the standard time to produce one unit is 10 minutes and the actual time used to produce this unit was 11 minutes then the productivity rate would be approximately 91% (10 minutes ÷ 11 minutes = 0.909 or ≈ 91.0%). Both facilities provided management with a weekly report comparing standard labor hours to actual labor hours. This weekly productivity rate was used as the dependent measure of production for all four groups.

The two facilities maintained different quality measurement systems. Facility One utilized a loss material (scrap) rate as a measure of production quality. A material requirements sheet was developed for each product ordered by a customer. The amount of materials issued to produce the product was collected by order number. Materials issued counts were maintained only for the costly “bar stock” material used to produce this product. This raw material (bar stock) was measured by length in inches. The required material, measured in inches, was then compared to the issued material (inches) to determine a “lost material” rate. A weekly report showing the lost material rate was created and issued only to top management. This lost material rate was used as the dependent measure of quality for both departments in Facility One.

Facility Two required a 100% inspection of each product produced in both departments. Inspectors utilized a final criteria checklist of the required quality characteristics. When the inspector discovered a nonconformity they issued a “write-up” for that particular unit. The number of write-ups for each unit produced were maintained and posted in the department area. The average number of write-ups per unit was not calculated, in fact, Facility Two personnel discussed quality based on the number of write-ups for each particular unit. The average number of write-ups per unit was used as the dependent measure of quality for both departments in Facility Two.

Intervention

After establishing stable and substantial baseline data for each measured variable an intervention package of training, participatory goal setting, and graphical and verbal feedback was implemented in an effort to increase targeted safe behaviors only. The one-time training session lasted approximately one hour for each of the four departments. The author conducted each of the four on-site training sessions. The training sessions consisted of an explanation and a combination of pictures depicting the “safe” and “at-risk” performance of each targeted behavior. The training pictures were taken at each of the facilities using actual workers demonstrating each of the targeted safe behaviors. The pictures showing “at-risk” or unsafe behaviors were carefully “staged” using actual workers from the corresponding facility. The collection and analysis of productivity and quality data was not mentioned or discussed. Immediately after the training session a list of the targeted safe behaviors was posted on each department's bulletin board. During the training session employees were shown a graph with their department's targeted safe behavior baseline performance and were encouraged to increase their performance. The layout and components of the graph were explained in detail and employee questions were answered.

The training session concluded with discussing a goal for increased targeted safe behavior performance. Collectively and with guidance, the employees of each department agreed upon a performance goal. These goals remained constant throughout the study. The employees of Department R and Department TW both agreed on 85% as a reasonable and attainable goal. The employees of Department 1 agreed on 70% for their goal and Department 3 decided on a 75% goal.

After the intervention training, observations of targeted safe behaviors and productivity and quality data continued with the addition of weekly feedback to employees only on the targeted safe behaviors. Each week a short session was held explaining the preceding week's performance on the targeted safe behaviors and encouraging improvement. The first several feedback sessions were conducted by the observers, thereafter the departmental supervisors conducted the feedback sessions. The weekly graph showing percent of targeted behaviors performed safely was placed on the department's bulletin board. Again, productivity and quality measures were not involved in any part of the intervention package. The employees were only aware of the collection of targeted safe behaviors.

Following the multiple-baseline design, the intervention was staggered for each of the four groups. The intervention was introduced at the beginning of week 11 in Department R. After establishing a stable intervention period in Department R the same intervention procedure was conducted in Department TW at the beginning of week 27. This same process was repeated in the second facility with the intervention procedure conducted at the beginning of week 31 in Department 3, and week 36 in Department 1. Productivity and quality data were collected throughout the baseline and intervention periods for all four groups.

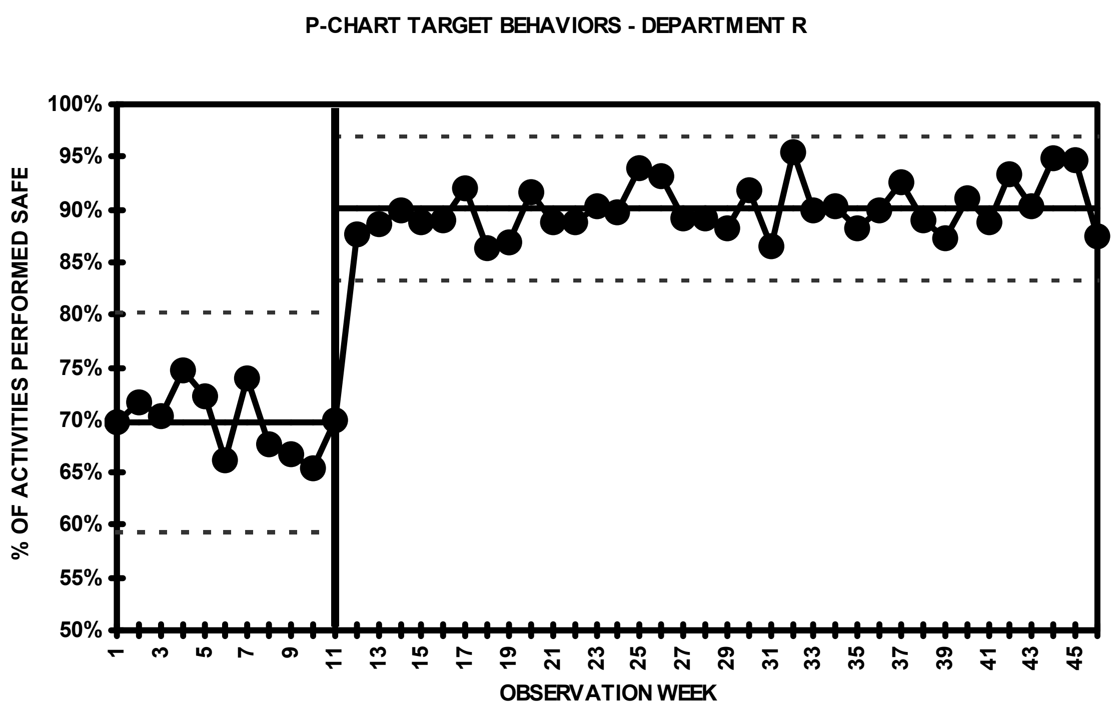
Results

The results of the observational data collected on the targeted safe behaviors and the productivity and quality data over the 50-week period are shown graphically. The first four graphs present data on the targeted safe behaviors, one per group (Figures 19 – 22). The targeted safe behavior data is presented using P-charts. The second set of graphs (Figures 23 – 26) provides the quality data for each of the four groups. The "lost material rate" data used for Departments R and TW from Facility One are presented using X/R charts. Normality test are shown in Appendix E. The "average write-up per unit" data used for quality measurement in Department 3 and 1 of Facility Two are presented using U-charts. The final set of graphs show the productivity data for each of the four groups (Figures 27 – 30). This productivity data is presented for all four groups using X/R charts. The normality tests are shown in Appendix E. Each of the graphs consists of a run chart and the associated control limits for each individual department. The vertical line in each graph indicates the implementation of the intervention package.

Targeted Safe Behaviors

Baseline "percent of activities performed safely" of targeted behaviors averaged 69.8% in Department R (Figure 19), 70.2% for Department TW (Figure 20), 63.5% for Department 3 (Figure 21), and 57.1% for Department 1 (Figure 22). The intervention was first conducted in Department R of Facility One resulting in a substantial increase in the performance of the targeted safe behaviors. Within the first week of the intervention phase, Department R had surpassed their goal of 85%. The average "percent of activities performed safely" of targeted behaviors during the intervention phase for Department R was 90.0%, an increase of 20.2 percentage points over the baseline average. The lowest weekly score during the intervention phase was considerably higher than the highest

FIGURE 19. Percent of target behaviors performed safely for Dept R – Facility One.



baseline weekly score for Department R. All other groups maintained baseline levels during the introduction of the intervention package to Department R including Department TW, which is in Facility One.

Similar increases in targeted behavior average "percent of activities performed safely" were noted in the other three groups after the introduction of the intervention. Department TW's average weekly score of targeted behaviors during the intervention phase was 87.7%, a 17.5 percentage point increase over their average baseline score. The two groups from Facility Two average intervention phase scores of targeted behaviors were 77.6% for Department 3 and 75.0% for Department 1, an increase over average baseline performance of 14.1 and 17.9 percentage points respectively.

FIGURE 20. Percent of target behaviors performed safely for Dept TW – Facility One.

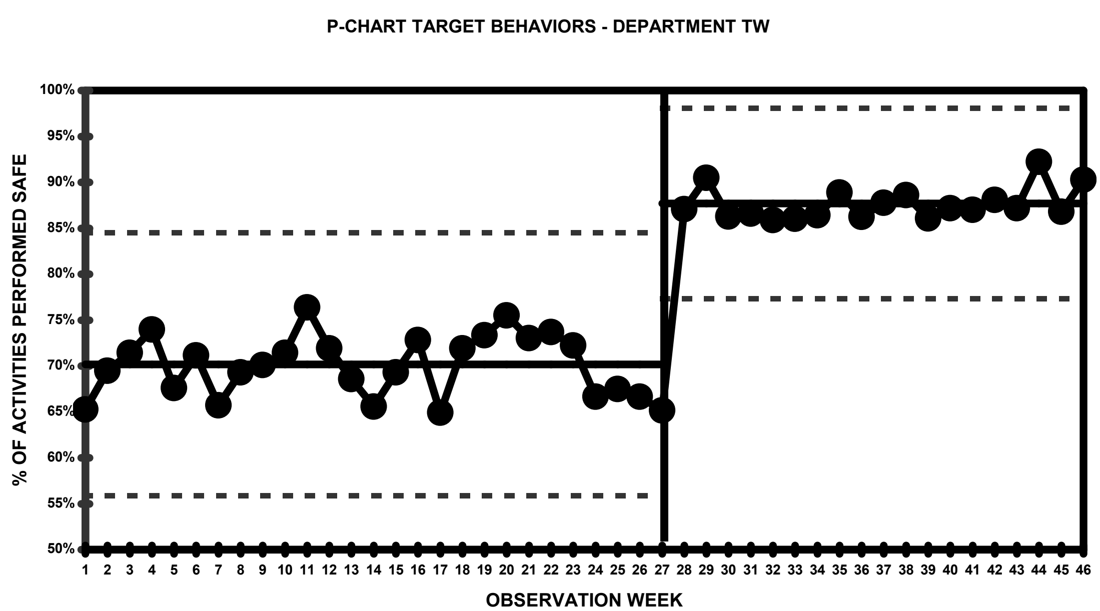


FIGURE 21. Percent of target behaviors performed safely for Dept 3 – Facility Two.

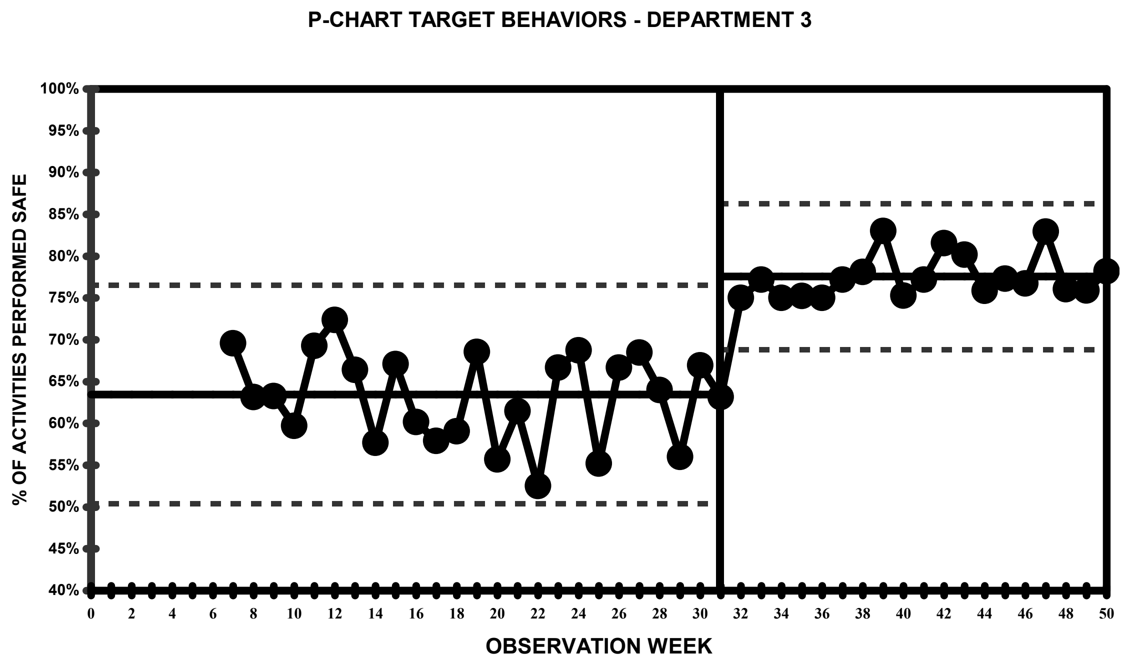
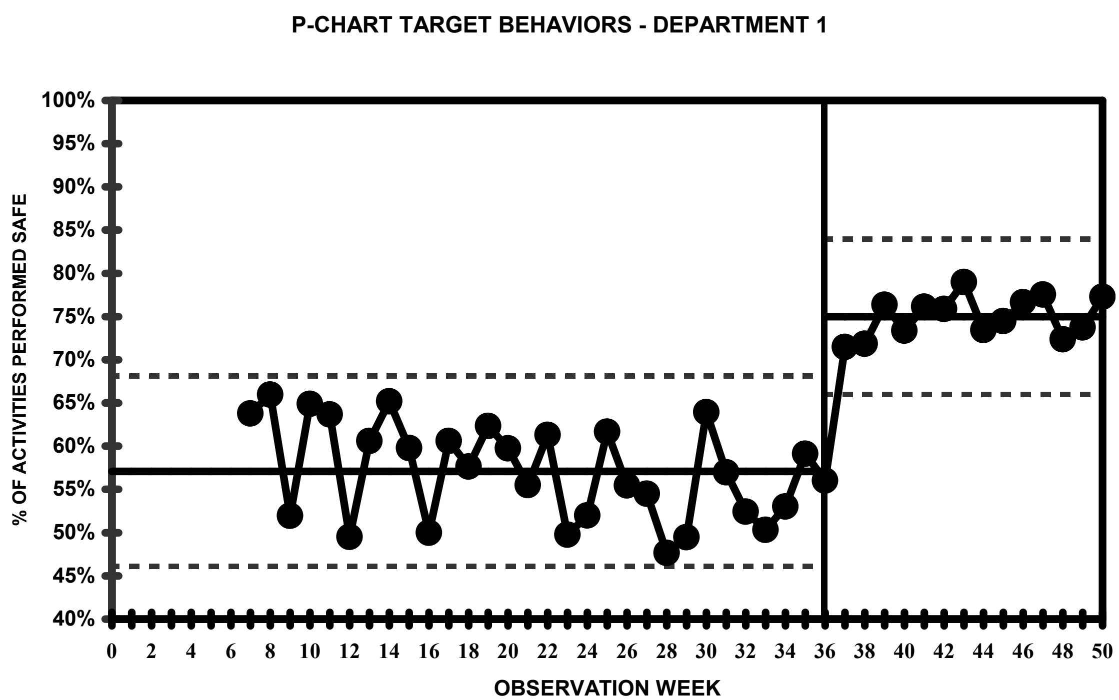


FIGURE 22. Percent of target behaviors performed safely for Dept 1 – Facility Two.



Quality Data

Figures 23 – 26 show the quality data for each of the four groups. The "lost material" rate for Departments R was 0.57% (Figure 23). This rate remained constant throughout the study. There were no out-of-control cases indicating the presence of a special cause variance. Department TW's weekly lost material rate averaged 6.67% (Figure 24) during both the baseline and intervention phase. Again, there were no indications of process variation in this quality measurement for Department TW. The moving range charts for both departments of Facility One are shown in Appendix D.

The average number of "write-ups per unit" for the two groups in Facility Two was 238.8 for Department 3 and 117.9 for Department 1 (Figures 25 and 26). Based on the statistical process control limits both groups were "in control" during both the baseline and intervention phase.

FIGURE 23. Lost Material Rate for Department R – Facility One.

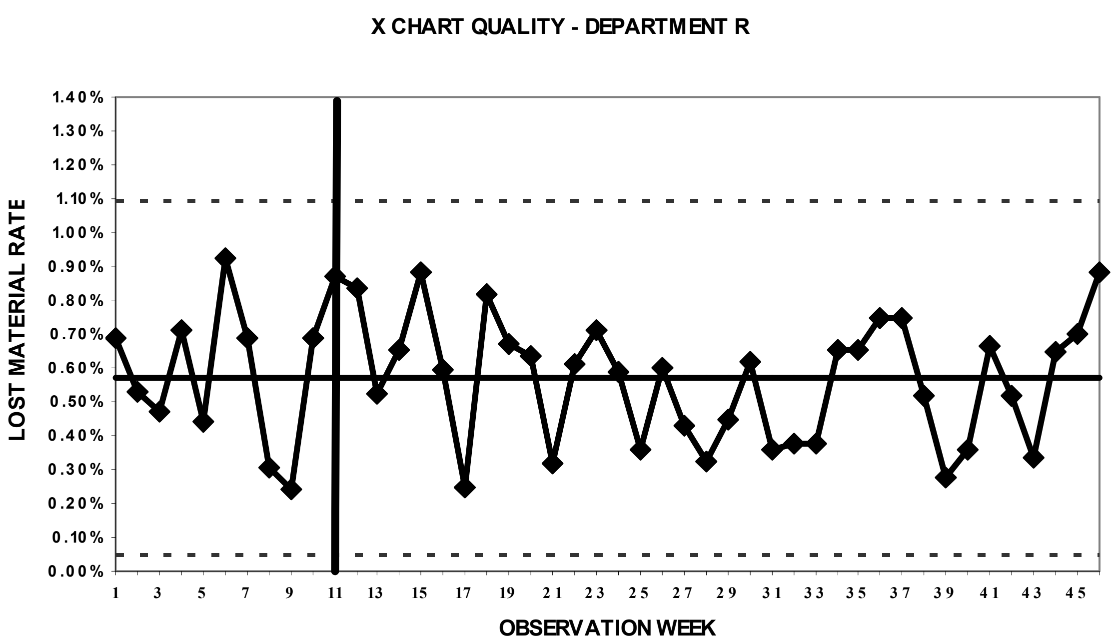


FIGURE 24. Lost Material Rate for Department TW – Facility One.

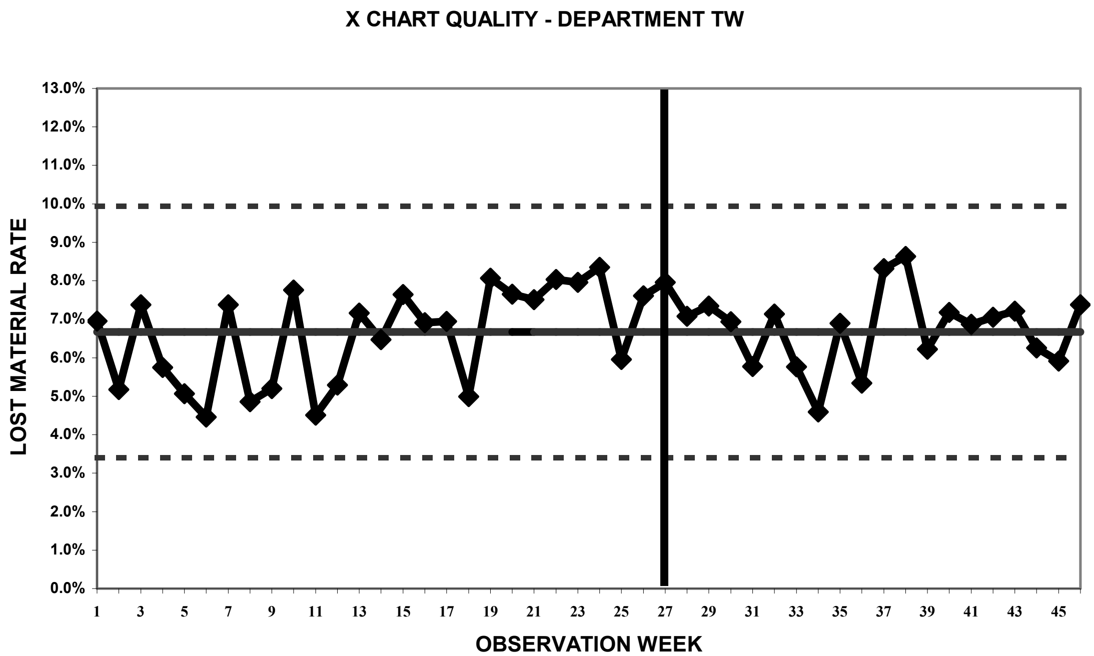


FIGURE 25. Average Number of Write-ups per Unit Department 3 – Facility Two.

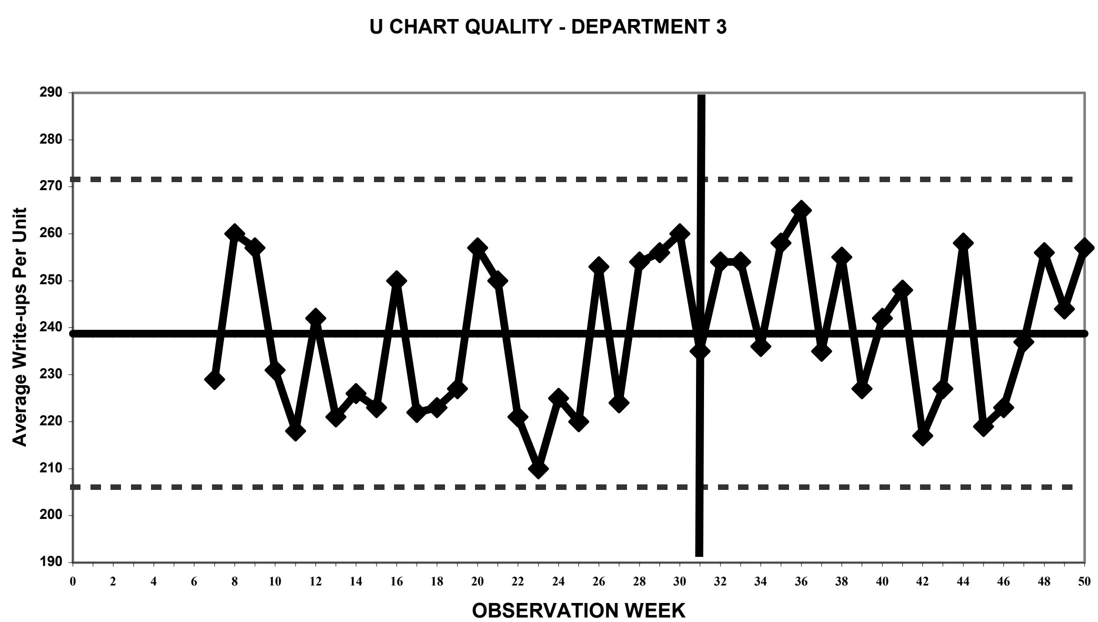
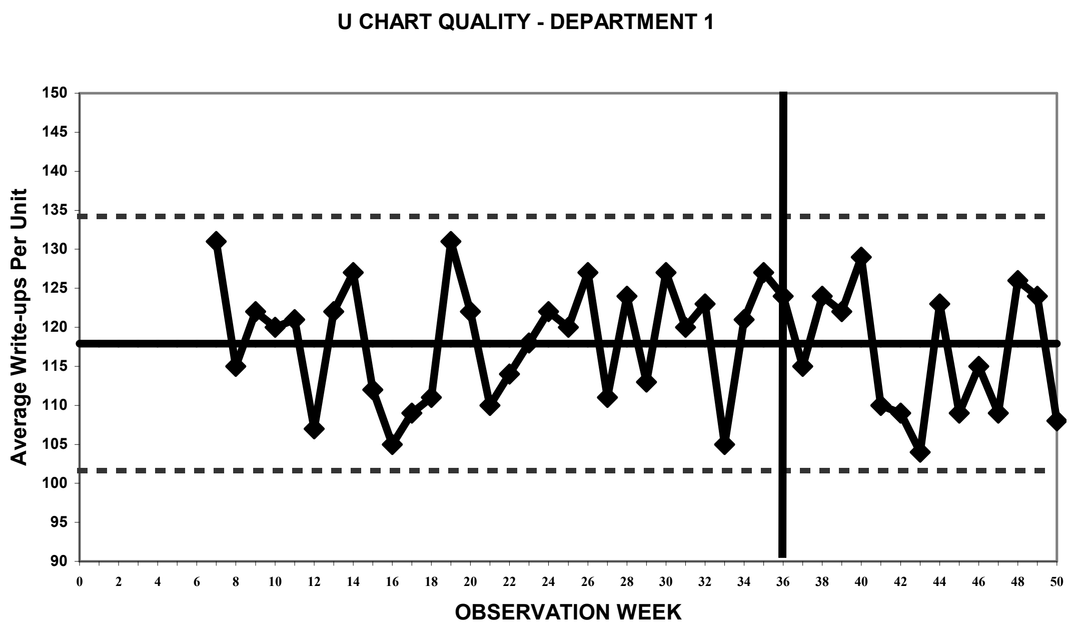


FIGURE 26. Average Number of Write-ups per Unit for Department 1 – Facility Two.



Production Productivity Data

Figures 27 – 30 show the production productivity data for each of the four groups. The average weekly productivity rate in both the baseline and intervention phase was 122.3% in Department R and 89.9% in Department TW for Facility One. The weekly average productivity rate in Facility Two also did not change between the baseline and intervention phase. In Department 3 the average weekly productivity rate was 75.3% while the average weekly productivity rate in Department 1 was 66.2%. The average weekly productivity rate remained constant throughout the study. There were no out of control cases indicating the presence of a special cause variation in any of the four groups. The moving range charts for all four groups are provided in Appendix D.

FIGURE 27. Weekly Productivity Rate for Department R – Facility One.

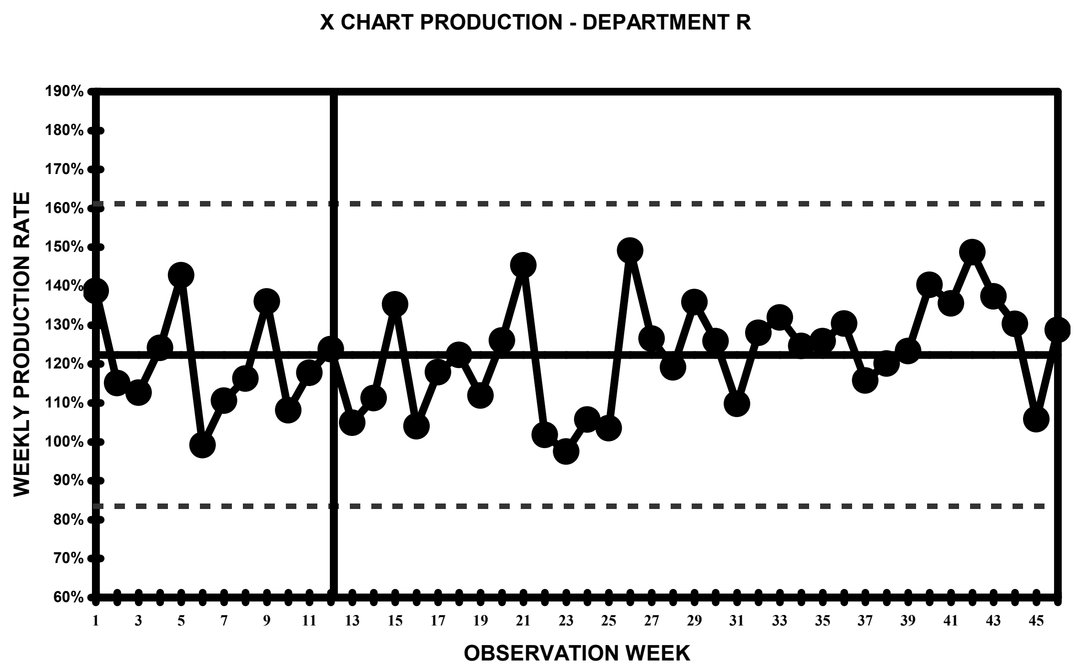


FIGURE 28. Weekly Productivity Rate for Department TW – Facility One.

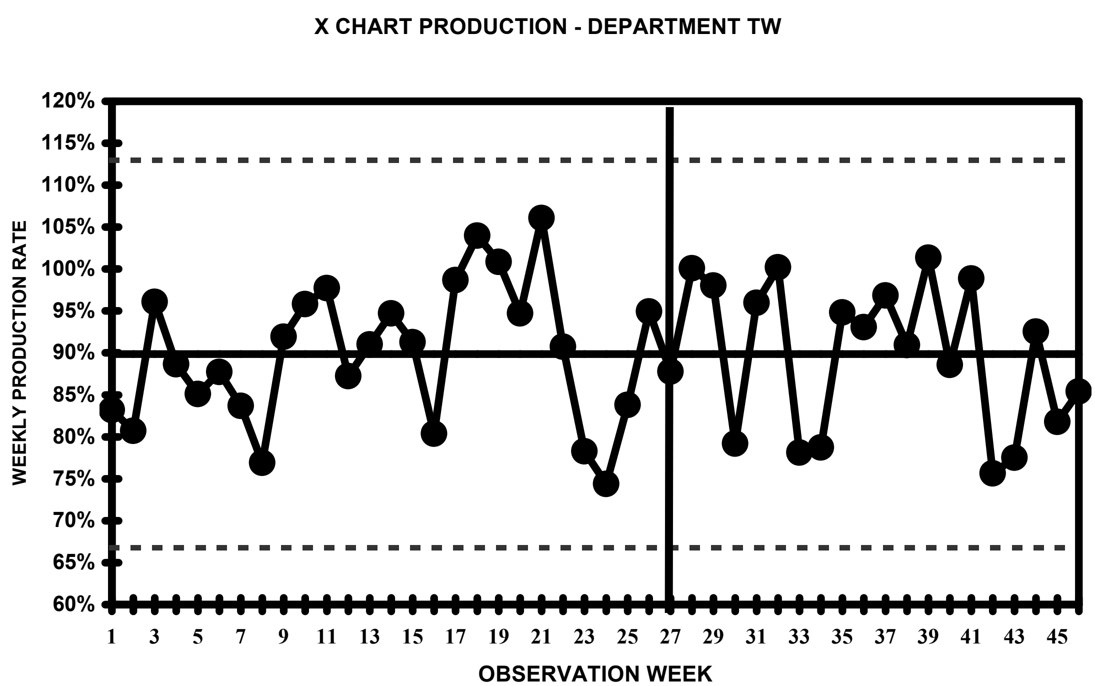


FIGURE 29. Weekly Productivity Rate for Department 3 – Facility Two.

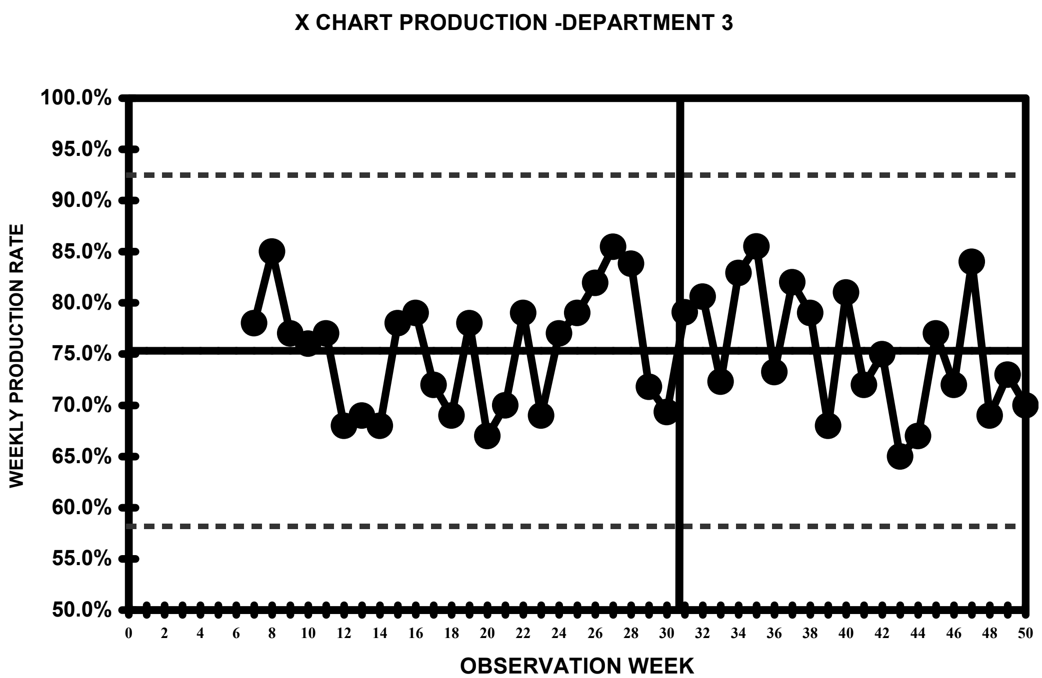
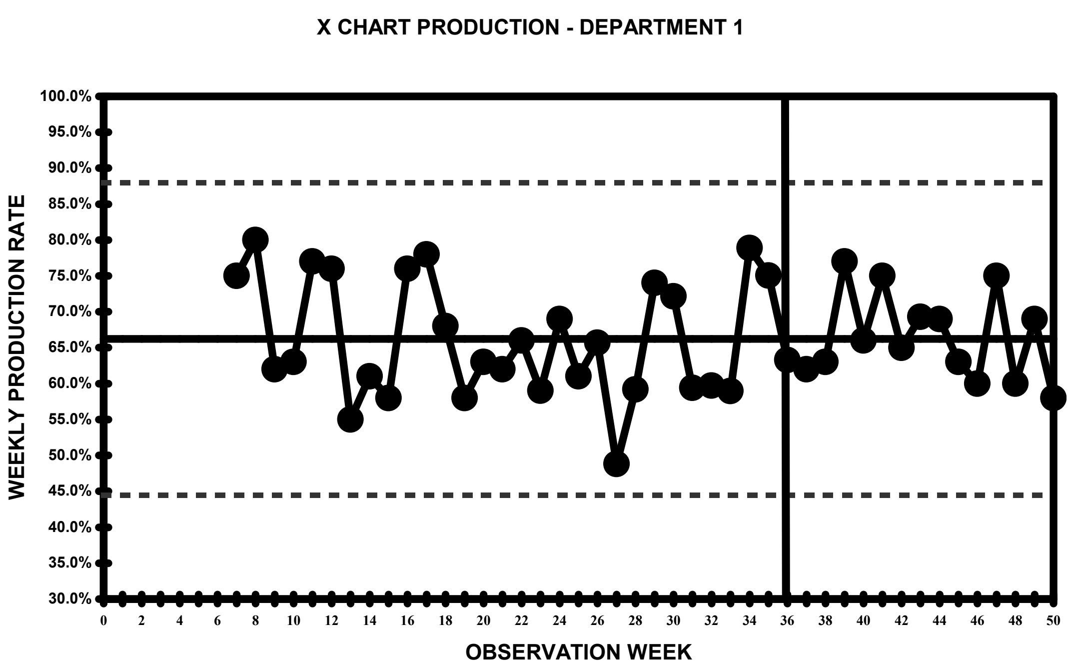


FIGURE 30. Weekly Productivity Rate for Department 1 – Facility Two.



Discussion

The results of this study reaffirm the benefits of behavior-based safety techniques on targeted behaviors. Targeted safe behaviors increased significantly and were maintained throughout the intervention phase in all four groups as shown in a number of previous research studies. This study provides another example confirming the effects of positive reinforcement in the form of feedback on targeted safe behavior performance and the use of training and participatory goal setting as intervention procedures.

The results of this study also indicate that fundamental behavior-based safety techniques used to increase the frequency of targeted safe behaviors had no significant impact on other organizational variables, in particular productivity and quality. The "observed" increase in productivity reported by other researchers was not noticeable in the present study (Komaki et al., 1978; Sulzer-Azaroff and Santamaria, 1980). The performance of both productivity and quality measures did not significantly shift after the introduction of the intervention, as did the performance of targeted safe behaviors. Examination of productivity and quality control charts show no evidence of special cause variation throughout the study. This suggests that the targeted safe behaviors and the behaviors related to production and quality activities may belong to separate conceptual classes as Austin and Wilson (2001) discussed. In other words, workers behaving safely, such as wearing proper eye protection, did not significantly increase or decrease organizational productivity or quality.

It may have been rational to expect an increase in productivity and quality based on the improved performance of specific targeted safe behaviors. For example, improvements in housekeeping may be expected to decrease worker hesitation and delays thereby increasing productivity and reducing scrap. Improved manual material handling techniques, such as improved pallet height in the packaging area of Facility One, may have resulted in less efficient body motion and movements increasing overall productivity. The results of this study, however, do not indicate this possibility of improved productivity and quality.

On the other hand, the hesitation expressed by one of the departmental supervisors that "workers don't always have the time to follow every safety rule" seems to be unfounded. The workers did have the time to work safely and even increased their frequency of safe behavior with no adverse effect on productivity or quality.

The results of this study and the corresponding increased performance of targeted safe behaviors also had an impact on incidents and injuries at the two facilities. The Total Case Incident Rate (TCIR) of "recordable" injuries for Facility One was 22.2 at the beginning of the study. At the end of the study the annualized TCIR for Facility One was cut by more than 50% to 10.6. Facility Two experienced a similar impact on incidents and injuries. Facility Two had a TCIR of 18.4 at the beginning of the study. This measure of "recordable" injuries was reduced to 12.8 for the year. Again this study involved approximately 85% of production workers while the TCIR covered the entire facility. During the study employees informally expressed a noticeable increase in general safety at the two facilities and, in particular, an increase in management involvement with safety concerns.

Conclusion

The purpose of this research was to investigate the relationship between "targeted" safe behavior variation and other organizational variables such as productivity and quality. This investigation included the systematic application of the fundamental behavior-based safety techniques of pinpointing critical behaviors, developing precise definitions, collecting and measuring observational data using an observational checklist, and implementation of training, participatory goal setting, and both graphical and verbal feedback as an intervention package to increase target safe behaviors and examine the resulting affect on productivity and quality measures. The results reaffirm the effectiveness of these fundamental techniques on improving targeted safe behaviors. This study also provides an elementary observation into the relationship between targeted safe behaviors and productivity and quality. The results of this research seem to indicate that increases in safe behavior do not readily translate to increases in productivity and quality. Perhaps more importantly, however this study suggests that increases in safe behavior, as initiated by fundamental behavior-based safety techniques, have no adverse effect on productivity and quality.

This research only measured a few worker safe behaviors and did not examine the effects of other safety controls such as changes in workstations and tools. As stated earlier, there are many practical examples of safety improvements that increase productivity and quality. This study did provide evidence that increases in safe behavior improve workplace safety resulting in lower accident and injury rates. Therefore, the conclusion may be drawn that over a longer period of time the cost savings from accident and injury prevention caused by this increase in worker safe behavior would be an overall benefit to the organization.

CONCLUSIONS

Summary of Findings

There exists a relatively new but growing body of knowledge concerning the effects of behavior-based safety techniques. Although the founding principles of behavior-based safety techniques are not recent, their organized application to occupational safety and health is particularly contemporary. It is important to review the results of this study and examine its relationship within the existing research. It was the author's intention to enhance the basic understanding of behavior-based safety within an organization and to provide findings that could be used to solve problems currently experienced by manufacturing facilities. This is an important area of research not solely based on the economic costs of workplace injuries but also the moral and humanitarian costs to society.

The present study looked at specific variables in an attempt to understand what happens within a manufacturing organization when the fundamental techniques of behavior-based safety are implemented over a staggered time period. In particular, the fundamental behavior-based safety techniques used during this study were pinpointing critical behaviors, developing precise definitions, collecting and measuring observational data using an observational checklist, and implementing training, participatory goal setting, and both graphical and verbal feedback. This research investigated the relationship between target safe behavior variation and other non-target safe behaviors.

This research also examined the association between target safe behavior variation and productivity and quality measures.

One major outcome of this study is the reaffirmation of the benefits of behavior-based safety techniques on targeted safe behaviors. Targeted safe behaviors increased substantially and were maintained in all four experimental groups throughout the duration of the study. It is practically important to demonstrate the generality and functionality of behavior-based safety techniques as a successful approach to improving workplace safety.

Another major finding of this study is the relationship between targeted safe behavior variation and other non-targeted safe behaviors. Previous research has explored the relationship between target and non-target behaviors in a non-manufacturing environment and between one or two behaviors only. The results of the present study indicate a concurrent impact on safe behaviors. The performance of non-target safe behaviors increased even though they were not specifically included as part of the behavior-based safety intervention package. This indicates, as many previous researchers have suggested, that the benefits of implementing behavior-based safety techniques expand beyond the bounds of the targeted safe behaviors and provide positive side effects.

This study also examined the effects of behavior-based safety techniques on other organizational variables such as productivity and quality. As with non-targeted behaviors, many previous researchers "observed" increases in productivity. The present study compares measures of productivity and quality as targeted safe behaviors increased as a result of implementation of behavior-based safety techniques. The elementary findings of this study show that increases in targeted safe behaviors do not readily translate to increases in these other organizational measures. Expressing this finding in a slightly different manner suggests that increases in targeted safe behavior, as initiated by fundamental behavior-based safety techniques, have no apparent adverse effect on productivity and quality. The manufacturing organization would realize an overall benefit considering the cost savings associated with accident and injury prevention resulting from increased safe behavior.

A supplementary exertion of this study is the appropriateness of statistical process control techniques and the behavior-based safety process. Statistical process control techniques such as control charts provide an opportunity for continuous improvement of a process. This study demonstrates the usefulness of control charts as a way to identify and analyze the behavior-based safety process. In addition, statistical process control techniques provide an opportunity to document, communicate, involve employees, and publicize successful behavior-based safety programs and techniques. Statistical process control techniques provide an analytical tool for management decision-making concerning the behavior-based safety process.

Limitations of study

It is just as appropriate to discuss the limitations of a research study, as it is to discuss the findings. This study has several limitations. First, this study was conducted in an industrial setting and as a result experimental control was not precise. As in many studies conducted in real-world manufacturing facilities confounding variables may have had an impact on the data. The use of multiple-baseline design minimized but in no way completely eliminated this impact. Another limitation of this study was the examination of aggregate versus individual data. Behavioral, productivity, and quality data were collected and analyzed as composite data and as a result detailed information was not captured during the study. For example, group productivity measures were used in this study as opposed to individual productivity behavior data. Collecting and examining individual behaviors related to productivity may have resulted in more detailed or precise findings. Finally, the limitations of time may have had an impact on the findings of this study. The long-term effects of behavior-based safety techniques, beyond the 50-week period of this study, may be quite different. In brief, the findings of this study must be examined with these limitations in mind.

Recommendations for future research

There are many methods and variations of behavior-based safety programs and as a result behavior-based safety means different things to different people. Future research showing the repeatability of the fundamental behavior-based safety techniques is necessary to minimize confusion and misrepresentation. Further research should examine the individual relationship between safe behaviors and productivity and quality-related behaviors. The present study investigated the relationship between changes in safe behavior and productivity and quality. It would be interesting to examine the reverse, does a change in productivity-related behaviors have an impact on safe behaviors. Additional studies identifying and explaining the conceptual classes of target and non-target behaviors may provide insight into economical intervention methods.

Finally, further demonstration studies are necessary to illustrate the potential benefits of incorporating statistical process control techniques and behavior-based safety programs.

REFERENCES

Austin, J. and Wilson, K.G., (2001). Response-Response Relationships in Organizational Behavior Management. *Journal of Organizational Behavior Management*, 21, 39-53

Austin, J., Kessler, M.L., Riccobono, J.E., and Bailey, J.S., (1996). Using Feedback and Reinforcement to Improve the Performance and Safety of a Roofing Crew. *Journal of Organizational Behavior Management*, 16, 49-66

Brauer, R.L., (2006). *Safety and Health for Engineers* (2^{nd} ed.). John Wiley & Sons, Inc., New York

Cooper, M.D., Phillips, R.A., Sutherland, V.J., and Makin, P.J., (1994). Reducing Accidents using Goal Setting and Feedback: A field Study. *Journal of Occupational and Organizational Psychology*, 67, 219-240

Daniels, A.C., (1989). *Performance Management*. Performance Management Publications, Tucker, Georgia

DeJoy, D.M., (2005). Behavior change versus culture change: Divergent approaches to managing workplace safety. *Safety Science*, 43, 105-129

Deming, W.E., (1986). *Out of the Crisis*. Massachusetts Institute of Technology, Center for Advanced Engineering Study, Cambridge, Massachusetts

Eikenhout, N., and Austin, J., (2005). Using Goals, Feedback, Reinforcement, and a Performance Matrix to Improve Customer Service in a Large Department Store. *Journal of Organizational Behavior Management*, 24, 27-62

Fitch, H.G., Hermann, J., and Hopkins, B.L., (1976). Safe and unsafe behavior and its modification. *Journal of Occupational Medicine*, 18, 618-622

Fox, D.K., Hopkins, B.L., and Anger, W.K., (1987). The long-term Effects of a Token Economy on Safety Performance in Open-pit Mining. *Journal of Applied Behavior Analysis*, 20, 215-224

Geller, E.S., (2001). *The Psychology of Safety Handbook*. Lewis Publishers, New York

Geller, E.S., Rudd, J.R., Kalsher, M.J., Streff, F.M., and Lehman, G.R., (1987). Employer-based Programs to Motivate Safety Belt Use: A Review of Short-term and Long-term Effects. *Journal of Safety Research*, 18, 1-17

Glendon, A.I. and Litherland, D.K., (2001). Safety climate factors, group differences and safety behaviour in road construction. *Safety Science*, 39, 157-188

Grindle, A.C., Dickinson, A.M., and Boettcher, W., (2000). Behavioral Safety Research in Manufacturing Settings: A Review of the Literature. *Journal of Organizational Behavior Management*, 20, 29-68

Heinrich, H.W., (1931). *Industrial Accident Prevention*. McGraw-Hill, Inc., New York

Heinrich, H.W., Petersen, D., and Roos, N.R., (1980). *Industrial Accident Prevention: A Safety Management Approach*. McGraw-Hill, Inc., New York

Hopkins, A, (2006). What are we to make of safe behaviour programs? *Safety Science*, 44, 583-597

Hopkins, B.L., Conrad, R.J., Dangel, R.F., Fitch, H.G., Smith, M.J., and Anger, W.K., (1986). Behavioral Technology for Reducing Occupational Exposures to Styrene. *Journal of Applied Behavior Analysis*, 19, 3-11

Houchins, N., and Boyce, T.E., (2001). Response Generalization in Behavioral Safety: Fact or Fiction? *Journal of Organizational Behavior Management*, 21(4), 3-11

Ishikawa, K., (1976). *Guide to Quality Control*. Productivity Press, Tokyo

Komaki, J., Barwick, K.D., and Scott, L.R., (1978). A Behavioral Approach to Occupational Safety: Pinpointing and Reinforcing Safe Performance in a Food Manufacturing Plant. *Journal of Applied Psychology*, 63, 434-445

Komaki, J., Heinzmann, A.T., and Lawson, L., (1980). Effect of Training and Feedback: Component Analysis of a Behavioral Safety Program. *Journal of Applied Psychology*, 65, 261-270

Krause, T.R., (1997). *The Behavior-Based Safety Process: Managing Involvement for an Injury-Free Culture* (2nd ed.). John Wiley & Sons, Inc., New York

Krause, T.R., (2002). Cross-Functional Improvement: Behavior-based safety as a tool for organizational success. *Professional Safety*, 47(8), 27-33

Krause, T.R., Seymour, K.J., and Sloat, K.C.M., (1999). Long-Term Evaluation of a Behavior-Based Method for Improving Safety Performance: A Meta-Analysis of 73 Interrupted Time-Series Replications. *Safety Science*, 32, 1-18

Laitinen, H. and Ruohomaki, I., (1996). The Effects of Feedback and Goal Setting on Safety Performance at Two Construction Sites. *Safety Science*, 24, 61-73

Laitinen, H., Marjamaki, M., and Paivarinta, K., (1999). The Validity of the TR Safety Observation Method on Building Construction. *Accident Analysis and Prevention*, 31, 463-472

Locke, E.A. and Latham, G.P., (1990). *A Theory of Goal Setting and Task Performance*. Prentice-Hall, Inc., New Jersey

Ludwig, T.D., and Geller, E.S., (1997). Assigned Versus Participative Goal Setting and Response Generalization: Managing Injury Control Among Professional Pizza Deliverers. *Journal of Applied Psychology*, 82, 253-261

Ludwig, T.D., and Geller, E.S., (1999). Behavior Change Among Agents of a Community Safety Program: Pizza Deliverers Advocate Community Safety Belt Use. *Journal of Organizational Behavior Management*, 19, 3-24

McAfee, R.B. and Winn, A.R., (1989). The Use of Incentives/Feedback to Enhance Work Place Safety: A Critique of the Literature. *Journal of Safety Research*, 20, 7-19

Montgomery, D.C. and Runger, G.C., (1994). *Applied Statistics and Probability for Engineers*. John Wiley & Sons, Inc., New York

National Safety Council, (2004). *Injury Facts.*

Petersen, D., (1988). *Safety Management: A Human Approach* (2nd ed.). Aloray, Inc., New York

Petersen, D., (2005). *Measurement of Safety Performance*. American Society of Safety Engineers, Des Plaines, Illinois

Prevette, S.S., (2006). Charting Safety Performance: Combining Statistical Tools Provides Quality Data. *Professional Safety*, 51, 34-41

Ramsey, J.D., Burford, C.L., Beshir, M.Y, and Jensen, R.C. (1983). Effects of Workplace Thermal Conditions On Safe Behavior. *Journal of Safety Research*, 14, 105-114

Ray, P.S., Bishop, P.A., and Wang, M.Q. (1997). Efficacy of the components of a behavioral safety program. *International Journal of Industrial Ergonomics*, 19, 19-29

Reber, R.A., Wallin, J.A., and Chhokar, J.S., (1990). Improving Safety Performance With Goal Setting and Feedback. *Human Performance*, 3, 51-61

Robson, L.S., Shannon, H.S., Goldenhar, L.M., and Hale, A.R., (2001). *Guide to Evaluating the Effectiveness of Strategies for Preventing Work Injuries*. National Institute for Occupational Safety and Health

Sarkus, D.J., (1997). Collaboration & Participation: How Are You Doing? *Professional Safety*, 42(10), 37-39

Shewhart, W.A., (1931). *Economic Control of Quality of a Manufactured Product*. D. Van Nostrand Company, New York

Skinner, B.F., (1938). *The Behavior of Organisms; An Experimental Analysis*. Appleton-Century Company, New York

Stapenhurst, T., (2005). *Mastering Statistical Process Control: A Handbook for Performance Improvement Using Cases*. Elsevier Butterworth-Heinemann, Oxford

Streff, F.M., Kalsher, M.J., and Geller, E.S., (1993). Developing Efficient Workplace Safety Programs: Observations of Response Covariation. *Journal of Organizational Behavior Management*, 13, 3-14

Sulzer-Azaroff, B. and Austin, J., (2000). Does BBS Work? Behavior-Based Safety & Injury Reduction: A Survey of the Evidence. *Professional Safety*, 45, 19-24

Sulzer-Azaroff, B. and Santamaria De, M.C., (1980). Industrial Safety Hazard Reduction Through Performance Feedback. *Journal of Applied Behavior Analysis*, 13, 287-295

Wheeler, D., (1999). *Understanding Variation: The Key to Managing Chaos*. Statistical Process Controls, Inc., Knoxville, TN

Williams, J.H. and Geller, S.E., (2000). Behavior-Based Intervention for Occupational Safety Critical Impact of Social Comparison Feedback. *Journal of Safety Research*, 31, 135-142

Zohar, D. (1980). Promoting the use of personal protective equipment by behavior modification techniques. *Journal of Safety Research*, 12, 78-85

Zohar, D. and Luria, G., (2003). The use of supervisory practices as leverage to improve safety behavior: A cross-level intervention model. *Journal of Safety Research*, 34, 567-577

APPENDIX A

DEFINITION OF CRITICAL TARGET BEHAVIORS

Facility One: Department R

1. Eye Protection:

All employees wearing approved safety glasses with approved sideshields. Safety glasses are fitted on bridge of nose close to eyes but not touching eyelashes. Sideshields fitted flush to frame of glasses. Safety glasses are clean and free of scratches.

2. Hearing Protection:

Approved hearing protection worn by employees operating the mill and/or working for more than 15 minutes in the Mill/Teflon Area. Approved hearing protection worn by employees operating saws and/or working for more than 15 minutes within 10 feet of operating saw. Insert protectors worn so that they cover the entire ear canal or earmuffs worn so that they cover the entire outer ear.

3. Box Cutter and Knife Use:

Box Cutters and other sharp tools are closed when not in use. When using box cutters and other sharp tools the operator has a stable stance to the side of the object being cut with nothing else in their hands. The non-dominant hand is clear of the path of the blade. The blade is pulled back in a smooth cutting motion not pushed forward. All other personnel are clear of the blade path as well.

4. Lifting – Proper Lifting:

During lifting task the torso is not bent more than 10 degrees and the load is held as close to the torso as possible. The elbows and upper arms are close to the torso and the wrist is not bent. Employees do not twist the torso. They move feet to avoid twisting. During lifting task reaching is limited to shoulder to knee height vertically and 16 inches horizontally. Employees do not reach over pallet/cart they walk around to avoid reaching.

5. General Housekeeping – Aisle Debris:

All yellow-marked aisles are clear of debris larger than 2 square inches in area.

6. General Housekeeping – Protruding Objects:

All yellow-marked aisles are clear of protruding objects longer than 2 inches.

7. Rack Area – Housekeeping:

No more than 2 pieces of debris, 2 square inches or larger, on floor per aisle.

8. Teflon Area – Housekeeping:

The drip bucket is place directly under the drip edge and there are no wet areas on the floor.

9. Saw Area – Hands Clear:

All machine guards are in place. Saw is properly Locked Out during blade change. The operator's non-dominant hand is at least 2 inches from operating blade.

10. Packing Area – Bulk Pack Lift:

All finished Bulk Packs are lifted by at least two personnel.

11. Packing Area – Pallet Height:

Packing pallets are stacked a minimum of 3 high and a maximum of 6 high.

12. Packing Area – Housekeeping:

No more than 4 pieces of debris 2 square inches or larger on floor in working/walking area.

Facility One: Department TW

1. Eye Protection:

All employees wearing approved safety glasses with approved sideshields. Safety glasses are fitted on bridge of nose close to eyes but not touching eyelashes. Sideshields fitted flush to frame of glasses. Safety glasses are clean and free of scratches.

2. Lifting – Proper Lifting:

During lifting task the torso is not bent more than 10 degrees and the load is held as close to the torso as possible. The elbows and upper arms are close to the torso and the wrist is not bent. Employees do not twist the torso. They move feet to avoid twisting. During lifting task reaching is limited to shoulder to knee height vertically and 16 inches horizontally. Employees do not reach over pallet/cart they walk around to avoid reaching.

3. Lifting – Remove Cart Bars:

When lifting material from cart, support bars are removed from the side of the cart to prevent lifting material over the bars. Support bars are not removed if the material will shift or fall without the bars.

4. General Housekeeping – Aisle Debris:

All yellow-marked aisles are clear of debris larger than 2 square inches in area.

5. General Housekeeping – Protruding Objects:

All yellow-marked aisles are clear of protruding objects longer than 2 inches.

6. Rack Area – Housekeeping:

No more than 2 pieces of debris, 2 square inches or larger, on floor per aisle.

7. Saw Area – Hands Clear:

All machine guards are in place. Saw is properly Locked Out during blade change. The operator's non-dominant hand is at least 2 inches from operating blade.

8. Gasket Area – Housekeeping:

No more than 2 pieces of debris, 2 inches long or larger, on floor in working/walking area.

9. Packing Area – Pallet Height:

Packing pallets are stacked a minimum of 3 high and a maximum of 6 high.

Facility Two: Department 1 and Department 3

1. Eye Protection:

All employees wearing approved safety glasses with approved sideshields. Safety glasses are fitted on bridge of nose close to eyes but not touching eyelashes. Sideshields fitted flush to frame of glasses. Safety glasses are clean and free of scratches.

2. Face Protection:

Approved face shield, in addition to eye protection, worn by employees operating grinders. The face shield is worn so that it covers the entire face. The face shield is clean and free of scratches.

3. Lifting – Proper Lifting:

During lifting task the torso is not bent more than 10 degrees and the load is held as close to the torso as possible. The elbows and upper arms are close to the torso and the wrist is not bent. Employees do not twist the torso. They move feet to avoid twisting. During lifting task reaching is limited to shoulder to knee height vertically and 16 inches horizontally. Employees do not reach over pallet/cart they walk around to avoid reaching.

4. General Housekeeping – Aisle Debris:

All marked aisles are clear of debris larger than 2 square inches in area.

5. General Housekeeping – Spills:

There are no oils spills or wet areas in the aisles or in work areas.

6. Ladder and Step Stool:

No ladder or step stool has grease on the rungs or steps in excess of 1 square inch. Employees ascend and descend facing the ladder or stool. No employee uses the top step or rung. The ladder is properly placed to prevent slipping or tilting. Stepladders are fully extended when used. Ladders used to gain access to the roof of the bus shall extend at least 3 feet above the point of support.

7. Jack Stands:

There are no employees under a bus without a minimum of 4 (or 6 with extension bus) jack stands properly positioned.

8. Portable Power Tool and Drilling Operations:

Employee has a stable stance when using portable power tools. The operator's non-dominant hand is at least 2 inches from tool's operating end. All other personnel are clear of operating area. Portable power tool is used only for the designed purpose. For example, an electric drill is not used as a hammer. All portable power tools are connected to approved GFCI outlets or approved (yellow) GFCI extension cords. Portable power tools are properly stored when not in use either on workbench or toolbox, not on floor.

APPENDIX B

DEFINITION OF CRITICAL NON-TARGET BEHAVIORS

Facility One: Department R

1. Hand Protection:

Approved gloves worn by all employees handling stock/product except employees operating the packaging machine, employees working at bearing and setscrew installation operations, and employees working at bagging operations. Gloves fit tightly with no access room at tip of fingers. Gloves are clean of excessive contaminants and dangling threads.

2. Compressed Air Use:

When using compressed air for cleaning, air is directed away from other personnel and in the same direction as airflow from fans. When using compressed air for cleaning machinery the operator's hands do not enter the danger area of the machine. Mobile Fans are located so that the airflow does not travel through the machine toward the operator.

3. Rack Area – Material Storage:

Materials in rack storage are supported by a minimum of two support arms. Materials in rack storage do not extend beyond edge of rack toward aisle. There are no pieces of packaging larger than 1 square foot, no wood or banding dangling from rack material.

4. Rack Area – Forklift:

A daily forklift inspection card has been completed by the operator and properly filed prior to operating the forklift. When forklift is not in use the forks are down and the parking brake set. When the forklift is in operation the load is carried as low as possible. The operator sounds the horn at all intersections and travels in reverse when the load is blocking forward view.

5. Mill Area – Hands Clear:

The operator's hands are clear of machine operating points during clamping and operation in Cell 1. The operator's hands are clear of machine operating points during operation and hands are between clamps and on the outside during clamping in Cell 2 and Cell 3.

6. Mill Area – Housekeeping:

No more than 1 square foot of debris in walking aisle near mill.

7. Saw Area – Housekeeping:

No more than 1 large end, longer than 1 inch in length, on floor in working and walking area.

8. CounterSink Area – Hands Clear:

The operator's non-dominant hand is at least 2 inches from the operating drill.

9. CounterSink Area – Housekeeping:

No more than 1 square foot (area) of swirls on floor in working/walking area.

10. Cover/Bearing Area – Housekeeping:

No more than 5 bearings on floor in working/walking area.

11. Packing Area – Glue Gun:

The glue gun is properly place in storage rack when not in use.

12. Packing Area – Stapling:

The operator's non-dominant hand is at least 2 inches from operating end of Staple Gun. Operator walks around pallet to staple. The operator does not reach across pallet when stapling.

Facility One: Department TW

1. Hearing Protection:

Approved hearing protection worn by employees operating the mill and/or working for more than 15 minutes in the Mill/Teflon Area. Approved hearing protection worn by employees operating saws and/or working for more than 15 minutes within 10 feet of operating saw. Insert protectors worn so that they cover the entire ear canal or earmuffs worn so that they cover the entire outer ear.

2. Hand Protection:

Approved gloves worn by all employees handling stock/product except employees operating the packaging machine, employees working at bearing and setscrew installation operations, and employees working at bagging operations. Gloves fit tightly with no access room at tip of fingers. Gloves are clean of excessive contaminants and dangling threads.

3. Compressed Air Use:

When using compressed air for cleaning, air is directed away from other personnel and in the same direction as airflow from fans. When using compressed air for cleaning machinery the operator's hands do not enter the danger area of the machine. Mobile Fans are located so that the airflow does not travel through the machine toward the operator.

4. Box Cutter and Knife Use:

Box Cutters and other sharp tools are closed when not in use. When using box cutters and other sharp tools the operator has a stable stance to the side of the object being cut with nothing else in their hands. The non-dominant hand is clear of the path of the blade. The blade is pulled back in a smooth cutting motion not pushed forward. All other personnel are clear of the blade path as well.

5. Rack Area – Material Storage:

Materials in rack storage are supported by a minimum of two support arms. Materials in rack storage do not extend beyond edge of rack toward aisle. There are no pieces of packaging larger than 1 square foot, no wood or banding dangling from rack material.

6. Rack Area – Forklift:

A daily forklift inspection card has been completed by the operator and properly filed prior to operating the forklift. When forklift is not in use the forks are down and the parking brake set. When the forklift is in operation the load is carried as low as possible. The operator sounds the horn at all intersections and travels in reverse when the load is blocking forward view.

7. Punch Area – Hands Clear:

The operator's hands are clear of machine operating points during clamping and operation.

8. Saw Area – Housekeeping:

No more than 1 large end, longer than 1 inch in length, on floor in working/walking area.

9. Gasket Area – Working on Table Edge:

Employees place and work on material within 8 inches of table edge to avoid reaching and bending torso.

10. Packing Area – Housekeeping:

No more than 4 pieces of debris 2 square inches or larger on floor in working/walking area.

Facility Two: Department 1 and Department 3

1. Welding PPE:

In addition to approved tinted eye protection, all employees wear appropriate welding helmets with proper tinting during welding operations. Approved gloves, arm protection and apron are also worn during welding operations. Gas cylinders in use are placed on approved welding carts. All gas cylinders are properly secured with valve covered.

2. Compressed Air Use:

When using compressed air for cleaning, air is directed away from other personnel and in the same direction as airflow from fans. All compressed air nozzles are approved (yellow) nozzles.

3. Box Cutter and Knife Use:

Box Cutters and other sharp tools are closed when not in use. When using box cutters and other sharp tools the operator has a stable stance to the side of the object being cut with nothing else in their hands. The non-dominant hand is clear of the path of the blade. The blade is pulled back in a smooth cutting motion not pushed forward. All other personnel are clear of the blade path as well.

4. General Housekeeping – Protruding Objects:

All marked aisles are clear of protruding objects longer than 2 inches.

5. General Housekeeping – Work Area:

There are no large pieces of debris on the floor in working/walking areas larger than 6 square inches such as cardboard or pallets.

6. Horseplay/Smoking:

No employees are smoking in work area. Smoking is allowed only in the designated break areas. No horseplay or similar behavior such as running, pushing or throwing objects in work area.

7. Forklift:

When forklift or other material-handling vehicle is not in use the forks are down and the parking brake set. When the forklift is in operation the load is carried as low as possible. The operator sounds the horn at all intersections and travels in reverse when the load is blocking forward view.

8. Open Containers:

No unused containers of liquid material left open.

9. Hand Tool Operations:

Employee has a stable stance when using hand tools. The operator's non-dominant hand is at least 2 inches from tool's operating end. Hand tool is used only for the designed purpose. For example, a screwdriver is not used for prying or as a chisel. Hand tools are properly stored when not in use either on workbench or toolbox, not on floor.

10. Rolling the Line:

A minimum of 4 employees is used to push bus to next workstation.

APPENDIX C

CRITICAL BEHAVIOR CHECKLISTS

Facility One: Department R

Date: ___________ Day of Week:________________ Observer:____________________________
Department: **R**

Start Time: _____________________ Finish Time:______________________

Items	Safe	Safe Total	At-Risk	At-Risk Total	Total
PPE					
Eye Protection					
Hearing Protection					
Hand Protection					
TOOL USE					
Compressed Air					
Box Cutters					
LIFTING					
Proper Lifting					
HOUSEKEEPING					
Debris in aisles					
Protruding object-aisles					
RACK AREA					
Material Storage					
Forklift					
Housekeeping					
MILL AREA					
Hands Clear					
Housekeeping					

TEFLON AREA					
Housekeeping					
SAW AREA					
Hands Clear					
Housekeeping					
CounterSink Area					
Hands Clear					
Housekeeping					
Cover/Bearing AREA					
Housekeeping					
PACKING AREA					
Glue Gun Storage					
Hands Clear - Stapling					
Team Lift Bulk Pack					
Proper Pallet Height					
Housekeeping					
	SAFE TOTAL		**AT-RISK TOTAL**		

NOTES:

Facility One: Department TW

Date:_____________ Day of Week:___________________ Observer:__________________________
Department: **TW**

Start Time: ____________________ Finish Time: ___________________

Item	Safe	Safe Total	At-Risk	At-Risk Total	Total
PPE					
Eye Protection					
Hand Protection					
TOOL USE					
Compressed Air					
Box Cutters					

LIFTING					
Proper Lifting					
Remove Cart Bars					
HOUSEKEEPING					
Debris in aisles					
Protruding objects					
RACK AREA					
Material Storage					
Forklift					
Housekeeping					
SAW AREA					
Hearing Protection					
Hands Clear					
Housekeeping					
PUNCH AREA					
Hands Clear					
GASKET AREA					
Working Stock on Table Edge					
Housekeeping					
PACKING AREA					
Proper Pallet Height					
Housekeeping					
	SAFE TOTAL		**AT-RISK TOTAL**		

Notes:

Facility Two: Department 1 and 3

Date:_____________ Day of Week:_______________ Observer:___________________________ Depart No.: ___

Start Time: ____________________ Finish Time: __________________

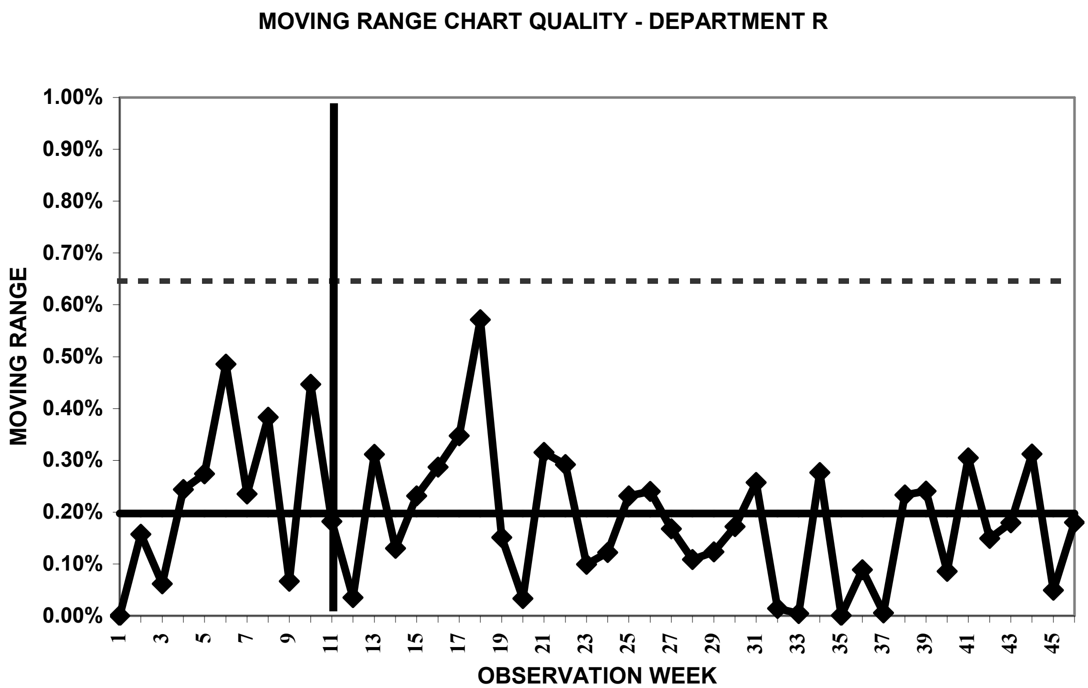
Item	Safe	Safe Total	At-Risk	At-Risk Total	Total
PPE					

Eye Protection					
Face Protection					
Welding PPE					
Horseplay/Smoking					
TOOL & EQUIPMENT USE					
Compressed Air					
Box Cutters					
Hand Tools					
Portable Power Tools					
Jack Stands					
Ladder & Step Stool					
Forklift					
LIFTING					
Proper Lifting					
Rolling Line					
HOUSEKEEPING					
Debris in aisles					
Protruding objects					
Spills					
Work Area					
Open Containers					
	SAFE TOTAL		**AT-RISK TOTAL**		

Notes:

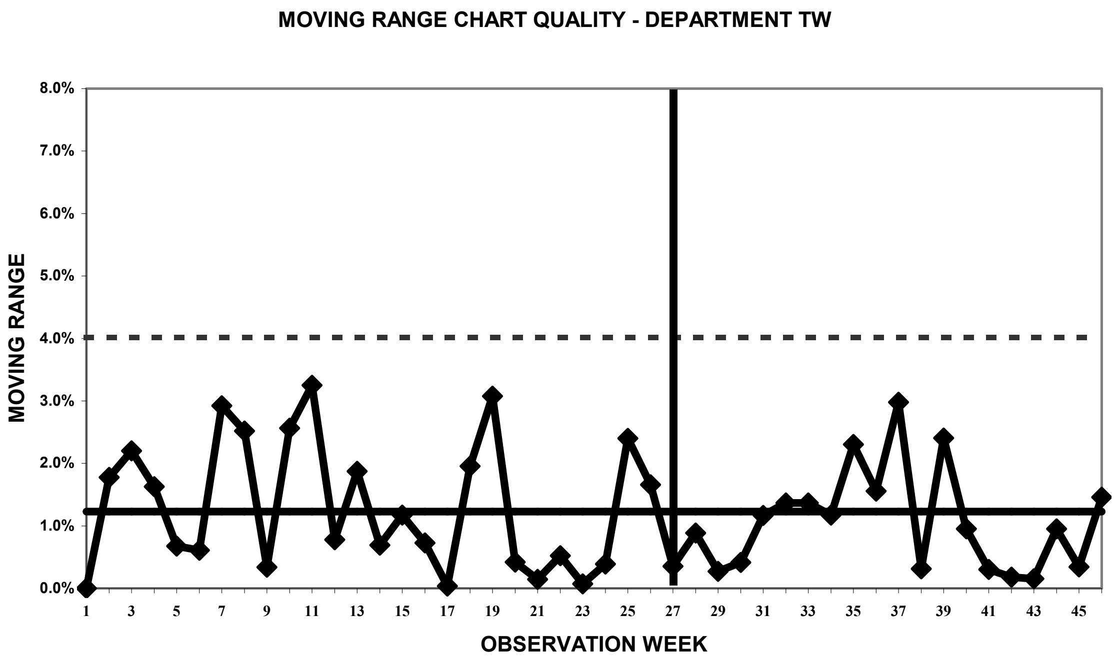
APPENDIX D

MOVING RANGE CHARTS

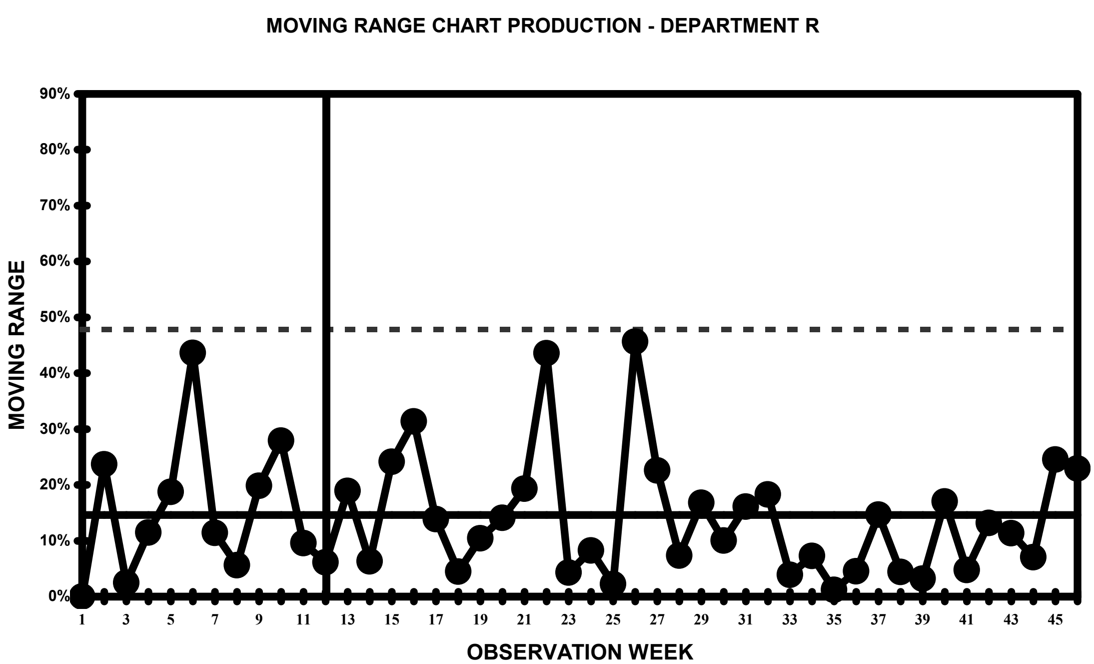


Moving Range (Lost Material Rate) for Department R – Facility One.

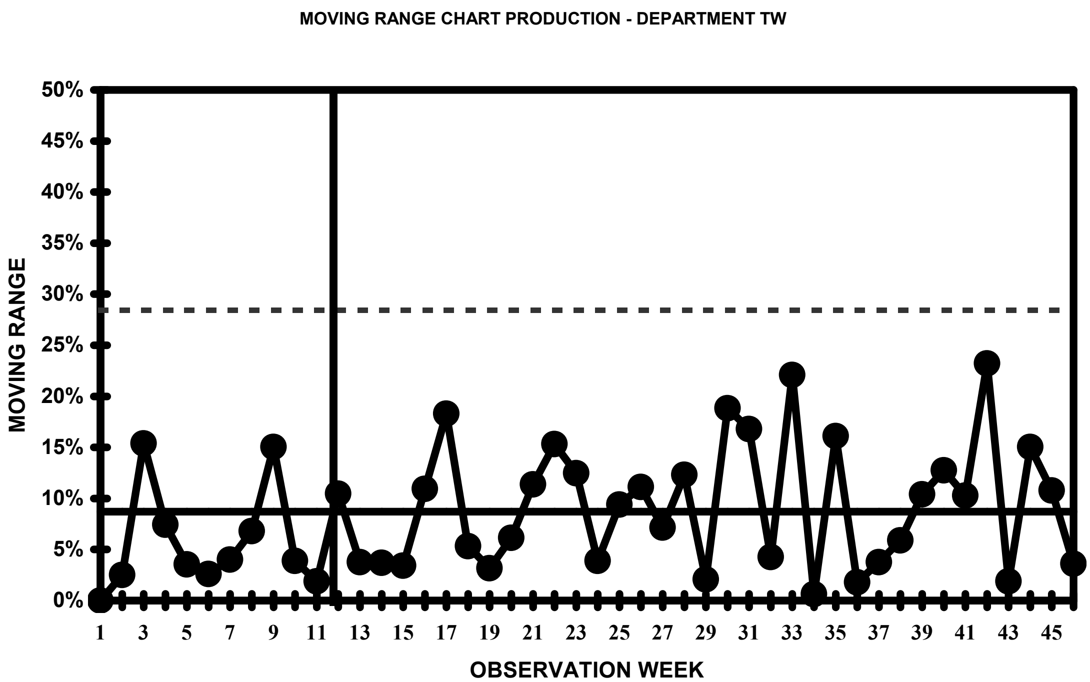
Moving Range (Lost Material Rate) for Department TW – Facility One.



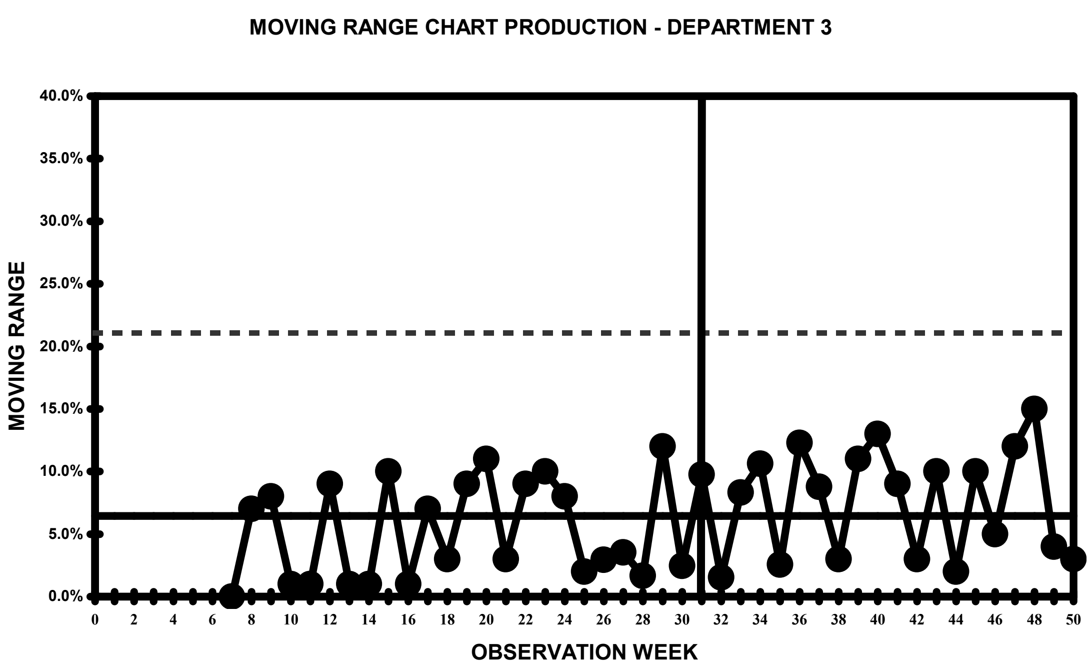
Moving Range (Productivity Rate) for Department R – Facility One.



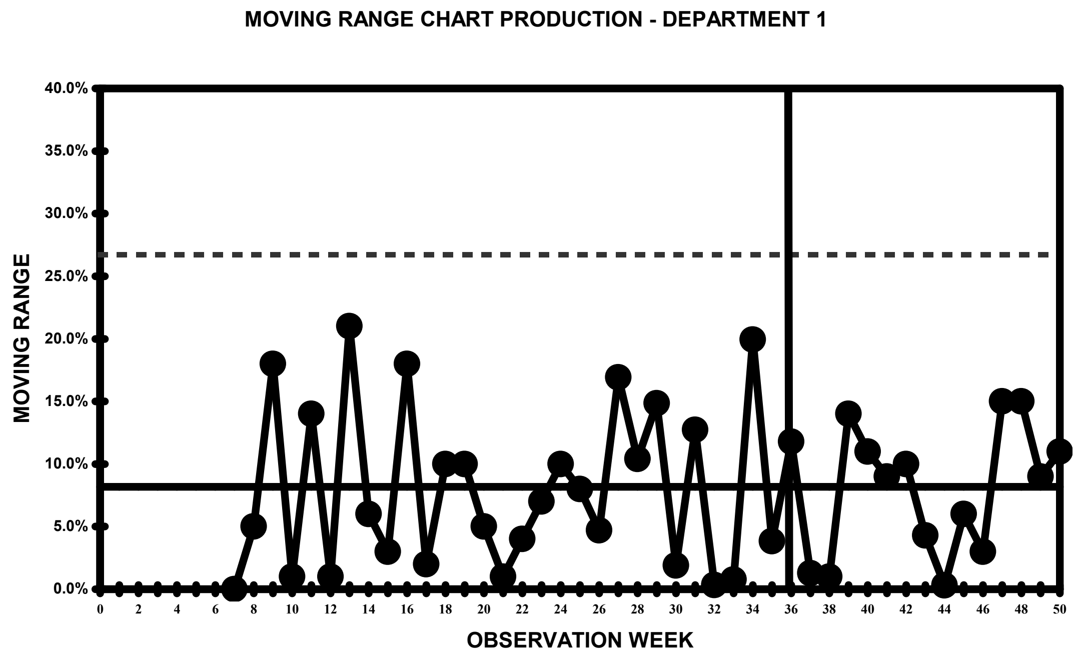
Moving Range (Productivity Rate) for Department TW – Facility One.



Moving Range (Productivity Rate) for Department 3 – Facility Two.



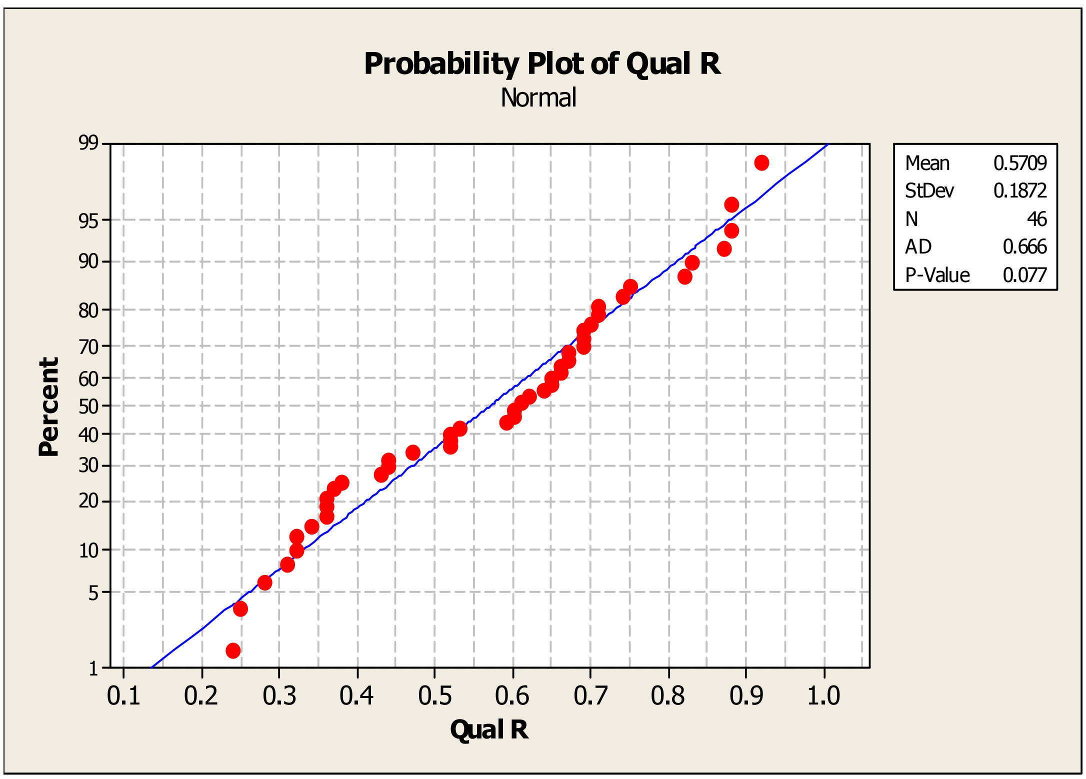
Moving Range (Productivity Rate) for Department 1 – Facility Two.



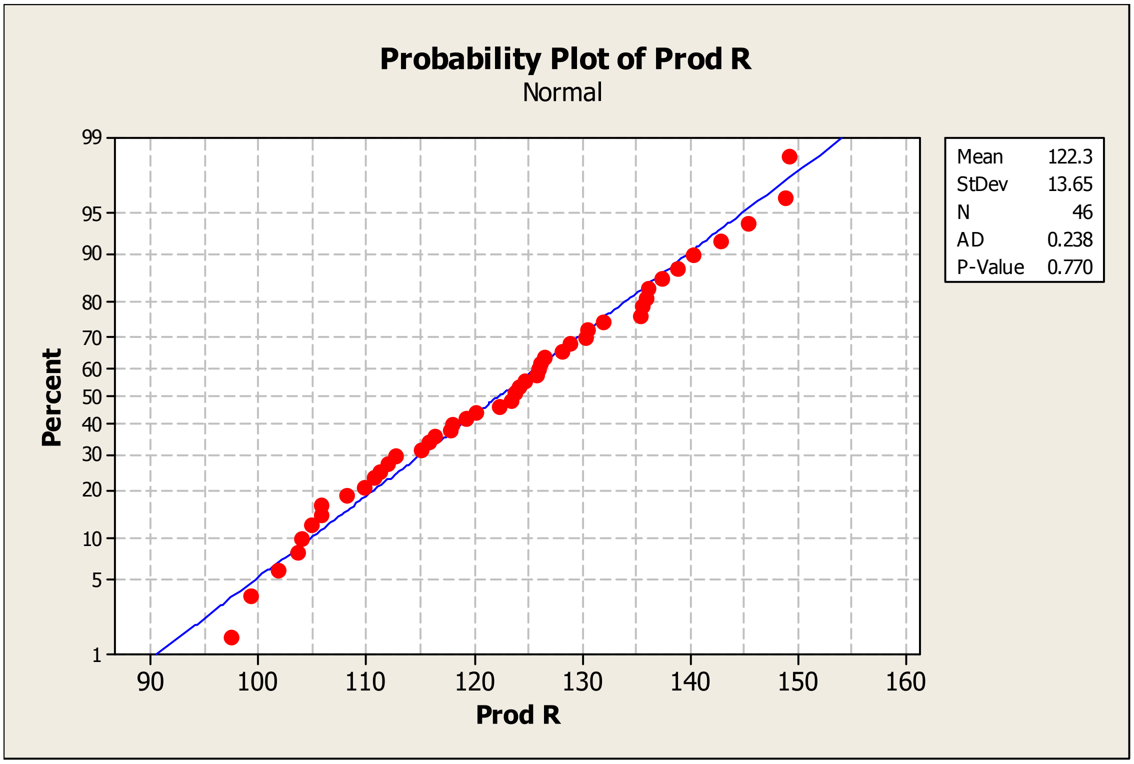
APPENDIX E

NORMALITY TESTS

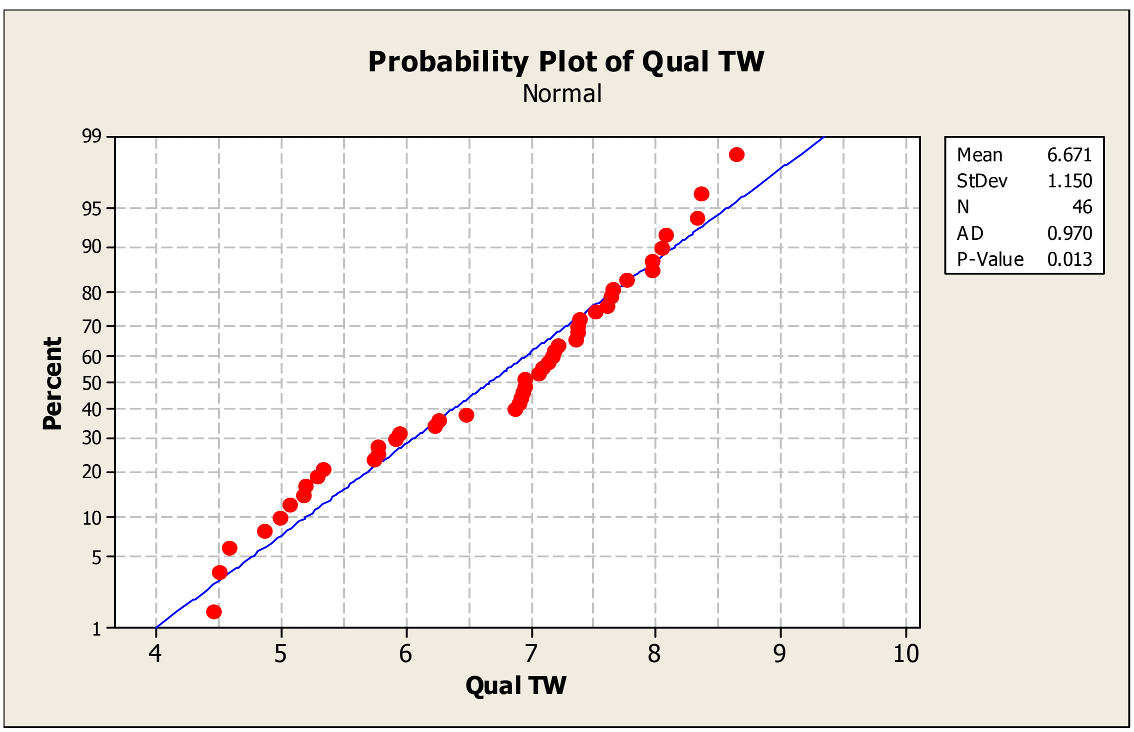
Normality Test (Quality Data) for Department R – Facility One.



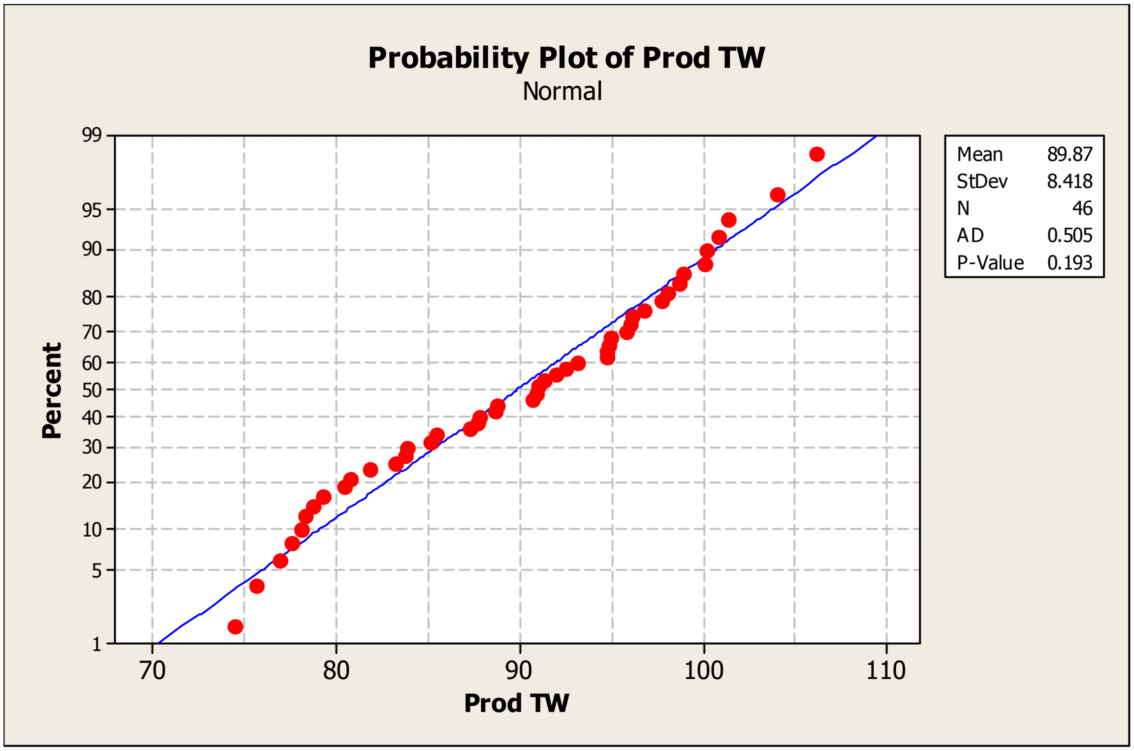
Normality Test (Productivity Data) for Department R – Facility One.



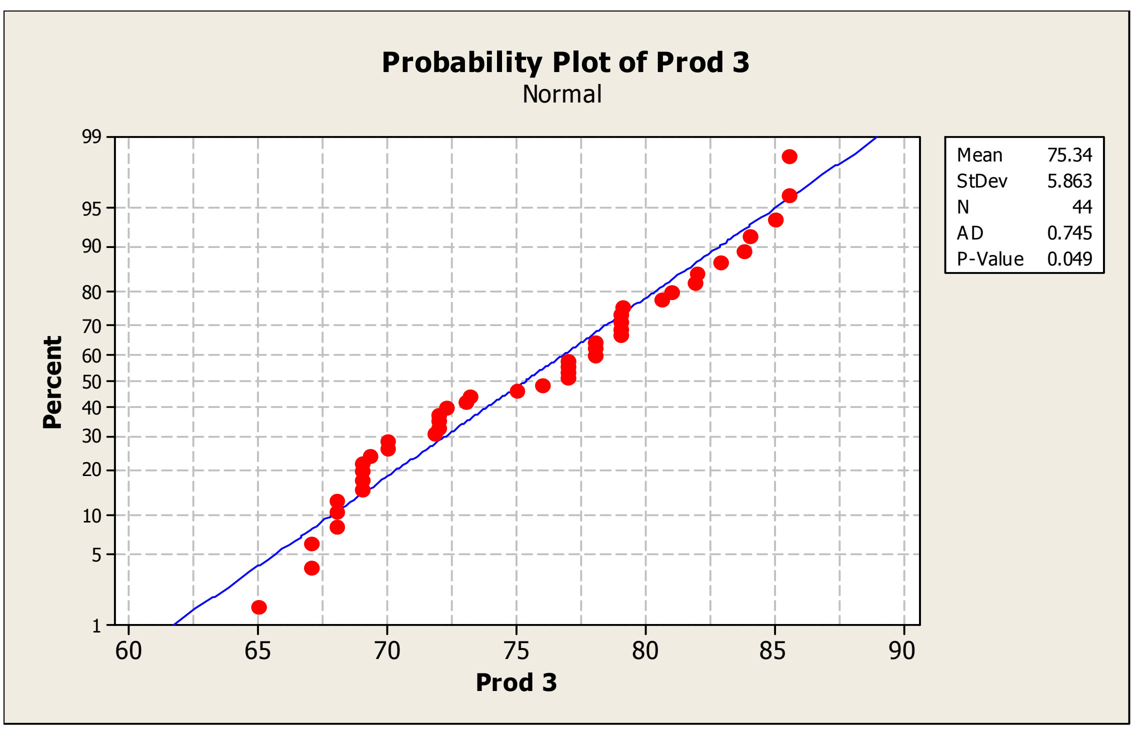
Normality Test (Quality Data) for Department TW – Facility One.



Normality Test (Productivity Data) for Department TW – Facility One.



Normality Test (Productivity Data) for Department 3 – Facility Two.



Normality Test (Productivity Data) for Department 1 – Facility Two.