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CONSEQUENCES OF IMPLEMENTING STATISTICAL
PROCESS CONTROL: AN EXPLORATORY FIELD STUDY

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ABSTRACT

This article reports the results of a field study of the effects of implementing statistical process control (SPC) in a manufacturing organization. The hypothesized effects were divided into three broad categories: effects on (1) product quality and cost, (2) employee attitudes, and (3) organizational structure. The study found significant effects on the organization's quality and manufacturing cost, no significant effect on employee attitudes, and evidence that the organizational structure will change as a result of implementing SPC.
CONSEQUENCES OF IMPLEMENTING STATISTICAL PROCESS CONTROL: AN EXPLORATORY FIELD STUDY

From the end of World War II until the late 1960's, the United States was the unchallenged world leader in manufacturing. Since then, wide gaps have developed in many sectors between the quality and cost of domestic products and products produced by the Japanese. Although this gap has been narrowing in recent years, it is far from being closed. A variety of possible explanations has been advanced to explain how this gap occurred. The Commission on Industrial Competitiveness (1985) cited four causes for the decline of American competitiveness: (1) failure to competitively develop human resources; (2) inadequate incentives for savings and investment; (3) inadequate and inappropriate trade policies; and (4) shortcomings in commercialization of new technology. The Commission's emphasis was largely on factors external to the manufacturing organization. W. Edwards Deming has focused on causes internal to the manufacturing organization.

Deming is credited with helping to institutionalize a system of strategic manufacturing emphasizing product quality which enabled the Japanese to surge ahead of the Americans (Deming, 1967; Walton, 1986). Deming's philosophy stresses the role of top management in establishing an environment where all employees can focus on continually improving the performance of the organization. According to Deming (1986) sales can be
built and markets captured only when operations efficiently produce a superior product. The answer to eliminating the competitiveness gap lies in improving quality and productivity.

A key element of Deming's approach to improving quality and productivity is the use of statistical methods to analyze and control the manufacturing process. Statistical process control (SPC) is a system of statistical procedures designed to be employed on the factory floor to prevent defects. The focus of SPC is the identification and elimination of special causes of process variation through process capability analysis and the use of control charts to continually monitor the process. SPC is a significant departure from traditional quality control methods employed in most U.S. manufacturing plants.

Traditionally, manufacturers relied on mass inspection and sampling large lots of products at the end of the production line to assure quality. This approach results in high inspection costs and often high costs to sort or rework defective lots of product. SPC uses statistical methods to optimize the production process and then continually monitor the process for signs that it may have drifted out of control. Because SPC is employed on the factory floor at the time the product is being produced, problems with the process can be detected and corrected before large quantities of defective products have been produced. SPC works best when used by the machine operator (Beals, 1990; Juran, 1945, p.
223). Who better knows the process than the operator who runs it?

In order to employ SPC, extensive training in statistical methods must be provided for operating employees. Putting SPC in the hands of the operators increases the operators' power and ability to control their workplace. Besides this increased level of control over the workplace, management also must listen to operators when they have suggestions for process improvements. SPC involves abandoning traditional methods of supervision, control, and evaluation in favor of more participatory methods which stress quality over quantity.

The types of changes which must occur in order for SPC to be used overlap those required for other participatory management practices. Among these are the adoption of quality circle concepts. While the organizational and individual consequences of the implementation of quality circles have been studied and reported (Griffin, 1988), those associated with the implementation of SPC have not. The purpose of this paper is to evaluate the changes in product quality and consistency in the company which implements SPC, changes in the attitudes of employees who complete training in SPC, and changes in the structure of the organization which implements SPC.
HYPOTHESES

SPC training is presumed to have three types of effects on the organization and its members. First, the quality and consistency of the products will improve. Concurrently, productivity will increase, and unit costs will decrease. These effects have been frequently reported in the practitioner literature (Clutterbuck, 1986; Nyndyal and Thomas, 1989; Hansel, 1985; Bajaria and Jones, 1989) and investigated in at least two research studies (Depew, 1987; Keefer, 1986). All except Depew (1987) report improvements in quality, consistency, productivity, and/or decreased production costs as a result of training employees in SPC and implementing an SPC program.

Second, the attitudes and individual and group behaviors of the participants are expected to change. There has been little attention paid to this type of effect in previous studies. However, SPC is a participatory management system (Beals, 1990; Hill, 1990). Attitudinal and behavioral effects of other participative quality programs, for example quality circles, have been documented (Ebrahimpour and Lee, 1988; Griffin, 1988; Marks, et al., 1986). These studies document increased employee participation and at least short run improvements in employee attitudes as a result of training in and implementation of quality circles. In addition, Garvin (1988) states that in order for any quality ethic to be internalized, employees must change their attitudes. They
must view quality as their responsibility rather than the responsibility of the quality department.

Third, the structure of the production department will change to adapt to the introduction of a more technologically sophisticated system of quality management (SPC) within the organization. Most prominent will be the increased size and authority of the technical support staff. Montgomery (1985) indicates that there are varying levels of sophistication in quality systems. The least sophisticated is acceptance sampling, followed by SPC, followed by design of experiments. Movement from acceptance sampling to SPC represents an increase in technological sophistication. Mintzberg (1979) hypothesizes that as technology becomes more sophisticated the size and authority of the technical support staff will increase.

The expected changes to the organization and its members as a result of implementing SPC are summarized in the six hypotheses tested in this research.

**Statement of Hypotheses**

The first three hypotheses relate to the effects on quality, consistency, productivity, and cost which are most frequently associated with SPC. The variables examined in these hypotheses are product consistency (operationalized as product weight consistency), proportion of defective products produced, and average amount of material required per product. These variables were measured by collecting objective process data during the course of the study.
Hypothesis 1: The implementation of SPC will result in reduced variability in the individual product weights as evidenced by a reduced variance for the distribution of sample means.

Hypothesis 2: The implementation of SPC will result in a lower proportion of defective products produced by the process.

Hypothesis 3: The implementation of SPC will result in a decrease in the average amount of material required to produce one acceptable unit of product.

Hypotheses four and five relate to the effects on employee attitudes expected to occur as a result of the implementation of SPC. The variables examined in these hypotheses are perceived control over quality and attitude toward the company and management. These variables were measured by means of a questionnaire administered before and after SPC implementation.

Hypothesis 4: Employees who participated in SPC training will report an increased feeling of control over the quality of their work than will those who did not.

Hypothesis 5: Employees who participated in SPC training will report a more favorable attitude toward management and the company than will those who did not.

Hypothesis six relates to the structural changes which occur in the organization as a result of the implementation of SPC. The variable examined in hypothesis six is size and authority of the technical staff. This variable was measured by direct observation and examination of company records.
Hypothesis 6: After SPC implementation, the technical support staff will be larger and will exercise increased authority in the production organization.

METHODOLOGY

Overview

To test these hypotheses, a field study was conducted in a single manufacturing plant of a large diversified corporation. The plant manufactures plastic parts, most of which are sold to other plants within the corporation.

The quality and cost variables, product consistency, proportion of defective products produced, and average amount of material required per product were evaluated using data collected from the process. A pre-implementation study established the baseline performance of the process. A post-implementation study determined changes which may have occurred.

Attitude changes were measured using a pretest-posttest, nonequivalent control group quasi-experimental design. Both the experimental and control groups were taken from the same manufacturing plant and were selected by the plant management. The experimental group was comprised of the employees currently assigned to the processes to which SPC would be first introduced. The control group was a convenience sample of other employees who worked in similar jobs within the same department. A questionnaire designed to measure the attitude variables, perception of control over
quality and attitude toward the company and management, was administered immediately before SPC training (time 1) and after SPC implementation (time 2).

Structural changes were observed and recorded by one of the authors who was a participant-observer during the training and implementation process. Observed changes in the size and authority of the technical staff were recorded during the course of the SPC training and implementation.

Organization and Participants

The study was conducted in a single manufacturing plant of a large diversified corporation located in Texas. The corporation has more than 20 manufacturing plants located world-wide. Each plant is operated in a highly decentralized manner with considerable autonomy vested in each general manager. There are few functional relationships with central corporate staff units. Each plant is responsible for its own personnel, engineering, training, purchasing and manufacturing decisions, but such decisions must comply with general corporate guidelines. The majority of the study plant's sales was to other divisions of the corporation.

One of the authors was engaged as a consultant to provide initial training in SPC to the managers of the plant, and to train the instructor and provide the curriculum for the training of the production supervisors and operators. As part of the initial training process a pilot SPC implementation was conducted for technical and middle management employees
which convinced management of the benefits of proceeding with full implementation of SPC. According to Juran (1945), a pilot study is a good way to assure support for new quality systems by actually demonstrating the benefits to the organization.

The actual training given the participants in this study was provided by the plant's quality engineer, who had been a participant in the pilot study, using the curriculum developed by the consultant. SPC implementation was accomplished by company personnel under the consultant's guidance.

Procedures

Nineteen employees who worked in the molding and fabrication processes were selected by management to receive SPC training. The eight remaining employees who worked in these same processes comprised the control group. The selections were based upon current work assignments. Those employees assigned to the initial process to use SPC were assigned to the training group. The remaining employees in the department were assigned to the control group. The control group employees were aware that other employees were participating in a training program.

The consultant conducted a two-week pre-implementation study of the molding process which would be used in the SPC training. The critical variable used to reflect the variability of the process was part weight. Sample parts were collected at two-hour intervals, and the sample means
and ranges plotted on X-bar and R charts, respectively. The X-bar control chart was used to plot the mean part weight of each sample taken from the process and was used to control the centering of the process. The R chart was used to plot the range of the part weights within each sample and was used to control the dispersion of the process. The proportion of defective parts produced was recorded on a p-chart which provided a time-sequenced view of the proportion of defective products produced by the process. The amount of material consumed by the process was monitored along with the number of acceptable parts produced. These same data were collected during a two week period after the process had been brought under statistical control.

A pre-implementation attitude questionnaire (Appendix A) was administered separately to both the experimental and control groups on-site. This was accomplished immediately prior to beginning the SPC training program. The employees were told that the survey would be used to assist the instructor in determining what topics to emphasize in the training program and to determine their current attitudes about quality related subjects. They were told that a follow-up survey would be taken at the end of the training. Participants were asked to use their mothers' names on the questionnaires rather than their own to assure confidentiality. It was explained that no one other than the consultant would have access to their individual questionnaires. The same questionnaire was administered to both groups two weeks after the training program had been
completed. The consultant was present during questionnaire administrations.

The training methods employed emphasized "hands-on" reinforcement of classroom material. During the training program, participants studied the process on which they worked, and by the end of the training program had determined the capability of the process to meet product specifications, had identified sources of unnatural variation in the process, and had implemented control charting for the process. The training group initiated action to eliminate sources of unnatural variation over which they had control (for example initiating a formal communication system between shifts), and secured the assistance of the support staff to correct sources of variation outside their control (for example replacing a worn part on a process machine). By providing the operators the opportunity for immediate participation in the improvement of their process, rather than promising that they would be involved after completing training, it is felt that some attitudinal and behavioral change could be observed soon after training had been completed.

The consultant observed the organization of the production department during the six months preceding this study. During this time baseline observations were made of the production department. Specific attention was paid to the size of the support staff and to the relationships between the support staff and the line staff.
SPC Training

SPC training was conducted on-site during normal work hours. Because the work schedules of the participants varied, they were divided into four classes. Phase one of the training consisted of approximately fifteen hours of training in basic statistical methods. Emphasis was placed on the use of the methods in controlling the process rather than on theory or computation.

Phase two consisted of constructing a cause and effect chart for the process where SPC was to be implemented. Each participant independently developed a list of causes for variation in the critical variable, part weight. The lists were then consolidated in a meeting of all training group participants. This master cause and effect chart was then distributed to each participant and posted in the process area.

Phase three consisted of a process capability study conducted by the entire training group. The training group periodically measured the weights of sample parts selected from the process. Key process variables, identified by referring to the cause and effect chart, were also monitored. The participants maintained X-bar and R charts for part weight at the work station. The quality engineer combined the daily charts into one weekly chart with updated control limits. Weekly meetings were conducted in which the training group discussed the chart results and determined actions to be recommended to reduce the variability of the process. When the training group and the process engineer agreed on a set of operating conditions
for the process, and the process had run in statistical control for one week, the formal training program was declared to be over. The training group asked that they be allowed to continue meeting weekly to review the control charts and to discuss ways that further process improvements could be achieved.

Measures

Process variability was measured with control charts using part weight as the variable. Variation in the process mean was measured with the X-bar chart on which were plotted the sample means. Control limits were set at three standard deviations (3-sigma) above and below the grand mean. Variation in process dispersion was measured with the R-chart on which were plotted the sample ranges. The upper control limit was set at three standard deviations above the grand range. Data for these charts came from samples of size three taken at two-hour intervals from the process.

Proportion defective was measured with a proportion defective or p-chart. Data collected at the two-hour sampling intervals included the number of acceptable and defective (for all reasons) parts produced since the last sample was taken. The proportion defective was plotted on a p-chart with the upper control limit set at three standard deviations above the center line.

Material was delivered to the work station in equal weight containers. The time each container was delivered was
recorded. The number of acceptable parts produced since the last material change was divided into the material weight delivered. The result was a measure of the amount of material required to produce one acceptable part.

**Feeling of control over the quality of work** was measured by a two-item instrument using a five-point Likert scale. The scale extremes were strongly agree and strongly disagree. The coefficient alpha at time 1 was .58.

**Attitude toward management** and the company was measured by a four-item instrument. Responses were on a five-point Likert scale whose extremes were "strongly agree" and "strongly disagree." The coefficient alpha at time 1 was .77.

Questionnaire items were developed specifically for this study. All items were evaluated for face validity by a panel of four academic researchers from three different universities. These researchers regularly use such measures in their research. Reliability of the instruments was assessed using the internal consistency method (Cronbach, 1951; Peter, 1979).

The extent of support staff authority was determined by observing the number of staff personnel who exercised significant functional authority within the production department. The size of the support staff was documented prior to the pilot study and two weeks after the completion of the study training program.
RESULTS

Effects on Quality

Table 1 presents the baseline (time 1) and post-implementation (time 2) data for the process selected for SPC implementation. The process variability data were taken from the part weight X-bar and range control charts for the process. This analysis was conducted to determine if support could be found for hypothesis 1. A significant reduction in the variance of the individual observations for part weight would indicate that the variability of the process had change. Changes in the observed ranges of the sample means were also taken as an indication of changes in the variation of the process.

Table 1 shows that the variance of the individual observations decreased from 25 \( (n = 153) \) at time 1 to 0.16 \( (n = 357) \) at time 2. The value of the F statistic \( (v_1 = 152; v_2 = 356) \) is 0.0064. This value of F is significant at the 0.000006 level indicating that a significant reduction in part weight variance was achieved coincident with the implementation of SPC.

Table 1 also shows that the range of the sample means (maximum sample mean - minimum sample mean) is also substantially reduced. The time 1 range is 17.5 grams, while the time 2 range is 1.6 grams. This is a further indication of the decrease in part weight variation coincident with the implementation of SPC.
The range chart upper control limit was also reduced by a factor of three from +1.70 grams to +0.52 grams. This is an indication of a decrease in the within-sample part weight variation.

Insert Table 1 about here.

The proportion of defective parts produced was reduced by a factor of two from 0.00902 to 0.00430 (0.902% to 0.430%). The difference between these two values was tested using the normal approximation to the binomial distribution (Montgomery, 1985). The Z score obtained was 63.82 indicating the difference is significant below the 0.00004 level.

The average amount of material used per acceptable part at time 1 was 295.0 grams and 293.4 grams at time 2. The value of the pooled t-test statistic (Montgomery, 1985) is 7.952 which indicates the difference is significant below the 0.0005 level.

These results reflect the benefits most frequently associated with statistical process control. The improved quality and productivity resulting from SPC is a key factor in Deming’s (1986) approach to rebuilding the competitiveness of the U.S. manufacturing sector. Mentioned far less frequently, but of equal importance -- we believe -- are the effects on employee attitudes and organizational structure. These issues are now discussed.
Effects on Employee Attitudes

Table 2 presents the baseline means and standard deviations for the three attitude variables for the participant and control groups. Mean differences between the two groups were assessed with paired t-tests. In comparing two means, the results of the Student's t test and analysis of variance (ANOVA) are equivalent (Mendenhall and Reinmuth, 1971). The analysis indicates that the experimental and control group scale scores were not significantly (.05) different at time 1.

Insert Table 2 about here.

Paired difference scores (the difference between the time 1 and time 2 scores) were computed between the two questionnaire administrations. Paired t-tests were used to determine changes in average responses between the experimental and control groups. These results are in Table 3. A significant difference in the difference score between the experimental and control groups at time 2 would be taken to represent the effect of SPC training and implementation on the employees' attitudes.

Insert Table 3 about here.

Support was not found for hypotheses 4 or 5. Analysis of the individual items in the scale indicated a significant
difference between the two groups at time 2 in their attitudes toward management but no difference in their attitudes toward the company. Interestingly, this is more a result of an unfavorable change in the control group attitude toward management than a favorable change in the experimental group attitude toward management.

Effects on Organization Structure

The perceived need for closer monitoring of operating procedures after the implementation of SPC led to the creation of a new position (cell supervisor) in the production organization. Figures 1 and 2 show the organization of the production department at time 1 and time 2, respectively. The department was divided at time 2 into three work cells, and a set-up technician was assigned as supervisor of each cell. The intent was to provide closer coordination between operators and set-up technicians and to provide closer supervision to the operators. This change resulted in an additional hierarchical level and a reduced span of control in the production department. The greatest span of control at time 2 was five, whereas at time 1 it was twenty.

Insert Figures 1 and 2 about here.

At time 1 the main source of technical support in process related areas came from within the production department.
One process control engineer was responsible for establishing process conditions. He and the process technicians did all the troubleshooting of process problems. At time 2 a functional relationship had been established between the quality engineer and the production department. Previously the quality engineer only became involved when defective parts were found in lots ready for shipment to customers. At time 2 he was involved in establishing and maintaining control of the process in order to prevent the production of defective parts. A process engineer was also added to the staff to assist in process design and process improvement. These changes are consistent with hypothesis 6.

DISCUSSION

The purpose of this study was to evaluate the changes in product quality and consistency, in the attitudes of employees who complete training in SPC and in the structure of the organization which implements SPC. The study consisted of a field study and employed a pretest-posttest, nonequivalent control group quasi-experimental design to determine attitude changes. The quality and consistency and structural change results were as expected; no significant attitude changes were found.

Process variability and the production of defective product was reduced due to the implementation of SPC. In addition,
the amount of material required to produce one acceptable unit of product decreased by 1 percent.

There was no significant change in the participants' feelings of control over the quality of their work. Participants' attitudes toward the company also did not change significantly. There was some evidence that the experimental group's attitude toward management was significantly better than the control group's at time 2.

Support was found for Mintzberg's (1979) hypothesis that as the technology becomes more sophisticated, the size and authority of the technical staff will increase. An indication was found that the number of hierarchical levels in the production department will increase as technology becomes more complex.

**Threats to Study Validity.**

There are five basic threats to validity inherent in this study. First is the threat to external validity created by the study of a single manufacturing plant. The generalizability of these findings can only be established by replicating this study in a variety of manufacturing organizations. This exploratory study establishes a methodology to employ in conducting the additional studies.

A second threat arises from the internal validity of the attitude scales employed in this study. The coefficient alpha was particularly low for the scale measuring feeling of control over the quality of work. Refinement of these scales
is necessary to increase the validity of the attitude findings.

A third threat arises from local history. During the latter stages of this study the plant entered a normal, cyclical decline in demand for its products. While no layoffs occurred, there was some transfer of personnel to different jobs. This could account for the decline in attitude toward management measured for the control group. By participating in a company sponsored training program, the experimental group could have felt insulated to a degree from the prospects of a layoff. Contamination of the control group by contact with the experimental group was minimized by having the two groups take their breaks at separate times.

A fourth threat to internal validity comes from mortality. Because of attrition and transfers of personnel to other jobs, the experimental group lost five members and the control group two members during the study.

A fifth threat arises from a Heisenberg effect. The Heisenberg principle, taken from the physical sciences, states that by measuring a system the observer alters the system. Some of the reduction in process variation could have resulted from the increased attention paid to the process during the pre-implementation study. During the pre-implementation study of the process, the process variability declined after the first week although no known improvements had been introduced. The attention paid to the process may have resulted in increased operator and
technical staff attention to the process leading to reduced variability. It is doubtful that this type of effect could be sustained without a system such as SPC. Heisenberg effects could lead to an understatement of the degree of improvement to the process resulting from SPC by understating the true baseline variance in the process.

**Study Implications.**

This study leads to the clear implication that SPC can be a significant factor in improving the competitiveness of a company's product. This study found clear evidence of reduced product variability as a result of SPC. SPC was also responsible for a reduction in the amount of material required to produce one acceptable unit. By reducing the proportion of defective products produced, less labor was wasted on rework.

Less definitive evidence was found for the effect of SPC on attitudes. The one clear finding of improved attitude toward management could lead to more productive relations between labor and management. The movement toward greater involvement of the technical staff leads to more effective teamwork in resolving process problems.

Properly managed implementations of statistical process control can have broad implications for companies trying to compete in markets dominated by products manufactured abroad. The implications of SPC encompass more than just technological advancement. The structural and attitudinal
effects can be as revolutionary as the technological effects. The key to effectiveness is to anticipate and properly manage all of the aspects of an SPC implementation to take advantage of the positive aspects of all levels of effects.
REFERENCES


Appendix A

Attitude Measurement Items

Feeling of Control Over the Quality of Work

1. The people most responsible for product quality in this company are in Q.C.

2. I have little control over the quality of the products I work with.

Attitude Toward Management and the Company

3. I have confidence in the management of this company.

4. The managers of this company are always willing to listen to my ideas for doing things better.

5. (Company Name) is the best company I have ever worked for.

6. I feel I have a good future with this company.
### Appendix B

**Attitude Instrument Intercorrelations**

<table>
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<td>.62*</td>
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* Significant at the .05 level.
Table 1
Baseline and Post-SPC Process Data

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<th>Process Parameter</th>
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<th>Post-SPC (Time 2)</th>
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<tr>
<td>Observations/Subgroup</td>
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<tr>
<td>No. of Observations</td>
<td>153</td>
<td>357</td>
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<tr>
<td>Observation Variance*</td>
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<td>0.16</td>
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<tr>
<td>Range of Sample Means</td>
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<tr>
<td>Sample Range UCL</td>
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</tr>
<tr>
<td>Proportion Defective**</td>
<td>0.00902</td>
<td>0.0043</td>
</tr>
<tr>
<td>Material/Part***</td>
<td>295.0 gms</td>
<td>293.4 gms</td>
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* Difference is significant at the 0.00006 level.
** Difference is significant at the 0.00004 level.
*** Difference is significant at the 0.00006 level.
<table>
<thead>
<tr>
<th>Attitude Scale</th>
<th>Experimental Group</th>
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<tr>
<td></td>
<td>Mean</td>
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<tr>
<td>Feeling of Control</td>
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<td>Attitude Toward Mgmt. and Company</td>
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<td>0.52</td>
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Differences in means are not significant at the .01 level.
Table 3
Paired Difference Scores: Time 1 - Time 2

<table>
<thead>
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<th>Attitude Scale</th>
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<td>S.D.</td>
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</table>

Differences in means are not significant at the .01 level.
Figure 1
Field Study Production Organization Prior to SPC Training

- General Manager
- Production Manager
  - Quality Control Manager
    - Quality Engineer
    - Quality Control Inspector
  - Shift Superintendent
  - Process Control Engineer
  - Lead Process Technician
  - Senior Process Technician
- Machine Operator
- Set-Up Technician
- Clerk/Relief Operator
- Material Handler
- Process Technician

Numbers represent the number of each role present in the organization.
Production Organization After SPC Training

- General Manager
  - Process Engineer
    - Quality Control Manager
      - Quality Engineer
    - Shift Supervisor
      - Senior Process Technician
        - Lead Process Technician
    - Process Control Engineer
      - Material Handler x2
      - Cell Supervisor & Set-Up x3
      - Machine Operator x4
    - Production Manager