

# QUALITY CONTROL: AN INVESTIGATION OF ALTERNATIVE MANAGEMENT POLICIES

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## ABSTRACT

*Determining product quality can be accomplished by quality control personnel or production personnel. Either approach has identifiable costs. This paper presents a computer simulation model for a single channel, two stage process with a buffer inventory. The model provides for a control group (where inspection is performed by quality control personnel at the end of each process) and an experimental group (where inspection is made by production personnel during each process). The model is described using hypothetical parameters for production levels, machine deterioration, and repair times.*

Quality is a measure of satisfaction that brings customers back to a company's products or services. Without quality, as some American firms are beginning to discover, manufacturers run the risk of losing market share, profits and jobs. Poor quality is also a concern in the areas of cost control and productivity. According to Business Week,

Auto industry sources estimate that as much as 25% of the price of a car is attributable to poor quality: scrappage, reject parts, inspection and repair, and warranty costs ... [and] the director of manufacturing services at Borg-Warner estimates the company has been spending an average of 20% of sales to correct poor quality [8].

The potential savings from improved quality control could be dramatic. A Hewlett-Packard vice president conjectured:

One division estimates the ultimate result of supplanting the usual detect-and-fix methodology with a zero defects philosophy could be a 33% reduction in factory workers, a 25% savings

in manufacturing floor space and a 66% decrease in inventories [8].

Some attribute the cause of the problem to the assignment of responsibility for quality. An attitude called the "Let-It-Go" syndrome has developed in many manufacturing environments where it is accepted that a certain amount of product will be defective and allowed to leave the factory. Feigenbaum estimated that as much as 40% of productive capacity is used to test, rework and replace low quality items. He contended that automation is not the solution to quality problems; that without a consistent management effort to improve quality, automation simply speeds the production of poor quality units [4].

Those who share this view feel steps must be taken to detect defects at the production level in order to improve quality. Early detection of defects would reduce the effort expended in the production of units that eventually are rejected. Schonberger concluded that the "responsibility for quality rests with the makers of the part" and that if manufacturers want to improve qual-

ity, the first step should be to transfer the responsibility for quality from quality control departments to the production arena [10, p. 48].

A major concern of many production managers is that a shift of responsibility to manufacturing personnel from trained quality control inspectors would slow the rate of production, thereby increasing the product cost. One solution, suggested by Schonberger, is for the workers themselves to check the quality of their production [10, p. 56].

## REVIEW OF PRIOR RESEARCH

The relationship between quality control and defect detection has been examined in a number of studies in recent years. One tool utilized in the examination has been Markov chain analysis. Use of Markov analysis assumes that production processes deteriorate in quality as production increases; it has been used to estimate the probability of the existence of defective units of production. Other studies have examined the question of when the inspection activity should be undertaken in order to optimize the production process.

Keller suggested that in a system with a relatively small cost of inspection that is subject to failure at a random time, frequent inspections of the product units will minimize the expected loss due to downtime. He developed a method of minimizing total costs (costs due to downtime plus the cost of inspection) through an ordinary nonlinear differential equation [7].

Ballou and Pazer examined serial production systems where defective units not identified at one stage of production were incorporated into units at later stages of the process. The defective units were identified at later inspection points. They concluded that increasing the amount of inspection was not a cost effective way of compensat-

ing for inspection error (in the cases examined) [1]. Their model assumed that inspection was an exclusive activity, however, and did not consider the impact on production cost if the inspection were performed by personnel already employed in the production process.

Gershwin and Schick, using a Markov chain, modeled the behavior of a buffered transfer line with unreliable work stations. They concluded that line efficiency decreased as failure rates of subsequent machines increased [5]. In other words, as machines failed, more units waited longer times before further production could be continued and the investment in inventory increased.

Shanthikumar and Tien developed an algorithm to compute the production rate of a system where units were scrapped when a machine failed. Their analysis showed that the scrap rate had an impact on the size of the idle buffer stocks between multiple processing centers [11].

## PURPOSE OF PRESENT RESEARCH

The purpose of this paper is to report the results of a model developed to investigate the cost of production when inspection occurs at the point of production. The basic question addressed by the model is: Will the cost of production be adversely affected if production rates decrease in response to lower defect rejection rates? The relationship between the cost of production and defect rejection rates can be examined through the use of a Monte Carlo computer simulation model. General characteristics are defined and a simulated environment created. The model uses hypothetical parameters, but provides a methodology useful for testing the effects of alternative quality control policies.

The advantages of using a simulation include savings in time, relatively low cost, and simplification. Actual obser-

vations may disrupt production activity whereas simulations can be separate from the production arena and not influence the activities under study. Simulation simplifies the problem under investigation by reducing the time period to complete the study; thus, many confounding variables are minimized. If observations take several months the possibility of changes in the economic environment may influence the results of the study while a simulation can look at the different alternatives in light of consistent economic conditions. The length of time for actual observations can result in changes in employee morale, again affecting the results of the study. Simulation deals with the problem in terms of consistent variables surrounding the subject under investigation.

The model provides a means of examining the question: if a company changes its inspection and maintenance policy, will the cost of production be reduced significantly. Specifically, if the rate of production is decreased and the workers give increased attention to the adjustment of the equipment, will the production slow-down be offset by

the reduction in rejected units and nonproductive time. Hypotheses which may be tested by the model are:

H<sub>1</sub> The effective rate of production (the rate at which acceptable units are produced) in the slower, more closely watched system will be greater than the effective rate of production in the system with a faster production rate.

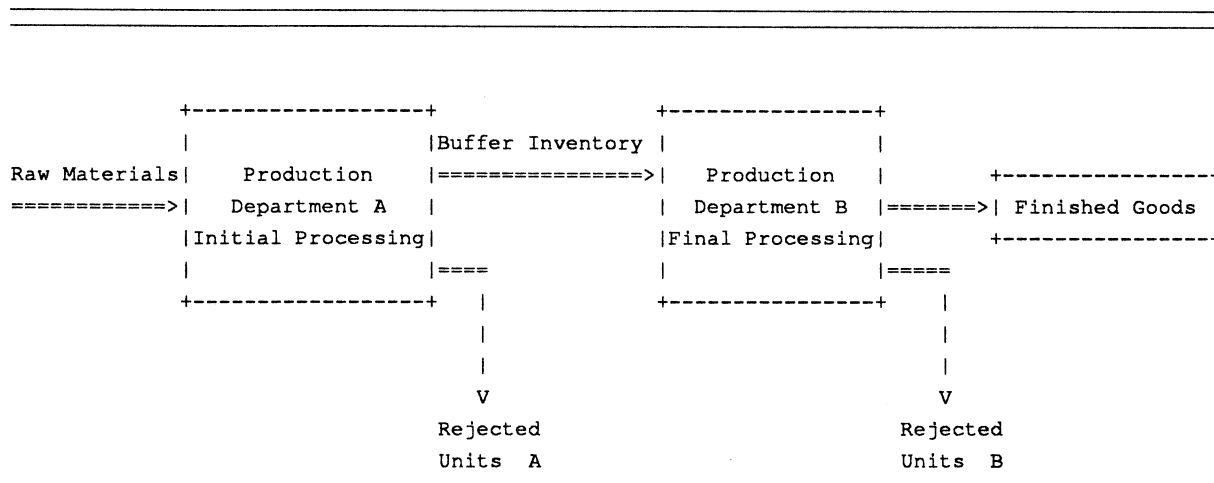
H<sub>2</sub> The number of rejected units and the amount of nonproductive time will be less for the slower system than for the faster system.

### THE PRODUCTION ENVIRONMENT

The production environment is a single channel, two stage process (see Figure I). The production departments (A and B) are sequentially arranged with a work-in-process buffer. Production activity occurs in batches and there are no partially processed units within the production departments.

The initial processing is completed in Department A before the product is transferred to Department B where processing is completed. There is an

Figure I



adequate supply of raw materials to allow uninterrupted production in Department A and no limit to the number of units that can be waiting in line between the two departments. There is an inspection of units at the end of each department but no inspection of units in the buffer inventory. The units are processed in Department B on a first in, first out basis.

As a result of variables not explicitly incorporated in the model (e.g., quality of the material and employee behavior), variability in production output in both departments is random. Resources for Department B are finite (i.e., only those units waiting in line from Department A can be processed in Department B). Thus, production activity in Department A has an effect on production activity in Department B.

Initially, quality control inspections are made at the end of production in each department; all units produced in the time period are either passed as acceptable or rejected as faulty. If all units are acceptable the process continues; if any units are rejected the department shuts down for adjustment. When a department shuts down, special maintenance teams are brought in to do the repairs. Variations in repair time are random as a result of variables not explicitly built into the model (e.g., the nature of the repair and availability of parts).

The cause of unacceptable units is assumed to be faulty equipment (an implicit assumption that the employees are qualified and highly motivated under all conditions). When defective units are found, the production process is temporarily halted for corrective action in order to bring the machines back into adjustment. Since the units processed by Department B are first processed by Department A, another cause for downtime in Department B is a lack of units in the buffer inventory. If there are no units in the buffer, Department B shuts down but there are

no rejected units.

## SIMULATION OF THE PRODUCTION ENVIRONMENT

The model of the production environment uses a Monte Carlo simulation. Cumulative probabilities of different production levels in Departments A and B are determined, and a random number generator is used to simulate the basic production process. Since there are no limits on the availability of raw materials, there are no constraints on simulated production levels for Department A. Simulated production levels for Department B are constrained by the units waiting in the buffer inventory between departments.

The sole cause for rejected production is assumed to be machine failure. The probability of machine failure (and rejection of production) is determined by Monte Carlo simulation. However, because of continual deterioration of machine adjustment, a single probability level is not appropriate. Since the probability of machine failure in any period is dependent on machine status in the prior period, a Markov chain is incorporated in the model to simulate the changing probabilities of machine failure. Probabilities for machine failure are:

$$P(F)_t = [P(F)_{t-1} \times P(C1)] + [(1 - P(F)_{t-1}) \times P(C2)] \quad (1)$$

where:

$P(F)_t$  = Probability machine will not fail at time t

$P(C1)$  = Transition state probability that machine will not fail

$P(C2)$  = Transition state probability that machine will self-correct from a state of failure.

Group I represents the control group; Group II represents a production environment where inspection and main-

tenance activities are routinely performed by production personnel during the production process. The results of the two groups differ because of different rates of production and different probabilities of machine failure. The production rate for Group II is assumed to be 90 percent of the production rate for Group I. The probability of machine failure in Group II is assumed to be 5 percentage points less than the probability of machine failure in Group I. The differences result from more intensive inspection and maintenance activities. The transition probabilities  $P(C1)$  and  $P(C2)$  are assumed to increase by 8 percentage points and one

percentage point, respectively. Specific case parameters appear in Table 1.

The distributions of random variables are assumed to be Poisson distributions. The use of Poisson distributions, incorporating greater probabilities for higher rates of production or repair times than for lower rates or times, implies the possibility that machines may have a minimum speed and repairs may have a start-up time.

### ANALYSIS OF THE RESULTS

The statistical technique used to analyze the data is analysis of variance

Table 1

Specific Case Group Parameters.

	Group I	Group II
Department A:		
Average rate of production per period	5.00 units	4.50 units
P (F)	85	90
P (C1)	80	88
P (C2)	10	11
Adjustment time	1.50 periods	1.80 periods
Department B:		
Average rate of production per period	4.50 units	3.96 units
P (F)	84	89
P (C1)	82	90
P (C2)	11	12
Adjustment time	2.00 periods	2.40 periods

(ANOVA). The general null hypothesis is:

$H_0$ : There is no difference between Group I results and Group II results.

Group II means relative to Group I means appear in Table 2. The reported values and the corresponding F-scores indicate the observed differences in downtime, acceptable production, rejected units, equivalent units of production, and buffer inventories.

### Downtime

The model generates estimates of downtime due to maladjustment of equipment (repair time) or lack of buffer inventories. Downtime for De-

partment A is due to repair activities; downtime for Department B is a result of repair activities as well as lack of buffer inventory. On the average, the expected downtime for Group II with frequent inspections is less than the downtime for Group I. The F-scores imply that the two groups are from different populations.

### Production Levels

The model generates four categories of data: (1) acceptable units, (2) rejected units, (3) buffer inventory at the end of each model run, and (4) total equivalent units of production.

Even though the overall mean rate of production in Group II is only 90% of

Table 2  
Group II Means Relative to Group I Means.

	Relative Mean Value Group II	F-score (df 1,48)
Downtime:		
Department A	0.826	20.909 ***
Department B	0.820	46.685 ***
Acceptable Units:		
Department A	1.089	4.208 **
Department B	2.828	22.857 ***
Rejected Units:		
Department A	0.756	23.444 ***
Department B	0.705	16.601 ***
Equivalent Units of Production	0.992	0.098
Buffer Inventory	1.337	1.448

\*\* Significant at 95  
\*\*\* Significant at 99.9

the overall mean rate of production in Group I, the analysis of acceptable production indicates that Group II has a higher mean rate of acceptable production than Group I. The F-scores imply that the two groups come from different populations.

The analysis also indicates a difference between the two groups in terms of defective units. The rate of rejection is lower for Group II than for Group I (as might be expected with a closer machine maintenance policy). The two populations represented by Groups I and II appear to be different.

The buffer inventory consists of units coming from Department A awaiting processing in Department B. The mean buffer inventory for Group II is slightly higher than the mean buffer inventory for Group I, but the differences are not statistically significant at a 90% confidence level.

Equivalent units are the number of units that would have been produced during a period if all efforts had resulted in completed units. The measure of equivalent units is computed by taking completed units and adjusting for partially completed units. The computation takes into account both acceptable units and defective units in measuring the amount of production effort expended in processing. The F-score indicates that the differences between the two groups are not significant at any confidence level greater than 90%. Thus, it cannot be concluded that the difference between the two groups is not attributable to chance.

Based on the results of the simulation, the following observations may be made. The level of equivalent units indicate that the reduced amount of downtime appears to offset the slower production rate. Even though the rate of production in Group II is diminished by 10 percent, the total amount of production (including both acceptable and defective units) is not significantly

different from Group I. A greater proportion of the effort expended in Group II produced acceptable units than in Group I.

The amount of production in Department B is significantly greater in Group II even though the rate of production is slower. This is due to two causes. First, the amount of idle time due to machine malfunction is less in Group II than in Group I. Second, the size of the buffer inventory in Group II is sufficiently large that idle time due to lack of waiting units is diminished.

## SUMMARY AND CONCLUSIONS

This paper presents the results of a somewhat simplistic model which should prove useful for investigation of possible outcomes of a change in production inspection policies. The model utilizes a computer simulation, incorporating hypothetical parameters, to simulate differences between alternative quality control policies. The results of the simulation, using hypothetical data, favor adoption of policies of inspection by production personnel where the process is slowed and the time is invested in more frequent machine checks.

To utilize the model in a specific production environment, parameters that reflect the activities must be estimated. Because the parameters used in this simulation are hypothetical, the conclusions drawn from the data can not be generalized to other environments.

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