Sampling programs for pre-service and in-service inspection

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1 INTRODUCTION

Pre-service and in-service sampling inspection of nuclear power plants is used for quality assurance, reinspection and reevaluation, and verification of compliance with different regulations. According to Cochran (1977) there are four principal advantages of sampling over a complete inspection of population:

reduced cost
greater speed
greater scope
greater accuracy

Pre-service and in-service inspections include examinations of the plant equipment, components, instrumentation, and structures. Many items cannot be completely inspected due to their large number, inaccessibility, and limited high-quality personnel. In this situation, sampling inspections are very useful. However, specific conditions of plant operation put certain limitations on the applicability of different sampling methods.

(1) Items due for inspection do not arrive in batches or lots from manufacturer and have been installed in the plant.

(2) We cannot reject the population based on our findings during inspection; we have to accept it or make all necessary repairs.

(3) The population we deal with is not necessarily uniform: items come from

different manufacturers, and are installed by different teams, sometimes, according to different procedures.

(4) It is usually impossible to select a truly random sample because of accessibility and accountability problems.

To make our evaluation based on sampling procedures dependable, we have to select or develop methods specifically designed to the conditions mentioned above. This paper provides such methods for practicing engineers and statisticians.

2 CLASSIFICATION OF SAMPLING PROCEDURES AND METHODS

Two types of sampling techniques are developed for two applications. One is developed for the quality control of the production process. Another is for evaluating the existing population's quality. These techniques are based on different statistical methods. Quality control utilizes hypothesis testing, and quality evaluation uses parameter estimation theory. Sometimes they are called acceptance and assessment samplings, respectively. Both techniques may use sampling by attributes and variables. Description of these techniques one can find in Eisenhart et al. (1947)

Estimation theory can be devided into classical and nonclassical. Noncalssical estimation theory has two modifications: Bayesian method and liklihood density function method. Detailed descriptions of all methods is given by Goodman (1984, 1985).

3 THE CHOICE OF SAMPLING METHOD FOR PRE-SERVICE AND IN-SERVICE INSPECTIONS

After discussing all sampling methods, we have to decide which one is more appropriate for the service inspection of nuclear power plants. First, we have to reject the acceptance sampling based on hypothesis testing. The population of inspected items is already installed at the plant and it is too late to control quality of manufacturing or craftsmanship. We are now interested in the quality of the population and we must choose methods that address directly this question. In fact, we have a choice between classical and nonclassical estimations. Due to a potential vulnerability of the prior distribution, we should discard the Bayesian method. Therefore, we have a choice between classical and likelihood estimations. For sampling by attributes, the likelihood method gives a narrower interval estimate. On this ground a more cost-conscious person would prefer it to classical estimation and a more conservative person would prefer

classical estimation to the likelihood density function method. However, one consideration takes a precedence.

All methods are applicable for the case when a random sample is drawn from the uniform quality population. Unfortunately, in practical use, this situation is rare. Therefore, to make our estimation defensible, we have to develop methods of estimating nonuniform populations and biased samples. The only method that provides such potential is the likelihood density function method. That is why we recommend this method for pre-service and in-service inspections.

4 CRITERIA OF ACCEPTABLE QUALITY

Using an estimation approach, we come up with an evaluation of the population quality with some uncertainty. After that, we have to decide whether this quality given uncertainty involved is satisfactory. The most frequently used criterion in the nuclear industry is a 95/95 criterion. The criterion requires no less than 95 percent confidence that at least 95 percent of the population is adequate. This interpretation corresponds to the estimation approach or assessment sampling. However, we should keep in mind that the definition of confidence is different for different treatments of the same sampling result. In our opinion, only the likelihood density function method provides direct estimation of the population quality. The classical estimation is indirect because it deduces the confidence interval of the population parameter from a confidence interval of the sample estimate. In Bayesian estimate, in addition to likelihood estimate, we use some prior information which can be challenged. The example of the most economical sample strategy to meet 95/95 criterion is given by Goodman (1984).

The sampling strategy considered there has two numbers which are inappropriately called "acceptance" and "rejection" numbers which may cause confusion with the acceptance sampling. Actually, the "acceptance" number means that we have met our criterion at the certain step and the "rejection" number means that chances are small to meet our criterion by continuation of sampling and increasing of the cumulative sample size. If we have reached the "rejection" number at the certain step of sampling inspection, we would have four alternatives to the 100 percent inspection.

(1) We may continue sampling against small odds for success.

(2) We may change the type of inspection shifting from the sample by attributes to the samples by kinds or variables.

(3) We may choose the engineering reevaluation of rejected items.

(4) We may reconsider applicable acceptance criteria.

The cost of every alternative can be measured in dollars, and the less expensive one should be selected.

5 EVALUATION OF BIASED SAMPLES AND NONUNIFORM POPULATIONS

The application of all methods discussed is limited by requirement to draw an unbiased random sample. In case of an infinite (practically, sufficiently large) population, we are limited to uniform populations. For many occasions, we cannot meet these assumptions, and therefore our estimation using the regular methodology is inconclusive and indefensible. Deviation from the theory will be especially large in case of a biased sample from the nonuniform population which is a mixture of subpopulations with significantly different qualities.

Here, we attempt to generalize the theory to cover cases of the biased sample and the nonuniform population.

According to definition, the sample is biased if the sample estimate is a random number which means not equal to the corresponding population parameter. Therefore, we can consider any biased sample from the population as an unbiased sample from some subpopulation with different properties than the origin population. Hence, we can divide the population into two subpopulations. The property of one is represented fairly by our sample, while the property of the second is completely unknown. We will call them tested and untested subpopulations, respectively.

Assume that the population size is N, and a biased sample of size n was drawn, and k discrepant items were discovered. Let us denote the size of the untested subpopulation as x and number of discrepant items in it as m_2. The size of the tested subpopulation will be N-x and the number of discrepant items m_1. The quality p of the population can be estimated as:

$$p = \frac{N-x}{N} \cdot \frac{m_1}{N-x} + \frac{x}{N} \cdot \frac{m_2}{x} = \frac{m_1 + m_2}{N} \qquad (1)$$

To find the uncertainty distribution for the population parameter p, we have to find distribution for x, m_1 and m_2 first and then propagate uncertainty. By using, for example, the Monte Carlo simulation method, we can obtain the uncertainty distribution in question.

One sample selected n items from the subpopulation of size N-x and zero items from the subpopulation of size x. The probability f(x) of this outcome is:

$$f(x) = \frac{\binom{N-x}{n}}{\binom{N+1}{n+1}} \qquad (2)$$

The probability $f(m_1)$ that the tested subpopulation has m_1 discrepant items is:

$$f(m_1) = \frac{\binom{m_1}{k}\binom{N-x-m_1}{n-k}}{\binom{N-x+1}{n+1}} \qquad (3)$$

The distribution $f(m_2)$ of discrepant items in the untested subpopulation is assumed uniform from $m_2 = 0$ to $m_2 = x$.

If the size of the population is large enough, then binominal likelihood functions can be used. The quality of the population can be presented as:

$$p = (1 - Q)\, p_1 + Qp_2 \qquad (4)$$

where Q is a proportion of the untested subpopulation in the population and p_1 and p_2 are qualities of tested and untested subpopulations, respectively.

Corresponding distributions $f(p_1)$ and $f(Q)$ are:

$$f(p_1) = \frac{(n+1)!}{k!(n-k)!}\, p_1^{\,k}(1-p_1)^{n-k} \qquad (5)$$

$$f(Q) = (n+1)\,(1-Q)^n \qquad (6)$$

The distribution $f(p_2)$ is uniform in the range from $p_2 = 0$ to $p_2 = 1$.

Now consider cluster sampling. Typical examples of clusters are welds on beams, columns, or bolts in connections. We can count clusters, but the number of items in individual clusters varies. Therefore, it is impossible to draw a really random sample from the item's population. One frequently used procedure is to draw a random sample of M clusters from the cluster's population of size N, count all items in M clusters and draw a random sample of n items from them. Unfortunately, this "random" sample is unintentionally biased. Using the above approach, we can evaluate the population quality p according to formula:

$$p = \frac{N-x}{N} P_1 + \frac{x}{N} p_2 \qquad (7)$$

where the distribution $f(p_1)$ for p_1 is given by Eq. 5, the distribution $f(p_2)$ for p_2 is assumed uniform and the distribution f(x) for x is:

$$f(x) = \frac{\frac{N-x}{M}}{\frac{N+1}{M+1}} \qquad (8)$$

Using formulas (1) -(8), we can develop sampling strategies for biased samples and non-uniform populations.

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