Glimpses of Basic Research in Sample Survey at IASRI

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1. Introduction

The Indian Agricultural Statistics Research Institute made a modest beginning in 1930 as Statistical Section of the Indian (then Imperial) Council of Agricultural Research. It subsequently evolved into a premier Institution in 1959. Since the very beginning one of the mandates of the Institute is to conduct research in agricultural statistics. The Institute has made a significant contribution in the field of experimental design, sampling methods, statistical genetics, bio-statistics, forecasting techniques, statistical economics and computer applications. Large numbers of research papers have been published in National and International journals of repute. Research papers published by the scientists/students of the Institute have been both basic and applied in nature. On the occasion of Golden Jubilee of the Institute it is appropriate to summarize the achievements made by the scientists/students from time to time in various areas. In what follows, we give an account of basic research carried out, in a chronological manner, in the Sample Survey at Indian Agricultural Statistics Research Institute.

The basic research in the Division of sample survey was carried out in all areas of sample surveys i.e. equal and unequal probability sampling, stratified sampling, cluster and multi-stage sampling, systematic sampling, ratio and regression methods of estimation, controlled selection and non-sampling errors. Besides, the scientists/students did basic research in newer areas of sample surveys like analysis of complex surveys which included regression and categorical analysis from survey data, variance estimation techniques, small area estimation, combinatorial aspects of sample surveys etc., conditional design based approach and model assisted approach of estimation. In many papers which appeared in earlier years the theory was illustrated with real data. Similarly, simulated as well as real data was used in large number of papers which appeared in later years.

2. Details of Basic Research in Chronological Order

The statistical efficiency of the interpenetrating sampling design in relation to the precision of the estimate and the cost involved was examined.

A general formula appropriate for the estimation of gains in precision due to stratification in a sub-sampling design from finite population was developed and illustrated on the yield data relating to sample surveys carried out in Delhi province.

The gain in efficiency achieved by avoiding the repetition of sub-units in a two-stage sampling plan was explicitly worked out. The percentage reduction in the within unit component of the variance was found to be very nearly equal to the over-all sampling fraction.

An attempt was made in the direction of measurement of non-sampling errors by the method of replicated samples. Necessary formulae were developed to give the estimates of the various components of non-sampling errors. Simple special cases of the replicated samples were discussed with illustrations from the surveys carried out under the auspices of Indian Council of Agricultural Research. Some of the

merits and limitations of method of replicate samples were examined.

It has been shown that for n>2, sampling with varying probability without replacement (PPSWOR) may not be more efficient than sampling with varying probability with replacement (PPSWR). The efficiency will depend on sample size, population size and size measure with which the units are selected.

Necessary theory of sampling with probability proportional to size when 2n psu's were selected from a stratum in two groups of n each, such that either the elements within a group were selected with pps and the rest with equal probability and the groups were selected with replacement. The theory was generalized to m groups. Efficient sampling systems were derived for two-stage sampling when the groups had overlapping psu's.

Efficiency of cluster sampling was examined in relation to two -stage sampling. Specific situations were discussed enumerating the merits of one method over the other.

The method of analysis of variance was used for studying the variance components of two/three-stage sampling designs.

The double sampling scheme was extended to multi-stage sampling design in the context of ratio method of estimation. Numerical illustrations were given in support of the theory.

A suitable sampling methodology was developed whereby the risk of drawing non-preferred samples was minimum but at the same time the sampling scheme confirmed to the principles of random sampling procedures.

The problem of estimation of population mean using ratio method of estimation when information on auxiliary character was unknown involving multi-stage sampling design was extended to the case of several auxiliary variables for a three stage sampling design. Optimum weights were determined. An estimate of variance was also developed. An empirical study was carried out using survey data on guava.

A more general form of an estimate of the variance of customary stratified simple random sample based on one sample unit per stratum was suggested.

It was shown that the usual ratio and regression estimators in controlled simple random sampling were at least as efficient as those in simple random sampling.

A more general result regarding non-negativity of Yates and Grundy's estimate of variance of Horvitz-Thompson estimate of the total was obtained.

A sampling scheme was suggested which not only minimized the selection probability of non-preferred units but also provided efficient estimators than the usual PPS sampling scheme

A slight modification of the usual systematic sampling procedure in the presence of a linear trend in the population was found to be very effective in reducing the error variance of the estimator for the population mean. The efficiency of the modified design in the presence of random, quadratic and periodic trends was evaluated in comparison with usual systematic methods. The adaptability and suitability of the modified systematic sampling procedure was illustrated by application to a survey for estimating the milk yield.

The problem of estimation of population mean in successive sampling under a multi-stage sampling design was considered. The optimum replacement problem was studied.

A selection mechanism was given by means of which one could easily construct a controlled simple random sampling design to draw a sample of any size from a population of any size.

Different estimators of annual milk production were developed. These were used to build estimates of milk production out of a survey carried out in Punjab and Eastern Uttar Pradesh.

A general method of collapsing any number of strata and the use of an ancillary character for collapsing was suggested. The same ancillary character was used in improving the estimate of the parameter under study. The case when the population mean of the ancillary character was unknown was also considered. Double sampling approach was proposed in such a situation

A comparison of estimates of population mean under a two-stage sampling design for two different sampling patterns i.e. when a fraction 'p' of the primary sampling units (psu) with their samples of second stage units (ssu) were retained from previous occasion to the current occasions and a fraction 'q' of the psu's were selected afresh and when all the psu's in the sample on the previous occasion were retained on current occasion but only a fraction 'p' of the sample of ssu's within each psu was retained and a fraction q of the ssu's were selected afresh. Estimators were developed for the current occasion, change over two occasions.

Relative efficiencies of the estimates obtained under different sampling patterns were studied in two-stage sampling on successive occasions. Relative efficiencies were also studied of some alternative replacement procedures when sampling was carried out on three occasions.

Reduction in bias of the ratio method of estimation of population mean was achieved by transformation of origin and scale of the measurement of the auxiliary variate.

It was shown that the Horvitz-Thompson estimator under Midzuno-Sen sampling was always inferior to that of Rao, Hartley and Cochran in all practical situations where PPS sampling was to be preferred. It was found to be worse than even the PPS sampling with replacement estimator in many situations. Some numerical examples were considered for illustration purpose.

The results obtained on controlled sampling with equal probabilities and without replacement were consolidated. A practical and convenient procedure for controlled simple random sampling was proposed.

Minimum variance linear unbiased estimates have been developed for population mean on the most recent occasion, change in the population mean from one occasion to another and overall estimate of population mean overall occasions under a two stage sampling design in which primary stage units were partially replaced and the second stage units in the retained primaries were kept fixed. The entire study was made under a general correlation pattern.

A PPSWOR technique was suggested which ensured sampling with probability exactly proportional to size, and facilitated the calculation of joint inclusion probability of two units for any sample size from a finite population.

A new approach to controlled selection, which ultimately lead to the method of controlled simple random sampling, was suggested which simplified procedures of controlled selection.

An estimation procedure was developed in two-stage successive sampling on the h-th occasion where primary as well as secondary units were partially replaced. Some corrections were made in a similar paper published earlier by different authors.

Necessary theory of non-response in successive sampling on two occasions was developed.

An estimation procedure was suggested which made use of multi-auxiliary information when information on some of the auxiliary variables was not available for the whole population, instead it was known for some parts of the population.

A new systematic sampling procedure was suggested which provides the unbiased estimator of sampling variance, besides maintaining simplicity. On comparing the efficiency of the suggested procedure with the usual systematic sampling and simple random sampling it was observed that in situations where usual systematic sampling performs better than simple random sampling the suggested procedure also leads to the similar results and for some situations it may provide better results than even usual systematic sampling.

A method based on PPS systematic schemes was proposed whereby 'm' unit were selected with PPS systematic sampling with revised probabilities and 'n-m' units with SRSWOR.

The general problem of regression analysis was studied when the population was finite. Expressions for the variance of the regression predictor were obtained depending on how the value of the auxiliary variate was chosen. It was observed that there was a component in variance of prediction which depended upon the sampling procedure used for the selection of the sample.

A method based on PPS systematic sampling, was proposed which selected large number of units through a specific procedure and then from these large number of units the ultimate sample of n units was selected by SRSWOR.

Necessary theory for estimation of population mean was developed using unbiased two-auxiliary variate ratio estimators. Two cases were considered i) when the population means of auxiliary variables were known ii) when the population means were unknown. The theoretical results were supported with empirical results.

Role of Sampling in prediction was examined. The expressions of variance of prediction were obtained for various situations and relative efficiencies were compared.

A procedure was suggested so as to make cluster totals almost equal. With the help of empirical study it was shown that the suggested procedure was more efficient than SRS. An added advantage was that the suggested procedure was simple, objective and convenient.

The limits on probability under which usual sampling model is to be prepared over binomial sampling model have been worked out

Using one auxiliary variable for selection and the other for estimation, the PPS and ratio estimator were suitably combined for estimation of population mean. The proposed estimator was shown to be more efficient than either PPS estimator or ratio estimator under PPS sampling scheme.

A modified ratio estimator was considered by utilizing the relationship between the study variable and the auxiliary variable. The efficiency gains of modified ratio estimator vis-à-vis the regression estimators were demonstrated theoretically as well as empirically.

Using multi-auxiliary information an efficient estimator was developed which utilized cluster sampling in conjunction with ratio/regression estimators. Besides theoretical results, some empirical results were obtained.

Almost unbiased ratio type estimators were considered for different sampling schemes. Efficiency comparisons were made. Usefulness of the sampling schemes was illustrated with the help of real data on price of vegetables.

A criteria based on information on several auxiliary characters was suggested for the purpose of selecting units with unequal probability sampling with replacement. Efficiency advantage of an estimator of total based on this criterion was demonstrated over the usual PPSWR based estimator. An empirical study was carried out for illustration purpose.

It is well known that the ratio estimator of finite population mean/total is unbiased under Lahiri scheme of sampling. A sampling scheme was developed in the institute under which the regression estimator of finite population mean is unbiased. A sampling procedure was given which provided an unbiased regression type estimator.

The problem of estimation of frequency distribution for the current occasion using different sampling designs under successive sampling approach was attempted. Cluster sampling design with PPS sampling was found advantageous for such situations.

Using modified form of sequential sampling, a class of acceptable estimators were developed with varying sample size.

A method was proposed which involved splitting the sizes of the population units arranged in ascending order. The splitting formed columns. The splitting was carried out in such a manner that there were at least n non-zero values in each column and each pair of units had a non-zero value in at least one column. A column was selected with probability proportional to column totals. From the selected columns n units were selected with SRSWOR.

Adopting size stratification when the auxiliary character was approximated by a continuous uniform distribution, a double sampling ratio strategy was suggested and compared with some of the known strategies. The applicability of the strategy to sampling on two successive occasions was also investigated.

A general class of unequal probability sampling schemes for selecting two units without replacement was given. Many known sampling schemes were shown to be members of this class. It was shown that for any member of this class, the Yates-Grundy estimator for variance of the Horvitz-Thompson estimator was always positive.

Two sampling schemes using auxiliary variables for cluster sampling were proposed. In one of the schemes, the auxiliary variable was used in selecting the clusters whereas in the other the elements within the clusters were selected using the auxiliary variables. The efficiencies of the proposed sampling schemes as compared to the conventional cluster sampling with unequal probabilities of selection as well as SRSWOR were worked out empirically for natural as well as constructed populations.

A sufficient condition that the variance of Horvitz-Thompson estimator for inclusion probability proportional to sizes sampling scheme of selecting two units was uniformly smaller than that of Rao, Hartley and Cochran estimator was obtained.

A simple method of inclusion probability proportional to sizes was proposed for samples of size three units. It was shown that the variance of the Horvitz-Thompson estimator based on the proposed sampling scheme was uniformally smaller than that of the customary estimator used in probability proportional to

sizes with replacement sampling. Further, the performance over Rao-Hartley_Cochran and Sampford sampling schemes was studied empirically for some natural populations.

An alternative to the usual regression estimator for a population mean in double sampling was suggested on the basis of a preliminary test of a simple hypothesis about the auxiliary variate-mean. Two-phase sampling was assumed from a bivariate normal population. The gain in efficiency was investigated theoretically and empirically.

A method of forming clusters of two units and their selection in such a way that the units in a cluster did not fall beyond a pre-assigned distance 'd' was suggested. The selection procedure ensured sampling without replacement. The results were empirically illustrated.

Sampling with partial enumeration was defined in the context of multi-character surveys. Efficiency of sampling with partial enumeration was examined vis-à-vis the usual two phase sampling for the study of two characters.

An attempt was made towards optimal use of several auxiliary variables in the form of a single auxiliary variable obtained as a linear function of the several auxiliary variables. The performance of the condensed auxiliary variable was studied in selecting the sample.

A sampling procedure in unequal cluster sampling for fixed sample size, where the number of units in the initial sample of selected clusters exceeds the planned size of units was proposed. A scheme for discarding the excess number of clusters from the initial sample of clusters was also presented. It was shown that the suggested procedure, taking into account simplicity and practical feasibility, could be used in practice in uni-stage unequal cluster sampling designs.

An inclusion probability proportional to size sampling scheme for selecting sample of two units was suggested. The sample selection ensured the non-negativity of Yates Grundy's variance estimator of the Horvitz –Thompson variance of the estimator . For a number of natural populations, the proposed sampling scheme performed better, in terms of smaller variance, than many of the existing unequal probability sampling schemes.

The theory of multiple frame surveys was developed for multi-stage sampling designs in the context of estimation of finite population mean. Efficiency gains vis-à-vis single frame situation were studied under different cases i.e. multiple frame at first stage and single frame at second stage, single frame at first stage and multiple frame at second stage and multiple frames at both the stages.

A ratio type estimator involving two auxiliary variates was suggested. The suggested estimator was found to be more practicable then the already available estimators in the sense that it was always positive.

A sampling scheme was proposed which involved creating a sampling design to ensure inclusion probability proportional to size selection. The sampling design was created through constructing a sample space in which the population units occurred in proportion to their sizes and every pair of units occurred in such a way as to provide a non-negative and stable variance estimator. The selection procedure was extremely simple and the values of the inclusion probabilities could be computed easily. Some examples were considered.

A modified systematic sampling scheme was suggested by combining the concept of random interval with the use of unequal selection probabilities. The suggested scheme had the merit of simplicity and it

was also possible to estimate the variance of the estimator. Empirical comparison with SRS and usual circular systematic sampling indicated that the suggested scheme could be used as an alternative to systematic sampling.

A procedure was given in the context of post-stratification in uni-stage unequal cluster sampling on the basis of the elements of the selected clusters. The results obtained were empirically studied.

An approach was developed to estimate population and sample sizes when units were selected sequentially. Both with and without replacement procedures were considered.

The efficiency of ratio estimator under size stratification was worked out depending upon the size character when it was discrete. Efficiency comparison was made with some of the well known sampling strategies. It was established that the stratified ratio sampling strategy performed satisfactorily.

A stratified ratio sampling strategy using discrete ancillary information was suggested. Relative efficiency comparisons revealed that the stratified ratio sampling strategy performed satisfactorily.

A πPS sampling was proposed by modifying the usual PPS systematic sampling. The proposed sampling scheme was compared empirically with the existing sampling schemes. The empirical results were promising.

The problem of estimation of population mean was considered for the case of sampling on two occasions when a fixed proportion of clusters of units were drawn on the first occasion and retained on the second occasion. Optimum allocation was considered under a suitable cost function. The efficiency of matching of clusters of units was examined in relation to the matching of an equivalent simple random sample of units. The theoretical results were empirically illustrated.

The effect of departure of optimum values of sample size and weight was studied in the context of estimation of finite population total under a multiple frame set up. The estimator was found to be robust with regard to departure from optimum values of the weights but not with regard to departure from optimum values of sample sizes.

The method of Balanced Repeated Replication (BRR) was extended to general sample design with arbitrary number of selections from each stratum. It was shown that mixed orthogonal arrays of strength two, or equivalently equal frequency orthogonal main-effect plans for asymmetrical factorials gave a set of balanced sub-samples useful in variance estimation.

The problem of estimation of finite population total in the context of sampling from two-dimensional populations spread over space and time was examined. Combinations of equal probability sampling and systematic sampling over time dimensions were considered. A scheme with double sampling and systematic sampling was also considered. Efficiency gains of the proposed procedure were studied empirically.

Narain's necessary condition for without replacement sampling to have smaller variance than with replacement sampling was modified.

The problem of estimation of finite population mean was attempted when the underlying population followed a simple linear model involving single auxiliary variable Two situations were considered i.e. i) the line of regression passes through origin and the variance of error terms increases with the increase in size of the auxiliary variable ii) there was an intercept term in the model and the variance of error terms

was constant. The errors terms were assumed to be uncorrelated. The method of double sampling was proposed when the information on the auxiliary character was assumed unknown. The efficiency gain of double sampling based predictor over a predictor which did not utilize auxiliary information were demonstrated under a suitably chosen cost function.

Suitable estimators were proposed for estimation of population mean for study of two characters from a two-stage sampling design when data were missing for one or both the characters from some preliminary stage units as well as some second stage units. The theoretical results were illustrated empirically.

A suitable method of estimation was proposed in the context of sampling from imperfect frame and a geographical ordering of units could be established.

An efficient method of estimation was proposed for the following two situations i) when the planned sample size was fixed but the realized sample size was a random variable ii) when the planned sample size itself was random variable. Theoretical results were supported with empirical results.

A sampling scheme was proposed under which the usual regression estimator was unbiased. The proposed scheme had not only the advantage of simplicity but it was found to be efficient than the conventional strategies under use.

Estimation theory for sampling from two dimensional populations with various sampling procedures along space and time dimensions were considered. Both aligned and unaligned sampling for various situations were investigated. While simple random sampling and two-stage sampling were considered along space dimension, systematic sampling was considered along time dimension.

A supplementary randomised response strategy was proposed. Rules for selection of design parameters were obtained. The relative efficiency of the supplementary information quantitative randomised response model over the optimized model was worked out.

Estimators of lactation yield were developed when the lactation records were incomplete. The performance of the proposed estimators were compared empirically using the data collected in Madras in 1980 under a survey entitled “A study of impact of milk supply schemes on rural economy in milk collection areas of Madhavaram milk supply schemes”.

A supplementary randomised response strategy was proposed. Rules for selection of design parameters were obtained. The relative efficiency of the supplementary information quantitative randomised response model over the optimized model was worked out.

A regression model which takes into account the clustering effect was considered. The effect of misspecification of model when the clustering effect was ignored was examined under some suitable cost function.

A sampling scheme for post stratification in two stage sampling was developed. Efficiency gains of an estimator of population mean based on the proposed scheme vis-à-vis an estimator based on the conventional unstratified two-stage procedure were demonstrated empirically.

Using Projective Geometry Approach, Minimum Variance Linear Unbiased Estimators of population parameters were proposed in sampling on two occasions for simultaneous estimation of two characters for levels, change and average over time.

The effect of correlated measurement errors on Ordinary Least Squares estimator was studied when both the variables were subject to measurement errors. The expressions for relative bias and relative mean-square error of regression estimates were derived.

Three variance estimation techniques namely Taylor Series Linearization, Jacknife Repeated Replication and Balanced Repeated Replication were compared in the context of cell proportions through the use of combined ratio estimator. The bias of Taylor Series Linearised estimator was found to be minimum.

Estimators were developed using randomized response models for binary and discrete data. It was shown that the unrelated question randomized response model under SRSWOR performed better than open interview with nominal untruthful reporting of order 5%.

Using available small area models composite estimators were developed. The performance of the proposed estimators were studied empirically.

It was shown that mixed orthogonal arrays of strength two are balanced subsamples needed for variance estimation.

A variance estimator for linear as well as non-linear estimator based on proportional frequency plan was proposed. The proposed variance estimator was shown to be asymptotically consistent.

An unbiased multiplicity estimator was considered in the context of overlapping clusters. The merit of the proposed estimator was studied under a specific situation.

Minimum Variance Linear Unbiased Estimator of any parametric function was developed using Hilbert space method for the case of sampling on h-occasions for univariate as well as multivariate populations.

A preliminary test estimator was proposed to test the significance of Ordinary Least Squares estimator of regression coefficient and the probability weighted estimator. The model based properties of the estimator were studied theoretically while the design based properties were studied through simulation approach. The proposed estimator was found to be better compromise between model based and randomization based inferential framework.

The various modified Chi-square test statistics were evaluated with respect to their actual size of the critical region through empirical investigation. It was observed that the second order corrected statistic based on Satterthwaite approximation performed better in terms of its actual size of the critical region as compared to the nominal level of the critical region at 5%.

Robust estimators of population mean were developed when there were outliers and the assumed model was wrong. The advantages of the proposed robust estimators vis-à-vis already available robust estimators were studied through a simulation study.

The problem of estimation of finite population mean for sampling on two occasions has been considered when the variables were subject to measurement errors. Efficient estimators have been developed for the current, previous and sum over the two occasions.

Empirical investigations on jackknife variance estimation under two-phase sampling when the first phase sample was used for stratification were carried out through simulation study. Under certain conditions, the jackknife variance estimator of reweighted expansion estimator performed satisfactorily

The problem of estimation of finite population mean square for the current occasion was considered for the situation of sampling on two occasions. Estimator of finite population mean square has been developed utilizing data of the two occasions. This estimator was shown to be better than an estimator which utilized only the current occasion data. However, the efficiency gains were less as compared to the case when the parameter was finite population mean.

A combined estimator of population mean under successive sampling which allowed one to take account of available auxiliary information in the matched portion at the estimation stage by means of conditional bias adjustment. The merit of the proposed estimator was studied through a simulation approach.

A new bootstrap technique of variance estimation for dealing with missing observations was developed. An optimum choice of bootstrap sample size in case of missing observations was obtained. The relative efficiency of the proposed technique was studied through simulation approach.

The problem of estimation of population mean when there was partial matching among first stage as well as second stage units was considered. The performance of both linear and non-linear estimators were studied empirically.

The problem of estimation of finite population regression coefficient was considered when the information on design variable was not available. The double sampling approach was suggested in this case. The efficiency of the double sampling based estimator of regression coefficient was examined vis-à-vis a probability weighted Ordinary Least Square (OLS) estimator.

A general result has been obtained whereby it was possible to obtain Minimum Mean Square Linear estimator which belonged to a particular class of biased estimator. The general result has been extended to the case of sampling on more than two occasions.

Necessary theory for estimation of finite population total in case of dual frame surveys has been developed when the domain sizes were assumed unknown.

An integrated approach for estimation of area under paddy has been developed using remote sensing and GIS.

The necessary theory for estimation of finite population regression coefficient in the context of sampling on two occasions was developed.

The bootstrap techniques were compared through simulation approach when the missing observations were imputed through different techniques

The Hansen and Hurwitz technique of obtaining response from the selected non-respondents has been extended to the case of sampling on two occasions for estimation of finite population mean on the current occasion. Three different situations have been considered viz. non-response on the first occasion, non-response on the second occasion and non-response on both first and second occasions. Efficiency gains of the proposed estimator were considered under a suitable cost function.

A finite population framework has been developed in the Institute for the method of Rank Set Sampling (RSS). This framework was further used to develop the method of RSS for two-stage sampling designs with the objective of estimating the finite population mean. Different situations were considered i.e. selection of first stage units by RSS and second stage selection using Simple Random sampling (SRS),

SRS at the first stage and RSS at the second stage and RSS at both the stages. Efficiency gains of RSS based estimators over SRS based estimators were demonstrated empirically with the help of real data.

The mixed model approach of estimation of population mean for the small area was used to develop district level estimates of the parameter amount of loan outstanding using 59th round of National Sample Survey Organization (NSSO) data for the rural areas of Uttar Pradesh. The performance of the Empirical Best Linear Unbiased Predictor (EBLUP) was studied vis-à-vis the direct district level estimates on the basis of the criterion of mean square error. The covariates used in this study were obtained from the 1996 Agriculture Census data.

A framework for estimation of finite population mean when the units were selected using the method of Double Rank Set Sampling (DRSS) was developed. Efficiency gains of the estimator based on DRSS procedure were demonstrated over estimators based on RSS and SRS with the help of real data.

The problem of estimation of finite population mean square has been attempted when the underlying population followed a simple linear model involving single auxiliary variable and the line of regression passed through origin. Further, the errors terms were assumed to be uncorrelated and the variance of error terms increased with the increase in size of the auxiliary variable. The method of double sampling was proposed when the information on the auxiliary character was assumed unknown. The efficiency gain of double sampling based predictor over a predictor which did not utilize auxiliary information was demonstrated under a suitably chosen cost function.

A Spatial Ranked Set Sampling (SRSS) scheme which took into account the spatial correlation between units was proposed. The merit of the proposed scheme vis-à-vis both Simple Random Sampling and Rank Set Sampling was demonstrated through a simulation study.

Two approaches to computer aided construction of Balanced sampling plans excluding contiguous units (BSEC)/polygonal designs were described. In the first approach polygonal designs were obtained using method of symmetrically repeated differences. In the second approach, BSECs were obtained using linear programming to minimize the probability of selecting samples which contained contiguous units subject to the constraints of specified first and second order inclusion probabilities of BSECs. The methods were illustrated with numerical examples.

A new family of distance balanced sampling plans was proposed where second-order inclusion probabilities were a non-decreasing function of the distance between the population units. Some properties of the proposed family of sampling plans were studied using Horvitz-Thompson estimator. Relative efficiency of the proposed family was compared with existing sampling plans. Some results on existence and constructions of the proposed family were discussed.

The problem of estimation of finite population total under nested stratified sampling plan was investigated. Allocation of sample sizes to different primary and secondary strata were obtained for fixed cost and fixed precision. The proposed plan under different allocation was compared with usual stratification.

Projective Geometry Approach was used to develop Minimum Variance Linear Unbiased Estimators of population parameters in sampling on two occasions with the simultaneous involvement of two correlated characters for the current occasion as well as change and average over time for both the characters.

Minimum Variance Linear Unbiased Estimator developed using Projective Geometry Approach was applied to estimate the foodgrain losses at harvest and threshing stage.