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Examining the Impact of Speed of Quality Improvement on Quality-Related Costs

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ABSTRACT

The Fine (1986) quality-based learning curve model is extended to include the consideration of speed of quality improvement. The model demonstrates that under different circumstances rapid quality improvement effects are either beneficial or detrimental to improvement in quality-related costs. Hypotheses are developed from the analysis of this speed of quality improvement model. The hypotheses are tested in an automotive parts manufacturing company with five similar plants. Results show that with an increase in the speed of quality improvement, the rate of growth in prevention and appraisal costs decrease and the rate of growth in failure costs are unaffected. Rapid speed of quality improvement does yield lesser decreases in failure costs than slower, steadier improvement. However, rapid speed of quality improvement does not yield the predicted lesser decrease in prevention and appraisal costs than slower, steadier improvement. Rapid speed of quality improvement might or might not benefit the organization, perhaps an explanation for some Total Quality Management (TQM) failures. A more deliberate, learning organization is suggested from this research.

Subject Areas: Case Study, Empirical Research, Learning, Mathematical Modeling, Quality, and Total Quality Management.

INTRODUCTION

Quality improvement has proven to be a difficult undertaking for many North American firms. Press reports are replete with articles claiming the demise of quality management processes. Further, American companies have dropped quality processes viewed as unprofitable and failing to yield desired effects. Creating greater skepticism, companies such as Florida Power and Light and Wallace Corporation have been financially unsuccessful in spite of internationally and nationally recognized quality improvement processes.

A number of studies have been performed relating variables such as leadership, data analysis, and teamwork to success in quality improvement (Anderson, Rungtusanatham, & Schroeder, 1994; Benson, Saraph, & Schroeder, 1991). A study was undertaken by Saraph, Benson, and Schroeder (1989) identifying eight key quality dimensions. More recently, Reger, Gustafson, DeMarie, and Mullans (1994) identified organizational behavior theories such as organizational identity theory, personal construct theory, and self-discrepancy theory as important explanations for failure of quality management processes. Through factor analysis, Adam (1994) examined results from a survey of midwestern U.S. firms and found that behavior, conformance and design, knowledge, rewards and SPC, and engineering were variables that could be used in studying quality results, operating performance, and financial performance.

While studies address important antecedents to quality improvement, many allude to, but do not specifically address, the quality-related variables of time and speed of quality improvement. A major study of best quality-related practices undertaken by Ernst and Young (Ozan, 1992) was critical of total quality management processes for not providing bottom-line results. At the same time, the Ernst and Young study advocated the gradual implementation of TQM. A comprehensive study by the United States General Accounting Office (1991) stated that, on average, 3.5 years were required for companies to begin to see significant results from quality improvement processes. In a study of the U.S. auto industry, Narasimhan, Ghosh, and Mendez (1993) found a 2.26-year lag between quality improvement and customer recognition of quality improvement. Shigeo Shingo (1981) stated that 25 years were required for Toyota Motor Company to achieve significant improvement and that time could be reduced to 10 years for competitors. Deming (1986) consistently stated that continuous quality improvement was a slow process that required commitment of resources and time. A review of these studies and writings suggests that time is an important variable to consider when managing successful quality improvement processes.

Firms will seek and attempt to attain rapid quality improvement in order to obtain benefits associated with improved quality such as greater market share and increased sales. However, setting short-term goals for higher quality levels and managing towards those goals may actually prove detrimental to the firm (Anderson & Sullivan, 1993; Deming, 1986). Managerial action that will lead to an optimal rate of quality improvement requires an understanding of the effects of rapid quality improvement.

The primary research question for this study concerns the propriety of a strategy of rapid quality improvement. The results suggest that rapid speed of quality improvement is only of benefit if quality increases to a higher level over time than would have occurred at a slower speed, a result that is accompanied by lower costs as well. This result is supported by the development and empirical validation of a speed of quality improvement model. The speed of quality improvement model suggests that when the extent of improvement in level of conformance does not increase, but the speed of quality improvement increases, the total amount of potential cost and conformance improvement decreases. Therefore, companies pursuing a strategy of rapid improvement may imperil competitive performance as a result of overemphasis on immediate results.

RELEVANT LITERATURE

A variety of models, both conceptual and mathematical, have been cited in the literature naming certain variables as antecedents to quality improvement. Conversely, researchers have identified a variety of variables leading to the failure of quality management efforts. This has resulted in a number of competing quality management models in the literature. Various reasons explain this existence of competing models. First, a generally accepted theoretical framework for testing the effects of key decision variables has not emerged. Therefore, many researchers view the development of models as a necessary step to developing testable research hypotheses (Adam, 1994; Flynn, Schroeder, & Sakakibara, 1994). Second, quality management research has lagged practice, leaving researchers to search for explanations of past observed phenomena. For example, the emergence of reengineering (Hammer & Champy, 1993) has caused researchers to question the fundamental assertions of continuous improvement. As a result, research has emerged treating quality management tools as content variables with no theoretical foundation (Powell, 1995).

In the operations management literature, two separate streams of quality-related research have developed: deductive research and empirical research (Swamidass, 1991). Deductive research refers to management science/operations research modeling. Alternatively, empirical research is observation-based involving data gathering from organizations and individuals. Deductive research in quality has centered on quantifiable variables; in particular, quality-related costs (Marcellus & Dada, 1991; Nandakumar, Datar, & Akella, 1993; Fine, 1986). Empirical research in quality management is becoming more common through the use of case studies and surveys (McCutcheon & Meredith, 1993; Benson et al., 1991; Powell, 1995). However, deductive research is increasingly viewed as theoretically rigorous but lacking validity (Meredith, Hyer, Gerwin, Rosenthal & Wemmerlöv, 1986). Alternatively, empirical research is perceived as valid but often lacking a sound theoretical foundation (Swamidass). A deductive/empirical paradigm is called for that encompasses the strengths of both forms of research, which this research employs. As a result, mathematical modeling is utilized with empirical model validation through a case study.

Conceptual Models in the Literature

Research and practitioner literature consistently emphasizes that quality improvement is of strategic importance (U.S. Department of Commerce, 1994; Saraph et al., 1989; Benson et al., 1991; Belohlav, 1993; Anderson & Sullivan, 1993; Schonberger, 1994; Powell, 1995). Deming stated that "support of top management is not sufficient, they must know what it is that they are committed to—that is, they must do" (Deming, 1986, p. 21). Flynn et al. (1994) identify top management performance as a key management practice affecting competitive performance. In the Flynn et al. study, quality is supported as a central element of competitive strategy actively involving the entire organization in quality efforts, developing a company culture of quality and implementing systems of communication and rewards. Adam (1994), in a study of quality practices, identifies key inputs to quality programs such as engineering, statistical quality control, conformance, and design. These quality inputs are found to be significantly related to numerous indicators of operating and financial performance. The ensuing choice of quality improvement input is under the purview and control of management. The Malcolm Baldrige National Quality Award Criteria (U.S. Department of Commerce, 1994) cites leadership and strategic planning as important variables in assessing quality management practices. Strategic quality planning implies the dynamic of long-term planning (Garvin, 1992) and reinforces long-term commitment, which is required for quality improvement efforts (Deming, 1986).

To improve quality, firms might be required to overcome cognitive inertia or resistance to changes that deviate from existing schema or frames (Reger et al., 1994). Overcoming cognitive inertia requires understanding the firm's current identity, visioning an ideal organizational identity, and accepting fundamental change to close the gap. Such change can be measured in years or possibly decades, depending upon the severity of the cognitive gap. Given current competitive pressures, managers might seek more rapid improvement techniques such as reengineering (Hammer & Champy, 1993) or set numeric goals mandating lower levels of defects (Deming, 1986) in an effort to achieve immediate breakthrough quality improvement (Juran, 1989). However, Deming reinforces the long-term view in his discussion of the two first crippling diseases: lack of constancy of purpose and overemphasis on short-term profit. Constancy of purpose implies that companies continually improve to bring the customer back again and again. An interesting note is that while Deming and other practitioners explicitly identify time as an important variable in managing quality, the conceptual research models allude to time only implicitly when measuring the success of quality programs. To address this gap in the literature, this research explicitly examines the issue of time by studying the effects of pursuing rapid quality improvement in a firm.

Deductive Models in the Literature

Among the variables affected by speed of quality improvement are the costs of quality (i.e., prevention, appraisal, and failure-related costs). Juran (1974) developed a model showing the relationship between conformance and quality-related costs. Fine (1986) extended the Juran (1974) model by including the effects of organizational learning resulting from quality improvement processes. Alternatives to the Fine model have emerged, such as the Marcellus and Dada (1991) interactive-improvement model. While Fine modeled continual improvement, Marcellus and Dada modeled the improvement process as an interactive process in which management responded to a disjointed environment. However, analysis of the Marcellus and Dada interactive model provided support for preventive control instead of reactive control, which implies support for a continuous improvement approach.

A model for product quality and pricing decisions (Narasimhan et al., 1993) was developed examining the effects of price, quality, perceived quality, and market potential on sales response. A deductive/empirical approach was employed and a regression study was performed to validate the model. They found that customer response lagged actual increases in quality conformance. Nandakumar et al., (1993) modeled costs of quality incorporating time and costs associated with time. In particular, Nandakumar et al. included the effect of poor quality on timeliness of delivery and response time. However, they did not evaluate the effects of varying rates of speed of quality improvement on quality costs. In other words, time was utilized by Nandakumar et al., as a dependent variable rather than as an independent variable.

The Fine (1986) model was termed a "quality-based" learning model. Quality-based learning is organization-wide and results from the production of high quality products leading to distinctive competency. Through close attention to process and quality improvement, Fine stated that workers would discover "bugs" and inefficiencies in the process. The elimination of these inefficiencies would result in permanent cost reductions. Hence the term "the learning organization" was used.

While the Fine model has been well accepted by researchers, it is limited by a variety of restrictive assumptions (Marcellus & Dada, 1991; Tapiero, 1987). Of particular interest is Tapiero, who noted that basing quality learning on past production volumes does not guarantee that managers will provide mechanisms to utilize accumulated experience during the production process.

However, the Fine model has been used as a basis for much of the current deductive quality research due to its particular strengths. For this research, the Fine (1986) model was utilized to evaluate speed of quality improvement, as the model reflects continuous improvement in a learning environment. In part, the Fine model was chosen for this research because the firm studied was characterized by management as a continuous improvement firm. Also, the Fine model was time based; thus, the Fine model can be extended to include differing rates of quality improvement. Third, the Fine model was found useful due to its simplicity in modeling varying rates of quality improvement in a nonmonopolistic environment. In addition, the Fine model allows for the evaluation of varying rates of quality improvement as an independent (predictor) variable.

SPEED AND QUALITY MODEL DEVELOPMENT

We modeled speed of quality improvement as:

$$S_q = \frac{\Delta Q}{\Delta T}, \tag{1}$$

showing the relationship between the speed of quality improvement (S_q), amount of quality improvement (ΔQ), and the change in time (ΔT). By solving (1) for ΔT, we found that:

$$\Delta T = \frac{\Delta Q}{S_q}. \tag{2}$$

If $\Delta T = T - T_o$, and letting $T_o = 0$ (as is assumed in the Fine (1986) model), then

$$T = \frac{\Delta Q}{S_q}. \tag{3}$$

Substituting (3) into the Fine quality-based learning model yields:

$$\underset{\substack{x(t),\, z(t) \\ 0 \le t \le \Delta Q/S_q}}{\text{Max}} \int_0^{\Delta Q/S_q} e^{-rt} \left[p(x(t)) - a(z(t))C_1\left(\frac{\dot{z}(t)}{x(t)}\right) - C_2\left(\frac{\dot{z}(t)}{x(t)}\right) - C_3 \right] x(t)dt, \tag{4}$$

where

r = interest rate,
t = time index,
$p(x(t))$ = demand at time t,
$x(t)$ = output at time t,
p = price,
$a(\dot{z}(t))$ = learning at time t,
$\dot{z}(t)$ = experience level at time t,
$C_1(q)$ = per unit cost of appraisal and prevention,
$C_2(q)$ = per unit failure costs, and
C_3 = per unit production costs.

Assuming that ΔQ does not increase, since $\lim_{S_q \to \infty} \Delta Q/S_q = 0$, as S_q increases, the cost improvement yielded by (4) decreases.

Graphical Presentations

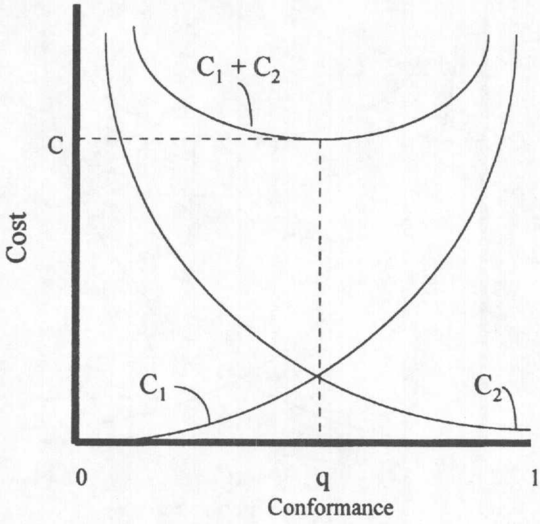
Let's examine the model graphically. The basic Lundvall-Juran curve (Juran, 1974) in Figure 1 demonstrates the base case of no improvement. The minimum point in the upper curve ($C_1(q)+C_2(q)$) represents equilibrium at which the marginal revenue generated by increasing one unit of quality is equal to the cost of increasing one unit of quality. That point represents the lowest combined costs and is the economic quality level. This basic model is static and implies no progress over time. In the Lundvall-Juran model, the choice of conformance level is under the purview of management. Curve $C_1(q)$ assumes that appraisal and prevention costs will be 0 if the conformance level is 0. From the origin, $C_1(q)$ is monotonically increasing and asymptotic to the conformance level of 1. This implies that quality costs increase in a continuous nondecreasing manner as conformance increases. On the other hand, failure cost continuously decreases as conformance increases and is asymptotic to the conformance level of 0.

Common definitions of quality include conformance, performance, features, reliability, durability, serviceability, aesthetics, and perceived quality (Garvin, 1984). Each of these definitions are applicable on a contingency basis. The conformance definition of quality was useful for this research because the analysis utilizing the Fine (1986) model required the use of conformance data. In this context, conformance refers to the ability of a product to consistently satisfy definitive design specifications.

The steady improvement case adapted from the Fine learning-based quality improvement model is illustrated in Figure 2. Fine (1986) optimized a quality-based learning model and showed that by considering learning effects, quality improved and costs decreased simultaneously. His formulation took the discounted value, summed over time, of profit. In the Fine model, profit was a revenue, less cost, expression. In Figure 2, this is reflected in a shift in the cost curves down and to the right, as shown by the dotted curves $C_1'+C_2$ and C_1'. Quality improvement resulting in reduced cost is supported by descriptive studies of Japanese just-in-time manufacturing and popular spokespersons such as Crosby, Deming, and Juran (Crosby, 1979; Deming, 1982; Juran, 1974).

Figure 3 presents the case of rapid improvement implied by the speed of quality improvement model in (4). Here, ΔQ is fixed, but S_q is allowed to increase. This causes T to decrease, thereby reducing the cost and conformance improvements

Figure 1: Basic Lundvall-Juran curve.



yielded by (3). In Figure 4, the case is illustrated in which both ΔQ and S_q increase simultaneously, but the rate of change of $S_q \leq \Delta Q$, where $Q \leq 1$. This results in an increase in T and, eventually, lower cost and higher conformance than is yielded by (1).

EXPERIMENTAL DESIGN TO VALIDATE MODEL

Hypotheses

The first case discussed in the previous section was the base-case of steady, continuous improvement implied by the Fine model. Notice, Figure 2 shows that as quality-based learning occurs, prevention and appraisal costs still monotonically increase. However, the *rate of growth*, or slope of the curve decreases. Behaviorally, this implies the case in which companies maintain steady speed (or rate) of quality improvement over long periods of time. The model predicts that learning firms will experience reductions in the rate of growth in prevention and appraisal-related costs, resulting in an overall decrease in quality-related costs. The following hypotheses emerge from this discussion:

H1a: When the speed of quality improvement (S_q) increases, the rate of growth in prevention and appraisal costs will decrease.

H1b: When the speed of quality improvement increases, the rate of growth in failure costs will be unaffected.

The above discussion and hypotheses reflect steady improvement. We are quite interested in what the model would predict concerning rapid improvement, since that would be the likely expectation of many managers.

Consider a second case: If speed of quality improvement increases and change in quality (ΔQ) does not increase, the amount of time required to achieve a change

Figure 2: Quality-related costs with learning effects.

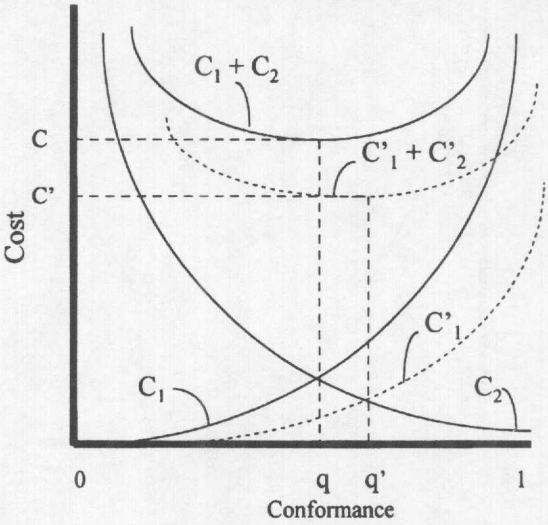
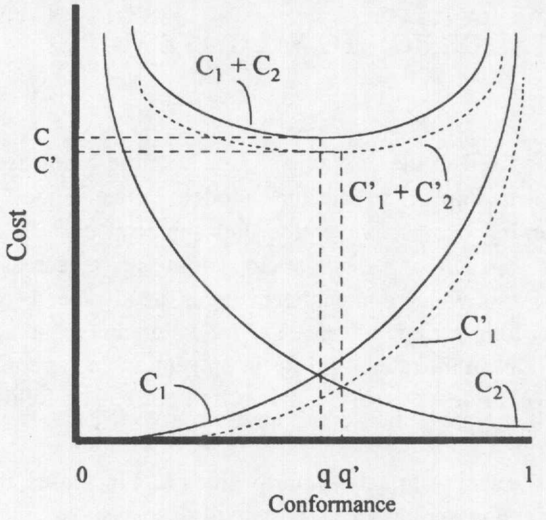
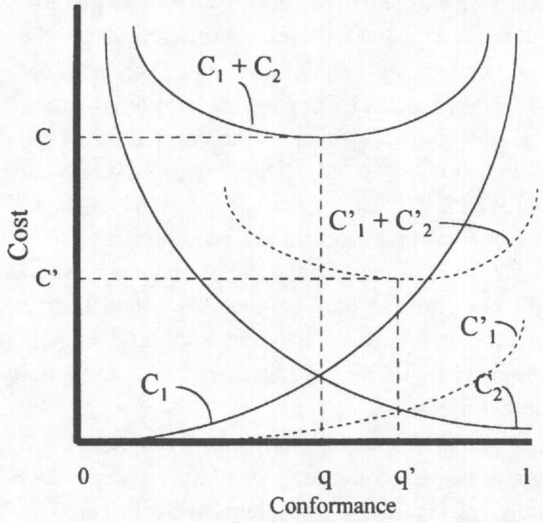


Figure 3: Case of rapid improvement with constant ΔQ.



in quality (ΔQ) decreases, thereby reducing the cost and conformance improvements yielded by the speed of quality improvement model [see (4)] when compared to the basic Fine model (1986). Cost and conformance will improve, but not to the extent shown previously in Figure 2. Therefore, the improvement in costs has been reduced as a result of greater speed of quality improvement. It is expected that this same

Figure 4: Quality cost improvement with increasing speed and quality.



relationship would hold for either the continuous or fixed-cost case. Hence, the following hypotheses:

H2a: Rapid speed of quality improvement will yield smaller decreases in prevention- and appraisal-related costs than will slower, steadier improvement.

H2b: Rapid speed of quality improvement will yield smaller decreases in failure costs than will slower, steadier improvement.

The rapid speed of quality improvement referred to in H2a and H2b is often characterized by intermittent spikes in conformance improvement that are not sustained. Such rapid spikes in conformance may be associated with breakthrough quality improvement that is not accompanied by a freezing of the improvement by changing work systems. By achieving conformance improvement too rapidly, organizational learning (also referred to as experience) is minimized, thereby negating improvements in quality costs. Therefore, rapid improvement in quality will be less likely associated with decreases in prevention, appraisal, and failure costs. This results from the failure of the prevention and appraisal curve to shift from C_1 to C_1' (as shown in Figure 2).

Design and Procedure

The overall research strategy was to develop a model and then utilize the case method to validate the model (McCutcheon & Meredith, 1993; Eisenhardt, 1989; Meredith et al., 1986). The primary weakness in the case method is the small sample size and, therefore, limited generalization. The case research methodology utilized in this study is similar to that of Hayes and Clark (1985), who studied different plants in three companies to examine how the decision patterns of managers contributed to changes in productivity.

The Company

This study analyzed historical quality conformance and quality cost data from a midwestern auto parts manufacturer (hereafter referred to as "the company"). The company supplied automotive subassemblies to major U.S. automotive manufacturers such as General Motors, Ford, and Chrysler, as well as to foreign auto makers as diverse as Toyota and Jaguar. Historically, the company had been recognized by customers for excellent product quality. This recognition has led to positive sales growth during recent years.

The company strived to be a world-class manufacturer and to effectively serve its customers. However, as with many automotive suppliers, customer quality requirements, particularly from North American customers, had been increasing rapidly due to competitive pressures. Large customers such as General Motors and Ford were demanding improved quality conformance and productivity improvements coupled with lower supplier prices.

The company consisted of a number of plants throughout the midwest producing similar parts using similar technologies, procedures, and product designs. In consensus with company management, five plants were selected for this study. The primary product-related differences between the plants were associated with specific part requirements and production volumes. Because of the similarities between the plants, many external variables, such as production technologies and accounting practices, were controlled.

Company Approach to Quality Improvement

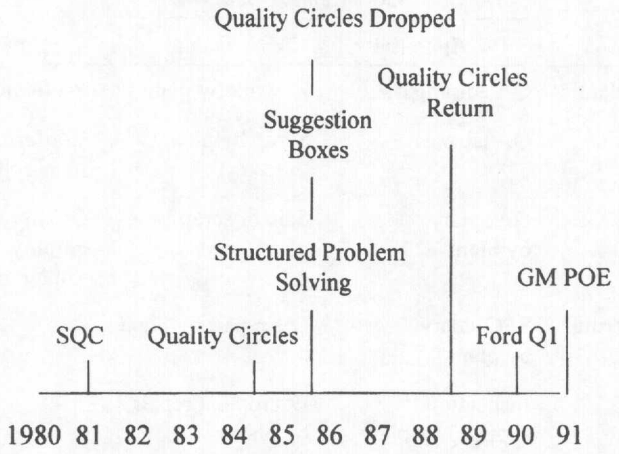
The company was characterized by two distinguishing features: continuous improvement and customer-driven quality. Continuous improvement implies the never-ending emphasis on detail concerning use of machinery, materials, labor utilization, and production methods through application of suggestions and ideas of employees. The company had not been characterized by large-scale programmatic implementations. Rather, the approach to quality improvement chosen was more closely aligned with the Deming plan-do-check-act cycle, also known as the plan-do-study-act. This implies a problem-solving orientation rather than a programmatic orientation. Therefore, isolating the implementation dates of specific quality initiatives was very difficult.

Much of the quality emphasis within the company was a result of customer-imposed requirements. This customer-driven quality was largely a reactive mode in which company management constantly attempted to meet customer requirements. In the auto industry, programs such as General Motors "Targets for Excellence," require suppliers to meet stringent quality and productivity goals. Included with goals are preferred supplier organization, required use of just-in-time, and required implementation of synchronized manufacturing. Figure 5 summarizes identifiable quality interventions and when they were introduced.

Data Gathering

At the initial research site meeting, the need to gather conformance-related data was discussed with plant A quality management. The need for consistency in the collection of data for the period from January 1987 to March 1992 was emphasized by

Figure 5: Quality implementations 1980-1991.



the researchers. Of the alternatives discussed, agreement was reached that the required data could be gathered using quality checksheets. The analysis of the quality checksheets was a lengthy process in that checksheets were tallied for five plants over a period of 5 years. This resulted in a total of 22 years of data collected. One plant had not opened until 1988 and 2 years of conformance data could not be found in another plant. Table 1 summarizes the prevention, appraisal, and failure cost data collected. Prevention costs are those costs associated with training and designing quality into the products. Appraisal costs are inspection-related and failure costs have to do with the failure of the system to prevent and detect errors.

Data Analysis Procedures

This section summarizes the hypotheses and discusses the statistical procedures used in the analysis of the data. Prior to analysis of hypotheses, the 5 years of conformance and quality cost data were analyzed to determine the presence of autocorrelation. The techniques utilized to detect autocorrelation were the Durbin-Watson statistic and residual plots. The Durbin-Watson tests showed that autocorrelation was present in both the conformance and the cost data at a statistical significance level of .01.

Next, time-series plots were used to aid in the analysis of the five plants. Because autocorrelation was present, the AUTOREG procedure in SAS was used in the place of least-squares regression to analyze data. A practical concern with time-series quasi-experimentation is the failure of the least-squares assumption:

$$\text{Covariance}(e_t, e_{t-1}) = 0. \qquad (5)$$

In the past, conventional wisdom held that if regression models were highly significant, serially correlated errors would not present a strong threat to the validity of the conclusion. However, it has been found that serially correlated errors may inflate the standard errors of ordinary least-square parameters by 50% (Foster & Franz, 1995;

Table 1: Data collected.

	Cost-Related Data		
Prevention	Appraisal	Failure	Non-Cost Data
Education by plant	QA administration	Rework by plant	Profit and loss data
Training by plant	QA labs	Scrap by plant	Conformance by plant (checksheets)
Product design costs by plant	QA salary by plant	Sale of scrap by plant (offset)	Quality techniques employed and implementation dates
Design engineering by plant	SPC salary by plant	Die repair by plant	
Continuous improvement department	Inspection supplies by plant	Equipment repair by plant	
Training department	Inspection equipment by plant		
	Receiving inspection by plant		

Box & Tiao, 1965). To overcome this problem, researchers may empirically model serial dependence as a time-series process. Once modeled using AUTOREG, serial dependence is statistically controlled. The AUTOREG procedure in SAS invokes the default Yule-Walker iterative transformation as a remedial measure to remove autocorrelation from serial data (SAS, 1993).

Residual plots performed after the AUTOREG adjustment were used to observe the reduction of autocorrelation in the time-series data. In addition, the data were adjusted for inflation, employing government industrial price indices, and for changes in sales volume, as sales volume affected quality-related costs.

Table 2 presents H1a and H1b, H2a and H2b, independent variables, dependent variables, and statistical procedures used in the test. To test the first set of hypotheses, conformance cost, prevention and appraisal cost, and conformance data for each plant were partitioned into 22 separate 1-year data sets and placed into a table (recall 3 years of data were unavailable). The 1-year slopes provided statistics for speed of quality improvement, and rates of change in prevention, appraisal, and failure costs that could be used to further analyze the relationships between these variables. Rate of change statistics facilitated testing of hypotheses relating to the quality-based learning effects shown by the Fine model. From these 1-year data sets, 22 separate autoregressive least squares time-series correlation coefficients (i.e., 1-year slopes for the time series) were computed using the AUTOREG procedure. The resultant data set contained 22 sets of observations consisting of 22 conformance slopes paired with 22 prevention and appraisal cost slopes and 22 failure cost slopes for

Table 2: Hypotheses, variables and statistical procedures.

	Hypothesis	Independent Variables	Dependent Variables	Statistical Procedures
H1a:	When speed of quality improvement increases, the rate of growth in prevention and appraisal costs will decrease.	Speed of quality improvement	Prevention and appraisal costs	Partition data set into five 1-year subsets, compute slope for each year. Correlate speed and costs to determine the relationship between speed and costs.
H1b:	When speed of quality improvement increases, the rate of growth in failure costs will be unaffected.	Same as above	Failure costs	Same as above
H2a:	Rapid speed of quality improvement will yield lesser decreases in prevention and appraisal costs than slower, steadier improvement.	Rapid factor Slow factor	Prevention and appraisal cost factor	Utilize factor analysis as a means of combining plant data into new latent variables. Correlate the factors to observe the relationships between rapid improvement, slow improvement, and quality-related costs.
H2b:	Rapid speed of quality improvement will yield lesser decreases in failure costs than slower, steadier improvement.	Same as above	Failure cost factor	Same as above

the five plants. These paired data were then analyzed using least-squares regression to determine the relationship between rate of growth in conformance and changes in quality-related costs.

The preliminary results revealed that certain plants experienced either rapid, slow or negative improvement in quality over the 63 months. These preliminary results were utilized in the analysis of H2a and H2b. To test these hypotheses, conformance, prevention and appraisal, and failure costs by plant were combined through factor analysis. This factor analysis provided the equivalent of a weighted average for the data to examine the relationships between the different variables.

Utilizing a varimax orthogonally rotated principal component factor analysis, rapid improvement plants were combined into a single factor and slow improvement plants into a second factor. Factor analysis is an appropriate statistical method for defining fundamental constructs underlying original variables (Hair, Anderson, & Tatham, 1987). In this study, the primary purpose for using factor analysis was data reduction. The varimax orthogonal rotation was useful in that mathematically independent latent (dimensional) variables were created. As shown in Figure 6, the factor analysis resulted in two new latent variables—rapid improvement (*RAPFAC*) and slow improvement (*SLOFAC*). Also utilizing factor analysis, failure costs, and prevention and appraisal costs for the various plants were combined creating new latent variables entitled Failure Cost Factor (*FFAC*), and Prevention and Appraisal Cost Factor (*PAFAC*). Pearson correlation was then used to determine the relationship between these factors.

RESULTS

H1a and H1b Results

Recall that prevention and appraisal, failure, and conformance-related data were partitioned into 22 sets of annual data, each set containing 12 months of conformance and cost-related statistics. For each of the inflation and growth adjusted 1-year data sets, regression coefficients were computed using the AUTOREG procedure and are reported in Table 3. This created a database with 22 observations and three variables. The variables were 1-year speed of quality improvement, rate of growth in prevention and appraisal costs (i.e., prevention- and appraisal-related costs divided by cost of goods sold) and rate of growth in failure costs (i.e., failure-related costs divided by costs of goods sold). The letter *S* at the beginning of a variable name indicates speed of improvement in conformance. For example, the variable *SB* refers to the rate of change in conformance for plant B during a 1-year period. Recall, the speed of quality improvement was defined as the rate of improvement in conformance.

These variables contained in Table 3 were then analyzed using least-squares regression. Regression, rather than autoregressive analysis, was performed to test H1a and H1b as the comparison required for these tests no longer involved time-series data. Regression, then, provided a means for observing the significance and the nature (direction and slope) of the relationships between these variables (e.g., speed of quality improvement, prevention-related costs, and failure-related costs). The regression results are displayed in Table 4. The generalized regression model used in this analysis was simple linear regression:

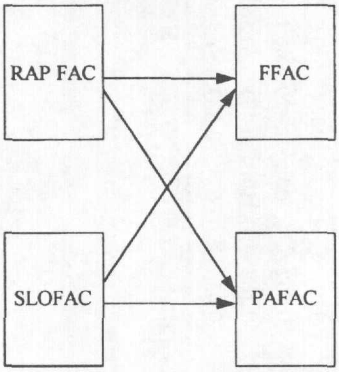
$$\hat{Y} = b_0 + b_1 X_i, \tag{6}$$

where

$\hat{Y}$ = mean value of Y during month t,
b_0 = Y intercept,
b_1 = slope coefficient, and
X_i = level of the independent variable.

Table 4 shows that the slope coefficient (b_1) for the dependent variable *PA* (i.e., prevention and appraisal costs) and the independent variable Speed (rate of change in conformance) was –.365 with a significance level of .038. This means that speed

Figure 6: Latent variables used to test Hypothesis 2 (H2).



of quality improvement as measured by conformance was negatively associated with prevention- and appraisal-related costs. In simpler terms, as speed increased, the rate of growth in prevention and appraisal costs decreased significantly. Alternatively, the regression slope coefficient for the dependent variable *F* (i.e., failure-related costs) was not significantly associated with speed of quality improvement.

Interpreting H1a and H1b Results

For H1a, when speed of quality improvement increases, the rate of growth in prevention and appraisal costs will decrease, the hypothesis was not rejected. Both the negative coefficient of the regression coefficient and the *p* value (.038) suggested that speed of quality improvement led to reductions in the rate of growth in prevention and appraisal costs. Therefore, the underlying thesis of the Fine Model and Speed of Quality Improvement Model concerning the reduction of growth in prevention and appraisal and prevention curve in Figure 2 was validated.

Concerning H1b, when speed of quality improvement increases, the rate of growth in failure costs will be unaffected, the sign of the regression coefficient (.048) was positive and the *p* value (.665) large and nonsignificant. This lent support to the assertion in H1b. Referring to Figure 2, no shift was assumed in the failure-related cost curve.

H2a and H2b Results

Factor Analysis

In testing H2a and H2b, a factor analysis was performed. Since the factor analysis procedure in SAS does not allow for missing values, the factors were developed using data from January 1989 through March 1992. Conformance data for plant D did not include observations from 1987 or 1988. The plant A plot for the conformance data for this period is displayed in Figure 7. Conformance (1% defective) was less than 80% in period 25 and greater than 90% in period 60.

Table 3: Speed of quality improvement by year.

Year	*SA*	*CPAA*	*CFA*	*SB*	*CPAB*	*CFB*	*SC*	*CPAC*	*CFC*	*SD*	*CPAD*	*CFD*	*SE*	*CPAE*	*CFE*
87	-0.040	-1.610	0.068	-0.026	0.442	-0.054	-4.070	1.905	-0.293	N/A	N/A	N/A	N/A	N/A	N/A
88	-0.040	1.610	0.090	1.000	-0.442	0.113	-0.210	-1.910	0.004	N/A	N/A	N/A	0.273	-0.690	0.016
89	0.459	0.347	-0.044	0.363	0.142	0.008	1.693	0.218	0.125	0.568	0.249	0.052	-0.700	1.350	1.139
90	-0.454	0.406	0.990	0.391	0.273	0.120	-0.965	0.332	-0.041	0.054	0.423	-0.162	0.210	0.071	0.343
91	-0.134	-0.070	0.607	-0.322	-0.118	0.003	0.313	-0.109	0.542	0.541	-0.246	0.455	0.007	-0.337	1.854

Note: *S* = speed of conformance, *CF* = cost failure, ***A,B,C,D,E*** = plants, *CPA* = cost prevention and appraisal.
N/A = not available

Table 4: Regression analysis for H1a and H1b.

	Speed	Level of Significance, *p* value
Prevention- and appraisal-related costs (*PA*) (H1a)	-.365	.038
Failure-related costs (*F*) (H1b)	.048	.665

Table 5 displays plant conformance regression coefficients for the 39 periods. The interpretation of the regression coefficient for conformance for plant A is that the plant conformance quality was improving at an average rate of 0.313% per month. This is equal to a 3.756% per year increase in conformance or a 12.207% increase over the 39 periods. Plant C was similar, while plants B and D, respectively, were much slower and the rate of improvement for plant E was negative.

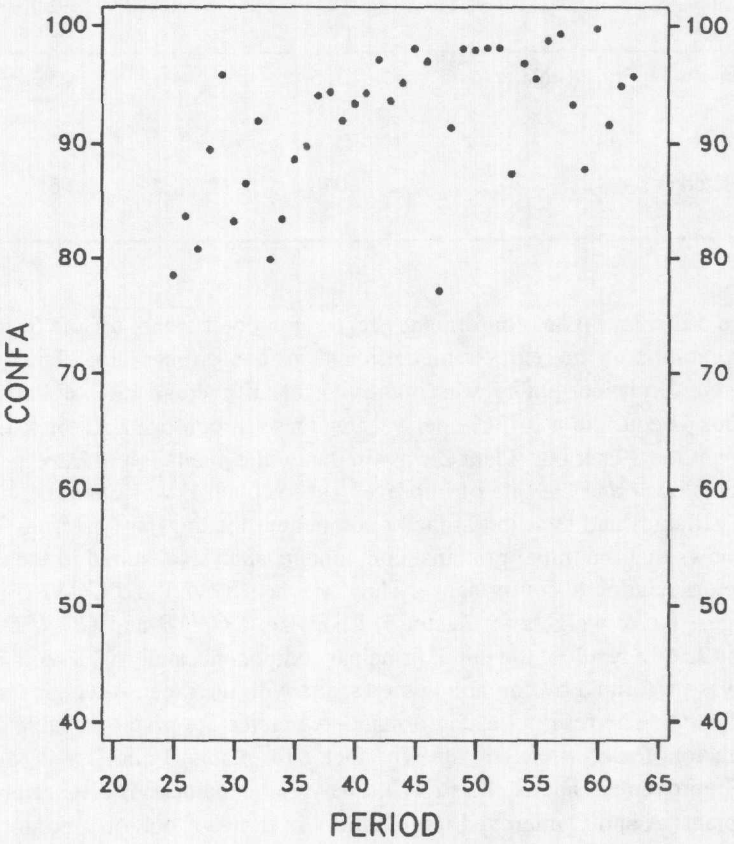
The variables and their initial factor component loadings are given in Table 6. Table 6 shows that the initial principal components analysis resulted in the creation of two factors relating to conformance. The variables *CONFA* and *CONFC* resulted in the largest factor weights for Factor 1. Likewise, *CONFB* and *CONFD* loaded into Factor 2. As a result of the initial principal components analysis, a second factor analysis was performed by combining the factors with the greatest weights into two separate factors. The results for conformance variables are given in Table 7 along with the factors for cost-related data. The factor for plants A and C was identified as Rapid Improvement Factor (*RAPFAC*). The variable name *RAPFAC* refers to the fact that plants A and C improved more rapidly in terms of outgoing conformance. The factor for plants B and D was identified as Slow Improvement Factor (*SLOFAC*), as they were the slowly improving plants in terms of outgoing conformance.

In order to determine the effect of speed of quality improvement on the dependent cost-related variables, factor analysis was used to combine data from the four plants into common cost-related dependent variables. These variables were prevention and appraisal-related costs (*PAFAC*), failure-related costs (*FFAC*), prevention and appraisal costs adjusted for inflation and sales growth (*CPAFAC*), and failure-related costs adjusted for sales growth and inflation (*CFFAC*) for the plants A through D. Component loadings for each of these factors are provided in Table 7. This was executed to reduce the cost data into individual variables that could be correlated to the rapid and slow improvement factors to investigate the relationship between speed of quality improvement and quality-related costs.

Hypothesis Test Results for H2a and H2b

Table 8 is arranged into columns and rows and Rapid (*RAPFAC*) and Slow (*SLOFAC*) quality improvement factors are correlated with quality-related cost factors. H2a addresses the relationship between speed of quality improvement and prevention- and appraisal-related costs, H2b addresses speed- and failure-related quality costs. The reported statistic is a simple correlation coefficient (*r*) for the relationship between the variables.

Figure 7: Conformance data for Plant A during periods 24-63.



Interpreting H2a Results

The sign and level of significance of the correlation coefficient are important for interpreting the results. For example, the *r* value for the association between rapid speed of quality improvement (*RAPFAC*) and unadjusted prevention and appraisal costs was .114. Similarly, the *r* value for the correlation of slow speed of quality improvement (*SLOFAC*) and unadjusted prevention and appraisal costs is -.208. An important note is that these *r* values were not significant. A Pearson correlation coefficient (*r*) was also computed comparing rapid and slow speed of quality improvement with adjusted prevention and appraisal costs. These also were not significant. Therefore, the statistical test performed failed to lend support to H2a.

Interpreting H2b Results

H2b examines the relationship between speed of quality improvement and failure-related quality costs. However, unlike the test for H2a, rapid speed of quality improvement was significantly associated with failure-related costs (.391 and .474). The positive sign of the significant relationship between rapid quality improvement

Table 5: Simple time series regression coefficients utilizing AUTOREG procedure for 3-year conformance.

Variable	Regression Coefficient
	Time Period
CONFA	.313**
CONFB	.087
CONFC	.298*
CONFD	.086
CONFE	-.206*

**p*<.05
***p*<.005

Table 6: Initial component loadings on first round of factor analysis for conformance.

Variable	Factors	
	Factor 1	Factor 2
CONFA	.761	.118
CONFC	.641	.333
CONFB	.384	.611
CONFD	.032	.818
Percentage of Variation	33.64	30.73

and failure-related costs indicates that rapid quality improvement was actually positively associated with failure-related costs. Or in simpler terms, rapid improvements in conformance led to higher internal failure costs. Reasons for this unexpected outcome will be discussed in the conclusions section.

On the other hand, slow speed of quality improvement was negatively associated with failure-related costs at $p<.10$. While this result should be interpreted cautiously due to the significance level ($p<.10$), the negative sign of the relationship implies a reduction in costs and should be carefully considered. In addition, slow speed of quality improvement (*SLOFAC*) was shown to be negatively associated with both unadjusted and adjusted failure-related costs (*FFAC* and *CFFAC*).

CONCLUSIONS

While this paper represents a first attempt to study speed of quality improvement from a research perspective, insights into speed of quality improvement begin to emerge. As was stated, rapid quality improvement, if sustained and permanent, can lead to higher levels of learning. However, under certain conditions discussed in this

Table 7: Factor analysis component loadings for Hypothesis 2 (H2)—Rotated.

	Factors					
	Rapid Improvement (*RAPFAC*)	Slow Improvement (*SLOFAC*)	Prevention and Appraisal Cost (*PAFAC*)	Failure Cost (*FFAC*)	Adjusted Prevention and Appraisal (*CPAFAC*)	Adjusted Failure Costs (*CFFAC*)
CONFA	.853					
CONFC	.853					
CONFB		.808				
CONFD		.808				
PAC			.872			
PAB			.837			
PAD			.827			
PAA			.794			
FC				.891		
FB				.877		
FD				.866		
FA				.813		
CPAC					.933	
CPAA					.869	
CPAB					.777	
CPAD					.765	
CFC						.845
CFB						.836
CFD						.818
CFA						.772
Percentage of Variation	70.80	65.21	69.40	74.29	77.26	66.94

Note: *CONF* = conformance; *PA* = perception and appraisal costs; *F* = failure costs; *CPA* and *CF* = respective costs divided by cost of goods sold; ***A,B,C,D*** = plants.

paper, rapid speed of quality improvement can also impede organizational learning. This was the case of the company studied in this research. Rapid speed of quality improvement resulted in reductions in the rate of improvement in quality-related costs. In addition, slower quality improvement was more closely associated with reductions in quality-related costs.

This is explained by understanding and accepting that quality improvement is accompanied by significant organizational learning. However, an important variable affecting the permanence and the extent of organizational learning is time. As a result of organizational learning over time, the marginal effort required to achieve additional incremental quality improvement declines. For example, inspection is more efficient resulting in less required inspection, thereby reducing inspection-related costs. As supplier quality is improved, the need for acceptance sampling of raw materials is reduced and eliminated. As organizational learning occurs, prevention-related costs decline as prevention activities become more focused on specific

Table 8: Pearson correlations of factors for Hypothesis 2 (H2).

	Rapid Improvement Factor (*RAPFAC*) (Correlation Coefficient)	Slow Improvement Factor (*SLOFAC*) (Correlation Coefficient)
Failure Cost Factor (*FFAC*)	.391*	-.272$^+$
Prevention and Appraisal Cost Factor (*PAFAC*)	.114	-.208
Adjusted Failure Cost Factor (*CFFAC*)	.474**	-.288$^+$
Adjusted Prevention and Cost Factor (*CPAFAC*)	-.072	.154

$^+p<.10$
$^*p<.05$
$^{**}p<.005$

problems and less general in nature. The combined result of these improvements is to decrease the rate of growth in prevention and appraisal-related costs due to learning effects. Again, such learning requires careful attention to detail over time.

The popular literature has expounded the positive attributes of quality improvement processes. Paradoxically, recent articles in the popular literature have brought into question the effectiveness of quality improvement, particularly those processes described by the appellation Total Quality Management (TQM) (Ozan, 1992). This research suggests a reason for the findings of ineffectiveness of some TQM processes. We propose that rapid improvement is of benefit when resulting in higher levels of conformance quality than would have been attained at a lower speed. However, rapid improvement is not indefinitely sustainable. As a result, a slower, steadier speed of quality improvement with learning was more strongly associated with decreases in quality-related costs than with rapid improvement. In addition, the results of the Ozan study might be premature as U.S. firms might not, in aggregate, be mature enough for a definitive evaluation of the success of quality improvement.

Another explanation has to do with the "push" associated with rapid quality improvement. Since the measure of quality conformance is related to final inspection quality, internal failure costs increase. For example, if management imposes goals for reduced numbers of defects and if systems are not in place to achieve those goals, costs will increase. An increase in internal failure costs resulting from greater emphasis on inspection is illustrative of this point. This study suggests that the learning organization might well be the answer to long-term competitiveness. Under the learning scenario, both modeling and field validation would suggest improved quality at reasonable costs. In summary, rapid speed of quality improvement can be detrimental on the cost side of the business. Inspection is effective in the short term, but costly. In addition, costs can increase due to sampling errors resulting from statistical sampling plans (i.e., 100% inspection doesn't occur). A slower, continuous improvement in a learning environment might be the best approach to achieve quality improvement at reasonable costs.

The model was supported by the empirical findings, but the empirical findings have limited generalizability. This is due to the small sample size associated with case-related research. This shortcoming needs to be addressed with further field-testing. A further limitation is the use of conformance as the definition by which quality improvement was measured. A more comprehensive view of quality would include design quality as a quality component. The goodness of the design should be evaluated, not just the goodness of the product or service against the design specifications (conformance). Studies in other environments where major resource expenditures in training, the quality process, or technology would also be of interest. This case environment was one of continuous improvement and customer-initiated quality change. Not all organizations have these quality improvement characteristics. [Received: April 27, 1995. Accepted: March 20, 1996.]

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