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A Long Walk of Survey Sampling with Modern Methodologies

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Abstract

Survey sampling emerged as a crucial methodology to overcome the impracticality and high cost of full censuses. This article aims to synthesise the historical trajectory of survey sampling and review the rationale and application of modern techniques. A narrative review methodology was employed this study to trace the evolution from early probability-based methods, which prioritised representativeness, to contemporary non-probability methods that address challenges in big data and hard-to-reach populations. Key findings highlight that while probability sampling remains the gold standard for unbiased inference, modern methods like network, encounter, and composite sampling offer practical, cost-effective alternatives, though they require advanced techniques for bias-correction. The study provides a comparative framework to guide researchers in selecting context-appropriate sampling strategies across fields such as agriculture, ecology, and social sciences.

Keywords: non-probability sampling, sampling technique, survey sampling history

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INTRODUCTION AND STUDY OBJECTIVES

"Sampling, statisticians have told us, is a much more effective way of getting a good census'' it's a well-known quote given by an American famous actor Rob Lowe. For thousands of years people have been habituated to using sampling in their daily life and applied it unconsciously when sampling was not familiar to people. Till now we can realise the importance of sub-samples from population for its time and cost-saving nature. In everywhere such as agriculture, business

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studies, engineering, medical science, social science etc. survey sampling is a common technique for research. Survey sampling was introduced in ancient times but at that time people did not know about the formal terminology. Survey sampling categorises into two types; probability sampling is one of them and other types is non-probability sampling. Probability sampling was formally developed in the late nineteenth century and applied extensively at the early period of twentieth century (Fienberg & Tanur, 2001) People were accustomed to applying probability sampling at that time but there were some important non-probability sampling methods also. In recent times there are many non-conventional sampling techniques that are used by the researchers. This article reveals how sampling technique initiates from census and the application of sampling in past research. In contrast, it is also an effort to focus on concepts and applications of various non-probability sampling methods. This article has continued with the history of survey sampling followed by a discussion of the importance of sample survey, a classification of sampling techniques, applications in past research and then includes non-probability sampling methods, serving as a practical guide to assist researchers select the most suitable technique for their needs. The objectives of this article are

- to accumulate the history of survey sampling with its importance.
- to organise the concepts and applications of different non-probability sampling techniques.

Although extensive research exists on individual sampling methods, a comprehensive synthesis linking the historical rationale of probability sampling with the practical drivers for adopting modern non-probability techniques remains untouched. This article fills that gap by presenting an integrated historical overview and a systematic analysis of current approaches. Its originality lies in offering a comparative framework that guides researchers in balancing methodological rigor with real-world constraints across various disciplines.

REVIEW METHODS

This study has adopted a narrative review methodology and presents a detailed summary on survey sampling by drawing large-scale historical sources, foundational textbooks, and journal articles. The relevant literature were reviewed to mark the key milestones in the history of sampling and to explain the rationale and application of prominent modern non-probability techniques.

History of Survey and Sampling

Census is the collection of observations on every element in the population for the characteristics of interest (Singh & Mangat, 1996), while survey research is expressed in words by taking the response from questions, it is the process of collecting observations from individuals (Check & Schutt, 2012). The data collection technique used to carry out survey research is defined as a survey. It serves to evaluate necessity, explore demand and measure impact (Salant & Dillman, 1994). Central to this process is Sampling, a scientific process, where a predetermined number of observations are drawn from a large population. Sampling theory has played a significant role throughout human history, as this technique is used to collect observations almost in nearly every field.

A sample is a representative part of the population that researchers use as main raw materials to learn about the entire population. So, survey sampling means a scientific approach of selecting a sample to know or learn regarding the whole part from a population (Islam, 2014).

The practice of agricultural censuses dates back to Babylonian times, though it became more systematic after the invention of writing. In ancient Rome, regular censuses of people and property were conducted every five years. Actually, the term ‘‘census’’ came from the Latin word ‘‘censere’’ meaning “estimate”. At the starting time of Jesus, there was a known picture of numbering people. Biblical accounts reference censuses, including the well-known story of Mary and Joseph had travelling to Bethlehem for enumeration around the time of Jesus birth. The most famous early census was taken by King William of England in 1086 AD. A book named ‘Domesday Book’ documented to preserve observations about each manor and village in the country over 13,000 locations with 10,000 facts of each province. This monumental survey used a systematic approach dividing the country into some areas with commissioners. The commissioners made a standard chart of queries or questions. As for instance, questions respecting the number of the region of woodland, the number of mills, the number of fish ponds etc. The Book still exists. The detailed history of this survey is available online from “History Magazine” published in October/November 2001. Similarly sophisticated systems emerged in the Inca Empire between 1000 to 1500 AD, where official statisticians recorded population, the number of houses, the number of llamas, the number of marriages and the number of young men that could be recruited in the army using Quipus. A system of knots by coloured ropes recorded all of this information. These detailed local statistics were regularly delivered to the capital Cusco by couriers. Though the system was run well, it disappeared with the decline of the empire. Modern census practices emerged in England with decennial surveys beginning in 1801, and the first census listing people by name was taken in 1841 (Bethlehem, 2009).

The sampling strategy is defined into two parts; in one sampling, units are to be selected from a finite population which is called the selection procedure and another is the process in which generally inferences are to be made from sample to population is called estimation procedure. Sample surveys of people expressed firstly by the Norwegian Statistician Kiaer (1897) argued that it is not possible to collect whole enumeration data as census on many subject areas such as biology and in that situation the representative part of population can play a great role in that sampling was generally accepted and inferences can be made from sample data which are the estimate of population parameter. Kiaer proposed to employ sampling techniques when it is either much expensive or much time consuming to collect whole population data for the social researcher. In Norway, he described with examples that the selected samples could be a representative part of the population from which the sample is drawn. Some statisticians opposed his description. George Von Mayr of Munich University opposed that a part of population or sample can never be representative of complete census (Kiaer, 1901). In St. Petersburg at the ISI meeting and at a conference of Scandinavian Statisticians which was held in Stockholm in 1897, Kiaer again pressed his idea about samples. To get confirmation of his thoughts,

he tried to improve his idea and finally the conference approved his sampling ideas (Kiaer, 1897; Kiaer, 1901).

A concept of purposive selection has advanced from randomisation in sample survey by Bowley (1906). His research gave an empirical attestation for simple random sampling to a type of central limit theorem. He also considered the first stage to make inferences independently of any model that may apply to the population. Bowley has improved the method of random sampling (Bowley, 1926).

Ratio and regression estimators were given by Cochran (1942). Systematic sampling was initiated by Madow and Madow (1944) and with the particular assumption about population the accuracy of systematic sampling was checked out by Cochran (1946).

Different sampling techniques have been updated by many researchers nowadays. Model-based survey sampling theories (Chaudhuri & Stenger, 2005; Särndal et al., 2003).

Importance of Sample Survey

As Deming (1950) said, "Sampling is not mere substitution of a partial coverage for total coverage. Sampling is the science and art of controlling and measuring reliability of useful statistical information through the theory of probability". The importance of sample surveys over complete enumeration is less expensive and less time consuming; that means having a greater speed by choosing measurements on a representative part of an entire population (Singh & Mangat, 1996). Sample surveys are helpful for the sake of taking out information about education, agricultural particulars, social, population growth rate etc. and this collected information can be analysed by researchers in different fields as well as the government agencies can make developments through it. For instance, The National Centre for Health Statistics (NCHS), a centre within the United States Department of Health and Human Services which is directed by rule to perform a periodic plan of actions and on taking surveys for collecting data on sickness, the improvement of health care services in the United States.

Sampling methods are much helpful in the business sector and industry to raise operational efficiency. It plays an important part in problems encountered in market research like estimating the numbers of readership of news-magazines or newspapers to seek the opinions or reactions of the buyer in the market.

Sampling Techniques

Based on the objectives and purposes sample surveys can be classified into three categories as descriptive, analytical and both descriptive and analytical.

Many times, we can see that the total population is adequately small. Then the investigator can take the whole population in the research and it is generally called census but in general the population is excessively big that's why the researcher faces problems to survey every element. In that case, a small but representative part has chosen to estimate or represent the population.

Sampling methods are classified into two different groups as probability sampling and non-probability sampling. Sampling in which each unit in the population contains a known non-zero probability to be chosen is probability sampling. Four probability

sampling like as simple random sampling, systematic sampling, stratified sampling and cluster sampling are listed commonly. In non-probability sampling includes convenience sampling, judgment sampling, quota sampling, snowball sampling and so on (Bhardwaj, 2019).

Sampling in Past Research

If direct, easy access to the entire population is not feasible, a suitable sample must be selected to gather observations for market research analysis. Moreover, the method chosen depends upon a variety of statistical and practical factors. It needs to confirm the sample size sufficient for the purpose of analysis which intends to derive, to make sure the sample is representative of the population. Market research includes the collection of data to get insight and knowledge into the needs and wants of customers.

A special type of sample survey is known as "Opinion Polls" where opinions or attitudes of a group of people are taken based on political, economic or social topics. In the U.S. during 1824, two newspapers named the Harrisburg Pennsylvanian, and the Raleigh Star tried to find out the political preferences of voters about the presidential vote. The polls have no concern about taking samples. That's why the prediction was hard on finding out the exactness of results. Opinion polls at that time were named as Straw polls and it went back to rural America. Generally, farmers threw straws into the wind to observe the way of blowing wind. Newspapers started this type of poll process of the roads to know the political situations, and it stayed until nearly 1920. For estimating the American public's radio listening habits Archibald Crossley developed new methods at that time and to see reader eagerness in newspaper articles Goerge Gallup developed new works (Lindhard, 2003). Gallup used quota sampling, and he took hundreds of interviewers. Every interviewer got a quota for various classes of respondents and almost three thousand respondents' opinions were collected to conduct a survey. Gallup's work faced problems with a leading polling organisation named as Literary Digest magazine. Literary Digest magazine sampled about two million people from automatic vehicle registration records and telephone notebooks. In the presidential election in 1936, Gallup predicted correctly who will be the new president and Franklin Roosevelt it was. Again, literary Digest magazine forecasted incorrectly that Alf Landon will be elected. There is attention that the prediction from the large sample was not correct. The reason was that Literary Digest magazine took samples from automobile registration list and telephone notebooks only, which could be used by medium and higher class people. There were other classes of people who were not included in the sample taken by Literary Digest magazine and by this wrong prediction they closed up their publication in 1937 (Utts, 1996). So, the way of taking a sample or selection is more necessary than the size of the sample.

Non-Conventional Sampling Techniques

In this section, some non-probability sampling which has been very popular in recent years are introduced. Review of these methods is available in Imon (2016).

Network Sampling: In survey research, if infrequent populations are of interest in that case network sampling is applied. *Screening* and *salting* are two major methods which can be applied in surveys with an unknown population. At the time of interview, screening the respondents of

interest need to be done and then obtain the sample units by official records (Lavrakas, 2008). Due to the lack of sampling frame, it is advantageous in working with a hard-to-reach population. There is concern about precision and accuracy of network-based sampling techniques (Mouw & Verdery, 2012). In HIV studies, network sampling would be subsequently applied.

To study rare populations, link-tracing designs make a different approach by applying a bunch of respondents. This kind (link-tracing) is sometimes reported like snowball sampling and primarily taken into account for convenience sampling. By extension of respondent-driven sampling this switching, vastly employed network sampling where link-tracing design is applicable for supplying inferential statistics (Heckathorn & Cameron, 2017). Some other popular names for network sampling are snowball sampling, respondent-driven sampling, multiplicity sampling, chain sampling, referral sampling etc.

Encounter Sampling: Encounter sampling (Huston, 2014; Otis et al., 1993) is a data collection procedure where surveys collect data from individuals who are encountered during an activity or behaviour by a surveyor that travels a random route through a survey area. Here population units are included in the sample as they are detected or encountered. Encounter sampling can be used when we must rely on whatever data is readily available or when we need to make efficient use of limited resources by controlling the cost and number of observations. It may also be applied when useful circumstantial information is accessible and can guide the selection process. This method is also commonly referred to as *targeted sampling* or *active sampling*.

A data set is labelled as encountered data when a researcher works directly in the study area, collects and lists what he/she notices or encounters. The long-established data collection methods require randomly chosen observations and under prescribed circumstances. That is sometimes impossible with agricultural problems - we have instead to make do with what forms or observations of confined numbers can be gotten, and on the occasions and at the areas they occur to arise.

For instance, fish and some other animals are confined to limited areas It is a common tool when the researchers select the habitats which are expected as target species rather than the surrounding environment. Due to freshwater fish as unevenly distributed the encounter sampling assists to find rare species (Trebitz et al., 2009). A known method of collecting samples for plants is a transect sampling (Hiby & Krishna, 2001).

Quadrat Sampling: To study ecology or more especially biodiversity, Quadrat sampling (Krebs, 1999) is a classic method. A frame where a certain region in the group needs to count as a sample in this sampling. It may be square in shape or rectangular or circular and in appropriate size. In any plant category for quantifying the plant group this technique is vastly used though there are some vegetation types where other methods suit good enough as a point-quarter tool for forests. This sampling is simple to apply but it is not applicable to study about very quick-moving animals as they run fast from quadrat boundaries. Uniform shape and size are used in quadrat plots which are distributed randomly throughout the area. A modified quadrat sampling method for urban ecosystem network monitoring is presented in Dong et al. (2013).

Composite Sampling: Composite sampling (Boswell & Patil, 1987) is a method which is cost-effective as well as it separates the selecting samples from assessing them, it is possible to achieve two conflicting goals simultaneously. On one hand, one can select a large number of sample units to ensure the desired sample support, so that the results of the analysis will be sufficiently reliable. On the other hand, by compositing several individual samples into fewer composites, one reduces the number of analytical measurements so that a study can be carried out without affecting the available financial resources.

In the group testing examples, there was trouble with the outbreak plant virus borne by insects and in the time of World War II of testing US service holders due to syphilis. The collected material from every element of a sample is pooled, and it conducts a single test to observe if the condition is consistent or abolished; as such, patients' blood samples might be compounded together and then examined for the existence of the HIV virus. It covers an extensive range of applications of composite sampling, by examining to observe the existence of disease for testing if materials go to unsuccessful to arrive at the secure boundary. More distinct instances are geostatistical sampling, screening of dangerous chemicals, air quality etc. The introduction of several composite sampling procedures is listed below. Many of them are outlined by Barnett (2004).

For instance, χ can measure the level of contamination χ_l in a river, then we wish to learn whether any observed in a sample of size n is above a control or standard value. If is the standard value for the sample total, we compute $\underline{\chi}$ first. If $\underline{\chi} > \chi_0/n$, we say the test is positive and declare that observation faulty. Otherwise, the test is negative, and we accept the observation. This procedure is known as the 'rule of n' composite sampling procedure.

Full Retesting: In *full retesting* we form a composite sample of n observations. If the test is negative, we stop there immediately and clear all n individuals. If the test is positive, we have to test each and every individual separately. In the full retesting approach it will demand either one test when negative or $n + 1$ tests when positive to pick out exactly which sample elements are influenced. Full retesting is not very popular because even if 1 out of thousands item is faulty the test is positive and we have to test one test more than testing every individual.

Sudden Death: A particular type of composite sampling is known as *sudden death retesting* (Gertsbakh, 1996). It follows a positive 1st test then needs to examine the individuals one at a time up to we get the first affected individual, after that perform a composite test on the rest part. When this composite test results negative it requires to stop the whole procedure, after that we have only one affected sample. It needs to perform the procedure repeatedly when the composite test is positive.

Group Retesting: In group retesting, first used by Dorfman (1943), we divide the group of samples of size n among k subgroups, when the 1st total composite test is positive. Every subgroup is dealt with as a second-stage composite sample. Then every subgroup is checked for full retesting.

Cascading: Cascading (Newson & Humphries, 2005) is known as a particular alternation of group retesting where it takes in hierarchical approach. If a composite test

consisting of *n* samples is negative, then it needs to stop the test and declare all items satisfactory. But if the first test is negative, we divide the entire sample into two groups and do one composite test for each subgroup of size *n*/2. Every positive subgroup or group is divided between two portions like *n*/4, *n*/8 and so on. We continue testing until all positive samples have been pointed out.

Ranked-Set Sampling: In many fields of environmental danger like radiation (disease clusters, air-borne hazard) or contamination (root disease of crops) we usually notice that the accepting measurement may comprise significant scientific processing of components with high attendant charge correspondingly. This sampling technique was originated by McIntyre (1952) as a cost-effective technique of choosing data when observations are very inexpensively ordered compared to measurements. In practical situations where the variable of interest for an observed component is time-consuming, this technique is applicable (Chen, 1999). This method requires fewer observations while potentially achieving higher accuracy compared to simple random sampling.

There are several ways of collecting ranked set samples. Let us assume we have a set of *n* observations of a random variable *X*. It can be arranged them in a square of size *p* so that $p_2 \approx n$. Within each array we order observations in increasing order. These would yield observations in the form

The ranked set sample is $\chi_{11},\chi_{22}, \ldots,\chi_{ii},\chi_{p\text{-}1p\text{-}1}),\chi_{pp}$. Out of *n*, the selected ranked set is of size *p*, which are in fact the diagonal elements of this square array. The sample mean $\underline{x}$ is computed on *n* samples, i.e., $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$. The ranked set sample mean is defined as

$$\underline{\underline{x}} = \frac{1}{p}\sum_{i=1}^{p} x_{ii}.$$

Barnett (2004) showed that $\underline{\underline{x}}$ is an unbiased estimator of the population mean and Var $(\underline{x}) \leq \text{Var}(\underline{\underline{x}})$, which makes the use of ranked set samples logically beneficial.

CONCLUSION

Survey sampling theories have been advanced over a period of years, supporting research in various fields and theoretical aspects from time to time. This evolution is not a replacement of old methods by new, but an expansion of the researcher's toolkit. While traditional probability-based methods have long been used to ensure reliable survey results, improper application can lead to biased or misleading conclusions. Recently, non-probability sampling techniques have

Table 1
Structure of a ranked set sampling matrix and selection of diagonal ranked unit

x_{11}	x_{21}	.	x_{i1}	.	x_{p-11}	x_{p1}
x_{12}	x_{22}	.	x_{i2}	.	x_{p-12}	x_{p2}
⋮	⋮	⋱	⋮	⋱	⋮	⋮
x_{1i}	x_{2i}	.	x_{ii}	.	x_{p-1i}	x_{pi}
⋮	⋮	⋱	⋮	⋱	⋮	⋮
x_{1p-1}	x_{2p-1}	.	x_{ip-1}	.	x_{p-1p-1}	x_{pp-1}
x_{1p}	x_{2p}	.	x_{ip}	.	x_{p-1p}	x_{pp}

gained popularity due to their practicality in situations where conventional methods are difficult or costly to implement. However, despite the growing use of these methods, there is limited synthesis of their historical development, contemporary applications, and methodological nuances across different research contexts. This study addresses this gap by reviewing both conventional and nonconventional sampling methods, highlighting their applications in current social and market research, and providing insights that can guide researchers in selecting appropriate sampling strategies. By combining historical perspectives with contemporary prac tice, the study offers a novel framework that informs both theory and applied survey research. Future research should focus on refining bias-correction models for non-probability samples and developing hybrid frameworks that combine the advantages of both methods.

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