THEORY EXPLICATING THE LINKAGE BETWEEN QUALITY, PRODUCTIVITY AND COMPETITIVE POSITION

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INTRODUCTION

Productivity has been of interest for generations, certainly since the beginning of the Industrial Revolution. Industrialists desired more output per person-hour and got it by using machines. Machine operators in sweat shops at low wages turned out phenomenal productivity. High productivity has always been linked to high profit.

Early improvers of productivity beyond this first great leap forward included Henry Ford with the moving production line and Frederick Taylor with the time-and-motion study and the management theory advocating interchangeability of people with all decisions "kicked upstairs".

In recent times, W.E. Deming [1] has noted that poor quality is the principal source of poor productivity in modern industry. Industrialists have chosen a mix of machines and operators within a set of processes to produce product at a desired profit. This profit is lowered by poor quality of the output. Poor quality due to a process may arise from two principle causes:

(a.) the process going out-of-control [2], and

(b.) the process having inadequate capability [3]. Deming notes that the cost to a firm of an instance of poor quality is much larger than the profit from an ordinary piece of production [4].

Deming advocates keeping the process under control and improving it continuously [5]. The Deming approach is empirical and operates upon the (successful) hypothesis [6] that improving quality raises productivity and enhances profitability.

In this research, the Deming hypothesis will be expressed in equations and hence will be elevated to the category of a theory. The research will also investigate the profitability of the output of a set of processes and its potential effects upon a firm. The research will address the question of using 100% testing (including NDE) as a supplement to "continuous improvement" to improve the output quality of processes.

Review of Progress in Quantitative Nondestructive Evaluation, Vol. 12
Edited by D.O. Thompson and D.E. Chimenti, Plenum Press, New York, 1993

The research results will be expressed as four equations displayed as (1), (4), (5), and (6) in the Theory section. They have the following verbal definitions which will be explained further below:

(a.) Productivity in dollars-per-dollar where poor quality is a negative term in the numerator,

(b.) Profitability which is positive when the productivity is greater than unity,

(c.) Dollar output of the process per unit time, and

(d.) Dollar output for the entire firm leading to profitability and competitive position.

Use of "continuous improvement" in Total Quality Management (TQM) and application of nondestructive evaluation (NDE) will be illustrated as methods to obtain quantitative improvement in quality.

THEORY

The productivity of a process is here defined as the value of the output of the process divided by the value of the input to carry on the process. This definition is not concerned with the value per person-hour which relates to standard of living. The assumption is that the firm has chosen a process with a mix of capital and labor which will be profitable if operated as planned. Obviously it cannot be profitable unless the output value is greater than the input value.

A. Process and Its Quality

A process in modern quality notation is sketched as in Figure 1. The process within the boundaries is composed of men, machines, materials, methods, and an environment (both physical and psychological). Raw materials coming in from the left are transformed into products exiting at the right. This sketch is helpful in trouble-shooting a process or in improving a process by providing a structure for visualizing all the influences acting upon or within the process.

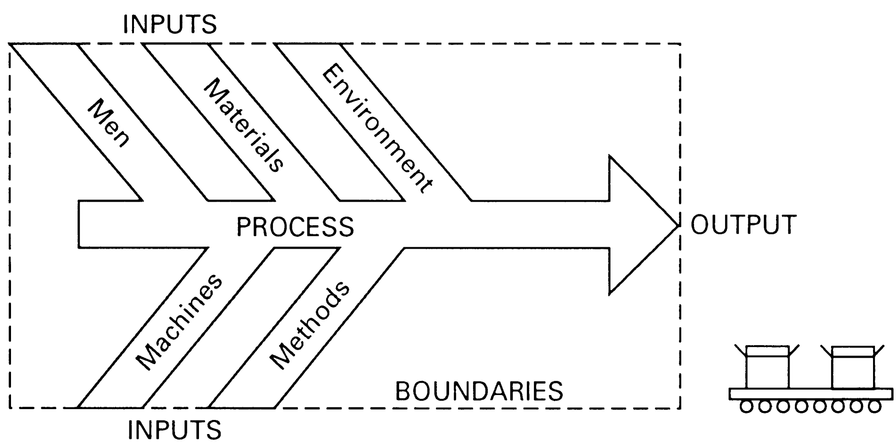

Fig. 1. A process with its internal contributing factors. Raw materials in is acted upon by the process to yield product out.

In an even more generic sense, the process can be sketched as in Figure 2. Here, the total input value per unit time, C, enters from the left. The quantity C includes not only the cost of the raw materials but also the cost of wages, utilities, work space, equipment amortization, inspection, SPC, insurance, and all the other costs a plant controller could pinpoint.

In this picture there are two outputs on the right, namely A and B. Here A is the value to the firm of all the conforming output made by the process in that unit time. The quantity B is the disvalue (or adverse costs) resulting from product of poor quality. An extensive list of cost categories contributing to B was given in Ref. (7) and is given here as Table 1. Following Deming, the adverse cost per nonconforming part is usually much larger than the profit per conforming part [4]. The magnitude of B for a single part could be the cost of a serious lawsuit.

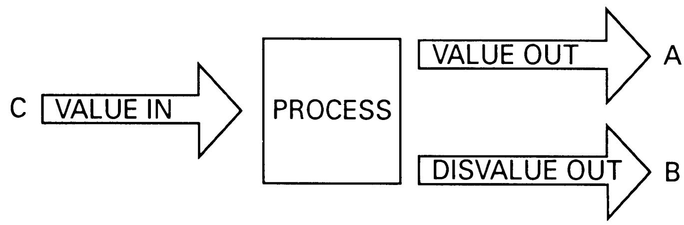

Fig. 2 A process seen generically. All the costs to run it per unit time enter as C. The value of its good output exits as A. Nonconforming output exits and detracts as a disvalue B. The productivity is based upon this figure.

Table 1

Partial List of Possible Detrimental Costs

The cost of reworking nonconforming items found immediately or later
The cost of scrapping nonconforming items (sunk cost) which cannot be reworked
The added costs of processing the nonconforming item further before detection
The cost of sorting lots later to find a nonconforming item
The cost of repairing batches of assemblies later
The cost of lost production later if lots of parts or batches of assemblies must be quarantined pending sorting and repair
Warranty costs
Cost of recalls
Law suits (cost unbounded for safety items)
Customer loyalty impinging upon future sales

Productivity

Using Figure 2 and the definition that productivity P is value out divided by value in, one writes

$$P = \frac{A - B}{C} \tag{1}$$

over unit time. The quantity A is the value outputted by the process, and can be expressed in terms of the number N of items made and the transfer price T as

$$A = NT \tag{2}$$

The quantity B is the disvalue or loss produced by the process; it is indeterminate or probabilistic because it depends not only upon the number n of nonconforming items produced but also upon the distance they proceed beyond the process before causing detrimental costs and also upon the type of damage they inflict upon the customer and ultimately back upon the production firm [7]. For instance, the best case is the junking of nonconforming parts detected early on by an inspection scheme. The inspection adds a small increment to C. The junking cost is J given as

$$J = nS, \tag{3}$$

where S is the sunk cost of the item up through the process in question. Then J is the entire magnitude of B for detection and elimination. The worst case as mentioned before could be costly lawsuits where each part could result in a cost several orders of magnitude greater than S.

At this point, it can be seen that poor quality resulting in nonconforming output can increase the detrimental costs B and hence lower productivity P in Equation (1).

Profit, Cash Flow, and Competitive Position

To turn a profit, productivity thus defined must be greater than 1.0. One can write the economic profit E as

$$E = P - 1 \tag{4}$$

where E is a fraction. (E = 1/2 would represent a 50% profit for the process.)

The dollars of profit D realized from the process in this time period is

$$D = EC. \tag{5}$$

Then for all the processes carried on by the firm the gross profit G before overhead, taxes, etc. is

$$G = \sum_{i=1}^{m} D_i \tag{6}$$

where the sum is over all processes i from l through m.

The analysis of P in terms of B shows that the value of E in Equation (4) is lowered by poor quality. Hence, the dollar output D in Equation (5) is also lowered by poor quality. Each process yielding poor quality will contribute to a decrease in G, the gross profit. G is related to the competitive position of the firm because G can be used for dividends, raises, quality improvement, advertising, buying out the competitor, or other goals. Hence, low quality is detrimental to the competitive position.

Summary of Theory

The above theory shows that improving quality increases productivity and that increased productivity enhances the competitive position. The Deming hypothesis has been systematized into a theory which may be substantiated further in the future by financial analysis to elevate it to the status of a law.

METHODS

Equation (1) can be impacted by SPC, continuous improvement, and 100% inspection.

First Stage of Study: SPC

Suppose a process is being studied for quality for the first time. Its instantaneous productivity is

$$P = (A - B)/C \tag{7}$$

which may be poor due to an out-of-control condition. With the introduction and use of SPC to keep the process under control [2], the productivity is raised to a baseline value of

$$P_o = (A_o - B_o)/C_o \tag{8}$$

where

$$A_o > A \tag{9}$$

and

$$B_o < B \tag{10}$$

since fewer nonconforming items are produced on the average. C_o may be slightly higher than C if SPC adds any cost. (Frequently there is no added cost for SPC because the machine operator can do it in his idle time.) Nevertheless, $B_o > 0$ by statistical fluctuation [8].

Continuous Improvement

To lower B_o, continuous improvement could be attempted. At some future point in time, one would find

$$P_1 = (A_1 - B_1)/C_1. \tag{11}$$

One would have

$$A_1 > A_o, \tag{12}$$

$$B_1 < B_o, \tag{13}$$

$$B_1 > 0, \tag{14}$$

and generally

$$C_1 > C_o. \tag{15}$$

The latter would occur because the cost of improvement (R&D) would have to be amortized. Upon occasion one might have $C_1 < C_o$ if the R&D resulted in a cheaper process. An internal rate of return calculation [9] would show whether a new process should be installed. It should be noted that

$$N_1 - N_o = n_o - n_1 \tag{16}$$

so that the increase in revenue arising from $A_1 > A_o$ is still much smaller in general than the decrease in detrimental costs arising from $B_1 < B_o$. The detrimental cost of poor quality is dominant rather than the profit from selling more good items.

According to Deming, a new process installed for continuous improvement or for any other reason should be inspected 100% for a period of time, say 6 months, until its continued operation at its design capability level is established.

100% Inspection (Including NDE)

Starting with the baseline value, again, one could install 100% inspection to lower B. One would have

$$P_2 = (A_2 - B_2)/C_2. \tag{17}$$

In this situation,

$$A_2 = A_o, \tag{18}$$

$$B_2 = 0, \tag{19}$$

and

$$C_2 > C_o \tag{20}$$

because the 100% inspection (NDE or other) would be cheap but not free.

Comparison

At this point a comparison could be made between P_1 and P_2 to determine the more advantageous quality strategy. While the common wisdom of the day dictates continuous improvement [10], it is possible that 100% inspection of an under-control existing process might result in higher productivity by making $B_2 = 0$. ($B_2 = 0$ only if the POD is high enough.)

CONCLUSION

W.E. Deming's hypothesis that improving quality will raise productivity and that raising productivity will enhance competitive position has been elevated to the status of a law by writing and analyzing simple algebraic equations for productivity and gross profit. The key factor is the negative term caused by poor quality in the numerator of the productivity equation. Methods to improve quality include SPC, continuous improvement, and 100% inspection. It has been shown that after a process has been brought under control by SPC, it might be advantageous to install 100% inspection (possibly NDE) instead of or during "continuous improvement". The equations may yield the decision to continue 100% inspection indefinitely depending upon the relative magnitudes of the detrimental costs to be encountered as a result of failures.

ACKNOWLEDGEMENT

This work was sponsored by NIST under cooperative agreement #70NANB9H0916 and was performed at the Center for NDE, Iowa State University.

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