



# An overview of sampling methods and sample size determination in statistical studies

**Dr. Amaresh Ranjan, Assistant Professor**

P.G. Department of Statistics and Computer Application

Tilka Manjhi Bhagalpur University, Bhagalpur

Email: amareshranjan1966@gmail.com

## Abstract

Applied statistics is integral to research in social sciences, agriculture, health, and business, with survey research forming the cornerstone of empirical inquiry. The validity and generalizability of survey findings are critically dependent on the appropriateness of both sampling techniques and sample size determination, as the choice of method must align with the specific research context. Employing unsuitable sampling strategies or inadequate sample sizes can yield biased or unreliable conclusions. This study presents a rigorous overview of fundamental sampling methods—including purposive, simple random, stratified random, systematic random, and quota sampling—detailing their application to diverse research scenarios. Additionally, it delineates essential statistical concepts such as population, sample, randomization, confidence interval, and statistical power, and articulates the methodological considerations underlying sample size calculation, thereby establishing robust standards for survey-based statistical inference.

**Keywords:** Sampling, Sample Size, Confidence Interval, Level of Significance

## Introduction

Sampling methods are essential techniques in research, enabling the selection of a representative subset from a larger group—referred to as the population—for the purpose of analysis. These methods facilitate the drawing of inferences about the entire population based on observations derived from the sample. Among the fundamental statistical techniques used in practical research, frequency measures such as rates, ratios, and proportions are commonly employed to quantify and compare characteristics within data sets. Sampling techniques are particularly valuable in research studies as they not only improve estimation efficiency but also reduce costs and time requirements while enhancing the precision of results. The appropriate selection of sampling methods and accurate calculation of sample size are vital components of applied statistical research because they directly impact the validity and reliability of study findings.

A sample that is too small may result in missed significant effects or relationships, or may produce estimates that are too imprecise to yield meaningful conclusions. Conversely, an excessively large sample size complicates the research process, increases costs, and may also lead to inaccurate findings due to logistical challenges. Thus, determining the correct sample size is a crucial element in scientific studies. Sathian (2010) emphasizes that the

process of establishing an appropriate sample size is complex and often necessitates expert input from those with expertise in medical statistics. Power analysis and sample size estimation techniques are dictated by the study's design and its primary measurement outcomes, with specific approaches available for various types of studies and outcome variables.

Moreover, whether statistical conclusions are derived using tests of significance or confidence interval methods, the methodology for determining sample size may differ. In recent years, the rapid expansion of academic journals has led to increased survey-based research, yet many studies employ suboptimal sampling techniques. To address this gap, the current study aims to consolidate key terminologies and methodologies concerning sample size calculation, while also outlining sampling techniques relevant to distinct research objectives, thereby providing a comprehensive resource for researchers.

## **Sampling**

The concept of sampling has its roots in antiquity and is referenced multiple times in sacred scriptures. A significant milestone in the formal development of sampling methods occurred in 1786 when Pierre-Simon Laplace applied a ratio estimator and sample technique to estimate the population of France. Laplace's approach was pioneering in that he not only used sample data from selected departments but also computed probabilistic errors to assess the accuracy of his estimates. His work involved selecting a representative sample of departments across various climatic regions to account for birth rate variability and employed the principle that the ratio of population to births was relatively stable. This ratio estimation and the quantification of associated errors marked an early integration of probability theory into demography, laying the groundwork for statistical inference. Later, in the 1870s, Alexander Ivanovich Chuprov introduced sample surveys to Imperial Russia, further advancing the practical application of sampling theory in research. Chuprov's contributions are noted alongside key historical figures and developments that shaped the evolution of sampling as a scientific discipline, reflecting its increasing importance in empirical research methodologies during the 19th century (Cochran 1963; Robert et al. 2004). These historical developments underscore the longstanding recognition of sampling techniques as fundamental tools for making valid inferences about populations based on smaller subsets of data.

## **Sampling Techniques**

The literature extensively discusses the criteria for selecting individuals to provide information, as outlined by Kish (1965) and Gupta and Kapoor (1970). Selection may involve either removing a representative from a group or investigating the entire group. It is imperative that every sample is chosen randomly to ensure unbiased representation. Furthermore, the internal variability within the population must be accounted for by applying an appropriate sampling methodology. Common sampling designs identified in the literature include purposive, random, and quota sampling, with detailed classifications of random sampling techniques described by Cochran (1963), Rao (1985), and Sudman (1976). These methodologies guide effective and valid data collection.

### ***Purposive Sampling***

This method chooses sampling units based on their intended use. Purposive sampling is not statistically recognized and yields biased estimates. There are just a few particular uses for this method.

### ***Random Sampling***

Every unit included in the sample using this sampling technique will have a predetermined chance of being included. Compared to purposive sampling, this sampling offers a more accurate approximation of the study's parameters. In

the sampling frame, each individual has a known and non-zero chance of being chosen for the sample. It is the best and most widely used single-stage random sampling technique.

### ***Lottery Method of Sampling***

A basic random sample can be drawn in a number of ways. The lottery system is the most popular approach. In this case, every individual or thing in the population is given a distinct number. After that, the numbers are well combined, as if they were placed in a bowl or jar and shaken. Next, the researcher chooses  $n$  numbers without looking. The sample then consists of the individuals or objects allocated that number.

### ***By Using Random Number Table***

The majority of research techniques books and statistics books include a table of random numbers in their appendices. Ten thousand random numbers between 0 and 9 are usually provided in rows and grouped in groups of five in a random number table. Every digit in the table has the same probability, and the digits that come before it has no bearing on that digit is likelihood.

### **Simple Random Sampling**

Every unit included in the sample has an equal chance of being included in the sample when using the simple random sampling approach. If the population is homogeneous, this method yields a more objective and superior estimate of the parameters.

### **Stratified Random Sampling**

If the population is diverse, stratified random sampling is a helpful technique for gathering data. This approach divides the total heterogeneous population into a number of homogeneous groups, sometimes referred to as strata, each of which is homogeneous in and of itself. Units are then randomly selected from each stratum. The relative significance of each stratum in the population determines the sample size for each stratum. Stratified sampling is the method used to draw this stratified sample. To put it another way, stratification is the process of dividing a population into subgroups or strata. Each stratum will next undergo a unique sampling procedure. Because there is evidence linking strata or subgroups to outcomes, they are picked. Local conditions and geographic location will influence the stratum selection.

Following stratification, sampling is carried out in each stratum independently. The sampling error in a stratified sample is determined by the population variance within the stratum but not between them. Another definition of stratified random sampling is when the population is divided into several different groups, and the frame can be arranged according to these groups into different "strata." After that, each stratum is sampled as a separate subpopulation, from which certain components may be chosen at random.

### **Cluster Sampling**

The entire population is separated into groups, or clusters, and a random sample of these clusters is chosen using the cluster sampling technique. The sample consists of all observations in the chosen clusters. When "natural" but comparatively uniform groupings in a statistical population are apparent, cluster sampling is a sample technique that is employed.

Cluster sampling is typically employed when a researcher has a complete list of groupings or "clusters" of the population but not a complete list of the units of the population they want to study. Compared to stratified sampling or simply random sampling, this sampling technique could be more cost-effective and useful.

Cluster sampling has benefits and drawbacks when compared to stratified sampling and basic random sample. For instance, cluster sampling typically yields lower precision than stratified sampling or simply random sampling when sample sizes are equal. However, cluster sampling might be more economical than the other approaches if contact costs between clusters are large.

### Systematic Random Sampling

The initial unit of the sample is chosen at random with this sampling technique, while the subsequent units are chosen methodically.  $R = N/n$  if there are  $N$  units in the population and  $n$  units need to be chosen (the sampling interval is denoted by  $R$ ). Out of the remaining  $R$  (Sampling Interval) to the previously chosen number, the first number is chosen at random.

### Multistage Random Sampling

Units are chosen at different phases in multistage random sampling. At each step, the sampling designs could be the same or different. Cluster sampling is another name for the multistage sampling approach, which uses samples that are somewhat clustered. This sampling strategy has the main benefit of allowing the available resources to be focused on a small number of frame units; however, the sampling error will be raised.

### Quota sampling

Similar to stratified sampling, quota sampling begins with the population being divided into subgroups that are mutually exclusive. The subjects or units from each section are then chosen using judgment according to a predetermined proportion.

This second step is what turns the procedure into a non-probability sampling technique. Quota sampling involves non-random sample selection. Interviewers may be inclined, for instance, to interview the people who appear to be the most helpful. The issue is that not everyone has an equal chance at selection, which could lead to bias in these samples. Its most significant random component

### Spatial Sampling

Survey sampling that involves sampling in two or more dimensions is known as spatial sampling.

### Independent Sampling

Samples chosen from the same population or from distinct populations that are unaffected by one another are known as independent samples. In other words, there is no relationship between the samples.

Some of the main sampling methods are presented in Table 1 which shows method, description and example

Table 1: Main Sampling Methods

Method	Description	Example
Simple Random Sampling	Every member has equal chance	Lottery-style selection from a full list
Systematic Sampling	Select every kth member after a random start	Every 10th name on a list
Stratified Sampling	Sample randomly from population subgroups (strata)	20% males, 80% females, proportional sample



Cluster Sampling	Randomly select whole groups (clusters)	Randomly pick schools, then sample students
Convenience Sampling	Select those easiest to access	Survey mall visitors
Snowball Sampling	Participants recruit future participants	Referral-based study in hidden populations

As such, employing the right sampling method and an appropriate sample size are both essential for the credibility of statistical research. The choice depends on study goals, available resources, required accuracy, and the structure of the population.

### Sample Size for Research Purposes

Carefully determining the sample size is necessary to ensure that it is sufficient for drawing reliable and broadly applicable conclusions. Determining the appropriate sample size necessitates precise knowledge of the issues being examined in the population being studied. Additionally, the subcategories of samples need to be analyzed, varied, precise, available, and inexpensive. The data gathered from samples throughout the study must be entered into a questionnaire or a pre-made timetable. The goals and resources for analysis determine the questionnaire's design. Choosing how many observations to include in a sample is known as sample size determination. Any study or investigation where the goal is to draw conclusions about the population from a sample must consider the sample size. Generally speaking, the expense of data collection and enough statistical power are the two main factors that decide the sample size utilized in a study. Advanced studies may use a variety of sample sizes. For instance, if the population is heterogeneous and stratified sampling is used in a survey, different sample sizes will be used for each population.

Since complete enumeration is used to gather data during a census, the sample size is equal to the population size. There may be varying sample sizes for each experimental group in an experimental study that is split up into many experimental groups. In general, estimating unknown parameters is more accurate with larger sample numbers. This phenomenon is explained by a number of basic mathematical statistics findings, such as the central limit theorem and the law of big numbers. In general, there are three methods for selecting sample sizes.

Include products that are easily accessible or handy to pick up in the cost basis. Even though they are occasionally required, using small sample sizes might lead to errors in statistical hypothesis testing or broad confidence ranges.

Variance base is using a target variance to determine an estimate from the final sample applying a target for a statistical test's power after the sample is gathered is known as statistical power basis.

The quality of the estimates that are produced is used to evaluate sample sizes; the power of a hypothesis test can also be used to do so.

### Importance of Sample Size

The means or proportions of a particular trait in two or more comparison groups are noted in comparative research. The significant difference between the means or proportions seen in the various groups is then ascertained using a statistical test.

The main reason sample size matters are because it affects statistical power. The likelihood that a statistical test will reveal a significant difference when one actually exists is known as statistical power. One could mentally replace the word "power" with "sensitivity" when drawing statistical conclusions because statistical power is comparable to a diagnostic test's sensitivity as described

by Browner and Newman 1978.

When comparing two groups of people, a statistical test's power must be high enough to identify any differences between the groups that are statistically significant, assuming any exist at all. If the study's findings show no statistically significant difference, this problem becomes crucial. The occurrence of such a negative outcome could be interpreted in two ways. According to the first interpretation, the statistical test findings are accurate and there is not a statistically significant difference (a true-negative result). The second interpretation holds that the statistical test results are incorrect and that there is, in fact, an underlying difference, but the research was insufficiently sensitive or powerful to detect it, resulting in a false-negative result. A false-negative result is referred to as a type II error in statistical nomenclature. In the event that the study finds no statistically significant difference, a sufficient sample size provides a statistical test with sufficient power to make the first interpretation—that a type II mistake occurred—much more likely. Many published clinical research studies are recognized to have low statistical power because of various design flaws or insufficient sample sizes as per the studies of Moher et al. 1994 and Freiman et al. 1978.

### **Determination of the sample size for parameters**

The minimal expected difference, also referred to as the effect size, predicted measurement variability, desired statistical power, significance criterion, and whether a one- or two-tailed statistical analysis is planned are the five research design parameters that typically determine the sample size.

#### ***Basis of Minimum Expected Difference or size effects***

The sample size required to detect statistical significance rises as the minimal predicted difference decreases. This parameter's setting is arbitrary and depends on clinical expertise or knowledge of the issue under investigation. Consider a study that compares a novel diagnostic technique with an unknown but possibly greater accuracy versus a traditional process with an accuracy of 85%. Let us say the researcher thinks that a 95% accuracy rate for the new treatment would be a clinically significant improvement. As a result, the researcher would decide on a 10% (0.10) minimum predicted difference.

#### ***Estimated Measurement Variability***

The expected standard deviation of the measurements made within each comparison group serves as a representation of this metric. The sample size required to find the minimum difference rises with statistical unpredictability. Preliminary data gathered from a comparable research population should ideally be used to calculate the predicted measurement variability. Estimates of this parameter can also be obtained by a survey of the literature. This parameter may need to be approximated based on subjective experience or a range of values may need to be assumed in the absence of preliminary data. Unlike a mean, a proportional measurement does not require a separate estimate of measurement variability because the standard deviation is mathematically determined from the proportion.

#### ***Based on Statistical Power***

The power required for the investigation is this parameter. The sample size grows as power increases. Given the typically restricted amount of time and resources available to conduct a research or investigational study, there is a clear trade-off with the number of people who can be researched, even though high power is always preferred. Writes 2002, Wood and Lombert 1999 mentioned that many clinical trial specialists now recommend a power of 0.90, statistical power in randomized controlled trials is typically set to a figure greater than or equal to 0.80.

### ***Significance Criterion (P – Value)***

The highest P value at which a difference is deemed statistically significant is this parameter. The sample size required to find the minimum difference rises as the significance level is lowered. It is standard practice to set the statistical significance level at 5 percent.

### ***One- or Two-tailed Statistical Analysis***

In certain instances, it may be known before to the study that there is only one conceivable direction of difference between the experimental or comparison groups. In these situations, a one-tailed statistical analysis might be used, which would need a smaller sample size than a two-tailed analysis to find the minimum difference. All other things being equal, the sample size of a two-tailed design with a significance threshold of  $2\alpha$  is identical to the sample size of a one-tailed study design with a given statistical significance criterion, such as  $\alpha$ .

### **Criteria for good Sample Size**

To determine the appropriate sample size, three criteria typically need to be specified in addition to the population size and study purpose: the degree of variability in the attributes being measured, the level of precision, and the level of confidence or risk as mentioned by Miaoulis and Michener, 1976. Below is a review of each of these:

#### ***The Level of Precision/The Accuracy Level***

The range in which the population's true value is estimated is known as the level of precision, or sampling error. Similar to how the media reports the results of political campaign polls, this range is frequently stated in percentage points (e.g.,  $\pm 5$  percent). Therefore, a researcher can conclude that between 55% and 65% of farmers in the public have adopted a recommended practice if they find that 60% of farmers in the sample have done so with a precision rate of  $\pm 5\%$ .

#### **The Confidence Level**

The Central Limit Theorem serves as the foundation for the risk level of confidence. The Central Limit Theorem's main tenet is that the average value of the attribute that is extracted from multiple samples of a population is equal to the actual population value. Additionally, the values that these samples yield are generally scattered about the genuine value, with some samples yielding values that are higher and others that are lower than the actual population value. About 95% of sample values in a normal distribution fall between two standard deviations of the actual population value. In statistical hypothesis testing, this confidence interval is sometimes referred to as the risk of error.

This indicates that 95 out of 100 samples will have the true population value within the designated accuracy range if a 95% confidence level is chosen. There is always a chance that the sample that the investigator or researcher took does not accurately reflect the population value. Extreme values are reflected in these samples. According to Gupta and Kapoor (1970) and Singh and Masuku (2012), this risk is enhanced for 90% or lower confidence levels and decreased for 99% confidence levels.

#### **Degree of Variability/Level of Variability**

The distribution of qualities in the population is the subject of the third criterion, which is the degree of variability in the attributes under investigation. The smaller the sample size used, the more homogeneous the population. The

higher the sample size needed to achieve a particular level of precision, the more diverse the population. A 50% proportion, for instance, denotes a higher degree of variability than either 80% or 20%. This is due to the fact that 80% and 20%, respectively, show that a sizable majority possess the desired quality. A proportion of 0.5 is sometimes used to determine a more conservative sample size, meaning that it may be bigger than if the true variability of the population attribute were used. This is because it shows the maximum variability in a population.

## Methods for Calculating the Sample Size

The sample size can be determined in a variety of ways. These include employing formulas to determine a sample size, using published tables, mimicking the sample size of comparable research, and using a census for tiny populations.

### *Using a Census for Small Populations*

Using the entire population as the sample is one method. A census is more appealing for small populations (e.g., 200 or less), but financial considerations make this unfeasible for huge populations. A census offers information on every member of the population and removes sampling inaccuracy. Furthermore, some expenses, like designing the questionnaire and creating the sampling frame, are "fixed," meaning they will not change whether the sample size is 50 or 200. Therefore, in order to attain a desired level of precision, the complete population will need to be sampled in tiny populations.

### *Using a Sample Size of a Similar Study*

Using the same sample size as studies that are similar to the plan is an additional strategy. There is a chance that mistakes made while calculating the sample size for a subsequent study could be repeated if the procedures employed in previous studies are not reviewed. Nonetheless, guidance of the usual sample sizes that are employed can be obtained by reviewing the literature in this field (Glenn 1992).

### *Using Published Tables*

Using published tables, which offer the sample size for a certain set of criteria, is a third method of calculating sample size. sample sizes required for specific combinations of variability, accuracy, and confidence level. Two tables (Tables 2 and 3) were provided by Glenn (1992) for the purpose of choosing the sample size. Please take note of two things. First off, these sample sizes are based on the quantity of replies received rather than the quantity of surveys sent or interviews scheduled. Second, Table 3's sample sizes are based on the assumption that the characteristics being tested have a normal or nearly normal distribution. It could be necessary to poll the entire population if this presumption is not true.

Table 2: Sample sizes for precision levels of  $\pm 5\%$  and  $\pm 10\%$ , with a 95% confidence level and  $P=0.5$

Population size	Sample Size (n) for precision (e)	
	$\pm 5\%$	$\pm 10\%$
500	222	83
1,000	286	91
2,000	333	95
3,000	353	97
4,000	364	98



5,000	370	98
7,000	378	99
9,000	383	99
10,000	385	99
15,000	390	99
20,000	392	100
25,000	394	100
50,000	397	100
100,000	398	100
>100,000	400	100

Table 3: Sample sizes for precision levels of  $\pm 5\%$  and  $\pm 10\%$ , with a 95% confidence level and  $P=0.5$

Population size	Sample Size (n) for Precision (e) of:	
	$\pm 5\%$	$\pm 10\%$
100	81	51
125	96	56
150	110	61
200	134	67
250	154	72
300	172	76
350	187	78
400	201	81
450	212	82

### Using Formulas to Calculate a Sample Size

Although the Glenn 1992 tables might serve as a helpful guide, you might need to compute the required sample size for a particular combination of precision, confidence, and variability levels. The sample sizes in Tables 1 and 2 were calculated using one of several formulas, which is the fourth method for estimating sample size.

### A few methods for determining the sample size

Determining sample size using the cumulative distribution function

Let  $X_i$ ,  $i = 1, 2, \dots, n$  be independent observations obtained from a normal distribution with unknown mean ( $\mu$ ) and known variance ( $\sigma^2$ ). Let us consider two hypotheses and a null hypothesis:

$$H_0 : \mu = 0$$

An alternative hypothesis:

$$H_1 : \mu = \mu^*$$

For some 'smallest significant difference  $\mu^* > 0$ '. This is the smallest value for which we care about observing a difference. Now, if we wish to reject  $H_0$  with a probability of at least  $1 - \beta$  when  $H_1$  is true (i.e. a power of  $1 - \beta$ ), and second reject  $H_0$  with probability  $\alpha$  when  $H_0$  is true,

then we need the following:

If  $Z_\alpha$  represents the highest  $\alpha$  percentage point of the standard normal distribution, then

$$P(X > Z_\alpha \sigma / \sqrt{n} | H_0) = \alpha$$

And hence, 'Reject  $H_0$  if our sample average sample mean is more than  $Z\alpha\sigma / \sqrt{n}$

is a decision rule for 1-tailed test.

Now we wish for this to happen with a probability at least  $1-\beta$  when  $H_1$  is true. In this case, our sample average will come from a Normal distribution with mean  $\mu^*$ . Therefore, we require

$$P[x > Z\alpha\sigma / \sqrt{n} | H_1] = 1 - \beta \text{ where } x = \text{sample mean}$$

Through careful manipulation, this can be shown to happen when

$$n \geq [\{\Phi^{-1}(1-\beta) + Z\alpha\} / (\mu^* / \sigma)]^2$$

Where  $\Phi$  is the normal cumulative distribution function.

### ***Formula for Calculating A Sample for Proportions***

Cochran (1963, 1975) developed the equation to yield a representative sample for proportions of large sample.

$$n_0 = Z^2 p q / e^2$$

Which is valid where  $n_0$  is the sample size,  $Z^2$  is the abscissa of the normal curve that cuts off an area  $\alpha$  at the tails ( $1 - \alpha$  equals the desired confidence level is 95%),  $e$  is the desired level of precision,  $p$  is the estimated proportion of an attribute that is present in the population, and  $q$  is  $1-p$ . The value for  $Z$  is found in statistical tables which contain the area under the normal curve.

To illustrate, suppose we wish to evaluate a state-wide Extension program in which farmers were encouraged to adopt a new practice. Assume there is a large population but that we do not know the variability in the proportion that will adopt the practice; therefore, assume  $p=0.5$  (maximum variability). Furthermore, suppose we desire a 95% confidence level and  $\pm 5\%$  precision. The resulting sample size is  $n_0 = Z^2 p q / e^2$ .

### **Summary and Conclusion**

Research studies with appropriate research designs provide objective parameter estimations that can be used to evaluate the community's health. However, research analysis is a component of a country's overall development in fields like agriculture, public health, education, and finance—all of which are markers of a higher standard of life for people. Better life management-based practical research nowadays is intricate and calls for a wide range of expertise, including social, technical, medical, mathematical, and statistical. Advance research offers objective estimates of indicators, findings, and their interpretations based on high-quality samples with a suitable sample size by utilizing the right statistical techniques and sampling research designs. The significance of sampling and calculating sample size in statistical research was emphasized in the current study. The normal distribution, the confidence interval (the chance of error in statistical hypothesis testing), and the allowable error in the estimate are the most widely used techniques for determining sample size in contemporary statistical research. Based on the above-described study design, an investigator or researcher can determine the appropriate sample size and then measure the outcomes. A more pertinent study should be produced by paying attention to sample size, and the data and interpretation should be given top priority for publishing.

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