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Selecting a Sampling Plan for Reinforcement Bars

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Abstract

In this study we employ modern statistical methods to the sampling problem. The application of statistics by engineers dates back a long while in solving industrial, management, and research problems. Quality and reliability engineers, technicians and laboratory analysts, inspectors, operators, opinion pollsters and other scholars are known users of sampling methods. Sampling techniques save time and cost and obtain relevant data that is representative. The methods described here are viable alternatives to the sampling problem. Ultimately the cost factor comes out as the loudest voice in the debate on best choice of sampling plan for reinforcement bars in Kenya.

Keywords: normal distribution, standard deviation, variance, opinion poll, random sampling, confidence level, acceptable error, representative sample, population size, sample size, accidental sampling.

1. Introduction

Sampling is the process of obtaining information of an entire population by only examining a part of it. The sample should, where possible, be truly representative of the population without any bias so that it results in valid and viable conclusions.

The distribution can be modeled on normal, t, beta, chi-squared, F, etc.(Kreyszig, 1988).

Sampling saves time, money and effort. Sampling also has the advantage that by studying a small portion of a population, the sample data can be useful in drawing conclusions about the population provided that we use an appropriate sampling method and we choose an appropriate sample size. Another reason for sampling applies to the special cases where the act of measuring the variable destroys the individual; such as mechanical tensile, impact and U-bend weld tests as well as destructive testing of explosives.

2. Selecting a Sample-Sampling Methods

A sampling frame is a list of the members of the target population. In many studies it does not exist or is unavailable to the researcher. There may be other lists which do not constitute proper sampling frames for various reasons. For example, a telephone directory is not a sampling frame for householders as it does not contain ex-directory numbers or homes without a telephone. Even reliable sampling frames like electoral registers become out of date remarkably quickly. In spite of these problems it is always advisable to attempt the acquisition of as accurate a sampling frame as possible. It enables a representative sample to be chosen and consequently reduces the risk of bias in the final conclusions.

We now consider some methods of selecting a sample. They are presented in decreasing order of statistical desirability. The first few require a sampling frame while the remainder can, and often do, give correspondingly poor results, (Cohen, 1991).

2.1 Random sampling

In this method every single member of the target population has exactly the same probability of being included in the sample. The random sample this produces is the basis for the theory behind all the standard statistical tests and procedures. The items in the sampling frames are numbered and tables of random numbers consulted to select them, (Cohen, 1991).

2.2 Systematic Sampling

This is a variant of random sampling whereby only the first item in the sample is chosen at random. Subsequent items are selected from the sampling frame at regular intervals from that point onwards. For example, suppose a sampling frame consists of 2000 subjects and we want a sample of 500. A random number between 1 and 4 provides us with the first item. This could be obtained by rolling a die until such a number occurs. Selecting every fourth item thereafter through the sampling frame gives a sample of the required size. It can be argued that if the sampling frame lists the subjects in some logical sequence, like alphabetical order, then this method produces a representative sample across that classification, (Cohen, 1991).

Ideally there should be no periodicity; accomplished by first having the population arranged in some order in a range, and assigning random numbers to pick individual members in given parts of the range, (Rees, 1995).

2.3 Stratified Sampling

There is often an attribute, like age, which divides the target population into subsets called strata. Stratified sampling is the selection of a random sample from each stratum. If the size of the sample is proportional to the number of items in the stratum, then the method is proportionate stratified sampling. Sometimes the survey is concerned with a a group of specific strata and larger samples are taken from them than their size warrants. This is called disproportionate stratified sampling, (Cohen, 1991).

2.4 Cluster sampling

Many populations fall into natural and representative groupings like families or geographical localities. One or more of these clusters can be selected at random and either the whole group used as a sample, called one stage cluster sampling, or random samples chosen from each one, called two stage cluster sampling. It has the cost-beneficial consequence that field workers need visit only a relatively small geographical region rather than tour an entire area interviewing respondents scattered far and wide, (Cohen, 1991).

2.5 Other methods

The procedures above presuppose the availability of a sampling frame even if only within the clusters of cluster sampling. We now consider techniques that do not require such a list but are correspondingly less desirable as they give unrepresentative and self selecting samples.

2.5.1 Quota sampling

Quota sampling is popular in marketing research and opinion poll surveys. Each field worker is given a quota of respondents like `20 middle aged men carrying briefcases'. Clearly the field workers' perceptions of the description itself and of how it should be applied affect the extent to which the sample can be representative. Respondents who appear approachable or otherwise attractive will be selected. Respondents who see the survey in progress and volunteer information will likewise be accepted. The sample is therefore not representative and certainly not random. Where no sampling frame exists, then quota sampling is a practical method of obtaining a sample.

2.5.2 Judgement sampling

In judgement sampling subjects are selected because they are judged to be indicative or typical of the population as a whole. For instance in the period before an election voters in a marginal constituency are canvassed in the hope that they act as some sort of political barometer. Similarly in economic surveys `captains of industry' are consulted about the future prospects for commerce and the economy.

2.5.3 Accidental sampling

Accidental sampling is the least statistically desirable method of all. A sample is formed of those subjects who present themselves as respondents. Radio phone-in programmes are a good example of this although basing ideas about public opinion on the letters received by women's magazines comes a close second. Large organizations sometimes have forms on which customers can register suggestions or complaints, and while they may prove valuable for gathering certain types of information they cannot be considered as providing a random or representative sample. This kind of sample is completely self-selecting and may be likened to eating sphagetti with a fork, only the longer strands are picked up, (Cohen, 1991).

3. Practical Sampling-Sample Design

In 1972, the National Reasearch Council (NRC) of Canada published the results of a study analyzing the mechanical properties of reinforcing steel (Allen, D. E, 1972). Two data samples were used, one consisting of 132 mill test results, provided by Steel Company of Canada, of bars from a Canadian manufacturing plant (Contrecoeur plant) and the other consisting of tests by NRC of 102 bars obtained from five separate heats sourced from Steel Company of Canada.

(Allen Matthew, 2011), sourced his AISI 1117 steel bars from the Taubensee steel and wire company.

Mirza and MacGregor (1979) studied the variability of mechanical properties of reinforcing steel. In this study, variations in yield stress and tensile strengths and in the modulus of elasticity were examined. The study was based on a sample that included 3947 bars taken from 13 sources (Allen Matthew, 2011).

Matt Bournonville .et al.(Bournonville .M, 2004) analysed test data from 23,768 heats of steel from 33 US and Canadian steel mills; 29 mills provided data on heat by heat basis, 3 mills provided average values, one mill provided data on `No Grade' bars (this was not included in the analysis) while a 34th mill did not respond to the request for data.

Maria Szerszen, (Nowak, 2003), analyzed material properties based on material test data provided by the industry. This work was a contribution towards the new Edition of ACI Building Code (ACI 318-02).

Allen D.E. and Matthew Allen appear to be using accidental sampling. Matt Bournonville requested for data from mills; he did not sample nor carry out experiments to obtain data. Mirza and McGregor had a sample from 13 sources, but the sampling method employed is unclear. Szerszen analysed material test data provided by the industry.

3.1 Standards

With rebars, for bar sizes #3 to #11 (ø10mm to ø36mm) inclusive, one tension test and one bend test shall be made of the largest size rolled from each heat. If however, material from one heat differs by three or more designation numbers, one tension and one bend test shall be made from both the highest and lowest designation number of the deformed bars rolled. For bar size #14 and #18 (ø43mm and ø57mm) one tension test and one bend test shall be made of each size rolled from each heat (ASTM, 2003).

Alternatively, the unit of production from which test specimens are selected shall be the cast, with tensile test specimens being at least 600 mm long or 20 times the nominal size, whichever is greater (BS 4449, 2005). The testing rate shall be:

1) for casts of 100 tonnes or less, three tensile tests and one rebend test.
2) for casts greater than 100 tonnes, three tensile tests for the first 100 tonnes and an additional tensile test for

each full (or part over) 30 tonnes remaining.
This is highly indicative of, at best, systematic sampling.

In view of the above one can note that where the respondents are human beings, they have been known to suffer from mortality, mobility, willingness to co-operate (or the lack of it). Picking samples from a factory entails being there when every heating is conducted. Even here one would still require to decide whether to pick a sample from among the earliest bars, mid-heat bars or end heat bars. Liaising with the factory sounds nice, but how to make sure that the factory, forewarned of the intended sampling, do not manufacture their best in that instance, only to relapse later?

Add the fact that this would need to go on for a year or two and the full impact of the difficulty can begin to be appreciated. Should an assistant be designated the sampling task only? In three or four companies? At what cost? Will this then guarantee an unbiased sample?

Replies to the above queries simply indicate high costs obtaining not much better representation. Industry captains may frown on such an idea and conduct it with even less enthusiasm.

4. Making a Choice

4.1 Basing the Sample on Production Levels

According to Machira .et al. (Machira, 2010), the steel making industry in Kenya had a combined maximum production capacity of 3,605,000 metric tonnes in 2008, with a design capacity of 5,950,000 metric tonnes. In 2007, the construcion industry used 847,000 metric tonnes. Since standards require a tensile and bend test for every 30 tonnes produced, then systematic sampling requires 847,000/30 tests; that is, 28,333 tests annually. If each bar cost Ksh 1,500.00, then the cost of purchasing the bars would be Ksh 42,500,000.00; clearly out of the question for a Masters student on a hamstring budget. Collecting samples from a single days output would cost Ksh 116,436.00; that is while ignoring troubles and concerns we might have to encounter to physically procure the bars, as well as transport costs.

4.2 Basing the Sample on Infinite Population

According to Rouncefield, (Rouncefield M. 1989), the sample size for opinion poll is 1111 for an infinite population. This is for a 95% confidence level with a 3% error. Due to the impracticality of reaching every respondent, the sample size is often quoted as 1500 to 2000.

To obtain an area of 95% under the normal curve, z=±1.96. To ease calculations , z is taken as ±2. Thus:

$$2 = \frac{e*\sqrt{n}}{\sqrt{pq}} \quad (1)$$

$$\frac{2*\sqrt{pq}}{e} = \sqrt{n} \quad (2)$$

$$\frac{4pq}{e^2} = n \quad (3)$$

Since the largest value of pq is ¼, then;

$$\frac{1}{e^2} = n \quad (4)$$

If e is 3% then, for 95% confidence level:

$$n = 1111.11. \quad (5)$$

4.3 Sample Based on Available N, σ and e

From literature on statistics:

Mean of the population,

$$M = \frac{\sum x_i}{N} \qquad (6)$$

and the standard deviation of the population is given by

$$\sigma = \sqrt{\frac{\sum(x - X)^2}{N}} \qquad (7)$$

The number of samples, n, will be given by Equation (8), (Kothari, 2004).

$$\{(N\text{-}1)e^2 + z^2\sigma^2\}n = z^2N\sigma^2 \qquad (8)$$

Where; e: is the acceptable error (the precision); N: is size of population; n: is size of sample; z: is the standard variate at a given confidence level (to be read from normal tables giving the area under the normal curve). For example, at 97.5% confidence level the accepted error (e) is ±3. σ: is the standard deviation of the population (to be estimated from past experience). If the standard deviation of the population is not available, the estimate of standard deviation is calculated as indicated below.

Given the range (i.e. the difference between the highest and lowest values) of the population, the confidence level and the acceptable error (e), the estimated standard deviation of the population is given by the following equation:

$$\sigma = \frac{\textit{The given range}}{2e} \qquad (9)$$

5. Discussion

In the factory, bars can be categorized according to the heat. At the hardware, bars can be sourced from various rolling mills which in turn will have obtained the bars from different heats. At the construction site, bars could be sourced from different hardware stores and factories.

Random sampling is to be preferred. After establishing the sample size and the distribution, the reinforcing steel bars can be procured. It is the considered opinion of the author that since bars are manufactured in a factory, then it makes perfect sense to source samples from the factory. This was easily the case with Allen D.E., Matt Bournonville et al, Mirza and McGregor, Matthew Allen etc.

Getting bars from the factory has the advantage that the manufacturer's data and bar history is available, although I must state that in my experience the industry captains I've met were mean with information.

In some circumstances it might be meaningful to source bars from hardwares and/or construction sites; for example where the bars are imported from halfway around the world. But by this time securing manufacturer's data and bar history is certainly more difficult.

Most researchers make do with mill results or source samples from one mill by accidental sampling. Mirza and McGregor sourced 3947 bars from 13 sources; even here it is ambiguous how the average of 311 bars per source was selected.

Systematic sampling for rebars was seen to be expensive. The standards require the mill to `conduct' systematic sampling. Here a major bias can be introduced by periodicity.

A sample size of 1111 is needed for infinite population. If it is the heats that are infinite, one has to know that there would be even more bars to choose from. If what is infinite is the bars, there is the problem of picking 1111 bars by some random method. This would entail identifying the volumes of production for the various mills in Kenya, visiting the given mill, marking all bars with serial numbers (1,2,3,4,....etc), dividing the series into ranges and then using random numbers to pick a bar from each range to make the requisite 1111.

If classifying the bars according to the heat is needed, then we have the hallmarks of stratified sampling.

To use Equation (8) we need to have a known population size N, known standard deviation σ and a decided precision, e. Unfortunately, this information is not always available, (Cohen 1991). The standard deviation is initially estimated from past experience. Once the sample size is established, the bars could be marked in serial numbers (1,2,3,4,.........etc), the numbers set in a range, and random numbers used to pick the sample.

To conduct random or systematic sampling, one notes that we need all the bars to be available so that we can mark them. How can one person achieve this? At the godown, bars will usually be placed carelessly. Even when arranged neatly, the bars are quite heavy and long and require some handling. It is also to be wondered at whether industry captains would accept this `interference' gracefully, i.e. can a mill restrain from selling, and hold bars in store for a year, for the convenience of a researcher?

If one decides to pick bars hot from the production line, then the researcher would need to be available 24 hours a day, in the particular mill, so that, even on systematic sampling he can follow the random numbers and avoid periodicity.

When data is obtained from the mill, how representative is it? Both ASTM-615 and BS 4449 indicate a systematic sampling scheme.

6. Conclusion

Random sampling, though ideal, is difficult to achieve. The best and practical sampling method for rebars is systematic sampling as in the standards (ASTM 2003) and (BSI 2005). Motivations of cost quite often indicate accidental sampling; or even doing away with testing altogether and having to be content with mill results analysis.

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