

Developments In Business Simulation & Experiential Exercises, Volume 17, 1990

PRODUCT QUALITY IN BUSINESS SIMULATIONS

Precha Thavikulwat, Towson State University

ABSTRACT

Quality is defined as the absence of defects. Models and procedures that address product quality in production, in a modeled market, and in a real market are presented. For production, the proposed model makes defects an exponential function of a floor, a ceiling, a number of causes, a rate of reaction, and a random variable. For a modeled market, the proposed model makes lost demand a constant multiple of each defective unit sold. For a real market, the proposed caveat emptor procedure of giving no points to the purchase of defective products has two variants: informed and uninformed. The all-or-none principle of inspection is considered, and a rule for applying it to the modeled market is developed. This rule may apply also to real-world problems.

INTRODUCTION

Although product quality has been a much-discussed issue in management for decades, business simulations have either ignored the issue or treated product quality as a product attribute. Thus, THE BUSINESS POLICY GAME (Cotter & Fritzsche, 1991) defines quality as a choice among three models, and ENTERPRISE (Hauser, 1989) relates it orthogonally to the attribute of versatility. In neither case does the simulation address defects, the central issue in product quality.

A quality product is one without defects.¹ Defects are not attributes, but inadequacies in one or more attributes. Whereas attributes are designed, defects are inadvertent. Accordingly, models that assume perfect products, such as Teach's (1990) model of product attributes and Gold's (1991) and Gold and Pray's (1989) models of production, cannot be extended directly to cover product quality without violating its inadvertent character. Moreover, product quality also affects both the production side and the marketing side of business. A simulation that accounts for quality has to address both sides. Accordingly, this paper will present models and procedures that embody the character of product quality, accounting for product quality on both the production side and the marketing side.

Although much has been written about the design of business simulations, how participants might apply previous learning to enhance their performance in simulations has been infrequently discussed. Frazer's (1983) analysis of strategy in BANKRUPT and Goosen's (1990) discussion of a pricing algorithm being notable exceptions. Inasmuch as "gaming lends itself to the pragmatic interpretation of a general principle in a specific situation" (Hsu, 1989: 429), this paper also will indicate how participants can apply principles of experimental design, of probability, and of statistical quality control to the resulting simulation.

Finally, this paper will examine the all-or-none principle of inspection put forth by Shingo (1986), and develop from it a rule that participants can apply. To the extent the models presented here are reflected in a real-world situation, the rule will have real-world application.

1.

¹ This definition is equivalent to "conformance to requirements" and narrower than "fitness for use." The advantage of the narrower definition is its objectivity (Crosby, 1979).

THE PRODUCTION SIDE

Emergence of Defects

Defects occur; they are not selected. Although the appearance of a defect is an uncertain event, each defect has a definite cause that can be found by analysis and experimentation. Thus, to capture product quality on the production side, the model should allow defects to arise as random events influenced by variables participants can control, but participants should not be cognizant of the causative variables at the start.

Consider a model where each unit of product has associated with it a probability (p) of being defective that is constrained by a floor (L), a ceiling (H), a number (n) of causes (x_1, x_2, \dots, x_n), a rate of reaction (k), and a random variable (E), as follows:

$$P = f(L, H, X_1, X_2, \dots, x_n, k, \epsilon) \quad (1)$$

Causes can be scaled as positive ratios. The ratios might be measures of slack resources, such as slack equipment capacity divided by equipment usage; of resource stability, such as the number of experienced workers divided by the number of total workers; of management attention, such as expenditures on training divided by expenditures on wages; and so forth. Provided the ratios are consistently defined such that higher values are associated with lower defect rates, the ratios can reasonably be aggregated by their geometric mean (x), as follows:

$$x = \sqrt[n]{x_1 x_2 x_3 \dots x_n} \quad (2)$$

For example, if $x_1 = .2$; $x_2 = .3$; and $n = 2$, then x would be the square root of .06, or .24.

As is well known, the geometric mean is generally less than, and never exceeds, the arithmetic mean. (The arithmetic mean is .25 for the example above.) Accordingly, this method of aggregation gives more weight to smaller ratios. In the extreme case when one of the ratios is zero, the aggregated value will be zero, mirroring the position that an absolute deficiency in one cause cannot be remedied by excesses in others.

Consider now an explicit formulation of Equation 1, as follows:

$$P = L + \frac{H - L}{e^{kx}} + \epsilon \quad (3)$$

Equation 3 gives rise to an average defect rate that drops exponentially from its ceiling value to its floor value as the geometric mean of causal ratios increases from zero to infinity.

In administering a simulation incorporating this model, the administrator would set all values excepting the causal ratios. These the participants would control. Participants may be told the possible causal ratios, but the precise ratios that the administrator selected to be causative in any gaming session would be kept from them. Thus, their task would be to identify quickly the active causal ratios by experimentation and statistical analysis, to compute the cost and benefit of action on the identified causes, and to make decisions that maximize profit. In this task, a knowledge of Taguchi (Ross, 1988) and other methods of experimental design would be advantageous.

Developments In Business Simulation & Experiential Exercises, Volume 17, 1990

Inspection Of Products

For the causal search, the simulation must allow for inspection to determine if each product is good or defective. Lot sampling methods discussed in many textbooks on production and operations management are unsuited for this purpose, because lot sampling presumes immediate corrective action cannot be taken when a defective item is discovered. Continuous sampling methods are suitable, but these are usually discussed only in specialized texts on statistical quality control (e.g., Duncan, 1986).

Among the simplest of continuous sampling methods is Dodge's (1943) method, commonly called CSP-1. CSP-1 is a cycling plan that begins with 100% inspection of items as they are produced, changing to random inspection at a specified sampling rate (f) when a clearance number (i) of consecutive items has been found to be nondefective, and reverting to 100% inspection when one defective item is found. Thus, a CSP-1 plan with a sampling rate of .2 and a clearance number of 4 might give rise to the results shown in Figure 1, where products flow to the right; where pluses (+) and minuses (-) represent nondefective and defective items, respectively; where f and i each represent an item at the sampling phase and the clearance phase, respectively; and where arrowheads (→) point to inspected items.

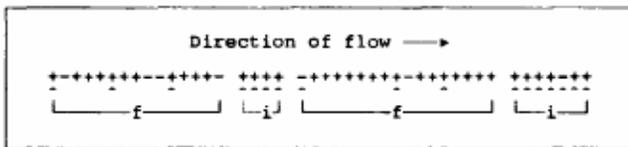


Figure 1
Inspection of Products Under CSP-1

If items found to be nondefective are passed, and items found to be defective are destroyed, then CSP-1 rectifies as well as informs. Thus, when large numbers of defective products are being produced, 100% inspection will dominate over sampled inspection, and large numbers of defective products will be eliminated.

Implicit in CSP-1 is the understanding that when defects are found under 100% inspection, incoming product quality is Out of control. Thus, production supervisors will respond immediately to correct the problem. This allows for two levels of control: tolerance control, corresponding to Taguchi's tolerance design (Ross, 1988), and parameter control, corresponding to Taguchi's parameter design. If tolerance control is automated whereas parameter control is effected by participants' decisions on causative variables, then the two levels will be distinctly separated.

Tolerance control can be automated by making the random variable (E) of Equation 3 an incrementing function wherein each item produced has a probability of causing an upward increment. When a defective unit is found under 100% inspection, supervisory action is simulated by a reverse increment. Thus, if the controlling defect rate had incremented from .05 to .20 in three steps of .05 each, subsequently, the first defect found under 100% inspection will lower the control rate to .15; the second, to .10; and the third, back to .05, provided nothing else has affected the defect rate in the interval.

THE MARKETING SIDE

The means of addressing product quality on the marketing side depends on how the simulation orders the market. If the market is modeled, then a model accounting for product quality is required; if it is real, then a procedure is required. Models for market demand have been proposed by Carvalho (1991), Goad & Pray (1990), Goosen (1986), Teach (1990), and Thavikulwat (1989). Procedures for a real market have been proposed by Thavikulwat (1990). But those models and procedures do not provide for defective products.

Modeled Market

When products can be defective, sales of defective products should depress demand such that the net demand (D') will be less than the potential demand (D) by the demand lost (L) due to defective products sold, as follows:

$$D' = D - L \quad (4)$$

Consider a model where the lost demand is a constant (M) for each defective item sold in the same period. Then given a defect rate of products sold (p) and a quantity sold (s), the lost demand will be as follows:

$$L = Sp^2M \quad (5)$$

Now if a company has available for sale sufficient units to meet the net demand, then the quantity sold will equal the net demand, as follows:

$$S = D' \quad (6)$$

Incorporating Equation 5 into 4, and 4 into 6, gives

$$S = D - Sp^2M \quad (7)$$

Collecting terms, we have

$$S = \frac{D}{1 + p^2M} \quad (8)$$

On average, the defect rate of products available for sale (p') equals the defect rate of products sold. Accordingly, on average

$$S = \frac{D}{1 + p'M} \quad (9)$$

Thus, in computing sales of products that may be defective, the simulation can use either an algorithm that considers each product unit individually, or one based on the average. The individual approach is exact; the average, simpler.

By the individual approach, the algorithm would "sell" products one unit at a time as long as net demand was greater than zero. The quality of each unit sold would be determined by a random number taken from a uniform distribution bounded by zero and one. If the chosen random number was less than the defect rate of products available for sale, that unit would be considered defective, the number of defective products available for sale would be reduced by one, and subsequent demand would be reduced by one plus M. Otherwise, the number of nondefective products and subsequent demand would both be reduced by one.

By the average approach, sales would be computed by Equation 9. Both defective and nondefective products available for sale would be reduced by the same proportion, rounded to the closest integer.

Real Market

In a real market, sales result from participants purchasing products made by companies. Participants receive income for their purchases, and get points towards grades proportional to the number of products they buy. Transactions are kept at arms length by disallowing participants from buying their own company's products. No modeling of demand is needed in this scheme. The procedures, however, affect the possibilities for learning.

Consider a caveat emptor procedure that makes all purchases final and gives no points to the purchase of defective products. Consider two variants: informed and uninformed. The informed variant lets buyers know the defect rate of the products a company has offered for sale. The uninformed variant keeps this information secret.

Developments In Business Simulation & Experiential Exercises, Volume 17, 1990

With both variants, when some products bought are defective, the true price to the buyer will be higher than the offered price. The intelligent buyer will want to know the true price.

Given a price (v) and purchasing quantity (Q), the total cost (C) to the purchaser of accepting an offer is as follows:

$$C = VQ \quad (10)$$

Given the defect rate of the products purchased (p''), the quantity of nondefective products the purchaser received (Q') is as follows:

$$Q' = Q(1 - p'') \quad (11)$$

Accordingly, the true price (V') of the purchase is as follows:

$$V' = \frac{C}{Q'} \quad (12)$$

Incorporating Equations 10 and 11 into 12, we have the following:

$$v' = \frac{v}{1 - p''} \quad (13)$$

Because the defect rate of the products offered for sale (p^*) equals, on average, the defect rate of the products purchased (p''), for the informed variant, the buyer could substitute p for p'' , and compute the estimated true price at once. For the uninformed variant, the buyer could purchase a sample quantity first, and use the defect rate of the sample instead. Thus, intelligent purchasing under the informed variant requires an understanding of probability; intelligent purchasing under the uninformed variant requires, in addition, an understanding of lot-sampling statistics.

Whereas in the case of a modeled market, sales may be computed by either an individual approach or an average approach, in the case of a real market, only the individual approach is suitable. The average approach permits anomalous results due to rounding.

By the individual approach, when a sale is made, the product quality of the sale would be determined by an algorithm that randomly selects the items sold, one at a time, from those available. Thus, if the items available for sale are 40% defective, the purchaser could conceivably realize a purchase that is anywhere from 0% to 100% defective, although, on average, the purchaser will realize the 40% defective rate.

By the average approach, the number of defective products the purchaser bought would be computed by taking 40% of the total number purchased. The anomaly arises when the purchaser buys unit. Taking 40% of 1 and rounding the result gives 0. Thus, by successively buying a unit at a time so long the defective rate of the products available is less than 50%, the purchaser will never get a defective product.

THE ALL-OR-NONE PRINCIPLE

Statistical quality control can be entrancing. Shingo (1986), the noted authority on zero quality control, confesses to having been caught in its spell for 26 years. The statistics of even a scheme as apparently simple as CSP-1 can be seductive enough to entrap the mind, luring attention away from the fundamentals of the situation. Success in quality control, however, depends on grasping fundamentals (Karatsu, 1988).

As Shingo (1986) has argued, zero quality control demands that if inspection is performed at all, one should "always use 100 percent inspection rather than sampling inspection" (p. 54). By this principle, the fundamental choice is between no inspection and 100% inspection. A ruse can be derived from this all-or-none principle for companies that supply the modeled market.

The decision variables controlling inspection are the sampling rate (f) and clearance number (i) of the CSP-1 plan. The two fundamental possibilities are no inspection ($f = 0$, $i = 0$) and 100% inspection ($f = 1$, $i = \infty$).

The first concern of business is to maximize profit (y), which can be defined as the difference between total contribution (G) and total inspection cost (C), as follows:

$$Y = G - C \quad (14)$$

The total contribution is the unit contribution (g) from each unit sold multiplied by the number of units sold (S), as follows:

$$G = gs \quad (15)$$

The total Inspection cost is the inspection cost per item inspected (c) multiplied by the sampling rate² and the number of incoming units (I), as follows:

$$C = cfi \quad (16)$$

When inspection is random and items that are found to be defective are destroyed, the number of incoming units can be derived from the incoming defect rate (p), the sampling rate, and the number of units sold, as follows:

$$I = \frac{S}{1 - fp} \quad (17)$$

Incorporating Equation 17 into 16, and Equation 15 and 16 into 14, we have

$$Y = (g - cf')S \quad (18)$$

where

$$f' = \frac{f}{1 - fp} \quad (19)$$

Incorporating Equations 9 into 18, we have

$$Y = \frac{(g - cf')D}{1 + p'M} \quad (20)$$

where³

$$p' = \frac{p(1 - f)}{1 - fp} \quad (21)$$

³ The profits computed by Equation 20 must be equal at the point of indifference between no inspection ($f = 0$, $V = 0$, $p = p$) and 100% inspection ($f = 1$, $f' = 1/(1-p)$, $p = 0$). Thus,

$$\frac{gD}{1 + p'M} = gD - \frac{cD}{1 - p} \quad (22)$$

which simplifies to

² The inspection rate, accounting for items inspected in both the sampling and clearance phases of the CSP-1 plan, would generally be more correct. But because this analysis considers only two possibilities, no inspection and 100% inspection, the sampling rate is its equivalent.

³ Equation 21 can be derived by observing that the total number of outgoing units is $1(1 - fp)$ and that the number of outgoing units that are defective is $Ip(1 - f)$.

Developments In Business Simulation & Experiential Exercises, Volume 17, 1990

$$\frac{c}{q} = (1 - p) - \frac{1 - p}{1 + pM} \quad (23)$$

Thus, if the ratio of unit inspection cost to unit contribution is greater than the right hand side of Equation 23, no inspection is more economical than 100% inspection, and conversely also. Plots of Equation 23 are shown in Figure 2. The rule is to forgo inspection when the cost-contribution ratio falls above the applicable curve, and to inspect all items when it falls below the curve.

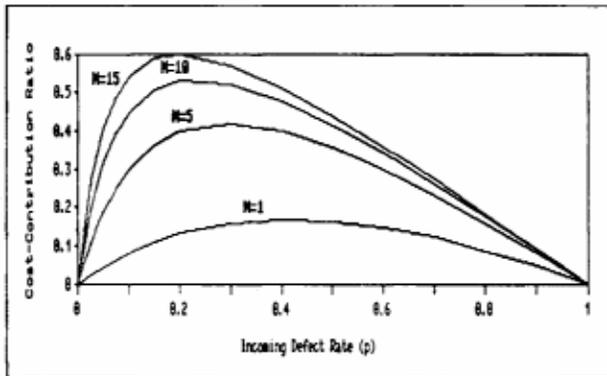


Figure 2
Critical Cost-Contribution Ratios
as a Function of Incoming Defect Rate

DISCUSSION

The models and procedures presented respect the inadvertent character of product quality. A simulation that includes such models and procedures will enable participants to apply principles of quality control at any level of analysis, and to learn from the experience.

Models and procedures that are true to the underlying character of a concept mean that answers will be correct only when they come from principles that are right. Such designs allow students and researchers to test the soundness of business principles, for these will suggest rules that are effective.

The cost-contribution rule derived from Shingos all-or-none principle may have real-world application. If it should prove generally useful, it will demonstrate simulations contribution to the understanding of real-world problems.

REFERENCES

- Carvalho, G. F. (1991), Theoretical derivation of a market demand function for business simulators *Developments in Business Simulation & Experiential Exercises*, 17, 11-15.
- Cotter, R. V., and Fritzsche, D. J. (1991), *THE BUSINESS POLICY GAME* (3rd ed), Englewood Cliffs, NJ: Prentice Hall.
- Crosby, P. B. (1979), *Quality is Free*, NY: McGraw-Hill.
- Dodge, H. F. (1943), "A sampling inspection plan for continuous production," *Annals of Mathematical Statistics*, 43, 264-279.
- Duncan, A. J. (1986), *Quality control and industrial statistics* (5th ed), Homewood, IL: Irwin.
- Frazer, J. R. (1983), *BANKRUPT - A deceptively simple business strategy game*, - *Developments in Business Simulation & Experiential Exercises*, 10, 98-100.
- Gold, S. C. (1991), Modeling short-run cost and production functions using Sheppard's lemma in computerized business simulations," *Developments in Business Simulation & Games*, 20, 300-318

- Gold, S. C., and Pray, T. F. (1989), "The production frontier: Modeling production in computerized business simulations," *Simulation & Games*, 20, 300-318.
- Gold, S. C., and Pray, T. F. (1990), "Modeling demand in computerized business simulations," in J. W. Gentry (Ed.), *Guide to business gaming and experiential learning (ABSEL)*, (pp. 117-138), East Brunswick, NJ: Nichols/GP Publishing.
- Goosen, K. R. (1990), Pricing strategy algorithms for playing business simulations," *Developments in Business Simulation & Experiential Exercises*, 17, 192.
- Goosen, K. R. (1986), "An interpretation approach to developing mathematical functions for business simulations," *Developments in Business Simulation & Experiential Exercises*, 13, 248-255.
- Hauser, J. R. (1989), *ENTERPRISE: An integrated management exercise*, Redwood City, CA: Scientific Press.
- Hsu, E. (1989), "Role-Event gaming simulation in management education: A conceptual framework and review," *Simulation & Games*, 20, 409-438.
- Karatsu, H. (1988) *TQC wisdom of Japan* (D. J. Lu, Trans.), Cambridge, MA: Productivity Press.
- Ross, P. J. (1988), *Taguchi techniques for quality engineering*, NY: McGraw-Hill
- Shingo, S. (1986), *Zero quality control: Source inspection and the poka-yoke system*, Cambridge, MA: Productivity Press.
- Teach, R. D. (1990), "Demand equations for business simulations with market segments," *Simulation & Gaming*, 21, 423-442.
- Thavikulwat, P. (1989), "Modeling market demand in a demand-independent business simulation," *Simulation & Games*, 20, 439-458.
- Thavikulwat, P. (1990), "Consumption as the objective in computer-scored total enterprise simulations," *Developments in Business Simulation & Experiential Exercises*, 17, 167-169.