ROTATION OF SAMPLE IN MULTISTAGE DESIGNS

by

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Sample surveys are conducted in the Philippines either semi-annually or annually for the purpose of providing current and reliable statistics on some echelons of the country's economy. The Philippine Statistical Survey of Households (PSSH) is one of these current surveys useful for planning the socio-economic programs of the government. Others are developed and included for implementation in our annual Philippine Statistical Program in order to provide for the gaps which exist in our statistical system.

There are about six current major statistical surveys in the Philippines and more than six other major sample surveys on fishing, crop cutting, trade, construction, transportation and communication, services and others are being envisioned in the statistical program for the coming fiscal years. For purposes of economy and efficiency, efforts are being exerted to conduct these other surveys within the existing organizational framework like that of the PSSH. The statistics from these surveys will give a bigger picture of the nation's developing economy.

Practically, all national sample surveys are designed to sample the same population, repeadtedly, and if this is the case, some considerations must be given to the aspects of frequency of visits to panel households or establishments and the pattern in which the sample will have to be changed from visit to visit. Response resistance seems to increase with subsequent visits. Even if we assume that there exists complete cooperation, the panel or respondent may be influened by the information which it gives and receives and this constant exposure may act as a conditioning effect resulting in a non-randomness of the panel in subsequent visits. A rotation scheme must be provided to answer these questions of response resistance and non-representativeness of 'panel' samples.

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Hansen, M.H. Hurwitz, W.N. and Madow, W.G. **Sample Survey**

The purpose of this paper is to indicate the relevant uses and theoretical approaches in a stratified two-stage design without replacement and with equal probability at each stage of simple and rotation sampling. An attempt will also be made to show the approaches to other methods of selection of sample.

REVIEW OF LITERATURE

In February 1955, Hansen, et al introduced a redesign of the Current Population Survey (CPS), from which information on employment, unemployment, and other related data are compiled each month. One feature of the subsampling which has an important bearing on the estimation procedure introduced in the new sampling involves changing a part of the sample each month. To accomplish this rotation, eight systematic subsamples or rotation groups of segments are identified for each sample. A given rotation group is interviewed for a total of eight months, then returns for the same four calendar months of the next year. It is then dropped from the sample. In any one month, one-eight of the sample segments are in their first month of enumeration, another eight are in their second month, etc. with the last eight in for the eight time. Under this scheme, 75 per cent of the sample segments are common from month to month and 50 per cent are common from year to year. Composite estimates and their variances were derived and some empirical results were given. These techniques are now used in the U.S. sample of retail trade.

The author (1960) developed a finite population theory in a two-stage rotation sampling as this applies to the development of the design of the PSSH. The basic idea of the proposed rotation is to dissect the sampling area into a finite number of recognizable segments and each rotation group will consist of three segments in which two segments (or 67 per cent) are common from visit to visit and one segment (or 33 per cent) is common from year to year. Composite estimates for current total, visit-to-visit change and visit-to-visit a year ago change and their variances are derived. The relevant results of the theory developed in the author's work (1960) will be utilized in the subsequent discussions.

SAMPLING SCHEMES

1. Without Replacement and Equal Probability at Each Stage.

In a stratified two-stage design in which the units are drawn *without replacement* and with equal probability at each stage, the estimate of the h^{th} stratum total, X_h is

$$\hat{X}_h = \frac{N_h}{n_h} \sum_i{}' \frac{M_{hi}}{m_{hi}} x_{hi} \qquad (1)$$

where N_h is *total number* of primary sampling units (psu) in h^{th} stratum,

n_h is number of sample psu's in h^{th} stratum,

M_{hi} is total (listed) number of hh's in i^{th} psu of the h^{th} stratum,

x_{hi} is *sample total* of the X-characteristic in the i^{th} psu of the h^{th} stratum, and

the ' on Σ indicates sample summation on i

It can be shown (see Hartley, 1959) that the variance of $\hat{X}_h$ is

$$\text{Var}\,(\hat{X}_h) = \frac{N_h}{n_h} \sum_i \frac{M^2_{hi}}{m_{hi}} \left(1 - \frac{m_{hi}}{M_{hi}}\right) S^2_{hi} \qquad (2)$$

$$\frac{N^2_h}{n_h} \left(1 - \frac{n_h}{N_h}\right) \sum_i \left(\frac{X_{hi} - X^*_h}{N_h - 1}\right)^2$$

where X_{hi} is the i^{th} primary total of the h^{th} stratum,

$$X^*_h = \sum_i X_{hi}/N_h$$

$$S^2_{hi} = \sum_j \frac{(X_{hij} - \bar{X}_{hi})^2}{M_{hi} - 1},$$

and $\bar{X}_{hi} = \sum_j X_{hij} / M_{hi}$.

As usual, the sum of the $\hat{X}_h$'s will provide an unbiased estimate of the population total X with variance equal to the sum of the Var $(\hat{X}_h)$'s.

The first term in (2) is usually designated as the between secondary within primary contribution while the second term is known as the between primary contribution to the Var $(\hat{X}_h)$.

The complete or exact estimate of (2) is

$$\text{var}\,(\hat{X}_h) = \frac{N_h}{n_h} \sum_i{}' \frac{M^2_{hi}}{m_{hi}} \left(1 - \frac{m_{hi}}{M_{hi}}\right) s^2_{hi} + \frac{N^2_h}{n_h}\left(1 - \frac{n_h}{N_h}\right) \sum_i{}' (M_{hi}\bar{x}_{hi} - x^*_h)^2 / n_h - 1 \qquad (3)$$

where $s^2_{hi} = \frac{1}{m_{hi} - 1} \sum_j{}' (x_{hij} - \bar{x}_{hi})^2$

$$\bar{x}_{hi} = \frac{1}{m_{hi}} \sum_j{}' x_{hij}$$

$$x^*_h = \frac{1}{n_h} \sum_i{}' M_{hi}\bar{x}_i$$

and the rest of the symbols is defined as in (1) and (2). Note that the first term in (3) is a sort of a correction and is usually negligible. For economy and in actual practice, where the survey is interested in many characteristics only the second term is computed as estimate of (2).

2. Stratified Two-Stage Sample With Rotation of Segments

Let us apply this theory (Oñate, 1960) to a particular precinct in the urban area of the PSSH (semi-annual collection) where S_{hi} (the number of segments) is usually small. *Split the precinct* (psu) *into* segments and carry out the listing operation only for a sample of three of the segments to be rotated from visit to visit.

In general, each rotation group will consist of three segments; two segments or 67 per cent of the segments are common from visit to visit and one segment or 33 per cent is common from year to year. See, for example, figures 1 and 2 for $S_{hi} = 8$. We introduce a random element into the selection of segments by attaching at random the S_{hi} actual segments to the ordinal segment numbers. There are $S_{hi}!$ possible permutations which form the reference set of our probability sample. A particular random selection from the $S_{hi}!$ possible permutations is referred to as a 'rotation set' R. The problem of making the segments approximately equal in size and the problem of availability of 'natural' boundaries must be reckoned with in the application of this theory.

One new feature in the rotation scheme involves changing a part of the sample each visit to avoid a decline in respondent cooperation which may happen when a constant panel is interviewed indefinitely. This scheme afforded also a reduction in cost due primarily to listing of the entire hi^{th} psu.

The rotation of sample will now be utilized in a new estimation procedure which may result under certain circumstances into a reduction of variances of sample estimates. The new estimation procedure makes use of what is referred to as a composite estimate. The estimate for each characteristic is a composite or weighted average of two estimates. These two estimates of the same characteristic are not independent but when given proper weights may yield a composite estimate with a smaller variance than either of the component estimates (Hansen, et al, 1955).

The weights for the two components of such a composite estimate need not be equal, and optimum weights may be determined for estimating any particular characteristic. The composite estimate takes advantage of accumulated information from earlier visits or samples as well as information from the current visit or sample and results in smaller variances of estimates of both level and change for most characteristics, but the larger gains are achieved, for most part, in the estimates of change. The weights, $\propto W_{hij}$ and $\propto {W^2}_{hji}$ are shown in Tables 1 and 2, respectively, for size of segments, S_{hi} and for time periods $\propto \doteq 0$ and $\propto < 0$.

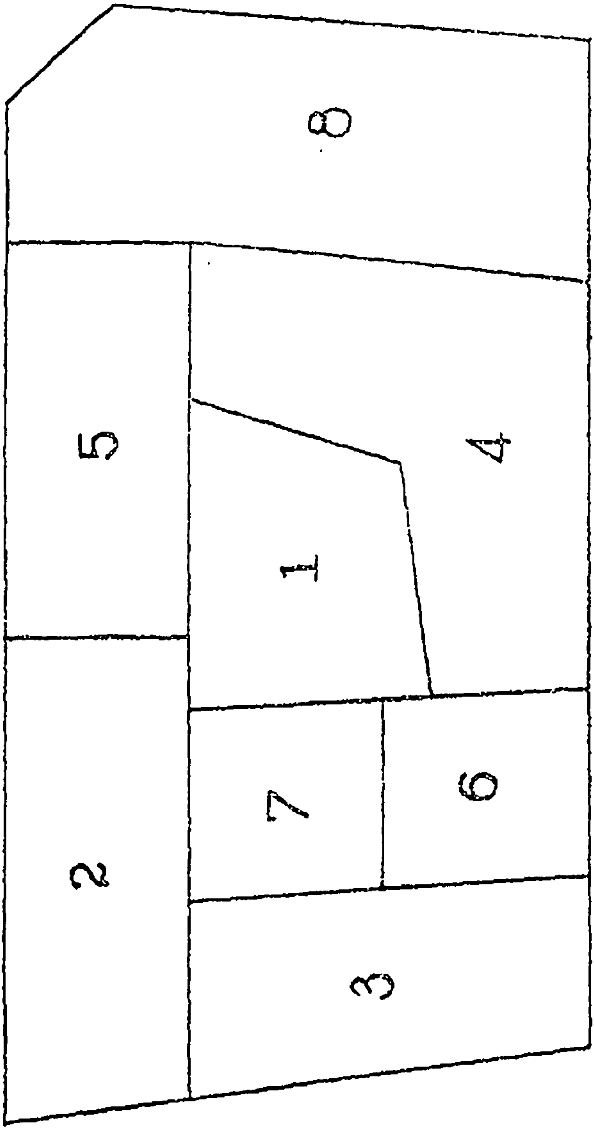

Figure 1. A sampling area (precinct) with eight segments

Figure 2. Rotation Scheme for Eight Segments in Sampling Area (precinct)

Segment Number	Time α									
	-9	-8	-7	-6	-5	-4	-3	-2	-1	-0
1	*	*						*	*	*
2	*	*	*						*	*
3		*	*	*						*
4			*	*	*					
5				*	*	*				
6					*	*	*			
7						*	*	*		
8	*						*	*	*	

If the hi_{th} psu is dissected into a finite number of segments S_{hi} as for example in the PSSH (see Oñate, 1960), the unbiased composite estimate of the hi^{th} psu total with rotation at time $\alpha = 0$, ${}_{o}X_{hi}$ is

$$ {}_{o}\hat{\hat{X}}_{hi} = \sum_{\alpha = -\infty}^{0} \sum_{j}^{S_{hi}} {}_{\alpha}W_{hij} \; {}_{\alpha}\hat{X}_{hij} \qquad (4) $$

where $${}_{\alpha}\hat{X}_{hij} = \frac{K_{hij}}{k_{hij}} \cdot {}_{\alpha}x_{hij}$$

is the sample total estimate of the hij^{th} segment at visit α ,

K_{hij} is the number of hhs in the ij^{th} segment and is assumed to be independent of α

k_{hij} is the number of sample hhs in the ij^{th} segment and is also assumed to be independent of α ,

${}_{\alpha}x_{hij}$ is the sample total of the ij^{th} segment at time α ,

and ${}_{\alpha}W_{hij}$ is the weight attached to the ${}_{\alpha}\hat{X}_{hij}$ at time α

(These assumptions are given for simplicity sake, although these may be dropped and adjustments can be made in the derivation of the variance).

The variance of ${}_{o}\hat{\hat{X}}_{hi}$ is evaluated by the relation,

$$ \begin{aligned} Var\,({}_{o}\hat{\hat{X}}_{hi}) = \underset{S_{hi}!R}{E} \left\{ Var\,({}_{o}\hat{\hat{X}}_{hi} \mid R) \right\} + \\ \underset{S_{hi}!R}{Var} \left\{ E\,({}_{o}\hat{\hat{X}}_{hi} \mid R) \right\} \end{aligned} \qquad (5) $$

Table 1. Weights ($_{\alpha}w_{hij}$) of Segment Totals for
Number of Segments, S_{hi}, and for Time
periods $\alpha = 0$ and $\alpha < 0$

Segment in sample for	$\alpha = 0$	$\alpha < 0$
1st visit	$-\frac{S_{hi}}{3}(Q-1)$	$-\frac{S_{hi}}{3}Q^{-\alpha}(Q+1)$
2nd visit	$\frac{S_{hi}}{3}(\frac{Q}{2}+1)$	$\frac{S_{hi}}{6}Q^{-\alpha}(Q-1)$
3rd visit	$\frac{S_{hi}}{3}(\frac{Q}{2}+1)$	$\frac{S_{hi}}{3}Q^{-\alpha}(\frac{Q}{2}+1)$
Off 1 visit	0	0
Off 2 visit	0	0
Etc.	0	0
$\frac{1}{S_{hi}}\sum_{i}^{S_{hi}}{}_{\alpha}w_{hij}$	1	0

Table 2. Values of W^2_{hij} for Number of Segments, S_{hi}, and for Time Periods $\alpha = 0$ and $\alpha < 0$

Segment in sample for	$\alpha = 0$	$\alpha < 0$
1st visit	$(\frac{S_{hi}}{3})^2 (1 - Q)^2$	$(\frac{S_{hi}}{3})^2 \; Q^{-2\alpha} (Q + \frac{1}{2})^2$
2nd visit	$(\frac{S_{hi}}{3})^2 (1 + \frac{Q}{2})^2$	$(\frac{S_{hi}}{6})^2 \; Q^{-2\alpha} (Q - 1)^2$
3rd visit	$(\frac{S_{hi}}{3})^2 (1 + \frac{Q}{2})^2$	$(\frac{S_{hi}}{3})^2 \; Q^{-2\alpha} (\frac{Q}{2} + 1)^2$
Off 1 visit	0	0
Off 2 visits	0	0
Etc.	0	0
$\frac{1}{S_i} \sum_{j}^{S_{hi}} \alpha W^2_{hij}$	$\frac{S_{hi}}{3^2} (3 + \frac{3}{2} Q^2)$	$\frac{S_{hi}}{3^2} \; Q^{-2\alpha} \frac{3}{2} (Q^2 + Q + 1)$

The first term in (5) is the within rotation variance while the second term is the between rotation variance. This variance is approximated by using some truncation in the infinite series Thus,

$$
\begin{aligned}
\mathrm{Var}\,({}_{o}\hat{\hat{X}}_{hi}) \doteq\ & \frac{1}{1-Q^2} \quad \frac{S_{hi}}{3^2} \quad \Big(3 + \frac{3}{2} Q^3 \Big) \\
& - 2 \Big[\Big(Q + Q^2 - \tfrac{1}{2} Q^3 - \frac{3}{2} Q^4\Big) \rho_1 \\
& - \Big(Q^2 + \frac{5}{2} Q^3 + Q^4\Big) \rho_2 \Big] \sum_{i}^{S_{hi}} \mathrm{Var}\,({}_{o}\hat{X}_{hij}) \\
& + \frac{S^2_{hi}}{3} \Bigg\{ \Big(\frac{2}{S_{hi}} + \tfrac{1}{2} Q^2\Big) \; {}_{o}S^2_{hi} \\
& + \sum_{\alpha=-1}^{-3} \tfrac{1}{2} Q^{-2\alpha} \; (Q^2 + Q + 1) \; {}_{\alpha}S^2_{hi} \\
& - \tfrac{1}{2} \cdot \tfrac{1}{3} \Big[(Q^3 + 4 Q^2 + 4 Q)\; {}_{0,-1}S_{hi} \\
& + (2 Q^5 + 2 Q^4 - 4 Q^3) \; {}_{0,-3}S_{hi} \\
& + \sum_{\alpha=0}^{-1} Q^{-2\alpha} (2Q^4 + 5 Q^5 + 2 Q^2) \; {}_{\alpha,\alpha-2}S_{hi} \\
& + \sum_{\alpha=-1}^{-2} Q^{-2\alpha} (Q^3 - 2 Q^2 + Q) \; {}_{\alpha,\alpha-1}S_{hi} \Big] \Bigg\}
\end{aligned}
$$

where $0 \leq Q \leq 1$,

ρ_1 is the correlation of estimates from identical segments one visit apart,

ρ_2 is the correlation of estimates from identical segments two visits apart,

$$ {}_{\alpha}s_{hi} = \frac{1}{S_{hi}-1}\left\{\sum_{i} {}_{\alpha}X^2_{hij} - \frac{{}_{\alpha}X^2_{hi}}{S_{hi}}\right\}, $$

$$ {}_{\alpha,\alpha-v}s_{hi} = \frac{1}{S_{hi}-1}\left\{\sum_{j} {}_{\alpha}X_{hij}\;{}_{\alpha-v}X_{hij} - \frac{{}_{\alpha}X_{hij}\;{}_{\alpha-v}X_{hij}}{S_{hi}}\right\}, $$

$$ \text{Var}\,({}_{o}\hat{X}_{hij}) = \frac{M^2_{hij}}{m_{hij}}\left(1-\frac{m_{hij}}{M_{hij}}\right)\sum_{k}\frac{({}_{o}X_{hijk} - {}_{o}\bar{X}_{hij})^2}{M_{hij}-1} $$

and the other symbols are defined as in equation (2).
For Q = O, equation (5a) reduces to

$$ \text{Var}\,(\hat{X}_{hi}) = \frac{S_{hi}}{3}\sum_{j}^{S_{hi}} \text{Var}\,({}_{o}\hat{X}_{hij}) + \frac{S^2_{hi}}{3}\cdot\frac{2}{S_{hi}}\;{}_{o}s_{hi} \qquad (5b) $$

where the first term is the within segment component, and the second term is the between segment component in a two-stage sampling scheme with equal probability and without replacement at time O. Note that actually we started with a two-stage design but because of the segmentation procedure, we have added a third stage. Thus, with rotation, we have precincts as psus, segments as secondaries and households as tertiaries.

The unbiased composite estimate of hth stratum total ${}_oX_h$ is

$$ {}_o\hat{\hat{X}}_h = \frac{N_h}{n_h} \sum_i{}' \, {}_o\hat{\hat{X}}_{hi} \tag{6} $$

and

$$ \mathrm{Var}\,({}_o\hat{\hat{X}}_h) = \frac{N_h}{n_h} \sum_i \left\{ \mathrm{var}\,({}_o\hat{\hat{X}}_{hi}) \right\} + \frac{N^2_h}{n_h} \left(1 - \frac{n_h}{N_h}\right) \sum_i \frac{(X_{hi} - X^{**}_h)^2}{N_h - 1} \tag{7} $$

where the symbols are defined as in (2), (5) and (5a). This variance in equation (7) consists of three parts, namely: the between psu component, the between rotation component and the within rotation component. The last two (between and within rotation) are the components of the between secondaries within psu.

The method of evaluating (5a) is given by the author (1960) and will not be given here. The extent of the reduction in variance in (7) as compared with (2) will depend, by and large, on the lag correlation which may exist between visits and will emanate primarily from the component of the between secondaries within primaries. For a multi-purpose survey, the value of an 'optimum' O must also be studied.

For practical purposes, we may use as estimate of Var $({}_o\hat{\hat{X}}_h)$

$$ \mathrm{var}\,({}_o\hat{\hat{X}}_h) = \frac{N^2_h}{n_h} \left(1 - \frac{n_h}{N_h}\right) \sum_i{}' \, \frac{({}_o\hat{\hat{X}}_{hi} - x^{**}_h)^2}{n_h - 1} \tag{8} $$

where

$$ x^{**}_h = \frac{1}{n_h} \sum_i{}' \, {}_o\hat{\hat{X}}_{hi} $$

which is similar to the second term in (3).

3. With Complete Replacement of Primaries

This design is utilized in the PSSH. The sampling scheme in the h^{th} stratum is as follows: (a) sample the first primary with probability proportional to some measure of size, say p_{hi}; (b) within this primary, sample by any method which will permit for the computation of an unbiased estimate X^*_{hi} of the hi^{th} primary total, X_{hi} such that

$$\hat{X}_{hi} = \frac{1}{p_{hi}} X^*_{hi} \qquad (9)$$

is an unbiased estimate of the stratum population total, X_h; and (c) replace all primaries, secondaries, etc. and repeat steps (a) and (b) n_h times producting estimates $\hat{X}_{h1}, \hat{X}_{h2}, \ldots \hat{X}_{hn_h}$ of the stratum total X_h. This set is a random sample of size n_h from an infinite population of $\hat{X}_{hi}$'s, and, therefore

$$\begin{aligned}\hat{X}_h &= \frac{1}{n_h} \sum_i{}' \hat{X}_{hi} \\ &= \frac{1}{n_h} \sum_i{}' \frac{X^*_{hi}}{p_{hi}}\end{aligned} \qquad (10)$$

is an unbiased estimate of X_h and an unbiased estimate of the variance of $\hat{X}_h$ $(Var(\hat{X}_h))$ is

$$var(\hat{X}_h) = \frac{1}{n_h} \frac{1}{n_h - 1} \sum_i{}' (\hat{X}_{hi} - \hat{X}_h)^2 \qquad (11)$$

This scheme of sampling does not yield a Var $(\hat{X}_h)$ which may be written in terms of the finite components as indicated in equation (2). One may assume an infinite model and estimates of components are obtained from the analysis of variance approach for hierarchal classification. Note that in a two-stage design without rotation

$$X^*_{hi} = \frac{M_{hi}}{m_{hi}} \sum_j{}' x_{hij}$$

and with rotation $X^*_{hi} = {}_oX^*_{hi}$

where ${}_oX^*_{hi}$ is an unbiased composite estimate of the hi^th psu total, ${}_oX_{hi}$, at time $\alpha = 0$.

We can conclude that any reduction in the variance of ${}_o\hat{\hat{X}}_h$ as compared to the variance of $\hat{Y}_n$ ($= {}_o\hat{X}_h$) at time 0, will be due to the corresponding reduction in the within rotation component and the between rotation component of variance of $({}_o\hat{\hat{X}}_h)$ This situation is evident by an examination of the components of Var $({}_o\hat{\hat{X}}_{hi})$ in equation (5) and (5a) and on the fact that the between psu components are the same for the composite estimate $({}_o\hat{\hat{X}}_h)$ and the usual unbiased estimate $(\hat{X}_h)$ since the same panel of psus is used for both estimates.

The unbiased composite estimates of the visit-to-visit change and the visit-to-visit a year ago change and their variances will be given in a separate paper.

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Publisher: PHIL. STATISTICAL ASS'N.	P. O. Box 3223, Manila
Printer: VENTURA PRESS	2416 Juan Luna, Manila
Office of Publication:	1046 Vergara, Quiapo Manila

If publication is owned by a corporation, stockholders owning one per cent or more of the total amount of stocks: None

Bondholders, mortgagees, or other security holders owning one per cent or more of total amount of security: None

In case of daily publication, average number of copies printed and circulated of each issue during the preceding month of 19 :

In case of publication other than daily, total number of copies printed and circulated of the last issue dated DECEMBER, 1960:

1. Sent to paid subscribers	488
2. Sent to others than paid subscribers	38
Total	526

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