# ON THE USE OF SAMPLING IN MANAGEMENT AND RESEARCH

*by*

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**Purpose of this paper.** The purpose here is to bring to the attention of experts in law, traffic, management, administration, and research, some neglected points concerning the way in which statistical methods are being used in many fields. The ultimate aim is to loosen up some of the roadblocks that seem to stand in the way of proper use of modern statistical techniques in studies of traffic and in research on costs.

The purpose is not to tell anyone what business or research problems are important to him, nor to declare that sampling could solve them all. Only a quack doctor has all the cures. Neither is the purpose to describe statistical techniques.

What the reader will get, if the purpose of the paper is in any way fulfilled, is something more important than a bit of technical knowledge. He will instead learn something about the uses of sampling, and something about his own responsibilities in a statistical study.

Parenthetically, I wish that it were possible to communicate to the non-statistician, in a few minutes, the fundamental principles of the techniques of sampling, but I discovered long ago by trial and error and observation that most such attempts turn out to be misleading and fruitless. The plain fact is that sampling is a combination of science and art, and probably one of man's most difficult endeavors, not only for the knowledge of mathematical theory that is necessary, but for the arduous internship required for professional practice.

There is no simple way to teach or to learn any of the techniques of sampling. A little knowledge about them can be dangerous. It is fortunately not necessary for the lawyer or executive to understand the techniques, except superficially, as I shall explain later.

It is far more important for the lawyer or executive to learn the nature of statistical information, and how he could make better use of sampling, than it is for him to try to master techniques.

If I may speak in parables, any attempt to learn the techniques of sampling, without proper background and effort, is doomed to be about as successful as an attempt to study medicine by walking into the prescription department of an ethical pharmacy, pointing to some compound, and then to another, and expecting a doctor of medicine to explain that he uses this compound for gout, this other one for tonsilitis, and mixes the next two for severe headache, etc. Medicine just isn't that simple. Neither is sampling.

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There are a number of excellent books on modern statistical methods, and the person who wishes to read further, with a look at the technical details, will find them to be informative. The appendix will show a few authoritative titles.

The most interesting articles in any science are written by people that know little about it. Sampling is no exception. Unfortunately, no lustre of narration nor of personality can atone for teaching errors instead of truth. It is of course permissible for a professional man in medicine, law, statistics, or physics, for example, to write on cooking, marriage, religion, music, politics, or whatever entertainment takes his fancy outside his own specialization where neither he nor anyone else will take him seriously.

But when a professional man writes an article in his own field, he is accountable for what he says. What he writes will exhibit the care with which he protects his profession.

**What is sampling?** Sampling, in the hands of a statistician, means optimum allocation of human skills and machines to provide and interpret statistical information of demonstrable reliability and with speed, as aid to administration, management, and research. The chief tool of the statistician is the theory of probability. The statistician is interested in helping people to solve problems. The expert in subject-matter (law, traffic, management, industry) generates the problem: the statistician helps him to solve it.

Through use of the theory of probability, combined with adaptation, the statistician strikes an economic balance between (a) the cost of acquiring too much information, or more precision or more detail than is necessary, and (b) the losses that arise from insufficient information, or from insufficient precision.

Sampling is not a quick and dirty way of getting some figures. Sampling of freight bills, for example, in statistical practice, is not the processing of a batch of bills pulled out of the files in some nondescript manner, in the hope that they will yield some helpful information, nor is it the investigation of costs on a few loading platforms, selected by judgment, in the hope of learning something about the costs of running a business.

Sampling is not a part-time job. The plain fact is that sampling is difficult; at least it is to the statistician.

Sampling is a precision-tool. It is worth reflecting on the fact that most concepts can be defined only in terms of statistical theory. One might try, for example, to define round, square, precision, accuracy, uniformity, reliability, without statistical concepts and techniques: it is impossible. Thus, suppose that one decides that he wishes his billing department to achieve accuracy of 97 percent in the classification of commodity. How would he determine whether his clerks have achieved this accuracy? Still more difficult, how would he determine whether it is feasible to attempt to achieve this accuracy? And what is the meaning of the term, "97 percent accurate?" Statistical theory provides answers.

**Sampling is a cooperative work.** A fundamental rule for successful statistical practice is first for the statistician to know his business, which means that he must keep himself reasonably well informed of new theory and practice. Second, he must work only with clients that know their end of the business. Sampling is a joint venture between (a) the client (expert in traffic, management, engineering, medicine, etc.) and (b) the statistician. Management cannot abdicate its responsibility and look to the statistician to seek possible reasons why a business is losing money, nor possible reasons that might explain why certain other lines of goods or services would be more profitable. To think of possible causes is management's job. To investigate and evaluate the possible effects of various causes suggested by management is the statistician's job.

The actual decisions to make on the basis of the information supplied by a statistical system (as, for example, decisions on how to use the results of a continuous study of traffic in adjustment of rates) also belong to management; they are not statistical.

It is costly for management to dabble in sampling and to get wrong figures that lead one into costly decisions. The day is past when a lawyer or an executive can be satisfied with grab-samples. It is not difficult to imagine the possible magnitudes of error that lurk in estimates of diversions of traffic, and estimates of profits and losses for the year, calculated on a grab-sample collected during some week in February or March or August. We have all seen samples of bills, or pages of activities of delivery routes, covering a few days, multiplied by a certain factor to get the equivalent of a week, then multiplied by 4 to get the so-called "average month," and multiplied again by 12 or 13 to get a year's traffic, and a year's profits and losses.

It would be more difficult to explain why results so obtained are wrong than it would be to discover reasons why they could possibly ever be anywhere near right. The worst thing about them is that we can never know, not even afterward, how far wrong the results are.

I once heard of a sample (statisticians would call it a chunk) prescribed by an engineering firm that had been engaged to assist a railway company in a merger. The plan called for processing "every 10th abstract" for a given year. A little reflection would raise a lot of questions. In the first place, why would one look to an engineering firm for a sampling procedure? Why not go to a dentist? Second, what exactly is every 10th abstract? With a little care, one could process every 10th abstract and get almost any results that he is looking for. In the third place, why a 10 percent sample? Where were the calculations that showed that a sample of such size would be adequate?

In contrast, a probability sample delivers results whose precision is not a matter of opinion, but is calculated by mathematical formulas that depend on the theory of probability, and which make use of the results themselves in the calculations.

The financial hazards from wrong information are far greater than the hazards of informed guesses. The great Charles Darwin said that it is far better to proceed on a wrong theory than with wrong data. One discovers right away when his theory is wrong, but he may never know, until it is too late, that his data were wrong.

**"Our problems are different."** Most everyone knows about the impact that sampling and other statistical theory and techniques have made in industrial production, agricultural production, government statistical series, consumer research, and in other ways, as mentioned in the next section. The great success of statistical methods in the enhancement of quality and dependability of a manufactured product during the past 15 years, especially in Japan, are heralded in the papers almost daily.

Good examples of uses of sampling are also found in studies of traffic. For example, certain airlines settle their interline accounts by sampling. Some of them estimate their monthly income in advance by sampling. One could also mention delightful examples of sampling in studies of traffic in rate cases of railways, and in studies of diversion. The 1 percent study of waybills, conducted now 20 years by the Interstate Commerce Commission is well known. Statistical methods could be equally helpful in the day-to-day operations of motor, rail, and air-carriers.

Reluctance and timidity on the part of an executive to move into a statistical system that would improve operations in his company, and which would provide current information on shipments by mileage-bracket, by rate-basis, and better information on costs, are certainly understandable. Even inertia is understandable. We may forgive such excuses, but it is more difficult to forget them, as excuses do not pay the losses incurred. To the extent that reluctance and timidity have their roots in ignorance about the nature of statistical methods, and how they are used in other lines of business, an executive may overcome them most successfully, I believe, by giving up the idea of mastering techniques, and concentrating on the responsibilities that belong to him alone.

It is a mistake, I believe, for a lawyer or an executive to assume that he must understand a procedure pretty thoroughly before he can use it. People learn to drive automobiles without any education in thermodynamics or in electromagnetic theory. We all use the telephone, yet not one person in 4000 is able to write down the differential equations for the transmission of a signal under perfect conditions, and still fewer people have any understanding of the statistical nature of the theory of information that governs the transmission and unscrambling of a signal under actual conditions, complicated as they are with static and interference.

So it is with statistical methods: one may give up the idea of understanding the techniques, except in a superficial way, yet have the benefit of them.

A common remark on a success story concerning statistical methods in some other area is this: "Well, I understand perfectly well how sampling worked so well over there, but our problems are different."

A more enlightened attitude is to say: "Well, I don't understand just how sampling can help us, but we can't afford not to find out."

A frequent inquiry put to statisticians is how industry can make better use of statistical methods, in view of the severe shortage of competent theoretical statisticians. The answer is not simple, but I will suggest, as a long-range proposition, that companies and trade organizations should urge statistically inclined employees to go to school to complete their master's or doctor's degrees in statistical theory at some statistical teaching center, or at least to take specialized courses in or out of hours at nearby universities.

A further suggestion, short range if not long range as well, is to try to acquire the services of a competent consulting statistician to guide the statistical work within the company. This is especially effective in a company that has on its payroll one or more statisticians who are studying modern statistical methods, and are in a position to learn under the guidance of a master.

**Some everyday uses of sampling.** One of the most important uses of sampling in administration and in industry is to determine the so-called capability of the process. In manufacturing, this means the ultimate precision of uniformity in dimensions, color, hardness, or other quality characteristics. In administrative work it means the ultimate reasonable degree of accuracy that one may hope to achieve in computing charges, in transcription, punching, and other operations. In other types of business it might mean the minimum feasible variation in performance of drivers, trucks, and other equipment. Knowledge of the capability of a process has saved more than one company from entering into a contract to produce precision, uniformity, or quantity that they cannot deliver. Capability of a process can be defined and measured only by statistical methods.

**Some examples of applications of theory of sampling**

- Studies of traffic (rail, motor, air, automobile) for current information for management
- Studies of cost, and detection of costs that are out of line. (Merely being below average or above average is not necessarily out of line: a statistical test is necessary.)
- Improvement of performance of men and of machine
- Statistical tools for supervision
- Finding optimum operating conditions, and optimum patterns of service. Best use of equipment and of manpower. Results: (a) improved performance; (b) reduced costs
- Greater output and better quality from the same raw materials, and same machinery
- Hastening development of product
- Detecting errors in accounting records
- Determining the capability of a process or system (see text above)
- Government statistical series (current reports on the labor force index of prices, weekly and monthly sales at wholesale and at retail)

- Studies of expenditures of families
- Studies of sickness and time lost
- Surveys in sociological and demographic studies, and in population research
- Tests of drugs; bio-assay
- Consumer research
- Retrieval of information; theory of exploration
- Supplementation of complete censuses. Results: (a) broader scope at reduced cost; (b) greater accuracy; (c) greater speed
- Setting specifications of materials. Specifications have no meaning except in terms of tests dictated by statistical principles
- Ascertainment of inventory on hand. Evaluation of inventory in process. Evaluation of plant. Evaluation of buildings
- Standardization and refinement of tests and measurements
- Managerial accounting: (a) optimum level of inventory for maximum profit; (b) optimum investment in equipment; (c) optimum amount of overtime; (d) optimum allocation of resources
- Solution of complex mathematical calculations (for example, the so-called Monte Carlo method, used with the aid of electronic computers for calculations by which to predict and improve performance of complex equipment; problems in space trajectories)
- Theory for the transmission of information in the presence of noise

The reader may little suspect that these diverse applications are covered by one body of theory. Transferability of statistical theory makes it useful over a range of seemingly disjointed and unrelated fields of application. The material and the aims vary from one problem to another, but not the basic theory.

The reason for the wide applicability of statistical theory lies in the fact that the symbols and mathematical equations that appear in it don't care what the field of application be—traffic, sales, manufacturing, medicine, agricultural production.

Statistical theory has contributed heavily to new concepts in management. The theory and methods for reaching minimum loss (maximum profit) by rational choice of alternatives, and of continually improving operating conditions, came from people skilled in the theory of probability—not, be it noted, from businessmen, nor from economists, nor from people that teach and write books on business administration.

Few businessmen know, when they read in a newspaper or magazine that unemployment decreased two-tenths of one percent last month, that this figure comes from a miniature monthly census of 30,000 households, carried out by the Bureau of the Census by methods that people come from all over the world to learn about. The sampling methods are so accurate, and so economical, that the user of the data may concentrate on the definitions of unemployment, and on the meaning of the results, and not worry about the methods of sampling that are used.

As an example of the statistician's contribution to the design of experiments, I may cite the case of an analytic chemist who wishes to weigh 7 samples. The fact is that by proper statistical design, the chemist may achieve in 8 weighings the precision that he would otherwise get by 4 weighings on each sample. In other words, statistical design, applied in advance, has a leverage of four-fold, in this example. The statistician has a name for such applications: he calls them *factorial* designs.

Factorial designs might be applicable to studies of the cost of different kinds of handling and transport of materials. It might be possible, for example, by analogy, to lay out several simultaneous studies of different kinds of handling (different types, sizes, or handling of containers, for example), and obtain with a few observations the equivalent of a much larger number of experiments conducted in the usual way on one variable at a time.

A factorial experiment would furthermore measure interactions between types of handling and size of container. Such interactions might well be very important. They are entirely missing in the usual simple experiment.

I may cite an example in a study of adjustment of workers of different mentality to their jobs. Statistical techniques, in the hands of a competent theorist, multiplied the allotted research funds by a factor of 3: the budget of $75,000 for the study was made to do the equivalent of $225,000 under procedures originally intended.

As another example, some theory that I myself worked out just today to evaluate the probability of becoming schizophrenic at some specific age is immediately applicable to improvement of the reliability of complex apparatus.

It is an obvious conclusion, it would seem, that anyone who would attempt to conduct studies of costs without benefit of continuous competent statistical advice might easily waste a high proportion of his research funds.

**A rough idea of sampling for a continuing study of traffic.** One could describe at this point a rough but possible idea for a statistical system that would depend on regular samples of freight bills, for the general purpose of providing continuous information on traffic, costs, circuity, and other characteristics, by various categories of weight, mileage, revenue, rate-basis, commodity-group, terminal area, etc., on which to formulate a rational basis for rates, and for correlation with other costs. We shall suppose that members of a rate bureau have problems in rates and in shrinking profit-margins. The head of the rate bureau has some idea concerning the kind of information that may help his bureau to form a rational business-policy.

The first step would be for him to specify what car[illegible]s would supply his needs for information, under the supposition that [illegible]ad unlimited funds, and the eager cooperation of every carrier on the list; and that he could, if necessary, process a 100% sample of the freight bills of all these carriers. His list of carriers might be, for example, the 80 or 90 carriers whose revenue, under the rates published by the rate bureau, amount to $500,000 or more per year. He must then decide the type of information that he requires from the sample of freight bills, so that the statistician may have some idea concerning the precision required in the final tabulations.

Note that, so far, the steps in solving this sampling problem have been wholly the responsibility of the rate bureau.

The function of the statistician has so far been only the passive one of (a) patiently explaining to the head of the rate bureau the uses and limitations of the data that might come out of the study; (b) the advantages and disadvantages of extending the list of carriers to a lower level of revenue, say of $400,000 per year, or of contracting it to $800,000; (c) calling attention to the possibility of requiring on each freight bill in the sample some items of information in addition to the information that is regularly on its face (for example, rate basis on interline shipments); (d) inquiring into the possible effects of nonsampling errors, such as wrong classification of commodity, wrong rate, wrong charges, wrong division of revenue; (e) weighing the cost of correction against unrefined data; (f) pointing out how difficult items of information may be collected on only small subsamples of the main sample (actual miles, for example).

Though it is a passive role that the statistician plays in assisting the expert in subject-matter to state his problem, it is here that the statistician makes his most important contribution—namely, in formulating the problem in statistical terms, so that the statistical information to be derived from the study may be helpful on the problem.

The decision on the actual type of sampling procedure may occupy the statistician many weeks, and may require field-trials and experiments to reach a stage of smooth operation. The foundation of a good study is nevertheless careful recognition and formulation of the problem, the ultimate responsibility for which belongs to management. No statistical sampling plan, however clever, can outflank a hasty start, such as the wrong initial list of carriers, or inept choice of the information to tabulate. This is why it is much more important for the lawyer or executive to understand and discharge his own responsibility in a statistical study, and to leave the techniques of sampling to the statistician. The purpose of this paper may perhaps now be clear.

Every sampling procedure is different, but at the risk of being misquoted, I will give an example here of a type of plan that might be suitable for the rate bureau confronted with the problems of a rational rate structure, as outlined above. Thus, the sampling plan might involve (say) the top 20 carriers on the list of carriers, plus 1 in 4 of the remaining 60 or 70 carriers. Each of the 20 largest carriers would supply a continuous sample of freight bills, which might consist of 1 random truckload (10,000 pounds billed weight) in every 40, with a progressively lighter proportion of shipments of lesser weight. The smaller carriers would follow a similar but heavier sampling plan for the selection of freight bills, and these carriers might rotate—in the sample a year, out three years. Selection of the smaller carriers, and of all freight bills, would be made by random numbers (one of the most important tools of modern science), to permit use of the theory of probability in assessing the precision of the results.

Cooperation of all the carriers selected by the statistician to take part in the study is vital.

It is well to note further that the above rough description of a sampling plan is only one possibility. Circumstances might dictate other approaches. No two statisticians would design precisely the same procedure. Yet two plans, designed by two statisticians, would both be valid: they would give valid estimates of any of the information required, along with valid standard errors which measure the statistical precision of the results.

It is the job of the consulting statistician to evaluate the statistical reliability of the results when they are ready and to state, in simple terms, what the results mean. It is then the responsibility of management to put the results into action.

It is important to note that the cumulative uncertainty that arises from use of a proper sampling procedure diminishes month by month.

**A sampling procedure is not mere selection.** The technical portion of a sampling plan consists of 8 parts. The statistician acts as architect in laying out the plans, and prescribing responsibilities. M denotes responsibility of management (or of the expert in subject-matter), S denotes responsibility of the statistician.

1. Statement of the problem in statistical terms, and decision on the type of information to elicit. (M, S). Example: to acquire current information from freight bills on traffic, number of shipments and revenue by broad commodity-group, by rate-scale, by mileage-bracket, by weight-bracket, for intercity movement. This sounds simple, but a host of questions arise and must be resolved. In the first place, which carriers are we talking about? What is intercity traffic? What about assessorial charges? Will you need separate figures for them, by type of charge? What is a shipment? A shipment is one thing in the accounting records, and something else in the traffic department. Whose definition shall we use?

2. The procedure for the selection of the sample. Example: (a) the selection of carriers (some fixed, some to rotate) from the list supplied by the head of the rate bureau; (b) the selection of freight bills from the files of these carriers. (S)

3. Procedure for calculating estimates of the characteristics desired. Examples: number of shipments in mileage-brackets, within weight-brackets, by rate-scale, commodity-group, terminal area, etc. (S)

4. Procedures for laying out the results in a form that will permit easy calculation of the uncertainty in any figure attributable to sampling and to small accidental variations in transcription, editing, coding, punching. (S)

5. Procedures for carrying out certain controls, to detect departures from the sampling procedure, and to detect differences in definition. (S, M)

6. Evaluation of the statistical reliability of the results. How accurate are they? (S)

7. A continuous program for the evaluation and reduction of nonsampling errors, such as reduction of incorrect rates to some acceptably

low level; likewise for wrong commodity, wrong mileage, errors in transcription, and the like. A natural result will be continual improvement of precision and reduction of costs. (S, M)

8. Put the results to use. (M)

**Three kinds of statisticians:** There are (1) mathematical statisticians, (2) theoretical statisticians, (3) practical statisticians. The mathematical statistician engages himself in extension of man's knowledge through new mathematical theory. It is his work that circumscribes the boundaries of knowledge, providing a foundation for more efficient collection and use of statistical information in the future, and for long-range improvement of industrial processes, and of complex equipment, military and civilian. His interest is mathematical. His work is not glamorous, and he receives little recognition outside a close group of specialists.

Second, there is the theoretical statistician. A consulting statistician is a theoretical statistician because he is able to apply the power of theory to his work: he guides his work with the aid of the theory of probability. The theoretical statistician is interested in helping experts in traffic, marketing, medicine, engineering, production, chemistry, agriculture, etc., to solve problems. A theoretical statistician has mastered enough theory of statistics to use it safely in sampling, design of experiments and in a variety of related work. He develops new theory for almost every problem, and engages the help of a mathematical statistician when necessary.

Third, there is the practical statistician, described years ago by the great Thomas Henry Huxley who said, "The practical man practices the errors of his forefathers." This kind of practical man can be a real hazard in any field.

**Some common misconceptions about sampling.** Some of the folklore in lay circles about sampling needs correction. The following points might well constitute a syllabus for examination in courses in statistics in schools of business administration.

1. One-day studies of traffic, 1-week studies, or even 1-month studies, are samples. Wrong. They are, instead, what the statistician calls chunks, harboring unknown biases. The statistician takes the point of view that data of unknowable reliability are a hazard, not worthy of being called statistical.

2. One can offset poor preparation in management (failure to think through the problems), and can offset a biased sampling procedure, by increasing the size of the sample. Wrong.

3. Precision depends on size of sample. Wrong. The procedure of stratification, the choice of sampling unit, the formulas prescribed for the estimates, are more important. Once these features are fixed, then increase in size of sample may yield gain in precision (though the point of diminishing returns comes rapidly). All the freight bills for a day, or for even a week, contain far less information than the same size sample spread over the year by a continuous statistical plan.

4. Judgment and expert knowledge of the subject matter (e. g., law, traffic rates, costs, etc.) are not useful. Wrong. This type of

knowledge is vital, as I have explained earlier. However, judgment and knowledge of the subject matter will not alone produce an acceptable sampling procedure, nor serve as a basis for judging the margin of error in a statistical study.

5. The substantive-expert can delegate to the statistician the responsibility of specifying the kind of information that he needs, the questionnaire, the method of eliciting the information, the segregation of rare and important items, and the forms for the tables that will display the result. Wrong. It is the substantive-expert, not the statistician, who must testify to the usefulness and meaning of the results. The statistician only testifies to their range of validity, and to the proper method of inference.

6. The size of the universe determines the size of sample. Wrong. The number of freight bills that accumulate in a year is of no practical importance in deciding on the size of sample for a particular job. Given the procedures for selection, and for the computation of estimates, it is *the absolute size of the sample* (5000, 10,000), not its proportion to the whole, which determines the precision of the result. Thus, the size of sample prescribed for a universe of 100,000 accounts might be identical with the size for a universe of 100,000,000. I often prescribe the size of sample and its procedure before the company has furnished me with the figures for the size of the universe whence the sample will come. Thus, for two different cases of proposed mergers of railways, I specified the stratification and the size of sample for each as about 15,000 interline abstracts, before I knew how many abstracts were in the files of the two companies.

7. A sampling expert is a man who has enjoyed a run of successful selections by judgment. Wrong. He is a survey-expert, whose aim is service to business and to research, and whose distinguishing tool is use of the theory of probability.

8. The reliability of a statistical sample is a matter of luck. Wrong. Quality is built in. The margin of uncertainty of a result to be obtained by a proper sampling plan, carefully executed, is predictable pretty accurately in advance, and is calculable definitely and objectively afterward from the results of the sample.

9. Statistical precision of results obtained by modern sampling procedures is a matter of opinion and expert judgment. Wrong. Statistical precision is calculable as a mathematical consequence.

10. Errors of sampling are dangerous. Wrong, if you are talking about probability sampling. Under guidance of a competent theorist, the margin of uncertainty due to sampling and from small accidental errors is governed in advance, and in any case is calculable afterward, and hence known, not as a matter of opinion, but as mathematical calculations.

11. Errors of sampling are the only risks. Wrong. Most of the errors in statistical studies are *not* errors of sampling, but arise from failure of management or of the expert in the subject-matter (lawyer, traffic-expert, accountant, engineer, chemist, economist) to formulate questions suitable to the solution of the problem, or to specify ways

in which to procure the information, or in failure to provide a suitable frame (list). Moreover, errors in description of commodity, errors in charges, and in division of revenue, can be more serious than sampling, unless carefully and expertly held to a low level by skilful use of statistical aids to supervision.

12. The theory of sampling and the standard error of a result do not apply to studies that involve subjective measurements and opinions on each account (e. g., liability to diversion). Wrong. Sampling applies as well to subjective measures and to opinions as it does to studies where the measurements are quantitative (weight, revenue, miles, time).

13. Electronic machines, able to store and retrieve information on every shipment, with great speed, eliminate the need of sampling. Wrong. This fanciful hope turns out in practice to be but a pleasant dream. Unfortunately, the chief qualification of huge masses of data is too often sheer bulk and expense, failing to shed light on important problems at hand, either because the information needed was not recorded on the tape at all, or is too inaccurate to be useful. It is well to remember that the inherent accuracy in the original responses or records, as edited and coded, is the limitation to the accuracy that a machine can turn out.

Another point is that machine-time, where people keep records of costs, turns out to be expensive. Even where the information on a tape is accurate enough to be usable, it is often advisable to carry out tabulations on the basis of a sample, to conserve machine-time for work that is more productive than mass tabulation. Many of the tables published by the Census are in fact produced by sampling tapes that contain full information for every person in the country and household information for a sample of 1 household in every 4.

14. You can take a look at a sample of freight bills (or at a sample of carriers) and decide whether the selection constitutes a good sample. Wrong. Stratification, the procedure of selection (invariably with random numbers), the formulas for the calculation of estimates and of their standard errors, making use of results of the sample itself, along with statistical controls, are some of the necessary ingredients of the statistical part of a sampling procedure. Obviously, one cannot look at any one part and make a statement about the whole procedure. One must examine the entire plan.

15. Comparison of a sample of traffic with figures derived from the accounting department constitutes validation of the sample. Wrong. There are many reasons why a sample or an accurate 100 percent tabulation of all the freight bills in the files will not agree with the acounting records. For example, the number of intercity shipments, and the revenue derived therefrom, have one definition in the files of delivery receipts, and another definition in the accounting department. Moreover, the accounting department may show audited figures, whereas the files of freight bills may be unaudited. Billed weight and actual weight are frequently confused.

16. A complete study (100 percent of all bills, or of all carriers, or of all platforms, etc.) is more reliable than a sample. Wrong. There are three kinds of uncertainties in data. Type I arises from lack of information in the records, or lack of knowledge on how to procure the information desired. Type II comes from operational blemishes in carrying out a study, or from errors and omissions in the original records, such as recording the wrong commodity, computing the wrong rate, errors of transcription and of punching. Type III comes from the use of sampling and from small accidental errors. Unless great care is taken, errors of Type II may assume embarrassing proportions in a large study. They do not diminish with the size of sample, but will instead actually increase, unless the job is skilfully supervised. On the other hand, uncertainty from sampling (Type III) can be reduced to any desired margin by proper design of sample (though of course the more precision one demands, the more expensive will be the sample required).

In any case, as stated earlier, in a continuous study the cumulative uncertainty from sampling will diminish with time, whereas the other types of uncertainty (wrong rates, wrong entries, etc.) become more and more obvious.

This is not to say that all large studies are full of errors. Some huge operations, such as our own decennial Census of Population, or the five-year Census of Agriculture, are carried out with great skill, with accuracy evaluated by proper statistical controls.

17. This company punches a card and carries out a complete tabulation of all shipments. We don't need sampling. Wrong. Use of data for discovery of relationships and causes of change in pattern in any class of traffic requires the same statistical tests for a complete study as for a sample. Put another way, complete studies are samples of what the underlying causes can and do produce, and can be studied safely only by use of the theory of sampling.

Moreover, as just mentioned, too often the information needed for an analytic study was not punched into the cards, and can only be obtained by going back to a proper sample of the original records.

18. All probability sampling procedures are alike. Partly right, partly wrong. No two statisticians will design exactly the same plan. The results of their two samples will agree, however, within calculable limits, provided the definitions are applied equally in the two studies, and provided the workmanship is of the same quality in both.

Incidentally, one cannot expect two complete studies to agree. Careful examination will almost always detect differences in definitions, different rules, and varying levels of accuracy in processing.

## Appendix: Titles of a Few Books

A. C. Rosander: Elementary Principles of Statistics (Van Nostrand, 1951)

W. Allen Wallis and Harry V. Roberts: Statistics (Macmillan, 1956)

R. C. Sprowls: Elementary Statistics (McGraw-Hill, 1955)

E. Kurnow, G. J. Glasser, and F. Ottman: Statistics for Business Decisions (Irwin, 1959)
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