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NETWORK SAMPLE SURVEYS OF RARE AND ELUSIVE POPULATIONS: A HISTORICAL REVIEW

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ABSTRACT

This paper describes the sequence of serendipitous and unexpected events beginning in the late 1960's that led initially to the emergence of network sampling about a decade later, and led subsequently to the appearance of unforeseen applications of network sampling in the mid 1990's. The paper describes the conceptual framework of network sampling. Also, it discusses network sampling research findings and illustrates network sampling applications during the periods prior to and since the mid 1990's. Lastly, it very briefly discusses the future directions and prospects of network sampling.

KEYWORDS: Establishment Surveys; Household Surveys; Multiplicity; Serendipity Patterns.

1. INTRODUCTION

1.1 Background

Developing efficient methods of designing sample surveys of rare population has challenged survey researchers for decades, and the challenge continues. In her 1956 ASA presidential address (Cox, 1957), Gertrude Cox listed the development of efficient methods to sample for scarce items as one of the challenging statistical frontiers. Since Dr. Cox listed her statistical frontiers nearly 50 years ago, several innovative methods have been developed for surveying rare and other difficult-to-reach populations, and many of these methods are scheduled to be discussed at this Symposium. I am pleased to have been invited to discuss one of these methods namely, network sampling, at this opening session of Statistics Canada's 21st International Methodology Symposium.

This paper reviews the evolution of network sampling from its origins almost 50 years ago, barely two years after Dr. Cox's presidential address in 1956. Before proceeding with the history of network sampling, a few concepts and technical terms used in network sampling are defined, and the orientation of my version of the history of network sampling is previewed.

1.2 Counting Rules and Networks

Counting rules are essential design features of surveys (Sirken, 1973). They specify the kinds of relationships that link observation units to the selection units where they are enumerable in the survey. Counting rules group the selection units into clusters such that each cluster contains the observation units linked to the same selection unit and the same observation units may be linked to multiple selection units. Also, counting rules partition observation units into networks such that each network contains the observation units that are linked to the same set of selection units. The number of selection units linked to a network is called its multiplicity. Counting rules have sampling effects because they determine the ways that observation units are distributed over clusters and networks, and they have measurement error effects because they specify the selection units at which the observation units are eligible to be enumerated.

Network and conventional sampling use different kinds of counting rules. Conventional sampling uses unitary counting rules that uniquely link every observation unit to one and only one selection unit at which it is enumerable

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in the survey. For example, the de jure place of residence rule used in conventional household surveys is a unitary counting rule that uniquely links each individual to the household of his or her usual place of residence. Network sampling is not subject to this restriction. It uses multiplicity counting rules that may link the same observation units to multiple selection units. For example, the sibling counting rule, a multiplicity rule often used in network sampling of household surveys, links each sibling in a sibling set to all households that are the de jure residences of every sibling in the set. Multiplicities may vary from one sibling network to another depending on the number of households linked to the siblings in the set. Conventional sampling may be viewed as a special case of network sampling in which the multiplicity of every network equals one.

Flexibility with respect to network size provides network sampling with design options for addressing survey design problems that often challenge conventional sampling. That is certainly the case when the survey design inadvertently or unavoidably links the same observation units to multiple selection units. Of greater strategic importance, network sampling may be deliberately fostered as a strategy to improve survey efficiency when conventional sampling produces large sampling errors and/or measurement errors. For example, network sampling is usually more efficient than conventional sampling in household surveys of rare populations because households are more uniformly distributed over households by multiplicity rules than by unitary rules, and it likelier to be more efficient than conventional sampling when the rare populations are also elusive or sensitive populations that are hard to enumerate at de jure places of residence in conventional household sample surveys.

Network sampling does not come pro bono. Unbiased network sampling estimation requires collecting supplementary information to determine the values of the multiplicities – information that is not required for conventional sampling unbiased estimation because all multiplicities are equal to one. Because the multiplicities are required in network sampling only for the observation units reported by the sampled selection units, they are usually reported in the survey by the selection units that report the observation units. Nevertheless, supplementary data collection adds somewhat to the survey costs. Perhaps a more serious consequence than the incremental cost of collecting the multiplicities is the risk of response errors in the reporting of multiplicities. Thus, network sampling is not a panacea for dealing with survey design problems that challenge conventional sampling but when used judiciously and selectively, network sampling has the potential to improve survey design efficiency of population and establishment sample surveys (Sirken, 1997).

1.3 Historical overview

In tracing the history of network sampling over the past 45 plus years, I take the liberty of talking personally about my relationship with the technique for the opportunities it provides to describe first hand the important and interesting role of serendipity in its origins and evolution. In the preface to the delightful book "Travels and Adventures of Serendipity" by Robert Merton and Elinor Bender, Robert Shulman describes serendipity in the following way:

"Serendipity can be about finding something of value while seeking something entirely different or it can be about finding a sought-after object in a manner where it was not at all expected".

I have had the good luck and pleasure of experiencing both kinds of serendipity while conducting network sampling research on and off and then on again during these several decades.

Professor Merton proposes that the serendipity pattern in science involves a 3-stage process which I paraphrase, amend, and extend here to 4 stages:

Stage 1. Research directed toward one objective leads to an unanticipated anomalous finding or an unanticipated surprising solution.

Stage 2. The unanticipated finding or solution stimulates research to fit the new datum into a broader frame of knowledge.

Stage 3. The research initiated by the unanticipated finding or solution fosters ideas for new theory or technology.

Stage 4. The proposed new theory or technology is applied and tested experimentally.

It is convenient to divide the history of network sampling into 2 periods. Period I, The Emergence of Network Sampling, covers the 35 year interval , 1958-83, during which network sampling emerged as a serendipitous consequence of an unanticipated finding in a medical provider sample survey of rare disease prevalence. Period II, The Emergence of Linked Population/Establishment Survey, covers the 20+ year interval since 1983 during which new applications of network sampling emerged as a serendipitous consequence of an unexpected solution to an estimation problem in an establishment provider survey of the medical providers reported by respondents in a household sample survey. In each Period, historical events are presented in the chronology of the four stages of the serendipity pattern noted earlier. In the last section of the paper, I look backward over the history of network sampling for guidance in forecasting the future of the sampling technique.

2. ORIGINS OF NETWORK SAMPLING: 1960-1983

2.1 The Unexpected Finding

In 1959, a pilot of a national survey of physicians and hospitals was undertaken in 3 New England States to estimate the prevalence of medically diagnosed cases of cystic fibrosis (Kramm, et al (1962). The pilot survey of about 1600 physicians and hospitals had a stratified sample design with pediatricians and hospitals with pediatric residencies selected with certainty.

Cystic fibrosis, a relatively rare genetic disease of childhood, had been identified as a distinct entity in the mid 1930’s and in the late 1950’s, when the survey was conducted, diagnostic tests were still relatively crude and test results often difficult to interpret. The procedures by which the pilot survey sought to address the diagnostic issue provided information that would reveal an unanticipated survey design problem.

The queried medical sources reported all patients they had treated for cystic fibrosis since 1972, identified each patient by name and address, and reported the patient’s date of birth and sex, and the medical findings supporting the cystic fibrosis diagnosis. They also provided the names and addresses of referral medical sources, if any, that treated each of their patients, and the referral sources were subsequently queried for supplementary diagnostic information about the patients for whom they had been reported as referrals. After the survey was completed, the diagnostic information reported by the original and referral medical sources was reviewed and assessed for the certitude of the cystic fibrosis diagnoses.

After matching the patient reports, it was determined that the original sample of medical sources had reported about 650 distinct cystic fibrosis patients and these patients had been treated by over 1,000 different medical sources. On the average, each patient had been treated by about 1.6 medical providers – about half treated by one medical source, a third by 2 sources, a tenth by 3 sources and about 3 percent by 4 or 5 sources.

Unbiased estimation of cystic fibrosis prevalence was not a problem in the pilot survey because virtually all the cystic fibrosis patients had been reported by medical providers in the certainty strata. Otherwise, however, unbiased estimation would have been a problem because matching alone is insufficient to assure unbiased estimation when the patients are reported solely by sources selected from non certainty strata. Unbiased estimation posed a potentially serious problem for the proposed national medical provider survey of cystic fibrosis in which it was anticipated a substantial fraction of patients would be reported by medical providers in the non certainty strata.

2.2 Research Fostered by Unexpected Finding

Seeking a solution to the estimation problem highlighted by the cystic fibrosis pilot survey set in motion a research effort to develop the sampling theory, then unavailable, that would be appropriate for designing medical provider surveys like the proposed national medical care provider sample surveys of cystic fibrosis, in which the same patients are often treated by multiple medical providers. The research yielded three unbiased estimators of the parameter **N**, the total number of patients with a disease and yielded the variances of two of the estimators (Birnbaum & Sirken, 1965). All three estimators utilize information about the multiplicities of medical sources treating the same patients but differ in the kinds of multiplicity information required.

The multiplicity estimator, the simplest and most robust of the three estimators, counts the report of every patient in the survey and weighs each report by the inverse of the patient's multiplicity. The multiplicity estimator does not require matching the patient reports for duplications. For example, the multiplicities of the patients reported in the New England pilot survey might have been determined from the information reported about referral medical providers by the original sample of medical providers without matching to eliminate duplicate reports of the same patients. The multiplicity estimator is unbiased if every patient in the universe is linked to (reported by) at least one medical provider.

Curiosity about the efficiency of multiplicity estimator of the parameter **N**, led to research on the sample design effects of network sampling compared to conventional sampling in medical provider surveys. Here are a few research findings (Sirken, 1970a): (1) The difference between the sampling variances of network and conventional estimators depends on the configurations of linkages between selection and observation units that are formed by conventional and multiplicity counting rules; (2) network sampling is not necessarily more efficient than conventional sampling for all kind of linkage configurations but is likely to be more efficient than conventional sampling for most multiplicity rules; and (3) network sampling is necessarily more efficient than conventional sampling whenever multiplicity counting rules form specific kinds of linkage configurations.

The third is strategically the most important. For example, network sampling is necessarily more efficient than conventional sampling in estimating **N** whenever none of selection units are linked to multiple observation units by the multiplicity counting rule. Under this configuration, the expected value of the multiplicity estimator equals
$\mathbf{P = N / M}$ where **M** is the total number of selection units in the universe. When **P** is small, the design effect of network sampling, the ratios of the multiplicity and conventional variances, is less than the parameter **K**, where **K**, a fraction in the interval 0 to 1, is the mean value of the inverses of the number of selection units linked to the same the observation units (the inverses of the multiplicities of the observation units). The design effect improves as P declines and as the mean values of the multiplicities increase and the variances of the multiplicities decrease. When the variance of the multiplicities is ignorable, say all multiplicities equal the positive integer s, the network sampling design effect reduces to the equation $\mathbf{K < 1/s}$. [The proof of the equation is given in my paper (Sirken, Monroe G., 1970b)].

2.3 Research Findings Foster Network Sampling

Research on the design effects of network sampling highlighted the critical role of counting rules in designing sample surveys, and fostered new ideas about ways of improving survey design by capitalizing on the design options offered by multiplicity counting rules. The implications of the research findings on estimation are straight forward, namely, network sampling is unbiased and conventional sampling is biased whenever multiple selection units are inadvertently or unavoidably linked to the same observation units.

The implications of the research findings on the sample design effects of network sampling are less transparent than those on the unbiased estimation but far more strategic. They imply that network sampling is particularly worthy of serious consideration as a design option to improve sampling precision whenever the selection units in the conventional survey tend to be binomial with small **P** values. This conclusion inspired the notion of deliberately fostering network sampling in conventional household sample surveys of rare populations. The basic idea is to foster network sampling in household surveys by using multiplicity counting rules to form linkage configurations simultaneously satisfying to the extent possible these three conditions:

Condition 1. The multiplicity of every individual is equal to or greater than one.

Condition 2. The distribution of the multiplicities has large mean and small variance.

Condition 3. Individuals are linked to households that are able and willing to report the multiplicities and the variables of interest about them.

Condition 1 avoids coverage bias. This condition is usually satisfied by using composite counting rules that link individuals to their own households as well as other households. Condition 2 maximizes the sampling efficiency of network sampling. It is often satisfied by using counting rules involving a multiplicity of relationships. Condition 3 minimizes the response error effects of network sampling. It is satisfied by using counting rules such as those that link individuals to households of relatives, friends, neighbors, and colleagues with whom they have close and well defined relationships.

Subsequently, the notion of fostering network sampling was extended to surveys of elusive and sensitive populations to reduce coverage errors and response errors that arise in conventional household sampling because these kinds of individuals are hard to find and enumerate at their own households.

2.4 Empirical testing of network sampling

Often, counting rules that benefit sampling errors are not the ones that benefit measurement errors and visa versa. For example, the multiplicity counting rule that links every individual to every household totally eliminates sampling errors but is totally impractical from the viewpoint of response errors.

Figures 1 summarizes the findings of 4 survey experiments that tested the sampling error and response bias effects of network sampling in population surveys of rare populations and events. Experiments involving births and marriages were embedded in 1974 Israel Labor Force Survey (Nathan, 1976). The diabetes experiment was embedded in the National Health Interview Survey during 1976 (Sirken, et al, 1978) and the cancer experiment was conducted in Illinois by the Survey Research Center at the University of Illinois during 1981 (Czaja, et al, 1986). Each experiment compares the sampling errors and response biases of the conventional counting rule (i.e. the de jure place of residence rule) and two composite/ kinship rules in estimating the parameter N. Figure 1 ranks the relative efficiencies of the 3 counting rules used in the experiments of births and marriages, and Figure 2 ranks the relative efficiencies of 3 counting rules used in the experiments of diabetes and cancer.

Slide 1: Rankings of Counting Rules by Response Bias & Sampling Errors

Counting Rules	**Response Bias**	**Sampling Errors**	**Response Bias**	**Sampling Errors**
	Marriages		**Births**	
Surveys of Vital Events				
Conventional	**2**	**3**	**1**	**3**
Composite/parents	**3**	**2**	**3**	**2**
Composite/parents, siblings	**1**	**1**	**2**	**1**
	Diabetes		**Cancer**	
Surveys of Disease Prevalence				
Conventional	**2**	**3**	**1**	**3**
Composite/siblings	**3**	**2**	**3**	**1**
Composite/children	**1**	**1**	**2**	**2**

In every experiment, the conventional counting rule ranks third on sampling errors. In the diabetes and marriage experiments, the composite children counting rule and the composite parent/sibling rule respectively rank first on both types of errors – implying that these composite rules are uniformly more efficient than the conventional rule. In the experiments on cancer and births, the outcomes are mixed; the conventional rule ranks first on response biases, and last on sampling errors, and consequently these composite counting rules are more efficient when the prevalence rate is low and the household sample is less than a specified size. Otherwise, the conventional sampling is more efficient. For example, assuming a cancer site prevalence rate of one percent the composite children rule is more efficient than the conventional rule for household sample sizes up to about 40,000. Assuming a birth rate of 3 percent, the composite parent/sibling rule is more efficient than the conventional counting rule up to a sample size of about 19,000 households.

These experimental findings confirm that network sampling offers the potential of substantially improving sampling efficiencies and validity of population surveys of rare populations and events. Even when it adversely affects validity, network sampling has the potential to improve the mean squared errors especially when sample sizes and prevalence rates are small.

3. ORIGINS OF LINKED SURVEYS: 1983 –

3.1 The Unexpected Solution

About 1985, the NCHS embarked on a research program to integrate the sample designs of its families of independently designed population and health care provider surveys by using the National Health Interview Survey (NHIS) as the master sampling frame (Sirken & Greenberg, 1983). Listings of NHIS households and persons served as sampling frames of population surveys and listings of NHIS psu's as frames of the health care provider surveys. In 1992, a Panel of the Committee on National Statistics was convened to review NCHS's plans to restructure its health care provider surveys (Wunderlich, 1992). The Panel liked the integrated survey design concept but felt that integration of health care establishment surveys would be more efficient if linkages with NHIS occurred at the household level rather than the psu level. It recommended that NCHS investigate the feasibility and utility of using listings of the health care providers that are visited and reported by NHIS households as the sampling frames of its health care provider surveys instead of using free-standing sampling frames that list all health care providers and their size measures. The Panel's recommendation inspired a research project to investigate the design features of establishment surveys that use population survey-generated sampling frames. This kind of survey is called the linked establishment/population survey (LEPS).

Initially, LEPS was modeled as a two-stage establishment sample survey to estimate the parameter X, the sum of the x variable over the transactions of households with establishments. Establishments listed in the population survey-generated frame are first stage selection units and the selected establishments' transactions with households are second stage selection units. The error model assumed that the household sample of the population survey that generates the sampling frame is selected by simple random sampling (srs) with replacement (WR) and a transaction sample of each establishment is selected independently by srs without replacement (WOR) with sample size proportional to the number of establishment's transactions with households in the population survey. When viewed as an establishment sample survey, the error model yielded the expression of the asymptotically unbiased two-stage leps estimator of X, but failed to yield the expression of the leps variance (Judkins, et al, 1995).

It occurred to me that the estimation problem would become more transparent and tractable if LEPS was modeled as a two-stage household survey in which households are first stage selection units and all transactions of the establishments that have transactions with households are the second stage selection units. (Note: the second stage units are the transactions of establishments with all households and not the transactions of the sample households). When modeled in this manner as a population sample survey, the LEPS is a network sampling household survey because transactions of the same establishments are linked to multiple households with whom the establishments have transactions. The network sampling population survey model yielded expressions of the two stage LEPS estimator of X and its variance (Sirken, Shimizu, Judkins, 1995).

3.2 Research fostered by the unexpected solution

Deriving expressions of the leps unbiased estimator and variance opened the door to research that compared the sampling efficiencies of the two-stage LEPS estimator of X and the two-stage conventional survey Hansen-Hurwitz type estimator of X in which establishments are selected without replacement from a free-standing sampling frame with probabilities proportional to size (Sirken, & Shimizu, 2002).

The two-stage LEPS and two-stage conventional establishment survey estimators of equivalent expected establishment and transaction sample sizes are equivalent if and only if the transactions of the population that generates the leps sampling frame are uniformly distributed such that every household has a single transaction. Deviations from the uniform distribution, whether because some households do not have transactions, and/or because transactions are not uniformly distributed over the truncated population of households with transactions, increase the leps first stage variance component and virtually always makes the it less efficient than the first stage variance component of the conventional establishment survey. In two-stage sampling, the outcome is somewhat less tilted in favor of the conventional establishment survey because the second stage within establishment component of variance is less in leps than in the conventional survey whenever second stage transaction samples are selected without replacement and multiple establishments are linked to the same households.

Despite its likely adverse sample design effects, leps deserves serious consideration whenever it is infeasible or prohibitively expensive to construct or maintain free-standing sampling frames with reasonably complete coverage and good size measures that are relevant for the target populations and the topics of the survey. From the cost perspective, LEPS becomes particularly attractive when it can be piggy-backed on ongoing population and establishment surveys.

3.3 Research findings foster LEPS applications in population surveys

Researching the design effects of LEPS in establishment sample surveys fostered ideas for applying leps in population sample surveys of rare and elusive population particularly when the variables of interest in the survey are reported more accurately by establishments than by households (Sirken & Shimizu, in press). Viewed as a population survey, the leps is a network sampling population survey using a multiplicity counting rule that links the transactions of the same establishment to every household with whom it has transactions. The LEPS counting rule partitions the transactions into networks such that each network contains the transactions of a distinct establishment. In effect the establishments are networks and in the survey they are essentially proxy respondents and report the variables of interest about their own transactions at the households with which they have transactions.

Sampling efficiencies of the two-stage LEPS and the single-stage conventional household sample survey of equivalent household sample size are equivalent if and only if the within establishment component of variance is ignorable. Otherwise, sampling is virtually always less efficient in the conventional household sample survey than in the single-stage LEPS and also less efficient in the two-stage leps when sufficiently large second stage leps transaction samples are selected. For example, when none of the households has multiple transactions, a transaction configuration likeliest to occur in surveys of rare populations, a second stage leps sample size no larger than the number of transactions of the households in the population sample survey is sufficiently large to assure that leps is at least as sampling efficient as the conventional population survey.

In summary, LEPS has the potential to substantially improve the quality of conventional household survey estimates of the parameter X, particularly when observation units refer to rare, elusive or sensitive populations that are hard to reach or enumerate at their usual places of residence, and establishments are good sources of information about the variables of interest in the survey.

3.4 Empirical Testing of LEPS

To my knowledge LEPS has not been applied in health surveys to estimate the volume of transactions between establishments and households. However, listing of establishments enumerated in population sample surveys have been used as sampling frames in economic surveys and in surveys of organizations when comprehensive and reliable listings of the universes of establishments are difficult to obtain or compile or maintain.

Population survey-generated frames are being used in economic surveys of business establishments to estimate the expenditures of populations for goods and services. For example, the sampling frames of the CPI Pricing Survey, an ongoing survey of businesses conducted by the U.S. Bureau of Labor Statistics (BLS), are the listings of retail establishments generated by the CPI Continuing Point of Purchase Survey, a national household sample survey that asks respondents to report their purchases and identify the merchants who sold them the merchandise. BLS does not use the LEPS estimator to estimate the volume of expenditures (Leaver & Valliant, 1995).

Also, population survey-generated sampling frames are being used in surveys of religious congregations and in surveys of employing and voluntary organizations to estimate the characteristics of the organizations and their clients (Kallenberg, et al,). For example, sampling frames of surveys of religious congregations were generated in the 1992 and the 1998 General Social Survey, national population surveys conducted by the National Opinion Research Center (NORC), that asked respondents to identify the religious congregations they attend (Chaves, 1999). Sociologists frequently use the LEPS estimator in surveys of organizations and refer to the technique as multiplicity sampling or hypernetwork sampling.

4. LOOKING BACKWARD TOWARD THE FUTURE

Looking backward over the history of network sampling in survey research for guidance in predicting its future suggests that the future developments of network sampling will depend on the unanticipated anomalous findings and unexpected novel solutions and strategically using the unexpected findings and solutions to improve survey design. Predicting unanticipated events that occur by accident appears oxymoronic and I shall not try to be specific.

It seems to me that in the future, as in the past, network sampling will continue to be used in surveys when the same observation units are unavoidably linked to multiple selection units, and when observation units are hard to find or enumerate by the unitary counting rules that are used in conventional sampling. Also as I noted above, in the future as in the past, I expect that brand new applications of network sampling will emerge as serendipitous consequences of unanticipated survey findings and solutions to survey design problem under conditions that are beyond my capacity to imagine.

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REFERENCES

Birnbaum, Z. W. and Sirken, M. G. (1965), "Design of Sample Surveys to Estimate the Prevalence of Rare diseases: Three Unbiased Estimates", *Vital and Health Statistics*, PHS Publication, Series 2, No. 11.

Chavis, M. (1999), "Religious Congregations and Welfare, Reform: Who Will Take Advantage of Charitable Choice", *American Sociological Review*, pp. 836-846.

Cox, G. M. (1957), "Statistical Frontiers", *Journal of the American Statistical Association, 64*, pp. 1-12.

Czaja, R. F., Snowden, C. B. and Casady, R. J. (1986), "Reporting Bias and Sampling Errors in Surveys of Rare Populations Using Multiplicity Counting Rules", *Journal of the American Statistical Association*, 81, pp. 411-419.

Kallenberg, A., Knoke, D., Marsden,P. and Spaeth, J. *Organizations In America,*

Judkins, D., Berk, M., Edwards, S., Mohr, P., Stewart, K. and Waksberg, J, (1995), "National Health Care Survey: List Verses Network Sampling", unpublished report, National Center for Health Statistics.

Kramm, E. R., Crane, M. M., Sirken, M. G. and Brown, M. L. (1962), "A Cystic Fibrosis Pilot Survey in Three New England States", *American Journal of Public Health*, 52, pp. 2041-2057.

Leaves S. and Valiant R. (1995), "Statistical Problems in Estimating the U.S. Consumer Price Index", in B.G. Cox, et al (eds.), *Business Survey Methods*, New York: Wiley.

Nathan, G. (1976), "Empirical Study of Response and Sampling Errors for Multiplicity Estimators with Different Counting Rules", *Journal of the American Statistical Association*, 71, pp. 803-815.

Sirken, M. G. (1970a), "Household Surveys with Multiplicity, *Journal of the American Statistical Association*, 65, pp. 257-266.

Sirken, M. G. (1070b), "Survey Strategies for Estimating Rare Health Attributes", *Proceedings of the Sixth Berkeley Symposium on Mathematical Statistics and Probability*", University of California Press, pp. 135-144.

Sirken, M. G. (1973), "The Counting Rule Strategy in Sample Surveys", *Proceedings of the Social Statistics Section, American Statistical Association*, pp. 340-342.

Sirken, M. G. (1977), "Network Sampling", in *The Encyclopedia of Biostatistics*, Wiley, pp. 2977-2985.

Sirken, M. G., Graubard, B. I. and McDaniel, M. J. (1978), "National Network Survey of Diabetes", *Proceedings of the Survey Research Methods Section, American Statistical Association*, Alexandria, VA. 631-635.

Sirken, M., Roystin, P., Bercini, D., Czaja, R., Eastman, E. and Warnecke R. (1981), "Completeness of Enumeration of Cancer Cases in Health Surveys", *Proceedings of the Survey Research Methods Section, American Statistical Association*.

Sirken, M. G. and Greenberg, M. S. (1983), "Redesign and Integration of a Population Based Health Survey Program, *Proceedings of the 44th Session of the International Statistical Institute*.

Sirken, M. G., Shimizu, I. and Judkins, D. (1995), "Population Based Establishment Surveys", *Proceedings of the Survey Research Methods Section, American Statistical Association*, pp. 470-475.

Sirken, M. G. and Shimizu (2002), "Design Effects of Sampling Frames in Establishment Surveys", *Survey Methodology*, 28, No. 2, pp. 183-190.

Sirken, M. G. and Shimizu (circa 2005), "Establishment Based Population Surveys: Design Effects of Linked Population/establishment Surveys Compared to Conventional Surveys" in P.S.R.S. Rao and M.J. Katzoff (eds.) *A Handbook of Sampling Methods and Analysis*, Chapman Hall/CRC Press.

Wunderlich, G. S. (ed.) (1992), *Toward a National Health Care Survey: A Data System for the 21st Century*, National Academy Press.