OPTIMAL SAMPLING FOR SYSTEMS INTEGRATION: A CASE STUDY

G. Kent Webb, School of Business, San Jose State University, One Washington Square, San Jose, CA 95192. 408-924-1348, webb_k@cob.sjsu.edu

ABSTRACT

A leading technology company designs a new product according to customer needs then integrates components that are manufactured by contractors. Components are integrated before testing. This paper presents an optimal sampling analysis of one prominent product line that suggests the company could benefit from more thorough quality control.

INTRODUCTION

Researchers in many fields are faced with a decision on the optimal sample size given the cost and reliability of data [5] [4]. Variability of estimates in relationship to sample size is one of the oldest issues in the statistical literature [1], dating back to the 1700s. The market research literature contains numerous studies looking at the value of information and the best sample size [3]. Accounting auditors often face the decision of choosing an appropriate sample size, although in practice they often use subjective approaches to evaluate the economic efficiency of sample sizes [2].

A recent article in the operations research literature examines the information-economics of sampling in an effort to develop strategies for incorporating both the value and costs of information in deciding on whether to sample and what would be the appropriate sample size [6]. The authors summarize: "The statistical approach focuses on determining the probabilities of type I and II errors, while the information-economics approach focuses on maximizing the expected monetary value of the whole process."

The following case study applies optimal sampling tools to examine the decision of managers at a manufacturing company to forgo quality control of incoming parts that are then integrated into their products. No formal analysis seems to have been done to support this decision; instead the company relies on the high standards of quality control of its suppliers. The high cost of quality control was another reason given. This reasoning constitutes an informal decision analysis, the cost of sampling is high and the likelihood of finding a defect is low so the benefits are low.

Some defects are discovered during a final burn-in of integrated systems that lasts from about 24 to 36 hours. The precise time for the final burn in is based on historical data. The burn in process typically identifies loose connections or components that are dead on arrival, but less catastrophic problems that will eventually cause system failures evade detection.

QUALITY CONTROL FOR ONE PRODUCT LINE

As a basis for evaluating this decision, informal data was assembled for one of the company's most important products, a processor card. The failure rate for this card is about 3 percent for 99 percent of the shipments received from suppliers. Occasionally, the other 1 percent, a shipment arrives with a much higher rate, in the range of 20 percent. Sometimes these higher rates are associated with new suppliers, but also changes in circumstances at existing suppliers that would be unknown to the manufacturer can result in the higher failure rates.

About half of the defective cards are detected during system burn in. The cost of this detection process is estimated to be about $80 per card, mostly related to labor expense. The other half of the defective cards, those that are detected by the customer, have a significantly higher cost, estimated at about $750, mostly for labor expense. The cost of testing prior to systems integration is estimated to be about $25 per card.

These figures are combined into the payoff table based on the following calculations for a shipment of 2000. When a shipment arrives with a 3 percent defect rate, 0.5 of cards are detected during burn in at a cost of $80 per card for a cost of: 2000 * 0.03 * 0.5 * $80 = $2400. About 0.5 of the cards are detected by the customer for a cost of: 2000 * 0.03 * .5 * $750 = $22,400. Combining these costs: $2400 + $22,500 = $24,900.

When a shipment of 2000 arrives with a defect rate of 20 percent, the calculations for the cost, detected by burn in or by a customer, are: [2000 * 0.20 * 0.5 * $80] + [2000 * 0.20 * 0.5 * 750] = $166,000. Cisco could also test each incoming card, rejecting the notion that the supplier's quality control is adequate. When the card defect rate is 3 percent, the cost avoided is the cost associated with not replacing the cards during burn in or at the customer's request, less the cost of testing: $24,900 – [2000 * $25] = -$25,100. When the defect rate is 20 percent, this calculation is: $166,000 – [2000 * $25] = $116,000.

At least two simplifications have been made to the calculations that may be significant enough to change the result. First, the cost related to the loss of customer satisfaction resulting from hardware failures is not included. This cost may be significant but is difficult to estimate and controversial so is often excluded from industry analysis. Leaving this cost out will bias the results in favor of not testing. Second, the calculation assumes that quality control will detect all cards that will fail within the equipment warranty. This biases the results in favor of testing. With these simplifications, the Table 1 summarizes the result.

Table 1: No Test or All Test Payoffs

Percent Defective	Historic Probability	Accept without Testing	Reject, test all cards
P = 0.03	Pr = 0.99	- $ 24,900	- $ 25,100
P = 0.20	Pr = 0.01	- $166,000	$116,000
Expected Value		- $ 26,311	- $ 23,689

The expected value of the current policy of not testing incoming cards for a shipment of 2000 is a cost of $26,311. Testing all cards results in cost of $23,689. Since costs should be avoided, the current policy of accepting incoming shipments without testing seems to be inappropriate.

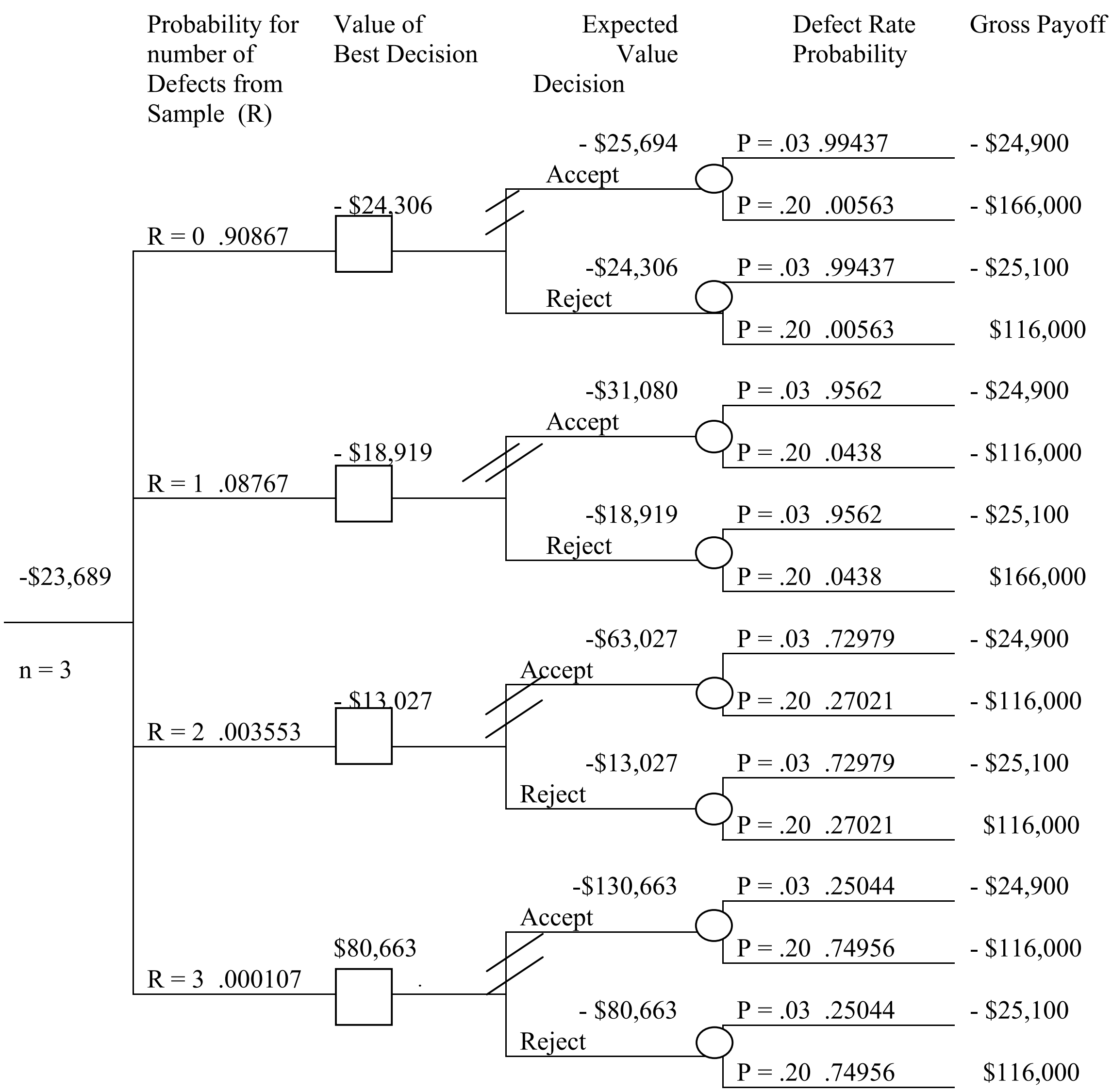
Optimal sampling may provide an intermediate solution that can be explored first using the Expected Value of Perfect Information (EVPI). A quality control manager who always tested high defect shipments, but allows low defect shipments pass would insure that maximum value for each these two scenarios represented by the two rows in Table 1. The expected value of always making this correct decision is: ((.99 * - $24.900) + (.01 x $166,000)) = - $ 23.491.

The Expected Value of Perfect Information (EVPI) represents the advantage offered by always making the right choice, calculated here as the expected value of the highest value in each row: EVPI = - $23,491 - (- $23,689) = $198. Since samples are available for less than this value, sampling costs are $25 per unit in this case, a sample might be beneficial. The following analysis describes how to determine the costs and benefits of the sample, and the optimal sample size. The optimal sample size represents the maximum difference between the benefits of sampling and the cost of sampling. The following sections illustrate the calculations involved in determining these values.

Cost and Benefit Analysis of Sample of Size 3

As an illustration of the procedure for identifying the optimal sample, consider the case for taking a sample of 3 from a shipment of 2000 cards. A shipment arrives that has a defect proportion of either 0.03 (P = 0.03) or 0.20 (P = 0.20). Historically, the chance for a defect rate of P = 0.03 is 99 percent, (Pr = 0.99). The chance for a defect rate of P = 0.20 is 1 percent (Pr = 0.01). Applying the binomial distribution, the quality control manager's decision tree can be represented by Figure 1.

Figure 1: Decision Tree for Quality Control Sample When N = 3



Poor decisions are pruned from the tree, indicated by the symbol two crosshatched lines. The expected value of making all of the right decisions is indicated at the left of the diagram, - $23,689. This expected value is the same, however, as the value reported as the best alternative in Table 1, the choice of sampling all of the incoming cards. There is no gain in what is commonly referred to as the expected value of sample information (EVSI), and the cost of sampling has not yet been included in the calculation. The expected net gain from sampling (ENGS) can be calculated by further reducing the EVSI for the cost of the sample, three cards at $25 each. This brings the ENGS to - $75. The result indicates that sampling all of the incoming cards would be preferred to just a sample of three. To complete the study, alternative samples sizes should be examined to find the value for n, the sample, which maximizes the expected net gain from sampling (ENGS).

CONCLUSIONS

Completing the analysis in this example over all values of possible sample sizes indicates that subjecting all incoming cards to quality control is the best solution. Cards go through some quality control during burn in, a step that would remain even with sampling. In addition, the EVPI is low in this example since the cost of total quality control is nearly the same as no quality control even when the defect rate is low. A relatively minor change in some of the assumptions would change the result, but adding some value for customer satisfaction would tend to favor testing of components before the integration process.

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