*ESTIMATION OF HIGHWAY NEEDS FOR
COUNTY PRIMARY ROAD SYSTEMS
IN MICHIGAN AND MINNESOTA
BY SAMPLE SURVEY METHODS*

DEC., 1958

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*Joint
Highway
Research
Project*

*PURDUE UNIVERSITY
LAFAYETTE INDIANA*

by

D.O. COVAULT

Final Report

ESTIMATION OF HIGHWAY NEEDS FOR COUNTY PRIMARY ROAD SYSTEMS IN MICHIGAN AND MINNESOTA BY SAMPLE SURVEY METHODS

TO: K. B. Woods, Director
Joint Highway Research Project

December 18, 1958

FROM: H. L. Michael, Assistant Director
Joint Highway Research Project

File: 3-3-27
Project: C-36-54AA

Attached is a copy of a report entitled, "Estimation of Highway Needs for County Primary Road Systems in Michigan and Minnesota by Sample Survey Methods." It has been prepared by Mr. D. O. Covault, Research Engineer on our staff, under the direction of Prof. H. L. Michael. Mr. Covault also utilized this report as his thesis in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

This research was also conducted as a cooperative project with the State Highway Department of Indiana utilizing 1½% funds. This final report on this project will, consequently, be sent to the State Highway Department of Indiana for their review and approval and for forwarding to the Bureau of Public Roads for their review and approval. After review by these two organization and after making any revisions suggested, this report will constitute the final report on this cooperative study.

Respectfully submitted,

H. L. Michael

H. L. Michael, Secretary

HLM:ac

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D. O. Covault, Research Engineer

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Purdue University
Lafayette, Indiana

December 18, 1958

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ABSTRACT

Covault, Donald Orville. Ph.D., Purdue University, January 1959. Estimation of Highway Needs for County Primary Road Systems in Michigan and Minnesota by Sample Survey Methods. Major Professor: Harold L. Michael.

Highway needs studies are costly and time consuming and require large engineering staffs for their performance. Sample survey methods can be used to reduce the time and work required to make these studies.

Complete inventory and cost data were available for the primary county road systems in Michigan and Minnesota and this information was used for statistical analysis. The rural and urban systems in each state were composed, respectively, of separate highway, bridge, and railroad crossings populations. A composite population composed of highway sections and bridge and railroad crossings located in the respective highway sections was also used. The total value of population characteristics and the variances of these characteristics was computed.

Four different sampling methods were investigated for required sample size using five different combinations of margin of error and α risk for the respective populations. The methods investigated were:

- (a) Simple random sampling
- (b) Optimum and proportional stratified random sampling
- (c) Simple cluster sampling
- (d) Optimum and proportional stratified cluster sampling

Using a specified margin of errors and α risks for each population, sample sizes required for the estimate of total cost were computed. Sample sizes required for the estimation of other population totals were also computed. Optimum stratified random sampling required minimum sample sizes compared to sample sizes required for proportional stratified random sampling and simple random sampling for the estimate of total cost. Optimum stratified cluster sampling required minimum sample sizes for the estimate of total cost compared sample sizes required for all other forms of cluster sampling.

For a given margin of error and α risk for each population all forms of cluster sampling used for the respective populations required substantially larger sampling rates for the estimate of the total cost than those required for simple random or stratified random sampling. For all forms of sampling used, optimum stratified random required the smallest rates and simple cluster sampling required the largest.

Estimated sample survey costs required for the estimate of total cost using the rural separate and rural composite

populations for five orders of accuracy were investigated for each sampling method studied. For all sample survey methods using the separate populations, minimum total sample survey costs were generally given by optimum stratified random sampling for the Michigan and Minnesota data. Simple random sampling required minimum total sample survey costs for the rural Minnesota composite population. For the rural composite Michigan population, simple random sampling required the smallest expenditure of funds for the three lowest orders of accuracy. However, for the two highest orders of accuracy, minimum sample survey costs occurred using optimum stratified random sampling.

The apparent difference in estimated total sample survey costs for simple random and optimum and proportional stratified random sampling for the respective composite and separate populations was small. All forms of cluster sampling required much larger expenditures when compared to the expenditures required for simple random or stratified random sampling for the various orders of accuracy studied.

The amount of information which can be obtained from the composite samples was more limited than the information which was obtained from the separate samples. However, a 70 to 150 percent increase in estimated sample survey cost occurred for the separate samples when compared to estimated cost of the composite samples for a specified order of accuracy.

INTRODUCTION

General Discussion

The performance of a complete highway needs study on all highway systems in a particular state is costly and time consuming. The typical study requires from one to three years and a large staff of engineers, technicians, and clerical personnel. Complete cooperation of all state, county, and municipal highway and street agencies is also necessary if the work is accomplished quickly and efficiently. A total expenditure of \$200,000 to \$600,000 is not unusual for the conduct of such a survey.

The evaluation of the needed improvements on municipal, county, and township highway systems always has been difficult because of the large mileage of highway involved in these systems and the lack of basic data. Moreover, the total cost of eliminating the inadequacies on these systems is comparatively low, but large expenditures are required to evaluate this small portion of the total cost of required highway improvements.

Highway need studies are used to influence financial and administrative policy within the state legislatures and highway departments. Recent and reliable estimates of

highway needs are, therefore, essential; but present methods used in making these studies require such a large expenditure of time and money that these studies are only performed infrequently, if they are made at all. To be most effective these studies must be made on a continuing or perpetual basis.

The application of sample survey techniques to the estimation of highway needs offers an ideal means whereby the time and expenditures required to make a needs study may be substantially reduced. Sample survey methods are especially adaptable to the county and township road systems because of their large mileage and the lack of necessity for detailed knowledge about the needs for every mile of highway. This system usually has comparatively low variability and thus requires small sample sizes for adequate accuracy.

Sample survey methods may also be applied to the estimation of needs for municipal street systems. Sampling methods, however, are not as adaptable to the estimation of the needs on state highway systems or high type county and municipal facilities, such as four-lane divided highways or freeways. More specific knowledge is required here concerning the construction requirements and costs of these highways because of their high cost and importance. Furthermore, large variances will be common with these populations and large sample sizes for reliable results will be required.

Estimation of County Primary Highway Needs
by Sample Survey Methods

This research was concerned with the development of methodology and techniques using sample survey theory for the efficient estimation of highway needs on county highways in Michigan and Minnesota. Complete highway needs data were available in these states for the county primary highway systems. The value of population characteristics and variances were computed and used to compute sample sizes and variances for different sampling plans using various combinations of margin of error and risk for each population (9). The sampling plans which were investigated are as follows:

- (a) Simple random sampling
- (b) Stratified random sampling, optimum and proportional allocation
- (c) Simple cluster sampling
- (d) Stratified cluster sampling, optimum and proportional allocation

Stratified random sampling with optimum or proportional allocation is designated as optimum or proportional stratified random sampling, respectively, in this study. Stratified cluster sampling with optimum or proportional allocation is designated as optimum or proportional cluster sampling, respectively.

Of basic importance to any sample survey is the choice of a suitable margin of error and a risk. For the several

sampling methods considered, five different combinations of margin of error and α risk were studied for each population as to required sample size and variance. No specific combination is recommended for the estimation of highway needs. This decision must be made by the highway agency making and using the results of the sample survey. Some questions which may be asked, however, that will help in making an objective decision as to the proper combination are:

- (a) Who will use the information obtained for highway needs?

For example, do the results from the survey information have a direct or indirect influence on administrative and fiscal policy for highway improvement?

- (b) How serious will be the consequences of a wrong estimate?

- (c) How quickly (in terms of another scheduled survey) can a possible error be corrected?

Generally, high accuracy is not required for an estimate of the total cost of making all needed highway improvements especially if the highway agency keeps its requirements current. If a substantial error is possible in the estimated needs, the next scheduled needs evaluation may quickly correct the previous estimate before it has seriously influenced policy. Furthermore, the concepts, costs, and

standards upon which highway needs are based are continually changing and the estimate of the total cost of these needs also will change.

The use of sample survey techniques, however, does not replace the requirement for reliable basic data. The amount of preliminary data required to perform simple random or simple and stratified cluster sampling may be small; however, the results which are obtained will be only as reliable as the data upon which the estimates are based. The need for reliable data is especially important if one desires to keep the cost of highway needs current.

The type and adequacy of data may determine the type of sampling plan which is most feasible. If data are available which will permit the use of a certain sampling plan at minimum total cost, it should be used. Sample survey techniques, in fact, are quite flexible.

The most efficient sampling plan that can be used is the plan that will give the desired estimate with a specified accuracy for minimum total cost. Minimum total cost implies that the survey will also be completed in minimum time because most of the cost of a sample survey is for the labor required.

Michigan and Minnesota data were used as a basis for the statistical analysis in this study. These populations, however, may not be similar to the populations in other states. The county road systems in these two states, however,

are typical of most of the states in the Midwest. Climate, topography, and soils are similar to all areas of the Midwest, although locally a great difference may occur. Furthermore, land usage in this area is similar and all of the states in the Midwest have a well developed county primary road system which is extensively used for agricultural purposes. The results obtained from the analysis of Michigan and Minnesota data, therefore, may be similar to values which would be obtained for other states, especially those which have a well developed county primary highway system.

This research was intended to serve two specific purposes. The first of these was to determine if the use of sample survey methods for the estimation of the total cost of eliminating highway needs for county primary road systems was practical. A second purpose was to apply sample survey theory to this problem in order to compute the magnitudes of various sample size and costs for various sampling plans. This type of information is essential for an agency attempting to estimate highway needs by sample survey techniques, and previous applications of this procedure to the highway needs problem have been limited.

Description of Populations

The population is the aggregate or universe from which a sample is chosen. In this sample survey problem several

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populations were used and these are defined as follows:

<u>Road System</u>	<u>Population</u>
Rural	1. All Highway Sections
	2. All Bridges
	3. All Railroad Crossings
Urban	4. All Highway Sections
	5. All Bridges
	6. All Railroad Crossings

Each of these six populations was sampled separately and the results added to estimate the total highway needs for the entire county road system.

The sampling units for the separate populations are different for each population when simple or stratified random sampling is used. The sampling unit for highway populations is a highway section; the sampling unit for the bridge populations is a bridge; and the sampling unit for the railroad crossing populations is a railroad crossing. However, the sampling unit for simple and stratified cluster sampling is the county for all populations. All highway sections, bridges, and railroad crossings in the sampled counties are evaluated if estimates of these populations are desired. The respective highway sections, bridges, and railroad crossings are called elements.

Another population is also used. This population is composed of all highway sections and included^s bridges and

railroad crossings in the highway sections in which they occurred. This type of population shall be referred to as a composite population in this report. The total needs or cost of improvement of a highway section includes the cost of improvement of the highway plus the cost of bridge improvements and the cost of improving railroad crossings which are located within the section.

When the composite population is used, the sampling unit for simple or stratified random sampling is the highway section while for simple or stratified cluster sampling it is the county. In the latter case, the highway sections are called elements.

CHAPTER I

COST FUNCTIONS

General Discussion and Concepts

Choice of Sampling Method

The proper choice of a sampling method should include a consideration of the estimated total cost of making the study. It is assumed, of course, that the amount and accuracy of information which would be obtained by use of the various sampling methods would be the same for the respective populations and that certain basic data-such as maps, traffic information and soil types-are available.

In a study of highway needs, however, the type and amount of data which are on file may dictate the sampling method. For example, Minnesota has ^{placed} information concerning their entire county and township road systems on punch cards, including complete identification, physical inventory, and traffic data. In the ensuing discussion, however, it is assumed that complete information of this type is not available but that only minimum data as mentioned previously are available.

Components of Total Cost

Estimated Total Cost. The total cost of a sample survey is composed of several component costs including those due to overhead and general supervision, sample listing, travel, data collection and data analysis. These costs will vary with the sample size and with the type of sample used. For instance, total travel costs between units for cluster sampling may be less than for simple or stratified random sampling. On the other hand, cluster sampling will usually require the collection of more data than simple random or stratified random sampling.

Overhead Cost. Included in the cost of overhead in a sample survey is the cost of office space, utilities, paper, pencils, and other supplies. Also included is a cost for general planning and administration, and for secretarial and clerical help. A cost for the use of office equipment such as typewriters and desk calculators is also included in overhead. It is assumed, however, that the overhead cost will be the same for all sample survey methods, and it is not included in the total cost computations of the sample surveys in this study.

Listing Cost. The listing of a sampling unit involves finding the location of termini of the unit on a map; writing a description of its location; determining traffic flow and topography if required; punching the information on a card and checking the information for errors. For simple

and stratified random sampling, this listing process must include every highway section, bridge, and railroad crossing in the road system being studied. On the other hand, complete listing need only occur in the units (counties) which are sampled when simple or stratified two-stage or cluster sampling is used.

Travel Cost. Travel cost is composed of several components. In addition to the actual expense of driving a vehicle from one sampling unit to another sampling unit, the salaries of the survey crew while traveling must be included. A certain amount of travel expense is also caused by travel from and return to home or headquarters if the survey crew does not stay overnight away from home. If the crew is required to stay overnight away from headquarters, as often happens, an additional subsistence expense occurs which is charged to travel cost.

Travel cost does not vary directly with the sample size. The more separate the units which are sampled, the larger will be the travel cost per unit. The larger the number of units sampled in a given area, the smaller will be the unit cost of travel. Assuming the sampled units as points distributed uniformly throughout an area, A , as indicated in Figure 1, the average travel distance between the units can be computed.

FIGURE 1. Distances Between Sampled Units in a Finite Area (22).

The vertical or horizontal distance between any two consecutive points is

$$d = \sqrt{\frac{A}{n}}, \quad (1.00)$$

where A is the area and n is the number of units sampled (22).

The total distance traveled if one visits each unit by the shortest possible route is approximately equal to the number of units to be visited multiplied by the average distance between them. The total travel, therefore, is nd , and because $d = \sqrt{A/n}$, the total distance is approximately equal to $\sqrt{nA}$. Because $\sqrt{nA}$ represents the total travel, the total travel cost is

$$C_{TR} = C_1 \sqrt{nA}, \quad (1.01)$$

where C_1 is the unit cost per mile of travel.

Sampled units are seldom uniformly distributed in the area in which they are located and this formula is only a general approximation of total travel cost.

Data Collection. The data collection cost includes salaries and wages paid to the survey crew for the physical work of taking measurements and filling out forms during the collection of inventory data on a highway system. Also included in the data collection cost are travel costs incurred while gathering information in the sampled highway section. Other minor costs such as the training of inventory crews, long-distance telephone calls, field supervision of the inventory crews and miscellaneous expenses are included.

Data Analysis. Data analysis is also composed of several operations which contribute to the total cost of the sample survey. Included in this cost, in addition to the actual statistical analysis of data, is the cost of selecting the sample, evaluating the needs from inventory data, coding and punching information on punch cards, preparing the report, editing, and listing and checking computations. The greatest cost of this phase of a study is usually the work required for computations and checking.

Usually for large sample sizes, the most economical way to perform the analysis of data is by business machines or high speed, digital computers. The use of digital computers is especially economical if computations are highly

repetitive. In the development of the cost data for this study, this method of computation is generally assumed.

Cost Functions for Various Sampling Methods

Simple Random Sampling

Highway Sections, Bridges and Railroad Crossings Treated as Separate Populations. When these components of the road system are treated as separate populations, the evaluation of the needs for each component consists of a separate sample survey. The total cost of the sample survey for a particular road system is, therefore, the sum of the costs for sampling and analysis of each highway, bridge, and railroad crossing population.

These populations are not totally independent however if the following procedure is used in collecting data. If bridges or railroad crossings are located in a highway section included in the sample, these bridges and railroad crossings are "forced" into the sample. Assuming that the highway sections are chosen at random and that each highway section contains one bridge and one railroad crossing, or one bridge and no railroad crossing, or no bridge and one railroad crossing, or no bridge or railroad crossing at all, any bridge and railroad crossing will also be chosen at random. Because some road sections may contain two or more bridges and/or railroad crossings, this assumption of randomness is not exactly true. However, this error will not be

serious because the multiplicity of bridges and railroad crossings in a highway section is not large. "Forcing" bridges and railroad crossings into the sample has the definite advantage of reducing travel cost for the collection of the total data required and should always be used.

The cost functions for a particular road system using simple random sampling, therefore, are as follows:

Highway Survey Costs:

$$C_H = L_H N_H + C_{1H} \sqrt{A_S} \sqrt{n_H} + C_{2H} n_H + C_{3H} n_H \quad (1.02)$$

where the symbols have the following definitions:

C_H = Estimated total highway survey cost

L_H = Unit cost of listing

C_{1H} = Unit cost of travel in dollars per mile

C_{2H} = Unit cost of data collection

C_{3H} = Unit cost of data analysis

n_H = Number of sampled units

N_H = Total number of sampling units in highway population

A_S = Area of the state in square miles

Bridge Survey Costs:

$$C_B = C'_B + C''_B \quad (1.03)$$

where the total estimated survey cost for the bridges, C_B , is composed of the cost of the survey for those bridges which

are "forced" into the highway sections, C'_B , plus the cost, C''_B , of the bridges which are sampled separately. The total cost for bridges "forced" into the sample is

$$C'_B = L_B N'_B + C_{2B} n'_B + C_{3B} n'_B. \quad (1.04)$$

The symbol, C_{2B} , is the unit data collection cost for the bridges sampled; C_{3B} is the unit cost of data analysis; n'_B is the number of bridges "forced" into the sample; L_B is the unit cost of listing the sampling units; and N'_B is the expected number of bridges from which the "forced" sample is chosen.

function for

The cost $\wedge$ bridges which are sampled separately is

$$C''_B = L_B N''_B + C_{1B} \sqrt{A_s} \sqrt{n''_B} + C_{2B} n''_B + C_{3B} n''_B, \quad (1.05)$$

where N''_B is the expected number of bridges from which the separate sample is chosen and n''_B is the number of units sampled separately. Adding formula (1.04) and (1.05) and noting that

$$n'_B + n''_B = n_B \quad \text{and} \quad N'_B + N''_B = N_B,$$

one obtains

$$C_B = L_B N_B + C_{1B} \sqrt{A_s} \sqrt{n_B - n'_B} + C_2 n_B + C_3 n_B. \quad (1.06)$$

Assuming the bridges "forced" into the sample were chosen at random, the unbiased estimate of the number of bridges forced into the sample is

$$n'_B = \frac{n_H}{N_H} N_B \quad (1.07)$$

Railroad Crossing Survey Costs:

Using logic similar to that developed previously for bridges, the following formula is obtained for the sample survey costs for railroad crossings,

$$C_R = L_R N_R + C_{1R} \sqrt{A_s} \sqrt{n_R - n'_R} + C_2 n_R + C_3 n_R . \quad (1.08)$$

An unbiased estimate of the number of railroad crossings "forced" into the sample is

$$n'_R = \frac{n_H}{N_H} N_R . \quad (1.09)$$

Estimated Total Survey Costs:

The estimated total cost, C_T , for a sample survey using simple random sampling can be expressed as

$$C_T = C_H + C_B + C_R .$$

Assuming that $C_{1H} = C_{1B} = C_{1R}$, the total cost is

$$\begin{aligned}
C_T = & L_{II} N_{II} + C_{1II} \sqrt{A_s} \sqrt{n_{II}} + C_{2II} n_{II} + C_{3II} n_{II} \\
& + L_B N_B + C_{1II} \sqrt{A_s} \sqrt{n_B - n'_B} + C_{2B} n_B \\
& + C_3 n_B + L_R N_R + C_{1II} \sqrt{A_s} \sqrt{n_R - n'_R} \\
& + C_{2R} n_R + C_{3R} n_R .
\end{aligned} \tag{1.10}$$

Composite Populations. A substantial reduction in

travel, data collection, and data analysis costs will occur for the composite population compared to costs required for the separate populations. The data are somewhat easier to obtain because only those bridges and railroad crossings located in the sample highway sections will be sampled.

However, the information which is obtained from the composite population may have limitations because of confounding of data. Furthermore, if estimates of bridge and railroad crossing improvement costs are desired, much larger sample sizes are required for comparable accuracy than are required for the separate populations. The decision to use this population must be made only after careful consideration of the information desired from the sample and the costs of the two sampling plans has been made.

The general cost function for simple random sampling using the composite population is

$$C_T = L_c N_H + C_{1c} \sqrt{A_s} \sqrt{n_c} + C_{2c} n_c + C_{3c} n_c \quad (1.11)$$

where the symbols are defined as follows:

- C_T = Estimated total cost of sample survey
 L_c = Unit cost of listing the composite sample
 N_H = Total number of sampling units in the composite population
 $C_{1c} = C_{1H}$ = Unit cost of travel
 C_{2c} = Unit cost of data collection
 C_{3c} = Unit cost of data analysis
 n_c = Sample size
 A_s = Area of the state

Stratified Random Sampling

General Cost Formula. A general cost formula can be

developed for stratified random sampling which can be applied when separate or composite populations are used. Furthermore, the general formula can be used to develop an expression for the stratum sample size (for a fixed n) which will minimize cost for a fixed variance or minimize variance for a fixed cost.

The expression for the cost formula is

$$C = L N + C_1 \sqrt{A_s} \sqrt{n} + \sum_{h=1}^L C_{2h} n_h + \sum_{h=1}^L C_{3h} n_h \quad (1.12)$$

It should be noted that only the data collection cost and the data analysis cost will vary from stratum to stratum. Travel from sampling unit to sampling unit is done without any distinction being made as to which stratum the particular unit is located. Essentially, travel between units in stratified random sampling occurs in the same manner as occurs in simple random sampling. The unit cost of listing for stratified random sampling will be higher than for simple random sampling because more information is required to permit stratification of the population. Usually such information as topography and traffic must be added to the identification information which was required for simple random sampling. The unit cost of travel, however, will not change between the two methods of sampling because the stratified sample will be distributed over a state-wide area as would the simple random sample.

The unit cost of data analysis will also be higher than for simple random sampling. Separate estimates of variance must be computed for each stratum in addition to other statistical computations which require substantial time. It is also more difficult to draw the sample from the population because more information must be considered before stratifying.

To determine the value of n_h which will minimize cost subject to a fixed variance, it is necessary to minimize formula (1.12) subject to the restriction that

$$\sum_h^L N_h (N_h - n_h) \frac{S_h^2}{n_h} - v(\hat{Y}) = 0 .$$

Multiplying this restriction by the Lagrange multiplier, λ , and adding the cost formula one obtains the function

$$\begin{aligned} F = & L_H N_H + C_{1H} \sqrt{A_s} \sqrt{n} + \sum_h^L C_{2H} n_h + \sum_h^L C_{3H} n_h \\ & + \lambda \sum_h^L N_h (N_h - n_h) \frac{S_h^2}{n_h} - \lambda v(\hat{Y}) . \end{aligned}$$

Differentiating with respect to n_h and setting the expression equal to zero,

$$\frac{dF}{dn_h} = C_{2h} + C_{3h} - \frac{\lambda N_h^2 S_h^2}{n_h^2} = 0 .$$

Solving for n_h :

$$n_h = \frac{\sqrt{\lambda} N_h S_h}{\sqrt{C_{2h} + C_{3h}}} . \quad (1.13)$$

$$\text{Since } \sum_h^L n_h = n = \sqrt{\lambda} \sum_h^L \frac{N_h S_h}{\sqrt{C_{2h} + C_{3h}}} , \quad (1.14)$$

the ratio of (1.13) to (1.14) gives

$$\frac{n_h}{n} = \frac{N_h S_h}{\sum_h^L \frac{N_h S_h}{\sqrt{C_{2h} + C_{3h}}}} \quad (1.15)$$

Formula (1.15) leads to the following generalizations for the sample size in each stratum

- (a) The larger the stratum, the larger is the sample
- (b) The more variable the stratum, the larger is the sample
- (c) The smaller the sum of the unit costs, the larger is the sample
- (d) The smaller the data collection unit cost, the larger is the sample
- (e) The smaller the data analysis unit cost, the larger is the sample

Substituting formula (1.15) in formula (B.20)* one obtains an expression for total sample size which involves the cost function:

* Refers to formulas given in Appendix B.

$$\begin{aligned}
 n &= \frac{\sum_h^L \frac{N_h^2 S_h^2}{w_{1h}}}{V(\hat{Y}) + \sum_h^L N_h S_h^2} = \\
 &= \frac{\sum_h^L \frac{N_h^2 S_h^2}{N_h S_h} \sum_h^L \frac{N_h S_h}{\sqrt{C_{2h} + C_{3h}}}}{V(\hat{Y}) + \sum_h^L N_h S_h^2} \\
 n &= \frac{\sum_h^L N_h S_h \sqrt{C_{2h} + C_{3h}} \sum_h^L \frac{N_h S_h}{\sqrt{C_{2h} + C_{3h}}}}{V(\hat{Y}) + \sum_h^L N_h S_h^2} \quad (1.16)
 \end{aligned}$$

Formulas (1.15) and (1.16) should be used as a general guide for the computation of total sample size and the allocation of stratum sample sizes when the stratum unit costs of the sample survey are known. Unit costs are never precisely known and are subject to some variability with sample size which can not be evaluated. This function can be used when the highways, bridges and railroad crossings are treated as separate or composite populations. When separate populations are used, three evaluations of n are required as compared to one when the composite is used.

If the unit costs are equal in all strata, formula (1.16) reduces to the allocation formula (2.18) for stratum sample size for optimum sampling.

Highway Sections, Bridges, and Railroad Crossings Treated as Separate Populations. When highways, bridges and railroad crossings are considered as separate populations, the evaluation of each population can be treated as a separate sample survey. The assumption that bridges and railroad crossings which are "forced" into the sample are chosen randomly is also considered valid.

The cost functions for a road system using stratified random sampling is as follows:

Highway Survey Costs:

$$C_H = L_H N_H + C_{1H} \sqrt{A_s} \sqrt{n_H} + \sum_h^L C_{2Hh} n_{Hh} + \sum_h^L C_{3Hh} n_{Hh} \quad (1.17)$$

where C_{2Hh} is the unit cost of data collection in the h th stratum, C_{3Hh} is the unit cost of data analysis in the h th stratum, and n_{Hh} is the highway section sample size in the h th stratum.

Bridge Survey Costs:

$$C_B = L_B N_B + C_{1B} \sqrt{A_s} \sqrt{n_B - n'_B} + \sum_h^L C_{2Bh} n_{Bh} + \sum_h^L C_{3Bh} n_{Bh} \quad (1.18)$$

where the symbols are defined similarly as in formula (1.06) and (1.12).

Railroad Crossing Costs:

The formula for total cost of the railroad crossing sample survey is

$$C_R = L_R N_R + C_{1R} \sqrt{A_s} \sqrt{n_R - n'_R} + \sum_h^L C_{2Rh} n_{Rh} + \sum_h^L C_{3Rh} n_{Rh} \quad (1.19)$$

All symbols are defined similarly as in formulas (1.08) and (1.12).

Total Survey Costs:

Assuming that $C_{1H} = C_{1B} = C_{1R}$, the total cost formula is

$$\begin{aligned} C_T = & L_H N_H + C_{1H} \sqrt{A_s} \sqrt{n_H} + \sum_h^L C_{2Hh} n_{Hh} \\ & + \sum_h^L C_{3Hh} n_{Hh} + L_B N_B + C_{1H} \sqrt{A_s} \sqrt{n_B - n'_B} \\ & + \sum_h^L C_{2Bh} n_{Bh} + \sum_h^L C_{3Bh} n_{Bh} + L_R N_R \\ & + C_{1H} \sqrt{A_s} \sqrt{n_R - n'_R} + \sum_h^L C_{2Rh} n_{Rh} \\ & + \sum_h^L C_{3Rh} n_{Rh} \quad (1.20) \end{aligned}$$

Optimum and Proportional Stratified Sampling. The general formula (1.12) can be used for optimum and proportional stratified random sampling by altering the unit cost of data analysis. The unit costs of listing, travel, and data collection will not vary with the particular type of stratified random sampling being used. However, the unit cost of data analysis for optimum sampling will be higher than for proportional sampling because the estimated value of the strata variance must be known before sample sizes in the various stratum can be chosen. Furthermore, proportional sampling requires only a knowledge of the total number of sampling units in the strata in order to estimate sample sizes.

Composite Stratified Random Sampling. The general cost formula for the composite population for stratified random sampling is:

$$C_T = L_c N_H + C_{1c} \sqrt{A_s} \sqrt{n_c} + \sum_{h=1}^L C_{2ch} n_{ch} + \sum_{h=1}^L C_{3ch} n_{ch} \quad (1.21)$$

where C_{2ch} , is the composite unit cost of data collection, C_{3ch} is the composite unit cost of data analysis, and n_{ch} is the composite sample size in the h th stratum. The unit costs of listing, data collection and data analysis will be greater for the composite sample than the unit costs for

these operations in the separate highway population. The unit cost of travel, however, for the composite population will not differ from the unit cost of travel in the separate highway populations. Data analysis unit cost will also be higher for optimum sampling than for proportional sampling. All other unit costs will be the same for optimum and proportional sampling.

Simple Cluster Sampling

The general cost function for simple cluster sampling is

$$C_T = L\bar{M}n + C_p \sqrt{A_s} \sqrt{n} + C_2 \bar{M}n + C_3 \bar{M}n \quad (1.22)$$

where C_p is the unit cost of travel between units, n is the number of sampled units, and $\bar{M}$ is the average number of elements in each unit. All other symbols have the same meaning as previously defined.

When the highways, bridges and railroad crossings are treated as separate populations, the cost functions are as follows:

Highway Survey Costs:

$$C_H = L_H \bar{M}_H n_H + C_{pH} \sqrt{A_s} \sqrt{n_H} + C_{2H} \bar{M}_H n_H + C_{3H} \bar{M}_H n_H \quad (1.23)$$

Assuming that bridges and railroad crossings located in the sampled counties required for the highway population are randomly "forced" into the sample, the cost functions for bridges and railroad crossings are as follows:

Bridge Survey Costs:

$$C_B = L_B \bar{M}_B n_B + C_{pB} \sqrt{A_s} \sqrt{n_B - n'_B} + C_{2B} \bar{M}_B n_B + C_{3B} \bar{M}_B n_B \quad (1.24)$$

where $n'_B = n_{II}$.

Railroad Crossing Survey Costs:

$$C_R = L_R \bar{M}_R n_R + C_{pR} \sqrt{A_s} \sqrt{n_R - n'_R} + C_{2R} \bar{M}_R n_R + C_{3R} \bar{M}_R n_R \quad (1.25)$$

where $n'_R = n_{II}$.

Total Survey Costs:

$$C_T = C_{II} + C_B + C_R.$$

Assuming that $C_{pH} = C_{pB} = C_{pR}$, the formula is

$$\begin{aligned} C_T = & L_{II} \bar{M}_{II} n_{II} + C_{pII} \sqrt{A_s} \sqrt{n_{II}} + C_{2II} \bar{M}_{II} n_{II} + C_{3II} \bar{M}_{II} n_{II} \\ & + L_B \bar{M}_B n_B + C_{pH} \sqrt{A_s} \sqrt{n_B - n_{II}} + C_{2B} \bar{M}_B n_B \\ & + C_{3B} \bar{M}_B n_B + L_R \bar{M}_R n_R + C_{pH} \sqrt{A_s} \sqrt{n_R - n'_H} \\ & + C_{2R} \bar{M}_R n_R + C_{3R} \bar{M}_R n_R. \end{aligned} \quad (1.26)$$

The cost function for the composite population is

$$C_T = L_c \bar{M}_{II} n_c + C_{pc} \sqrt{A_s} \sqrt{n_c} + C_{2c} \bar{M}_{II} n_c + C_{3c} \bar{M}_{II} n_c \quad (1.27)$$

where the total number of elements in the population, M_{II} , is equal to the number of highway sections.

Stratified Cluster Sampling

General Cost Formula. A general cost function can be developed for optimum sample size and stratum sample size for a fixed variance using a specified cost function if the stratum unit costs, sizes, and variances are known.

The general cost formula is

$$C_T = L \bar{M} n + C_p \sqrt{A_s} \sqrt{n} + \sum_h^L C_{2h} \bar{M}_h n_h + \sum_h^L C_3 \bar{M}_h n_h, \quad (1.28)$$

and the variance for the estimate of the total is given by equation (B.42). Using the Lagrange method, optimum n_h which will minimize total cost for a fixed degree of precision can be obtained. The function is

$$F = L \bar{M} n + C_p \sqrt{A_s} \sqrt{n} + \sum_h^L C_{2h} \bar{M}_h n_h + \sum_h^L C_{3h} \bar{M}_h n_h + \left\{ \lambda \sum_h^L N_h^2 \left(\frac{N_h - n_h}{N_h} \right) \frac{S_{hT}^2}{n_h} - v(\hat{Y}) \right\}.$$

Differentiating the function with respect to n_h , setting the resulting expression equal to zero, and solving for n_h the following expression is obtained:

$$n_h = \frac{\sqrt{\lambda} N_h S_{hT}}{\sqrt{C_{2h} \bar{M}_h + C_{3h} \bar{M}_h}}$$

$$n = \sum_h^L n_h = \lambda \sum_h^L \frac{N_h S_{hT}}{\sqrt{C_{2h} \bar{M}_h + C_{3h} \bar{M}_h}}$$

$$\frac{n_h}{n} = \frac{\frac{N_h S_{hT}}{\sqrt{C_{2h} \bar{M}_h + C_{3h} \bar{M}_h}}}{\sum_h^L \frac{N_h S_{hT}}{\sqrt{C_{2h} \bar{M}_h + C_{3h} \bar{M}_h}}} \quad (1.29)$$

Substituting equation (1.29) in the general equation for sample size (B.47) by noting that $n_h/n = w_h$, the equation for sample size for the estimate of the total is found to be

$$n = \frac{\sum_h^L N_h S_{hT} \sqrt{C_{2h} \bar{M}_h + C_{3h} \bar{M}_h} \sum_h^L \frac{N_h S_{hT}}{\sqrt{C_{2h} \bar{M}_h + C_{3h} \bar{M}_h}}}{V(\hat{Y}) + \sum_h^L \frac{N_h S_{hT}^2}{N_h}} \quad (1.30)$$

Some conclusions which can be made from formulas (1.29) and (1.30) for the h th stratum are as follows:

- (a) The larger the number of elements, the greater is n_h .
- (b) The greater the variability, the larger is n_h .
- (c) The greater the unit data collection cost, the smaller is n_h .
- (d) The greater the unit data analysis cost, the smaller is n_h .
- (e) The greater the sum of the unit data collection cost and data analysis cost, the smaller is n_h .

If the unit costs are the same in all strata, formula (1.30) will reduce to (B.48), the expression used for optimum stratified cluster sampling ignoring the cost function.

If the unit costs for data collection and analysis are precisely known, these equations can be used to compute an explicit value for n . However, these equations should, in most cases, be used as a general guide in the selection of n_h and n because the stratum unit costs usually are not known. For highway needs studies it is reasonable to assume that the unit costs for all strata are equal. Formula (1.26) then reduces to the following expression

$$C_T = L \bar{M} n + C_p \sqrt{A_s} \sqrt{n} + C_2 \bar{M} n + C_3 \bar{M} n$$

which is the general cost formula used for simple cluster sampling.

Highways, Bridges, and Railroad Crossings Treated as Separate Populations. The cost functions for these components of a highway system treated as separate populations are as follows:

(a) Highway Survey Costs:

$$C_H = L_H \bar{M}_H n_H + C_{pH} \sqrt{A_s} \sqrt{n_H} + \sum_h^L C_{2Hh} \bar{M}_{Hh} n_{Hh} + \sum_h^L C_{3Hh} \bar{M}_{Hh} n_{Hh} \quad (1.31)$$

(b) Bridge Survey Costs:

$$C_B = L_B \bar{M}_B n_B + C_{pB} \sqrt{A_s} \sqrt{n_B - n'_B} + \sum_h^L C_{2Bh} \bar{M}_{Bh} n_{Bh} + \sum_h^L C_{3Bh} \bar{M}_{Bh} n_{Bh} \quad (1.32)$$

(c) Railroad Survey Costs:

$$C_R = L_R \bar{M}_R n_R + C_{pR} \sqrt{A_s} \sqrt{n_R - n'_R} + \sum_h^L C_{2Rh} \bar{M}_{Rh} n_{Rh} + \sum_h^L C_{3Rh} \bar{M}_{Rh} n_{Rh} \quad (1.33)$$

The total cost for the entire survey expressed in terms of the previous formulas when $C_{pH} = C_{pR}$ is

$$\begin{aligned}
C_T = & L_H \bar{M}_{II} n_H + C_{pH} \sqrt{A_s} \sqrt{n_H} + \sum_h^L C_{2Hh} \bar{M}_{II} n_{Hh} \\
& + \sum_h^L C_{3Hh} \bar{M}_{II} n_{Hh} + L_B \bar{M}_B n_B \\
& + C_{pB} \sqrt{A_s} \sqrt{n_B} + \sum_h^L C_{2Bh} \bar{M}_B n_{Bh} \\
& + \sum_h^L C_{3Bh} \bar{M}_B n_{Bh} + L_R \bar{M}_R n_R \\
& + C_{pR} \sqrt{A_s} \sqrt{n_R} + \sum_h^L C_{2Rh} \bar{M}_R n_{Rh} \\
& + \sum_h^L C_{3Rh} \bar{M}_R n_{Rh} . \tag{1.34}
\end{aligned}$$

Composite Population. The cost function for the composite population is

$$\begin{aligned}
C_T = & L_c \bar{M}_{II} n_c + C_{pc} \sqrt{A_s} \sqrt{n_c} + \sum_h^L C_{2ch} \bar{M}_{IIh} n_{ch} \\
& + \sum_h^L C_{3ch} \bar{M}_{IIh} n_{ch} . \tag{1.35}
\end{aligned}$$

Optimum and Proportional Sampling. Optimum and proportional sampling were investigated for total estimated cost. Two methods of proportional sampling were studied. Sampling

units in the first method were chosen proportional to the number of units in each stratum. In the second method, units were chosen proportional to the number of elements in the highway population in each stratum.

All unit costs were assumed the same for all types of stratified cluster sampling methods except the unit cost of listing and data analysis. Optimum sampling requires the largest unit cost for data analysis because more computations and preliminary work are necessary before a sample is drawn and the stratum sample sizes are estimated. Unit cost of listing for optimum and proportional sampling when $n_h \propto N_h$ were the same. However, the unit cost of listing for proportional sampling when $n_h \propto M_{1h}$ requires a knowledge of the number of highway sections in the population.

CHAPTER II

ANALYSIS OF DATA

General Description of Data

Because complete highway needs information was available in Michigan and Minnesota for the rural and urban county primary road systems, data from these two states were used as a basis for statistical analysis. Each state had obtained the total cost of the construction needs and other pertinent information based on a 20-year improvement program. All data had been placed on I.D.M. punch cards and thus could be readily used for analysis in business machines and electronic digital computers after slight revision to suit the requirements of this project.

The Michigan data were collected in 1955 for a state-wide highway needs study made on all road systems. The Minnesota data were collected in 1956 for a system of roads classified as the County-State Aid System under the requirements of a new state law (40) which specified the allocation of receipts from the Highway User Tax Distribution Fund on the basis on relative need. This system of highways is comparable to the primary county road system in Michigan and shall be called the primary county road system in all further

discussions. Figures 2 and 3 show the forms used by the field survey crews for the collection of inventory data and needs evaluation in Michigan for highways, bridges, and railroad crossings located on this system. Figures 4 and 5 are data collection and evaluation forms used in Minnesota.* In both states, data were collected and evaluated by the various county highway engineers and reviewed by officials of the state highway departments.

Roads classified in the primary systems in the various counties in Michigan and Minnesota were subdivided and identified in homogeneous sections. These sections varied in length from one-half to approximately 15 miles with the average length being approximately 3 miles. Generally, each section had similar physical characteristics throughout its length such as pavement width, grade, alignment, and age; uniform traffic volume; and uniform roadside development. Bridges and railroad crossings contained in each road section were also located so that they could be recorded and identified on the inventory forms.

Figure 6 indicates the rural primary road systems in Missaukee County, Michigan, with appropriate identification for the highway sections, bridges, and railroad crossings. Figure 7 indicates the rural primary road system in Nobles County, Minnesota, with control section identification.

* For data collection and evaluation procedures see references (11) and (14).

WORK SHEET FOR DETERMINING COUNTY PRIMARY ROAD NEEDS *

1955
MICHIGAN LEGISLATIVE HIGHWAY STUDY COMMITTEE
AUTOMOTIVE SAFETY FOUNDATION, CONSULTANTS

FORM ASF - 61

CARD CONTROL

1	2

IDENTIFICATION			CODE BLOCK <small>DO NOT WRITE IN THIS SPACE</small>	
1. COUNTY _____	2. LENGTH _____ MI <small>(NEAREST ONE HUNDREDTH)</small>	3. MAP INDEX NO _____	REF NO	
4. LOCATION: RURAL ☐ INC. ☐ <small>DO NOT COMBINE RURAL AND INCORPORATED SECTIONS</small>			1	
5. TERMINI _____			2	
6. NO ROAD NOW EXISTS ☐	7. NEEDED FOR KNOWN NEW DEVELOPMENTS ☐			3
8. NOW CLASSIFIED ON LOCAL ROAD SYSTEM ☐	9. INCORPORATED PLACE _____			4-8
				5
CLASSIFICATION				
10. SPECIAL CHARACTERISTICS <small>(CHECK IF ANY)</small>	11. STUDY SYSTEM <small>(CHECK ONE)</small>	12. FEDERAL SYSTEM <small>(CHECK ONE)</small>		10
RECREATIONAL ACCESS ☐	ROAD SHOULD BE ON:	FA PRIMARY ☐		11
ARTERIAL STREET <small>(URBAN AREA)</small> ☐	PRIMARY SYSTEM ☐	FA SECONDARY ☐		12
OTHER <small>(SPECIFY)</small> _____ ☐	LOCAL SYSTEM ☐	FA URBAN ☐		13-14
		NON FEDERAL ☐		15
ROAD DATA				
13. SURFACE TYPE _____	14. GRADE WIDTH _____ FEET			16
14. SURFACE COND. GOOD ☐ FAIR ☐ POOR ☐	15. ALIGNMENT SAFE SPEED _____ M.P.H.			17
15. SURFACE WIDTH _____ FEET	16. GRADIENTS GOOD ☐ FAIR ☐ POOR ☐			18
16. YEAR BUILT <small>(BIT SURF TREAT OR HIGHER)</small> _____	17. SOIL CONDITION GOOD ☐ FAIR ☐ POOR ☐			19
17. EST. REMAINING SURFACE LIFE _____ YRS <small>(BIT SURF TREAT OR HIGHER)</small>	18. NUMBER OF BRIDGES _____			20
19. NUMBER OF R.R. GRADE CROSSINGS _____				21
TRAFFIC DATA				
20. 1954 A.D.T. _____	21. AVERAGE ANNUAL TRUCK TRAFFIC (PERCENT)			22
22. 1954 AVERAGE SUMMER TRAFFIC _____	HIGH ☐ OVER 25% NORMAL ☐ 20-25% LOW ☐ UNDER 25%			23
CHARACTER OF DEFICIENCIES				
24. HORIZONTAL OR VERTICAL ALIGNMENT	25. CAPACITY	26. BASE OR SURFACE CONDITION		27
27. SURFACE WIDTH	28. GRADE WIDTH	29. OTHER <small>(SPECIFY)</small> _____		28
30. TIME OF IMPROVEMENT	31. DEGREE OF ADEQUACY		29	
32. TIME OF IMPROVEMENT	33. DEGREE OF ADEQUACY		30	
33. TIME OF IMPROVEMENT	34. DEGREE OF ADEQUACY		31	
34. TIME OF IMPROVEMENT	35. DEGREE OF ADEQUACY		32	
35. TIME OF IMPROVEMENT	36. DEGREE OF ADEQUACY		33	
PROPOSED IMPROVEMENTS				
36. TYPE OF WORK _____	37. MILES _____	38. DESIGN DATA		34-38
38. RESURFACING AND/OR WIDENING _____	39. SURFACE TYPE _____	40. SURFACE WIDTH _____ FT		39
39. BASE AND SURFACE <small>(PRESENT LINE AND GRADE)</small> _____	41. NO OF LANES _____	42. ACCESS CONTROL YES _____ NO _____		40
40. RECONSTRUCTION <small>(MINOR LINE AND GRADE CHANGES)</small> _____	43. 1975 A.D.T. _____	44. 1975 A.D.T. _____		41
41. NEW CONSTRUCTION <small>(RELOCATION)</small> _____	45. TOTAL LENGTH _____		42	
42. EXPRESSWAY _____	46. TOTAL LENGTH _____		43	
COST ESTIMATE				
43. RIGHT OF WAY	44. CONTROL OF ACCESS	45. GRADING AND DRAINAGE		44
45. BASE AND SURFACE	46. TOTAL	47. TOTAL		45
REMARKS				
			46	
			47	
			48	
			49	
			50	
			51	
			52	
			53	
			54	
			55	
			56	
			57	
			58	

PREPARED BY _____ REVIEWED BY _____ COOED BY _____

* SEE REFERENCE 14 FOR ADDITIONAL INFORMATION

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WORK SHEET FOR DETERMINING COUNTY PRIMARY STRUCTURE OR RAILROAD PROTECTION NEEDS 1955

MICHIGAN LEGISLATIVE HIGHWAY STUDY COMMITTEE
AUTOMOTIVE SAFETY FOUNDATION, CONSULTANTS

CARD CONTROL

1	2
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IDENTIFICATION 1. COUNTY _____ 2. BRIDGE NO. _____ 3. MAP INDEX NO. _____ 4. R.R. CROSSING NO. _____ 5. RURAL ☐ INCORPORATED AREA ☐ 6. LOCATION _____ 7. NO STRUCTURE EXISTS AT PRESENT ☐ 8. NOW CLASSIFIED AS LOCAL ROAD STRUCTURE ☐ 9. NEEDED FOR KNOWN NEW DEVELOPMENT ☐ 10. INCORPORATED PLACE _____ (NAME)		CODE BLOCK DO NOT WRITE IN THIS SPACE <table border="1" style="width: 100%; height: 100px;"> <tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>16</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>3-7-8</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>10</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>11</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>12</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>13</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>22</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>23</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>24</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>25-26</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>27-28</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>29-30</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>31</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>32</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>33-34</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>37-40</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>41-44</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>45-47</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>48</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>49</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>50</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>51</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>52</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>53</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>54</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>55-58</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>59</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>60-61</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>62</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>63-65</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>66-68</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>69-72</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>73-76</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>77-80</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> </table>		1										16										3-7-8										10										11										12										13										22										23										24										25-26										27-28										29-30										31										32										33-34										37-40										41-44										45-47										48										49										50										51										52										53										54										55-58										59										60-61										62										63-65										66-68										69-72										73-76										77-80									
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CLASSIFICATION 11. SPECIAL CHARACTERISTICS (CHECK ONE OR MORE) RECREATIONAL ACCESS ☐ ARTERIAL STREET (URBAN) ☐ OTHER (SPECIFY) _____ 12. STUDY SYSTEM (CHECK ONE) ROAD SHOULD BE ON: PRIMARY SYSTEM ☐ LOCAL SYSTEM ☐ 13. FEDERAL SYSTEM (CHECK ONE) F.A. PRIMARY ☐ F.A. SECONDARY ☐ F.A. URBAN ☐ NON-FEDERAL ☐		14. TYPE OF SERVICE STREAM CROSSING ☐ HIGHWAY CROSSING ☐ R.R. UNDER HIGHWAY ☐ R.R. OVER HIGHWAY ☐ 15. TYPE OF STRUCTURE TIMBER ☐ CONCRETE SLAB ☐ CONCRETE T BEAM ☐ STEEL BEAM ☐ STEEL GIRDER ☐ STEEL TRUSS ☐ OTHER ☐ 16. LENGTH _____ FT 17. ROADWAY WIDTH _____ FT 18. NO. SPANS _____ CLEAR SPAN LENGTH _____ FT 19. YEAR BUILT _____ 20. VERT. CLEARANCE _____ FT 21. SAFE LOADING _____ 22. 1954 A.D.T. _____ 23. 1954 SUMMER TR _____																																																																																																																																																																																																																																																																																																																																																															
EXISTING CONDITIONS 24. NO TRAINS PER DAY _____ 25. NO. TRACKS _____ RAILROAD CROSSINGS ONLY 26. TYPE OF PROTECTION SIGNS ONLY ☐ SIGNALS ONLY ☐ SIGNALS & GATES ☐		CHARACTER OF DEFICIENCIES 27. R.R. CROSSING PROTECTION 28. TRAFFIC CAPACITY 29. STRUCTURAL 30. MINIMUM GEOMETRICS (CLEAR WIDTH & VERTICAL CLEARANCE) 31. OTHER (SPECIFY) _____ 32. TIME OF IMPROVEMENT 0-5 YEARS ☐ 5-10 YEARS ☐ 10-15 YEARS ☐ 15-20 YEARS ☐ OVER 20 YRS ☐																																																																																																																																																																																																																																																																																																																																																															
PROPOSED IMPROVEMENT 33. TYPE OF SERVICE STREAM CROSSING ☐ HIGHWAY SEPARATION ☐ R.R. UNDER HIGHWAY ☐ R.R. OVER HIGHWAY ☐ 34. TYPE OF WORK REFLOORING ☐ REBUILD OR RECONDITION ☐ REPLACE SAME LOCATION ☐ REPLACE NEW LOCATION ☐ NEW SEPARATION ☐ RAILROAD CROSSINGS ONLY 40. SIGNALS ONLY ☐ 41. SIGNALS & GATES ☐		STRUCTURES ONLY DESIGN DATA 35. TYPE (SPECIFY) _____ 36. LENGTH _____ FT 37. ROADWAY WIDTH _____ FT 38. DESIGN LOADING _____ 39. 1975 A.D.T. _____ 40. SIGNALS ONLY ☐ 41. SIGNALS & GATES ☐																																																																																																																																																																																																																																																																																																																																																															
COST ESTIMATE 42. RIGHT OF WAY \$ _____ 43. APPROACHES \$ _____ 44. STRUCTURE OR SIGNAL \$ _____ 45. TOTAL \$ _____ REMARKS _____ _____ _____		42. RIGHT OF WAY \$ _____ 43. APPROACHES \$ _____ 44. STRUCTURE OR SIGNAL \$ _____ 45. TOTAL \$ _____ REMARKS _____ _____ _____																																																																																																																																																																																																																																																																																																																																																															

PREPARED BY _____ REVIEWED BY _____ CODED BY _____

* SEE REFERENCE 14 FOR ADDITIONAL INFORMATION

FIGURE 4

MINNESOTA COUNTY STATE-AID NEEDS *
 DATA SHEET FOR COUNTY AND CITY NEEDS
 BASIC DATA FOR FUND DISTRIBUTION
 ROAD DATA

Sheet Number _____

IDENTIFICATION			Item No	For M. H. D. use only	Column No	
1. County _____	2. Control Section _____	3. Segment _____	1		1-2	
4. Termini _____			2-3			3-8
5. Incorporate Name _____	6. Length of Segment _____		5			9-10
7. Fed. Aid Sec. ☐ (1)	Fed. Aid Urban ☐ (2)	Non Fed. Aid ☐ (3)	6			11-13
8. System Designation:			7-8		14-15	
County State-aid ☐ (1) Municipal State-aid ☐ (2) Combination ☐ (3)						
ROAD DATA: EXISTING						
9. Existing Surface Type _____	10. Surface Width _____	11. Road Width _____	9-11		16-20	
12. Year of Latest Grading _____	13. Year of Latest Surface _____		12-13		21-24	
14. Number of Lanes _____	15. Divided ☐ (1) Not Divided ☐ (2)		14-15		25-26	
16. 1955 Traffic V.P.D. _____	17. Expansion Factor to 1975 Traffic V.P.D. _____		16		27-31	
18. Adequate for Present Traffic ☐ (1) Deficient for Present Traffic ☐ (2)			17		32-34	
			18		35-40	
ROAD DATA: PROPOSED						
19. Priority Number _____					41-49	
20. Proposed Surface Type _____			19		50-51	
21. Surface Width _____			20-22		52-56	
22. Roadway Width _____			23-24		57-58	
23. Terrain: Flat ☐ (1) Rolling ☐ (2) Mountainous ☐ (3)			25-26		59-60	
24. Design Load: Under 5 Ton ☐ (1) 5 Ton ☐ (5) 7 Ton ☐ (7) 9 Ton ☐ (9)			Type Proj.		61-62	
25. No. of Lanes _____			26. Divided ☐ (1) Not Divided ☐ (2)			
RANGE OF COST OF IMPROVEMENT						
27. Grading			Low (1)	Normal (2)	High (3)	
1. Complete Grading ☐			☐	☐	☐	
2. Reshape or Widen. % of grading cost _____ ☐			☐	☐	☐	
28. Base						
1. Complete Base Type _____ ☐			☐	☐	☐	
2. Base Strengthening % of base cost _____ ☐			☐	☐	☐	
29. Surface						
1. Initial Surface Type _____ ☐			☐	☐	☐	
2. Additional Mat Type _____ ☐			☐	☐	☐	
30. Right of Way			Est. Cost	\$		
31. Adjustment of Utilities			\$			
32. Traffic Signals			\$			
33. Street Lighting			\$			
34. Miscellaneous Const. (Includes curb & gutter, storm sewer, sidewalks, etc.)			\$			

County Engineer _____ Date _____

City Engineer _____ Date _____

* SEE REFERENCE 11 FOR ADDITIONAL INFORMATION

FIGURE 5

MINNESOTA COUNTY STATE-AID NEEDS*
 DATA SHEET FOR COUNTY AND CITY NEEDS
 BASIC DATA FOR FUND DISTRIBUTION
 BRIDGE AND RAILROAD CROSSING

FORM 3803

Bridge Sheet No. _____

IDENTIFICATION:			Item No.	For M. H. D. use only Column No.
1. County _____	2. Control Section _____	3. Segment _____		
4. Incorporate Name _____			1	1-2
5. Name of Stream, Road, or Railroad _____			2-3	3-8
6. Fed. Aid Sec. ☐ (1) Federal Aid Urban ☐ (2) Non Fed. Aid ☐ (3)			4	9-13
7. System Designation: County State-aid ☐ (1) Municipal State-aid ☐ (2) Combination ☐ (3)			6-7	14-15
EXISTING CONDITIONS: Structures Only				
8. Type of Service			8-9	16-18
9. Type of Structure			10	19-20
10. Roadway Width _____			11	21-22
11. Year Built _____			12	23-24
12. No. of Spans _____			13-14	25-26
13. No. of Lanes _____			15	27-31
14. Divided ☐ (1)			16	32-34
15. 1955 Traffic V.P.D. _____			17	35-40
16. Expansion Factor			18	41-42
17. Adequate ☐ (1)			19	43-45
Not Adequate ☐ (2)			20	46-49
18. Safe Loading _____				
19. Vertical Clearance _____				
20. Length in feet _____				
PROPOSED IMPROVEMENTS: Structure Only				
21. Priority Number _____			21	50-51
22. Type of Service			22-23	52-53
23. Type of Work			24	54
24. Type of Structure _____			25	55-56
25. Roadway Width _____			26	57-58
26. Design Loading _____			27-28	59-60
27. No. of Lanes _____			29	61-64
28. Divided ☐ (1)				
Not Divided ☐ (2)				
29. Length in feet _____				
EXISTING CONDITIONS: R. R. Grade Crossing Only				
30. No. Trains per day _____				
31. No. of Tracks (Main) _____				
32. No. of Tracks (Siding) _____				
33. Type of Protection				
Signs Only ☐ (1)				
Signals ☐ (2)				
Signals and Gates ☐ (3)				
PROPOSED IMPROVEMENT: R. R. Grade Crossing Only				
34. Signs Only ☐ (1) Signals ☐ (2) Signals and Gates ☐ (3)				
COST ESTIMATE:				
35. Structures \$ _____			35-36	
36. R. R. Protection \$ _____				

County Engineer _____ Date _____

City Engineer _____ Date _____

* SEE REFERENCE II FOR ADDITIONAL INFORMATION

FIGURE 6

KEY TO COUNTIES

SCALE OF STATUTE MILES
0 1 2 3 4

LEGEND

- FEDERAL OR STATE HIGHWAY
- COUNTY STATE-AID ROAD WITH ROAD IDENTIFICATION
- COUNTY OR TOWNSHIP ROAD (LOCAL SERVICE)

COUNTY STATE-AID ROADS
NOBLES COUNTY, MINNESOTA (34)

FIGURE 7

Each of these control sections were subdivided into road segments, and these segments are comparable to the road sections shown for the Michigan data. Highway segments, bridges, and railroad crossings are not shown in Figure 7 but must be identified from other maps.

Traffic volume information is essential to the evaluation of the cost of improvement of the highway system and also necessary if stratified random sampling is to be used. Figure 8 is a portion of a rural traffic flow map of Nobles County, Minnesota, and shows the 1955 traffic volume in vehicles per day (V.P.D.) for various road systems. Similar traffic data were used for Michigan.

Comparable information was required for the urban portions of the county primary system. City maps were used to locate the highway sections, bridges, and railroad crossings and identification numbers were used to identify their location.

Information was also required concerning the topography or the terrain in which the highway sections were located to provide information for stratification, if this sampling method was to be used, and to evaluate the road needs. Because Michigan has comparatively uniform terrain over large area, topography was classified on a county basis. Figure 9 shows the county topography classification that was used. No mountainous areas are located in this state.

COUNTY TRAFFIC FLOW MAP
PORTION OF
NOBLES COUNTY, MINNESOTA (35)

FIGURE 8

FIGURE 9

Minnesota classified the topography of each highway segment individually from field observation. Topography classification of each road segment was preferred over classification by county because local and substantial variations in a county could result in a substantial increase or decrease in road construction costs which could not be evaluated if a general topography classification were used.

The general topography, climate, and soils of Minnesota are quite similar to Michigan. Mountainous areas, however, are found in some isolated locations in the state. A general map of Minnesota is shown in Figure 10 which gives the name and location of its counties.

Sampling Methods

Basic Data Needed for Various Sampling Methods

The types of sampling requiring the least amount of basic data are simple cluster and stratified cluster sampling. Information required to draw samples for these methods can be easily obtained from available highway transportation maps and mileage records. Furthermore, listing of the elements is required only in those counties which are included in the sample.

A large quantity of information is not required for simple random sampling although prior knowledge of all highway sections, bridges, and railroad crossings is necessary. The location of these units also must be recorded so that

COUNTIES OF MINNESOTA (34)

FIGURE 10

a random sample from each population (if one desires to use separate populations) can be drawn. Drawing a composite sample is less difficult but requires substantially the same amount of data.

Stratified random sampling requires the greatest amount of prior information about the population. Not only the individual highway sections, bridges and railroad crossings must be located and recorded, but also additional information must be added to this identification data to permit stratification. If a highway agency has recent traffic data and reliable topographic information, stratification is not difficult.

Methods Used

Four Methods. Four methods of sampling were investigated and the required sample size determined for five combinations of margin of error and a risk for each population using the Michigan and Minnesota data. Because sample survey methods had not been used extensively for the estimation of highway needs, a thorough analysis of the populations for each state was made to develop methodology and techniques for several types of sample surveys. The sample sizes required for the different sampling methods were determined for possible use in future surveys.

In most highway needs studies population variances are not known, but must be estimated from the sample. This

situation must be realized when the data in this report with known population variances is studied. These data, however, give some idea of the general magnitude of variances for highway needs populations for most states in the Midwestern area that have a well-developed county and township road system. Usually this type of road system is the result of extensive use of the land for agricultural and recreational purposes. In arid and mountainous states where land is not used for these reasons, well developed road systems of this type are not found.

The sampling methods investigated were:

- (a) Simple Random Sampling
- (b) Optimum and Proportional Stratified Random Sampling
- (c) Simple Cluster Sampling
- (d) Optimum and Proportional Stratified Cluster Sampling

Using the Michigan data, population and strata totals and variances were computed for the separate highway, bridge, and railroad crossing populations. These values for a more limited number of characteristics were computed for the composite population.

Population and strata characteristics for total and variance used in simple and stratified random sampling for the separate and composite population were as follows. Each characteristic is listed in the order of importance for each population.

<u>Type of Population</u>	<u>Characteristics Evaluated</u>
Separate Populations	
(a) Highway Sections	<ol style="list-style-type: none"> 1. Total highway cost 2. Cost occurring at different time periods 3. Cost by type of construction 4. Mileage of type of construction
(b) Bridges	<ol style="list-style-type: none"> 1. Total bridge cost 2. Cost occurring at different time periods 3. Cost by type of construction 4. Cost by type of service 5. Number of inadequate bridges
(c) Railroad Crossings	<ol style="list-style-type: none"> 1. Total railroad crossing cost 2. Cost occurring at different time periods 3. Cost by type of construction 4. Number of inadequate railroad crossings
Composite Population	<ol style="list-style-type: none"> 1. Total cost: (All highway, bridge, and railroad crossing improvements) 2. Cost occurring at different time periods 3. Cost by type of construction 4. Total highway cost* 5. Total bridge cost 6. Total railroad cost

Population and strata characteristics were evaluated only for the rural separate and composite populations for use in simple and stratified cluster sampling. The characteristics are as follows:

*This characteristic was also evaluated in a separate population; its value and variance are equal in both populations.

<u>Type of Population</u>	<u>Characteristics Evaluated</u>
Separate Populations:	
(a) Highways	Total Highway Cost
(b) Bridges	Total Bridge Cost
(c) Railroad Crossings	Total Railroad Crossing Cost
Composite Population:	Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)

The Minnesota data were used to compute population and strata characteristics for totals and variance and sample sizes required for estimating these characteristics. The cost occurring at different time periods was not located in these data. The highway data also did not contain information concerning the general type of construction needed as was found in the Michigan data. Consequently, the information determined for the Minnesota data was more limited. Population and strata characteristics for total and variance of the Minnesota data were computed. The characteristics evaluated that were used in simple and stratified random sampling for the rural and urban systems are as follows:

<u>Type of Population</u>	<u>Characteristics Evaluated</u>
Separate Populations:	
(a) Highways	Total Highway Cost
(b) Bridges	Total Bridge Cost
(c) Railroad Crossings	Total Railroad Crossing Cost

<u>Type of Population</u>	<u>Characteristics Evaluated</u>
Composite Population:	<ol style="list-style-type: none"> 1. Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements) 2. Total Highway Cost* 3. Total Bridge Cost 4. Total Railroad Crossing Cost

Values similar to those obtained for the Michigan data for use in simple and stratified cluster sampling were found for the rural highway system using the Minnesota data. The urban system was not investigated.

When the costs of improvement were estimated for the separate populations on the rural and urban systems, a total of six populations were considered. The three separate populations for each system were not uniquely independent, however, because a portion of the sampled units required for the railroad crossing populations were randomly "forced" into the units required for the highway population. Only two populations were required for the rural and urban systems when the composite populations were used.

Modifications of Data Content. Slight revisions were made in the Michigan and Minnesota data before population values were computed. On the rural system all existing and proposed multilane facilities and the bridges and railroad

*This characteristic was also evaluated in a separate population; its value and variance are the same in both populations.

crossings located in these highway sections were removed from the original data. All existing or proposed facilities classified as expressways including their bridges and railroad crossings were also removed from the urban system. Finally, all existing and proposed railroad grade crossings on either the rural or urban systems which required grade separation structures were removed.

These facilities were removed from the populations for four reasons. The cost of improvement for multilane highways and bridges and for separated railroad crossings is extremely high and detailed, specific knowledge is required for each project. Secondly, these needs are easily identified because they are located on the most heavily traveled highways in the state and are usually near large urban areas. A large increase in the variance also can be expected when these facilities remain in the population because of their unusual characteristics. Finally, several difficulties in sampling would have occurred if these facilities were in the population. Each section of a multilane divided highway was evaluated on two punch cards, one for each section (one for the right-hand traffic lanes and one for the left-hand traffic lanes). This situation would have caused a bias to occur when a random sample was drawn because all other road sections had one punch card per section. Similar difficulties would have occurred with bridges.

The Michigan data contained nearly 750 miles of multi-lane highways and 200 multilane bridges and railroad grade

separations on the rural and urban systems. The Minnesota data contained about 75 miles of multilane highways and fifteen multilane bridges and railroad grade separations. All of the information on these facilities was removed from the original data.

Table 1 is a summary of the total number of sampling units that were present in the various populations for use in simple and stratified random sampling.

For simple and stratified cluster sampling, the county was chosen as the sampling unit. The highway section was chosen as the element for the composite population and the highway section, bridge, and railroad crossing were chosen as the element for the respective separate populations. Table 2 is a summary of the number of units and elements contained in the Michigan and Minnesota data.

These data represent 21,210 miles on the rural and 402 miles on the urban system in Michigan, and in Minnesota 27,000 miles on the rural system, and 1,350 miles on the urban system. For the 20-year program period used in both needs studies nearly every highway section required some type of improvement. The proportion of bridges and railroad crossings, however, which required improvement was considerably less.

Tables D1-D42 in Appendix D give a complete summary of the population and strata totals and variances for the separate and composite populations.

TABLE 1. TOTAL NUMBER OF SAMPLING UNITS USED FOR SIMPLE AND STRATIFIED RANDOM SAMPLING-MICHIGAN AND MINNESOTA DATA

<u>Population</u>	<u>Total Number of Sampling Units, N</u>	
	Michigan	Minnesota**
Rural Separate:		
(a) Highway Sections	6,321	7,905
(b) Bridges	1,985	2,761
(c) Railroad Crossings	521	662
Rural Composite:	6,321	7,905
Urban Separate:		
(a) Highway Sections	276	3,307
(b) Bridges	44	373
(c) Railroad Crossings	6*	467
Urban Composite:	276	3,307

TABLE 2. TOTAL NUMBER OF SAMPLING UNITS AND ELEMENTS USED FOR SIMPLE AND STRATIFIED CLUSTER SAMPLING FOR THE VARIOUS POPULATIONS-MICHIGAN AND MINNESOTA DATA

<u>Population</u>	<u>Michigan</u>		<u>Minnesota**</u>	
	Total Sampling Units, N	Elements (M)	Total Sampling Units, N	Elements (M)
Rural Separate:				
(a) Highways	83	6,321	86	7,905
(b) Bridges	83	1,985	86	2,761
(c) Railroad Crossings	83	521	86	662
Rural Composite:	83	6,321	86	7,905
Urban Separate:				
(a) Highways	83	276	86	3,307
(b) Bridges	83	44	86	373
(c) Railroad Crossings	83	6*	86	467
Urban Composite:	83	276	86	3,307

* Incomplete data

** Data from one county was missing containing approximately 90 road sections. However, the missing data did not seriously influence the results obtained for the various sampling methods studied. The population was assumed to consist of the number of sampling units shown in Table 1 and Table 2.

A comparison of the separate and composite population total costs and variances using Michigan and Minnesota data is shown in Table 3. The Minnesota data is less variable than the Michigan, although the total costs are similar. Michigan is composed of high concentrations of people living in large urban areas whereas Minnesota has a more uniform distribution of people. This difference in the distribution of people and the resulting economic activities probably are the major causes for the differences in variance because those factors have a direct relationship to highway needs.

Population Distribution. Extensive investigation of the separate populations was made to ascertain the distributions of total cost of improvements, costs occurring at different time periods, and other important information. Figures C1-C36 in Appendix C show a series of histograms for various population and strata characteristics using the Michigan and Minnesota data. All histograms show a marked positive skewness. Positive skewness is typical of most economic and census data (9). Although not extensively studied, the composite population would also probably exhibit extensive positive skewness. Figures C29 and C36 show the histograms for the distribution of total cost by counties for the composite populations, and the histograms are also positively skewed.

According to statistical theory, this lack of normality of the population will result in a distribution of sample

TABLE 2. POPULATION COST TOTALS AND VARIANCES FOR SEPARATE AND COMPOSITE POPULATIONS

Population	Michigan		Minnesota	
	Total Cost (\$1000)	S ²	Total Cost (\$1000)	S ²
<u>Rural Highway System:</u>				
Separate Populations				
a. Highways	\$536,722	7,073	\$479,080	3,133
b. Bridges*	63,957	2,634	55,724	1,122
c. Railroad Crossings	2,757	26.03	1,762	34.12
Composite Population (Highways, Bridges, and Railroad Crossings)				
	603,475**	9,316	536,566	4,011
<u>Urban Highway Systems:</u>				
Separate Populations				
a. Highways	90,515	315,991	96,334	2,654
b. Bridges	14,261	328,000	23,307	35,003
c. Railroad Crossings	Incomplete Data		2,283	46.49
Composite Population (Highways, Bridges, and Railroad Crossings)				
	Incomplete Data		121,924	7,584

* Includes approach costs for Michigan data only.

** Slight error in value because of minor coding errors in punch cards.

means or totals approximating the normal distribution if large samples are drawn. Because the cluster samples used in this study are composed of a small number of units, valid results for this type of sample may not be obtainable.

Margin of Error and α Risk. A margin of error, d_T , in the total and a small risk α that the actual ^{error} is larger than d_T should be chosen before a sample size is computed. Stated in terms of a probability formulas, n must be large enough so that (9)

$$\Pr \left\{ |y - Y| \geq d_T \right\} = \alpha \quad (2.00)$$

Alternately the sample size is sometimes specified as large enough to provide a confidence interval of one-half width d_T , with a confidence probability of $(1 - \alpha)$ (9).

The choice of the margin of error and α risk desired for the population characteristic being estimated is primarily a matter of policy which must be decided by the particular agency making and using the results of the sample survey. For this reason, sample sizes for the estimate of various population characteristics and their variances have been computed for five different combinations of margin of error and α risk for each population. These combinations define five different degrees of precision for the estimate of each population characteristic. The margins of error and accompanying α risk that were used are listed below in ascending order of accuracy.

<u>Order of Accuracy</u>	<u>Margin of Error, d_T</u>	<u>Risk, α</u>
1	20 percent of the total being estimated	0.10
2	10 percent of the total being estimated	0.10
3	10 percent of the total being estimated	0.05
4	5 percent of the total being estimated	0.10
5	5 percent of the total being estimated	0.05

It should be carefully noted that for the same order of accuracy, the margin of error, as defined above, will be different for each state unless the total is the same in each state. A comparison of sample size as obtained for one state for an order of accuracy as defined in this report, therefore, cannot be compared with a sample size obtained for another state for the same order of accuracy without evaluating the margin of error in actual dollars.

The variance of the estimate of the total is

$$V(\hat{Y}) \approx \frac{d_T^2}{Z^2(1 - \alpha)} \quad (2.01)^*$$

where $Z_{(1 - \alpha)}$ is the value obtained from the normal distribution. Tables F1-F7 in Appendix F give values of variances obtained for the five combinations of margin of error and a risk for various estimates of population characteristics in Michigan and Minnesota. These values were used to compute sample size.

* See formula (B.51) in Appendix B.

Simple Random Sampling

Example of Computation. Example 1 illustrates the computations required for the determination of sample size for the separate highway population when the specified margin of error and α risk are as follows:

$d_T = 10$ percent of the total highway cost

$\alpha = 0.10$

Sample size was computed by formula (B.13) after computing the value of population variance S^2 , by formula (A.C3) and the variance for the estimate of the population total cost by formula (B.11). The value of the variance for the estimate of the total also could be obtained from tables T1-T7.

Comparison of Sample Sizes. The sample sizes required for the estimate of a total was computed. This was done for various characteristics of the separate and composite populations using five combinations of margin of error and α risk and the values are given in tables E1-E5, E17-E18, E22, and E29 in Appendix E. These tables indicate how sample size varies with the specified margin of error and α risk and with the population characteristic being estimated. The minimum sample size, however, is always obtained for estimating the total cost of improvement.

Table 4 indicates sample sizes required using Michigan and Minnesota data for the rural and urban road systems. These values were computed for the estimate of total cost of

EXAMPLE 1. COMPUTATION OF SAMPLE SIZE-RURAL HIGHWAY POPULATION SIMPLE
RANDOM SAMPLE-MICHIGAN DATA

Sample Size for Estimating Total Cost
Margin of Error and α Risk: $d_T = 10$ Percent of Total Cost; $\alpha = 0.10$

Total Cost (\$1000)	Total Number Sampling Units N	$(\sum_i y_i)^2$	$\sum_i y_i^2$	$S^2 = \frac{N \sum_i y_i^2 - (\sum_i y_i)^2}{N(N-1)}$	Sample Size n
536,722	6,321	288,070,505,284	90,273,656	7,073	265

Computation of Population Variance:

Formula (B.03)

$$S^2 = \frac{\sum_i (y_i - \bar{Y})^2}{N - 1} = \frac{N \sum_i y_i^2 - (\sum_i y_i)^2}{N(N - 1)}$$

$$= \frac{6,321 \times 90,272,656 - 288,070,505,284}{6,321(6,321 - 1)} = 7,073$$

Computation of Sample Size:

$$d_T = 0.10 \times 536,772 = 53,672 \quad Z = 1.6448, \quad Z^2 = 2.7054$$

$$\text{Formula (B.51)} \quad v(\hat{\tau}) = \frac{d_T^2}{Z^2} = \frac{(53672)^2}{2.7054} = 1063 \times 10^3$$

$$\text{Formula (B.13)} \quad n_0 = \frac{N^2 S^2}{v(\hat{\tau})} = \frac{(6321)^2 \times 7073}{106 \times 10^3} = 265^*$$

*Since n_0/n is less than 5 percent, n_0 is acceptable as sample size, i.e., finite population correction is ignored.

highway improvements using the separate populations for two different combinations of margin of error and α risk. If the computed sample size were substituted in formula (3.64) for the variance of the estimate of the total, a slightly different value of $V(\hat{Y})$ would be obtained than is indicated in Table F1 of Appendix F. This difference is caused by rounding of the computed sample size to the nearest unit.

When $d_T = 20$ percent of the total and $\alpha = 0.10$ and when $d_T = 5$ percent of the total and $\alpha = 0.05$, the sample sizes obtained in Table 4 for the estimate of total cost for the rural highway and bridge populations are similar for the two states.

The rural railroad crossings, however, for the Minnesota data required 218 units for $d_T = 20$ percent of the total and $\alpha = 0.10$ while only 56 units were required for the Michigan data.

The costs of structure needs for the Michigan data not only included the cost of bridge improvement or replacement but also the approach cost (road improvement costs) to the bridge. These approach costs were generally low when compared to the cost of the structure and did not substantially effect the sample size and variance. The Minnesota data included only the cost of improvement or replacement of the bridge. Approach costs were included in the road costs. Tables D5-D9 and D16-D19 in Appendix D, Tables E2-E5 and E10

TABLE 4. SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE RURAL AND URBAN HIGHWAYS SYSTEMS-SIMPLE RANDOMING SAMPLING, SEPARATE POPULATIONS

Michigan

Minnesota

Population	Margin of Error and α Risk			Margin of Error and α Risk		
	$d_T = 20$ Percent of $d_T = 5$ Percent of			$d_T = 20$ Percent of $d_T = 5$ Percent of		
	the Total $\alpha = 0.10$ $\alpha = 0.05$			the Total $\alpha = 0.10$ $\alpha = 0.05$		
	Sample Approximate	Sample Approximate	Sample Approximate	Sample Approximate	Sample Approximate	Sample Approximate
	Size	Variance	Size	Size	Variance	Size
Rural Highway System:						
(a) Highways	66	426×10^7	1,212	12.7	$\times 10^7$	59
(b) Bridges*	152	60.5×10^7	1,212	2.67	$\times 10^6$	174
(c) Railroad Crossings	56	112	$\times 10^3$	232	4,950	212
Urban Highway System:						
(a) Highways	116	121	$\times 10^5$	260	5.32×10^5	199
(b) Bridges*	76	30.0×10^5	199	1.32	$\times 10^5$	231
(c) Railroad Crossings	Incomplete Data					

*Plus approaches for Michigan data only.

in Appendix E, and Tables F1-F5 in Appendix F show, respectively, the population totals and variances; sample sizes; and variances of the estimates of the totals.

Table 5 indicates that sample sizes obtained for the estimates of total cost (all highway, bridge, and railroad crossing improvements) for the rural composite populations were slightly larger than those required for estimating total cost for $d_T = 20$ percent of the total and $\alpha = 0.10$ and again for $d_T = 5$ percent of the total and $\alpha = 0.05$ for the separate highway populations. This increase was to be expected because the composite highway sections now contain bridge and railroad costs which has increased the population variance and total cost. Sample sizes required for the estimate of total cost of bridges and railroad crossings are several times larger than those required for the corresponding separate populations. The sample sizes required for the estimates of total highway cost for the Minnesota data are the same as the values obtained for the separate population. Because the increase in highway cost by the addition of the bridge approach cost in the Michigan data was small, sample sizes required for the estimate of highway cost were almost equal to the values obtained for the separate highway population. Sample sizes required for the estimate of mileage of the various types of construction as illustrated in Tables E2 and E13 in Appendix E also are the same as for the separate population.

TABLE 5. SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE RURAL AND URBAN HIGHWAY SYSTEMS-SIMPLE RANDOM SAMPLING, COMPOSITE POPULATION

		<u>Michigan</u>				<u>Minnesota</u>			
		<u>Margin of Error and α Risk</u>		<u>Margin of Error and α Risk</u>		<u>Margin of Error and α Risk</u>		<u>Margin of Error and α Risk</u>	
Desired Estimated Value		$d_T = 20$ Percent of the Total		$d_T = 5$ Percent of the Total		$d_T = 20$ Percent of the Total		$d_T = 5$ Percent of the Total	
		$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$
Sample Approximate Size		Variance	Sample Approximate Size	Variance	Sample Approximate Size	Variance	Sample Approximate Size	Variance	
Sample Approximate Size		Variance	Sample Approximate Size	Variance	Sample Approximate Size	Variance	Sample Approximate Size	Variance	
Rural Highway System:									
(a) Total Cost: (All Highway, Bridge and Railroad Crossing Improve- ments)		69	533×10^7	1,258	23.7×10^7	59	426×10^7	1,144	13.7×10^7
(b) Highway Cost		Same as separate population in Table 4		Same as separate population in Table 4		Same as separate population in Table 4		Same as separate population in Table 4	
(c) Bridge Cost		714	553×10^5	4,698	24.4×10^5	639	459×10^5	5,412	20.2×10^5
(d) Railroad Crossing Cost		1,223	112×10^3	5,341	4,950	3,056	45,000	7,339	2,021

TABLE 5 (Continued). SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE RURAL AND URBAN HIGHWAY SYSTEMS--SIMPLE RANDOM SAMPLING, COMPOSITE POPULATION

Michigan

Minnesota

Desired Estimated Value	<u>Margin of Error and α Risk</u>			<u>Margin of Error and α Risk</u>		
	$d_T = 20$ Percent of the Total	$d_T = 5$ Percent of the Total	$d_T = 20$ Percent of the Total	$d_T = 5$ Percent of the Total	$d_T = 20$ Percent of the Total	$d_T = 5$ Percent of the Total
	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$
	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size
Urban Highway System:						
(a) Total Cost: (All Highway, Bridge and Railroad Crossing Improvements)	Incomplete Data			339	220	$2,595 \times 10^6$
(b) Highway Cost	Same as separate population in Table 4	Same as separate population in Table 4	Same as separate population in Table 4			
(c) Bridge Cost	43	30.0×10^5	44	1.32×10^5	1,202	$3,072 \times 10^5$
(d) Railroad Crossing Cost	Incomplete Data			1,014	77,000	3,010
						3,382

The values shown in Table D24 in Appendix D for costs occurring at different time periods as computed for the rural Michigan data are confounded because highway, bridge, and railroad crossing costs in some highway sections occurred at different time periods. The time period used for the composite population was determined by the time of improvement of the highway section. Costs shown for the various types of road construction are also confounded with bridge and railroad crossing costs.

Tables 4 and 5 also compare sample sizes obtained for the estimate of total cost of urban improvements for the separate and composite populations. Such a large proportion of the units of the separate populations must be drawn for the Michigan data that the entire population should be evaluated for costs. On the other hand, reliable estimates of costs were obtained for the Minnesota data by drawing a much smaller sample from the population. As can be noted from Table 3, the variances of the separate populations for the Minnesota data are much less than those for the Michigan data. The Minnesota data also has many more sampling units than the Michigan information.

Tables E4 and E5 in Appendix E also give sample sizes for the estimate of the total number of inadequate bridges and railroad crossings for the Michigan data. The computation of sample size for these discrete data was similar to the method described in Example 1.

Sampling the Separate Bridge and Railroad Crossing Populations. More bridges and railroad crossings must be selected randomly than those "forced" into the highway sample. The expected number of bridges and railroad crossings which are "forced" into the sampled highway sections is given by formulas (1.07) and (1.09). Using the values for sample sizes computed for the separate populations of the Michigan data and when $d_T = 10$ percent of the total and $\alpha = 0.10$, the expected number of bridges and railroad crossings "forced" into the sample are:

$$n'_B = \frac{265}{6321} \times 1985 = 83$$

$$n'_R = \frac{265}{6321} \times 521 = 22$$

Therefore, the expected number of additional bridges which must be sampled is

$$n_B - n'_B = 510 - 83 = 427 ,$$

and the expected number of additional railroad crossings is

$$n_R - n'_R = 169 - 22 = 147 .$$

Similar values can be obtained for other data by applying the same methods.

Stratified Random Sampling

Choice of Strata

General Discussion. Because total cost is the most important characteristic to be evaluated in any needs study, strata must be chosen so that this value can be estimated effectively. These strata may or may not be the best choice for the estimation of other population values.

Rural and Urban Highway Systems. The most important factors which influence the rural highway costs are the design traffic volume, topography, and length of road section. Figure 11 is a histogram of the length of rural highway sections in Michigan. Lengths of 0 to 5.99 miles and 6.00 to maximum length were studied in addition to topography and traffic as a basis for stratification.

The sample sizes required for such stratification are shown in Table E6 of Appendix E for various combinations of margins of error and α risk. When compared to the sample sizes obtained for stratification based only on topography and traffic indicated in Table E7, some reduction in sample size is noted. However, stratification based on traffic, topography and length was not used further in this study because it required the population to be subdivided into numerous strata and required substantial prior knowledge about road lengths. Other physical characteristics such as soil type, surface and pavement width were not considered

HISTOGRAM REPRESENTING RURAL HIGHWAY SECTION LENGTHS
(MICHIGAN DATA)

FIGURE 11

when strata were defined because their influence on cost of road improvement was considered minor.

The predominant topography of Michigan and Minnesota is flat or rolling. Some mountainous areas are found, however, in isolated areas in Minnesota. The various design traffic volume groups and topographic features determine geometric design standards and some structural design standards for rural highways. Tables 6 and 7 show the design standards used for the rural systems in Michigan and Minnesota and illustrate how these standards are influenced by traffic and topography.

Topography generally does not have any substantial influence on bridge costs. Traffic volume, however, influences design loading and width of the structure. For some highway or railroad grade separations, the traffic volume also influences the choice of span length. Although the Michigan data included the bridge approach costs (highway costs) in the bridge costs, these costs were so minor that they had no influence on the choice of strata. Table E8 of Appendix E gives the sample sizes obtained with topography and traffic stratification. Comparison with Table E9 indicates that the increase in sample size with only traffic stratification is negligible. Therefore, strata for all further study for the rural bridge population were determined by design traffic groups.

TABLE 5. ILLINOIS DESIGN STANDARDS FOR COUNTRY PRIMARY ROADS (1975)

Note: Geometric design features such as gradients, curvature, sight distance, etc., not specifically covered below are to be equal to or above minimum values of AASHTO standards for Federal-Aid secondary roads.

RURAL PRIMARY ROADS

Average Daily Traffic	Surface Width	Grade Width	Design Load	Clear Width	Vertical Clearance
Over 1000	Use Standards for Rural State Trunklines				
100 to 1000	24'-0" 1/2	20'-0" 1/2	Bit. Aggregate 225' / 34' ft. W-10	24'	14'
50 to 100	24'	20'	Bit. Aggregate 170' / 31' ft. W-10	24'	14'
Under 50	24'	20'	Bit. Surface Treatment 170' / 31' ft. W-10	24'	14'
	20'	16'	Bit. Contact Gravel 170' / 31' ft. W-10	24'	14'

STANDARDS

1975

Average Daily Traffic

Surface

Width

Grade Width

Design Load

Clear Width

Vertical Clearance

Over 1000

100 to 1000

50 to 100

Under 50

E

E

D

C

Use Standards for Rural State Trunklines

24'-0" 1/2

24'

24'

20'

20'

20'

20'

Bit. Aggregate 225' / 34' ft. W-10

Bit. Aggregate 170' / 31' ft. W-10

Bit. Surface Treatment 170' / 31' ft. W-10

Bit. Contact Gravel 170' / 31' ft. W-10

Over 1000

100 to 1000

50 to 100

Under 50

E

E

D

C

Use Standards for Rural State Trunklines

24'-0" 1/2

24'

24'

20'

20'

20'

20'

Bit. Aggregate 225' / 34' ft. W-10

Bit. Aggregate 170' / 31' ft. W-10

Bit. Surface Treatment 170' / 31' ft. W-10

Bit. Contact Gravel 170' / 31' ft. W-10

1/ Use the above values for roads with vertical curves or sagging heavy loads. 2/ In business areas curb and gutter section should be used with a minimum pavement width of 16' gravel lane - 16' - callout mark.

Intermittent callout mark for roads with vertical curves or sagging heavy loads. 3/ In business areas curb and gutter section should be used with a minimum pavement width of 16' gravel lane - 16' - callout mark.

TABLE 7. MINNESOTA RURAL STATE-AID CANDIDATES - DESIRABLE VOTINGS (11)

[illegible]

NOTE: CONFIDENTIAL - ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED EXCEPT WHERE SHOWN OTHERWISE.

HISTOGRAM REPRESENTING URBAN HIGHWAY SECTION LENGTHS
(MICHIGAN DATA)

FIGURE 12

Rural railroad crossings also were stratified by traffic volume groups. Most of the railroad crossing improvements were determined by warrants based on the traffic volume multiplied by the number of trains per day using the crossing.

Investigation of various methods of stratification of the urban highway sections was also made. The primary factors considered to define strata were population group, topography, and length of highway section. Figure 12 is a histogram of the lengths of urban highway sections for the Michigan data. Sample sizes for the estimate of total highway cost were computed using population group, topography, and length stratification; population group and topography stratification; and finally population group stratification. Tables E12 and E13 in Appendix E give a comparison of required sample sizes using population group and topography stratification and those required using population group stratification. The difference in sample size was small and the reduction in size did not warrant stratification by topography and population group. Population group stratification was finally chosen for all further study. Urban bridges and railroad crossings were also stratified according to the population group in which they were located. No other method of stratification was considered for these populations.

Stratification of the rural composite population was on the basis of topography and design traffic volume groups similar to the method chosen for the separate rural highway sections. Bridges and railroad crossings were automatically divided into these strata because the sampling units were the composite highway sections. The urban composite population was stratified by population group. Figures 13 and 14 show diagrammatically how the separate and composite populations were stratified.

Computation of Sample Size

Illustrative Example. Example 2 illustrates the computations required for the determination of sample size for the rural highway population for the estimate of total cost. Computations of stratum sample sizes using optimum and proportional sampling are illustrated.

Comparison of Sample Sizes. Similar computations were made for other populations and other combinations of margin of error and α risk for the estimate of the total cost of improvements. Strata totals and variances are shown in Tables D1-D26 and D31-D38 of Appendix D. Sample sizes and variances required for the estimate of various population characteristics are found in Tables E6-E16, E19-E21, E23-E28, E30-E32, and E34-E36 of Appendix E and Tables F1-F7 in Appendix F. Table 8 illustrates sample sizes obtained for the estimate of total cost of improvement for the

TOPOGRAPHY

URBAN HIGHWAY SYSTEM

POPULATION GROUP

POPULATION GROUP

POPULATION GROUP

DIAGRAM OF STRATIFICATION OF SEPARATE POPULATIONS
FOR THE RURAL AND URBAN HIGHWAY SYSTEM

URBAN HIGHWAY SYSTEM

DIAGRAM OF THE STRATIFICATION OF THE COMPOSITE POPULATIONS
FOR THE RURAL AND URBAN HIGHWAY SYSTEMS

FIGURE 14

EXAMPLE 2. COMPUTATION OF SAMPLE SIZE-RURAL HIGHWAY POPULATION-
STRATIFIED RANDOM SAMPLE-MICHIGAN DATA
SAMPLE SIZE FOR THE ESTIMATE OF TOTAL COST

Margin of Error and a Risk
 $d_T = 10$ Percent of Total Cost
 $\alpha = 0.10$

STRATUM

Topo- graphy	1975 Traffic	Total Cost ($\times 1000$) N_h $\sum_{i=1}^{N_h} y_{hi}$	Total No. in Stratum, N_h	$(\sum_{i=1}^{N_h} y_i)^2$	$\sum_{i=1}^{N_h} y_i^2$
Flat	Under 100 V.P.D.	13,672	264	391,306,384	2,121,200
	100-1000 V.P.D.	127,661	1,727	16,251,105,721	15,121,197
	1000-10000 V.P.D.	99,422	1,201	9,884,728,081	15,170,112
	Over 10000 V.P.D.	110,799	51	12,272,176,401	27,022,17
Roll- ing	Under 100 V.P.D.	11,200	100	12,344,000	2,251,711
	100-1000 V.P.D.	71,268	1,003	5,078,127,729	5,110,601
	1000-10000 V.P.D.	42,255	620	1,785,622,025	1,555,205
	Over 10000 V.P.D.	54,195	137	2,937,60,025	21,170,001
Total		526,722	4,221		

Optimum Sampling:

Computation of Total Sample Size:

For $d_T = 10$ Percent of total cost = 52,672; $\alpha = 0.10$

$$k = 1.6448, Z^2 = 2.7051$$

$$\text{Formula (B.51): } V(\hat{Y}) = \frac{d_T^2}{Z^2} = \frac{(52,672)^2}{2.7051} = 1060 \times 10^6$$

$$\text{Sample Size: } n = \frac{(\sum_h N_h S_h)^2}{V(\hat{Y}) + \sum_h N_h S_h^2} = \frac{(130,401)^2}{1060 \times 10^6 + 11,225,297^*} = 217$$

Formula (B.51)

Computation of Stratum Sample Size:

$$\text{Stratum: Under 100 V.P.D. } n_h = \frac{N_h S_h}{\sum_h N_h S_h} = \frac{13,672}{130,401} \times 217 = 23$$

Formula (B.18)

* This term can be ignored because sampling rate is less than 5 percent in all strata i.e., finite population correction for each stratum was ignored.

EXAMPLE 2 (Continued). COMPUTATION OF SAMPLE SIZE-TOTAL POPULATION - STRATIFIED RANDOM SAMPLE - TECHNICAL DATA
SAMPLE SIZE FOR THE ESTIMATE OF TOTAL COST

Margin of Error and a Risk
 $d_T = 10$ Percent of Total Cost
 $\alpha = 0.10$

$$S_h^2 = \frac{N \sum_{i=1}^{N_h} y_i^2 - \left(\sum_{i=1}^{N_h} y_i \right)^2}{N_h(N_h - 1)}$$

	C_h	$N_h S_h$	$N_h^2 S_h^2$	Stratum Sample Size n_h	
				Optimum	Proportional
2,571	59.76	15,777	248,713	7	10
2,607	60.06	107,721	6,249,249	17	98
5,788	76.08	91,772	8,371,268	11	17
17,039	130.7	115,172	15,055,102	52	25
2,652	51.50	2,622	12,776	4	7
2,121	45.89	56,050	2,103,171	25	10
2,660	51.57	11,972	1,649,200	11	21
17,087	130.7	57,125	2,107,012	25	17
Total		180,621	11,226,287	216	110

Proportional Sampling:

Computation of Total Sample Size:

$$\text{Formula (B.22): } n_0 = \frac{n}{V(\hat{Y})} \sum_{h=1}^L N_h S_h^2 = \frac{6321 \times 11,226,287}{1,042,411,652} = 210$$

$$n = \frac{n_0}{1 + \frac{n_0}{N}} = \frac{210}{1 + \frac{210}{6321}} = 210$$

Computation of Stratum Sample Size:

Stratum: Under 100 V.P.D. $n_h = \frac{N_h}{N} n = \frac{261}{6321} \times 210 = 10$

Formula (B.1')

* This term can be ignored because sampling rate is less than 5 percent in all strata i.e., finite population correction is ignored.

TABLE 3. SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENTS FOR THE RURAL HIGHWAY SYSTEMS USING OPTIMUM AND PROPORTIONAL STRATIFIED RANDOM SAMPLING FOR THE SEPARATE POPULATIONS

Michigan

Minnesota

Population	Margin of Error and Risk			Margin of Error and Risk		
	$d_T = 20$ Percent of the Total			$d_T = 20$ Percent of the Total		
	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.01$	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.01$
	Sample Approximate Size	Sample Approximate Variance	Sample Approximate Size	Sample Approximate Variance	Sample Approximate Size	Sample Approximate Variance
<u>Optimum Sampling</u>						
(a) Highways	54	426 x 10 ⁷	1,006	18.7 x 10 ⁷	50	339 x 10 ⁷
(b) Bridges*	140	60.5 x 10 ⁶	1,172	2.67 x 10 ⁶	141	45.9 x 10 ⁶
(c) Railroad Crossings	50	112 x 10 ³	360	4,950	166	45.9 x 10 ³
					545**	2,021
<u>Proportional Sampling</u>						
(a) Highways	63	426 x 10 ⁷	1,155	18.7 x 10 ⁷	53	399 x 10 ⁷
(b) Bridges*	157	60.5 x 10 ⁶	1,316	2.67 x 10 ⁷	173	45.9 x 10 ⁶
(c) Railroad Crossings	52	112 x 10 ³	371	4,950	211	45.9 x 10 ³
					604	2,021

* Includes approach costs for Michigan data only.

** Sample size computed by formula (2.04).

separate populations on the rural systems in Michigan and Minnesota using optimum sampling. Similarity of sample sizes can be noted in this comparison for the estimate of highway and bridge cost. A large difference, however, occurs between the two states for the sample sizes required for the estimate of the total cost of railroad crossing improvements. Table 8 also compares sample sizes required for estimating total costs for the various populations using proportional sampling; only moderate increases in sample size occur when compared to optimum sampling. When sample sizes required for optimum and proportional sampling are compared to those required for simple random sampling, only a moderate decrease is noted when $d_T = 20$ percent of the total and $\alpha = 0.10$. The differences in sample sizes between these sampling methods increase as the order of accuracy increases.

A comparison of sample sizes required for the estimate of total cost using optimum and proportional sampling for the separate urban populations is shown in Table 9. The decrease in optimum sample size was small for each group of data and no decrease occurred for urban railroad crossings for Minnesota data when $d_T = 20$ percent of the total and $\alpha = 0.10$. Tables E12-E14 and E26-E28 in Appendix E give more detailed information concerning sample sizes required of various values for the separate urban populations.

TABLE 9. SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE URBAN HIGHWAY SYSTEMS USING OPTIMUM AND PROPORTIONAL STRATIFIED RANDOM SAMPLING FOR THE SEPARATE POPULATIONS

Michigan

Minnesota

Population	Michigan				Minnesota			
	Margin of Error and		Risk		Margin of Error and		Risk	
	$d_T = 20$	Percent of	$d_T = 5$	Percent of	$d_T = 20$	Percent of	$d_T = 5$	Percent of
	$\alpha = 0.10$	the Total	$\alpha = 0.05$	the Total	$\alpha = 0.10$	the Total	$\alpha = 0.05$	the Total
	Sample Approximate	Sample Approximate	Sample Approximate	Sample Approximate	Sample Approximate	Sample Approximate	Sample Approximate	Sample Approximate
	Size	Variance	Size	Variance	Size	Variance	Size	Variance
Optimum Sampling								
(a) Highways	83	121 x 10 ⁶	209	8.33 x 10 ⁶	170	137 x 10 ⁶	1,751	6.04 x 10 ⁶
(b) Bridges*	20	30.0 x 10 ⁵	27**	1.32 x 10 ⁵	150	80.3 x 10 ⁵	325**	3.54 x 10 ⁵
(c) Railroad Crossings		Inadequate Data			102	77.0 x 10 ³	402	3,392
Proportional Sampling								
(a) Highways	102	121 x 10 ⁶	257	5.33 x 10 ⁶	183	137 x 10 ⁶	1,889	6.04 x 10 ⁶
(b) Bridges*	35	30.0 x 10 ⁵	43	1.32 x 10 ⁵	227	80.3 x 10 ⁵	363	3.54 x 10 ⁵
(c) Railroad Crossings		Inadequate Data			102	77.0 x 10 ³	404	3,392

* Includes approaches for Michigan Data only.

** Equation (2.04) used to compute sample size.

Table 10 contains sample sizes required for the rural composite population. Similar sample sizes were required (Table 8) for the estimate of total cost of highway improvements in the separate populations as were required for the estimate of total cost (all highway, bridge and railroad crossing improvements) for the composite population. The sample sizes required for the estimate of highway cost for the composite population is the same as required for the separate populations because the total number of sampling units and strata variances are the same. When $d_T = 20$ percent of the total and $\alpha = 0.10$, larger sample sizes are required for the composite populations than for the separate populations for the estimates of total costs of bridges and railroad crossings. Similar results were found for other values of d_T and α . Tables E17-E21 and E29-E36 in Appendix E contain more detailed data for sample sizes for various margins of error and α risks.

Sample sizes required for the composite urban populations using optimum and proportional sampling are shown in Table 11. Only a small decrease in sample size is noted for optimum sampling when $d_T = 20$ percent of the total and $\alpha = 0.10$. Similar results were obtained for all other values of d_T and α used and are shown in Tables E34-E36 of Appendix E.

When Tables 10 and 11 are compared with Table 5, one notes that the sample sizes required for proportional sampling are nearly equal to the sizes required for simple

TABLE 10. SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE RURAL HIGHWAY SYSTEM USING OPTIMUM AND PROPORTIONAL STRATIFIED RANDOM SAMPLING FOR THE COMPOSITE POPULATIONS

Michigan

Minnesota

Desired Estimated Total Cost	Michigan			Minnesota		
	Margin of Error and α Risk			Margin of Error and α Risk		
	$d_T = 20$ Percent of the Total	$d_T = 5$ Percent of the Total	$d_T = 20$ Percent of the Total	$d_T = 20$ Percent of the Total	$d_T = 5$ Percent of the Total	$d_T = 5$ Percent of the Total
	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.05$
	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size
	Variance	Variance	Variance	Variance	Variance	Variance
(a) Total Cost: (All Highway, Bridge and Railroad Crossing Improvements)	59 538 $\times 10^7$	1,071 23.7 $\times 10^7$	51 426 $\times 10^7$	995 18.7 $\times 10^7$		
(b) Highway Cost	Same Information as in Table 9					
(c) Bridge Cost	636 55.3 $\times 10^6$	4,256* 2.44 $\times 10^6$	588 45.9 $\times 10^5$	4,610* 2.02 $\times 10^6$		
(d) Railroad Crossing Cost	944 112,000	4,418* 4,950	2,207	45,900 6,563*	2,021	

*Equation (2.04) used to compute sample size.

TABLE 10 (Continued). SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE RURAL HIGHWAY SYSTEM USING OPTIMUM AND PROPORTIONAL STRATIFIED RANDOM SAMPLING FOR THE COMPOSITE POPULATIONS

Michigan

Minnesota

Desired Estimated Total Cost	<u>Margin of Error and α Risk</u>				<u>Margin of Error and α Risk</u>							
	$d_T = 20$ Percent of the Total		$d_T = 5$ Percent of the Total		$d_T = 20$ Percent of the Total		$d_T = 5$ Percent of the Total					
	$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$		$\alpha = 0.05$					
	Sample Approximate Size	Sample Approximate Variance	Sample Approximate Size	Sample Approximate Variance	Sample Approximate Size	Sample Approximate Variance	Sample Approximate Size	Sample Approximate Variance				
<u>Proportional Sampling</u>												
(a) Total Cost: (All Highway, Bridge and Railroad Crossing Improve-ments)	64	538	$\times 10^7$	1,201	23.7	$\times 10^7$	54	426	$\times 10^7$	1,067	23.7	$\times 10^7$
(b) Highway Cost	Same Information as in Table 9											
(c) Bridge Cost	711	55.3	$\times 10^6$	4,689	2.44	$\times 10^6$	687	45.9	$\times 10^6$	5,405	2.02	$\times 10^6$
(d) Railroad Crossing Cost	1,185	112,000		5,243	4,950		3,037	45,900		7,382		2,021

* Equation (2.04) used to compute sample size.

TABLE 11. SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF IMPROVEMENTS FOR THE URBAN HIGHWAY SYSTEMS USING OPTIMUM AND PROPORTIONAL STRATIFIED RANDOM SAMPLING FOR THE COMPOSITE POPULATIONS

<u>Michigan</u>										<u>Minnesota</u>									
<u>Margin of Error and α Risk</u>										<u>Margin of Error and α Risk</u>									
Desired Estimated Cost		$d_T = 20$ Percent of the Total				$d_T = 5$ Percent of the Total				$d_T = 20$ Percent of the Total				$d_T = 5$ Percent of the Total					
		$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$		$\alpha = 0.05$			
		Sample Approximate Size		Sample Approximate Variance		Sample Approximate Size		Sample Approximate Variance		Sample Approximate Size		Sample Approximate Variance		Sample Approximate Size		Sample Approximate Variance			
		<u>Optimum Sampling</u>																	
(a) Highways, Bridges, and Railroad Crossings		Incomplete Data								243 220 $\times 10^6$ 1,794* 9.68×10^6									
		Same Information as in Table 9																	
(b) Highways																			
(c) Bridges		Incomplete Data								1,025 80.3×10^5 2,906* 3.53×10^5									
(d) Railroad Crossings		Incomplete Data								1,012 77,000 3,004 3,392									

* Equation (2.04) used to compute sample size.

TABLE 11 (Continued). SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF IMPROVEMENTS FOR THE URBAN HIGHWAY SYSTEMS USING OPTIMUM AND PROPORTIONAL STRATIFIED RANDOM SAMPLING FOR THE COMPOSITE POPULATIONS

Michigan

Minnesota

Desired Estimated Cost	<u>Margin of Error and α Risk</u>			<u>Margin of Error and α Risk</u>		
	$d_T = 20$ Percent of the Total	$d_T = 5$ Percent of the Total	$d_T = 20$ Percent of the Total	$d_T = 5$ Percent of the Total	$d_T = 20$ Percent of the Total	$d_T = 5$ Percent of the Total
	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$
	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size
	Variance	Variance	Variance	Variance	Variance	Variance

Proportional Sampling

(a) Highways, Bridges, and Railroad Crossings	Incomplete Data	321 220	$\times 10^6$	2,346	9.68×10^6
	Same Information as in Table 9				
	Incomplete Data	1,179	80.3×10^5	3,066	3.53×10^5
(b) Highways	Incomplete Data	1,014	77,060	3,010	3,392
(c) Bridges	Incomplete Data				
(d) Railroad Crossings	Incomplete Data				

random sampling. Furthermore, only a nominal decrease in size is evident for optimum sampling for the two combinations of margin of error and a risk illustrated for the respective populations in each state.

Optimum Sampling, Required Sample Size Larger Than the Stratum. When the overall sampling fraction is substantial and/or one or more strata are much more variable than others, some of the computed optimum stratum sample sizes may be larger than the stratum, and the formulas for sample size (B.21) is no longer correct. If oversampling is indicated in say k strata, the resulting variance formula for optimum sampling is (9)

$$v(\bar{y}_{st}) = \frac{1}{N^2} \frac{(\sum' N_h S_h)^2}{n - \sum'' N_h} - \frac{1}{N^2} \sum' N_h S_h^2 \quad (2.02)$$

where $\sum'$ denotes summation over all strata except those which are oversampled and $\sum''$ denotes summation over all strata that are oversampled. Solving this formula for sample size for the estimate of the mean one obtains

$$n = \frac{\sum'' N_h \left\{ v(\bar{y}_{st}) + \frac{1}{N^2} \sum' N_h S_h^2 \right\} + \frac{1}{N^2} (\sum' N_h S_h)^2}{v(\bar{y}_{st}) + \frac{1}{N^2} \sum' N_h S_h^2} \quad (2.03)$$

For estimate of the total the formula for sample size becomes

$$n = \frac{\sum'' N_h \left\{ v(\hat{Y}) + \sum' N_h S_h^2 \right\} + \left(\sum' N_h S_h \right)^2}{v(\hat{Y}) + \sum' N_h S_h^2} \quad (2.04)$$

For those strata which are not oversampled, the sample must be distributed according to the following allocation formula:

$$n_{1h} = \frac{N_h S_h}{\sum' N_h S_h} \left(n - \sum'' N_h \right) \quad (2.05)$$

The sample size for each oversampled stratum is equal to the total number of sampling units, N_h , in that stratum.

In Tables 8, 9, 10, and 11 sample sizes are shown which illustrate the situation where sample size computed according to formula (B.21) has given stratum sample size larger than the stratum. This occurs for estimates of total costs of bridges and railroad crossings when $d_T = 5$ percent of the total and $\alpha = 0.05$. This problem was solved by methods just indicated.

Strata Sample Sizes Equal to One. From Tables E6-E7, E11, E14, E23, and E30 in Appendix E one can note that some of stratum sample sizes for the lower orders of accuracy are equal to one. Because the stratum population variance S_h^2 was known, stratum sample sizes equal to one were usable in this study.

Simple Cluster Sampling

Choice of Equations for the Estimate of the Mean or Total

Several methods are available for the estimate of the mean or total when cluster sampling is used (9). The choice of the most feasible method depends upon the particular population being investigated. An unbiased formula was used in this investigation - see Formulas (B.24) and (B.25).

Population Variance

Table 12 compares the population cost totals and variances for the Michigan and Minnesota data. The Minnesota data exhibited less variability than the Michigan information.

Because the county was used as the sampling unit, the total number of sampling units in the respective highway, bridge, and railroad crossing separate populations were equal. The total number of units in the composite population also was equal to the number of counties in the state. Therefore, sample sizes computed for estimate of the respective total highway cost, bridge cost and railroad crossing cost in the separate populations were equal to the sample sizes required for the estimate of these values in the composite population.

Computation of Sample Size

Example 3 illustrates the computations required for estimation of sample size for $d_T = 10$ percent of the total

TABLE 12. POPULATION COST TOTALS AND VARIANCES FOR THE SEPARATE AND COMPOSITE POPULATIONS

Population	Michigan		Minnesota	
	Total Cost (\$1000)	S_T^2	Total Cost (\$1000)	S_T^2
Separate:				
(a) Highways	539,547*	$2,546 \times 10^4$	479,008	$9,486 \times 10^3$
(b) Bridges	61,164	$5,729 \times 10^2$	55,724	$3,669 \times 10^2$
(c) Railroad Crossings	2,721	4,318	1,762	1,644
Composite Population:				
(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	603,486**	$3,182 \times 10^4$	536,494	$1,223 \times 10^4$

* Bridge approach costs were included with highway costs for simple and stratified cluster sampling.

** Slight difference in values from those obtained for the sum of the separate populations because of minor coding errors in cards.

EXAMPLE 3. COMPUTATION OF SAMPLE SIZE COMPOSITE RURAL POPULATION USING SIMPLE CLUSTER SAMPLING-MICHIGAN DATA

Sample Size for Estimating Total Costs of (all Highway, Bridge, and Railroad Crossing Improvements)

Margin of Error and α Risk: $d_T = 10$ Percent of the Total, $\alpha = 0.10$

Total Cost (\$1000)	Total Number Sampling Units $\frac{N}{n}$	$(\sum_i^N Y_i)^2$	$\sum_i^N Y_i^2$	$S_T^2 = \frac{N \sum_i^N Y_i^2 - (\sum_i^N Y_i)^2}{N(N-1)}$	Sample Size $\frac{n}{n}$
603,486	83	$364,195 \times 10^6$	6997.5×10^6	31.82×10^6	29

Computation of Population Variance:

Formula (B.29)

$$S_T^2 = \frac{\sum_i^N (Y_i - Y)^2}{N - 1} = \frac{N \sum_i^N Y_i^2 - (\sum_i^N Y_i)^2}{N(N - 1)}$$

$$S_T^2 = \frac{83 \times 6997.5 \times 10^6 - 364,195 \times 10^6}{83(82)} = 31.82 \times 10^6$$

Computation of Sample Size:

$$d_T = 0.10 \times 603,486 = 60,348 \qquad Z = 1.6448; \quad Z^2 = 2.7054$$

$$\text{Formula (B.51)} \quad V(\hat{Y}) = \frac{d_T^2}{Z^2} = \frac{(60,348)^2}{2.7054} = 1346 \times 10^6$$

$$\text{Formula (B.33)} \quad n_o = \frac{N^2 S_T^2}{V(\hat{Y})} = \frac{(83)^2 \times 31.82 \times 10^6}{1346 \times 10^6} = 162.7$$

$$\text{Formula (B.34)} \quad n = \frac{n_o}{1 + n_o/n} = \frac{162.7}{1 + 162.7/83} = 55$$

cost (all highway, bridge, and railroad crossing improvements) and $\alpha = 0.10$ using the composite Michigan population. In addition to computing sample sizes for different combinations of margin of error and α risk for estimating total cost (all highway, bridge, and railroad crossing improvements), sample sizes were computed for the estimates of the costs of highways, bridges, and railroad crossings using the separate and/or composite populations. Table 13 compares sample sizes obtained for $d_T = 20$ percent of the total, $\alpha = 0.10$ and for $d_T = 5$ percent of the total, $\alpha = 0.05$ using Michigan and Minnesota data. Little difference occurs in sample size required for the estimate of total cost (all highway, bridge and railroad crossing improvements) and for the estimate of highway cost for each state. However, sample sizes required for the estimate of bridge cost and for the estimate of railroad crossing cost are substantially higher than corresponding sample sizes required for the estimate of total cost (all highway, bridge, and railroad crossing improvements). Tables E37 and E46 in Appendix E give a more detailed comparison of sample sizes for the five combinations of margin of error and α risk used for each population.

Stratified Cluster Sampling

Formulas for the Estimate of the Total and Variance

The formulas for the estimate of the total and variance (B.39) and (B.41), respectively, can be obtained from formulas used for simple cluster sampling.

TABLE 13. SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENTS FOR THE RURAL HIGHWAY SYSTEMS USING SIMPLE CLUSTER SAMPLING FOR SEPARATE AND COMPOSITE POPULATIONS

		Michigan			Minnesota			
		Margin of Error and α Risk		Margin of Error and α Risk				
Population	$d_T = 20$ Percent of the Total $\alpha = 0.10$	$d_T = 5$ Percent of the Total $\alpha = 0.05$	$d_T = 20$ Percent of the Total $\alpha = 0.10$	$d_T = 5$ Percent of the Total $\alpha = 0.05$				
	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Sample Approximate Size	Variance	Variance		
Separate:								
(a) Highways	29	490×10^7	76	189×10^6	17	339×10^7	73	149×10^6
(b) Bridges	38	553×10^5	79	244×10^4	35	459×10^5	81	202×10^4
(c) Railroad Crossings	64	112×10^3	82	4,946	65	45,900	85	2,021
Composite Population:								
(a) Total Cost: (All Highway, Bridge and Railroad Crossing Improvements)	27	538×10^7	76	237×10^6	17	426×10^7	73	187×10^6

Choice of Strata

Criteria for the choice of strata were investigated for this sampling technique. The use of the county as the sampling unit permitted the use of only general information about the county. Information used as a basis for stratification, however, had to be easily obtainable and highly correlated with the population characteristic to be estimated. Various economic data for each county such as annual gasoline sales, annual retail sales, gasoline sales per square mile, and an index computed by multiplying gasoline sales per square mile by the county primary road mileage were investigated to estimate the correlations between these factors and the total cost of county highway improvements. The correlation between county mileage on the rural primary road system and the total cost of county highway improvements was also studied. The highest correlation found was that between rural county road mileage and the total cost of improvements, and this variable was used as the basis for stratification in this study. Figures 15 and 16 are scatter diagrams for these variables using the Michigan and Minnesota data. The linear regression line and correlation coefficient are shown.

Three strata were chosen for the data in each state. For each state, the strata were chosen so that total costs of improvement within the strata were approximately the same. An attempt was also made to choose the strata so that

SCATTER DIAGRAM FOR TOTAL COST OF IMPROVEMENTS AND COUNTY PRIMARY ROAD MILEAGE IN MICHIGAN

FIGURE 15

SCATTER DIAGRAM FOR TOTAL COST OF IMPROVEMENTS AND COUNTY PRIMARY ROAD MILEAGE IN MINNESOTA

FIGURE 16

the mean of the total cost of improvement were as divergent as possible. Stratification according to these criteria will give a minimum sample size for a specified margin of error and α risk when compared to other methods which may be used (22). The following mileage groups for the Michigan and Minnesota data were used:

<u>Stratum Number</u>	<u>Mileage Group</u>
1	0-249.99 Miles
2	250.00-349.99 Miles
3	350.00-Maximum Miles

Computation of Sample Size

Illustrative Example. Example 4 illustrates the computations required for the estimation of sample sizes required for optimum allocation, proportional allocation when $n_h \propto N_h$, and proportional allocation when $n_h \propto M_{Hh}$, using a margin of error of $d_T = 10$ percent of the total cost (all highway, bridge, and railroad crossing improvements) and an α risk of 0.10. The computation of sample sizes required for estimating highway cost, bridge cost, or railroad crossing cost for the separate populations is similar to Example 4. One should note, however, that the computation of sample sizes required to estimate bridge cost and railroad crossing cost using $n_h \propto M_{Hh}$ were based on the number of highway sections in each stratum and not on the number of bridges or railroad crossings in each stratum. This allocation of sample

Sample Size for Estimating Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)
Margin of Error and a Risk: $d_T = 10$ Percent of Total Cost, $\alpha = 0.10$

Stratum: County Primary Village	Total Cost (11,000)	Number Primary Units N_h	Number of Elements M_h	$N \left(\sum_i Y_{hi} \right)^2$	$N \left(\sum_i Y_{hi} \right)^2$
C-260.99 (1)	250,216	41	1,008	23,505,795,856	642,768,112
250-269.99 (2)	281,176	30	2,778	79,059,912,976	2,802,853,196
250-Maximum (3)	168,991	12	1,675	28,558,975,000	2,505,527,256
Total	600,486	83	5,321	131,195,062,196	

Criticism Sampling:

For $d_T = 10$ Percent Total Cost = 60,049
 $Z = 1.6448,$
 $Z^2 = 2.7054$

Formula (P. 11): $V(\hat{Y}) = \frac{d_T^2}{Z^2} = \frac{(60,049)^2}{2.7054} = 1,316 \times 10^6$

$$n = \frac{\sum_h N_h S_{hT}^2}{V(\hat{Y}) + \sum_h N_h S_{hT}^2} = \frac{31,772,250,000}{1316 \times 10^6 + 1,165,119,011} = 30$$

Formula (P. 11): $n = \frac{31,772,250,000}{1316 \times 10^6 + 1,165,119,011} = 30$

$$V(\hat{Y}) + \sum_h N_h S_{hT}^2$$

Computation of Structure
Sample Sizes:

Formula (P. 14):

$$n_h = \frac{N_h S_{hT}}{\sum_h N_h S_{hT}}$$

For Stratum 1:

$$n_1 = \frac{51,019}{11,000} \times 30 = 14$$

Sample Size for Estimating Total Cost: (all Highway, Bridge, and Railroad Crossing Improvements)
Margin of Error and a Risk: $d_p = 10$ Percent of Total Cost, $\alpha = 0.10$

$N_h \sum_i Y_{hi} - \left(\sum_i Y_{hi} \right)^2$		$\frac{N_h^2 S_{hT}^2}{N_T}$		Optimum Isipcd 1 Method 2		Sample Sizes	
$= \frac{N_h \sum_i Y_{hi}^2 - \left(\sum_i Y_{hi} \right)^2}{N_T(N_T - 1)}$		$= \frac{N_h S_{hT}^2}{N_T}$		n_h		n_h	
1,736,551		71,211,011		6		21	
10,165,000		1,213,50,000		20		16	
15,099,000		1,298,000		7		6	
Total		1,129,011		33		33	

Proportional Sampling:
(Method 2, $n_h \propto M_{hh}$)

$$n = \frac{L \sum_i \frac{N_h^2 S_{hT}^2}{N_T}}{V(\hat{Y}) + \sum_i N_h S_{hT}^2}$$

Formula (5.50): $n = \frac{L}{V(\hat{Y}) + \sum_i N_h S_{hT}^2} = 36$

$$= \frac{621 + 20,120,111}{1,316 \times 10^6 + 1,129,011} = 36$$

Computation of Cluster Sample Size:

Formula (n.15): $n_h = \frac{1}{h} \times n$

For stratum 1: $n_h = \frac{1008}{321} \times 36$

$$n_h = 11$$

size was arbitrary and was chosen because of its simplicity. Furthermore, the number of bridges or railroad crossings in each stratum is approximately proportional to the number of highway sections

Table 14 indicates the sample sizes required for two combinations of margin of error and α risk for each state, using optimum sampling and the two methods of proportional sampling described. For the same population, optimum sampling require the smallest sample size, but proportional sampling when $n_h \propto M_{Ith}$ require sizes nearly equal to optimum. Proportional sampling when $n_h \propto M_h$ required larger sample sizes than either of the other two types.

The sample sizes required from the composite population for the estimation of total cost (all highway, bridge, and railroad crossing improvements) were only slightly larger or equal to those required from the separate population for the estimation of cost of highway improvements for a given method of sampling and order of accuracy. On the other hand, sample sizes required for the estimation of bridge costs and for the estimation of railroad crossing costs were much larger than those required for the estimation of highway costs. If one chooses a sample size for the estimate of total cost or of highway cost for a specified margin of error and α risk, the estimates obtained for bridge costs and railroad crossing costs will have a much lower order of accuracy than the estimate of total and highway costs.

TABLE 14. SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE RURAL HIGHWAY SYSTEMS USING OPTIMUM AND PROPORTIONAL STRATIFIED CLUSTER SAMPLING FOR THE SEPARATE AND COMPOSITE POPULATIONS

		<u>Michigan</u>			<u>Minnesota</u>		
		<u>Margin of Error and α Risk</u>			<u>Margin of Error and α Risk</u>		
<u>Population</u>	$d_T = 20$ Percent of the Total	$d_T = 5$ Percent of the Total		$d_T = 20$ Percent of the Total		$d_T = 5$ Percent of the Total	
		$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$	
		Sample Approximate Size	Variance	Sample Approximate Size	Variance	Sample Approximate Size	Variance
<u>Optimum Sampling</u>							
<u>Separate Population:</u>							
(a) Highways	12	430×10^7	189×10^6	10	339×10^7	61×10^6	149×10^6
(b) Bridges	27	553×10^5	244×10^4	28	459×10^5	72×10^4	202×10^4
(c) Railroad	39	112×10^3	$4,946$	55^*	$45,900$	83^*	$2,021$
<u>Composite Population:</u>							
(a) Total Cost: 12		538×10^7	237×10^6	11	426×10^7	60	187×10^6
(All Highway, Bridge, and Railroad Crossing Improvements)							

* Equation (2.06) used to compute sample size.

TABLE 14 (Continued). SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE RURAL HIGHWAY SYSTEMS USING OPTIMUM AND PROPORTIONAL STRATIFIED CLUSTER SAMPLING FOR THE SEPARATE AND COMPOSITE POPULATIONS

Michigan

Minnesota

Population	Margin of Error and α Risk			Margin of Error and α Risk		
	$d_T = 20$ Percent of the Total		$\alpha = 0.10$	$d_T = 5$ Percent of the Total		$\alpha = 0.05$
	Sample Size	Approximate Variance		Sample Size	Approximate Variance	
						Percent of the Total
						$\alpha = 0.05$
						Sample Size
						Approximate Variance

Proportional Sampling (Method 1, $n_h \propto N_h$)

Separate Population:						
(a) Highways	19	430×10^7	72	189×10^6	12	339×10^7
(b) Bridges	38	553×10^5	78	244×10^4	33	459×10^5
(c) Railroad	61	112×10^3	83	4,946	65	45,900
Composite Population:						
(a) Total Cost: 19		538×10^7	71	237×10^6	12	426×10^7
(All Highway, Bridge, and Railroad Crossing Improvements)					68	187×10^6
						149 x 10 ⁶
						202 x 10 ⁴
						2,021

TABLE 14 (Continued). SAMPLE SIZES REQUIRED FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE RURAL HIGHWAY SYSTEMS-OPTIMUM AND PROPORTIONAL STRATIFIED CLUSTER SAMPLING USING THE COMPOSITE POPULATION

Michigan

Minnesota

Population	Margin of Error and α Risk		Margin of Error and α Risk	
	$d_T = 20$ Percent of $d_T = 5$ Percent of		$d_T = 20$ Percent of $d_T = 5$ Percent of	
	the Total	the Total	the Total	the Total
	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$
	Sample Approximate	Sample Approximate	Sample Approximate	Sample Approximate
	Size	Size	Size	Size
	Variance	Variance	Variance	Variance

Proportional Sampling (Method 2, $n_h \propto M_{hh}$)

Separate Population:

(a) Highways	15	430 x 10 ⁷	58**	189 x 10 ⁶	11	339 x 10 ⁷	61**	149 x 10 ⁶
(b) Bridges	27	553 x 10 ⁵	70**	243 x 10 ⁴	29	459 x 10 ⁵	73**	202 x 10 ⁴
(c) Railroad	48**	112 x 10 ³	63**	4,819	62	45,900	83**	2,021

Composite Population:

(a) Total Cost: 15 (All Highway, Bridge, and Railroad Crossing Improvements)	538 x 10 ⁷	57**	237 x 10 ⁶	11	426 x 10 ⁷	61	187 x 10 ⁶
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* Equation (2.02) used to compute sample size.

A comparison of Tables 13 and 14 indicates that a smaller sample size is required for stratified cluster sampling for the estimate of total cost. A smaller sample size is required for optimum sampling than is required for proportional sampling when $n_h \propto N_h$. Proportional sampling when $n_h \propto M_{hh}$ requires sample sizes only slightly larger than optimum sampling. Tables E38-E40, E47-E50 in Appendix E show required sample sizes for three additional orders of accuracy.

Stratum sample sizes for optimum cluster sampling may be larger than the total number of units in the stratum when a large sampling fraction is drawn and/or when one of the stratum is highly variable. The usual equation for total sample size is no longer valid and a method similar to that described for stratified random sampling must be used. Proportional sampling when $n_h \propto M_{hh}$ (Method 2) may also require sample sizes larger than the stratum. The formula for optimum sample size for estimating the total is

$$n = \frac{\sum'' N_h \left\{ v(\hat{Y}) + \sum' N_h S_{hT}^2 \right\} + \left(\sum' N_h S_{hT} \right)^2}{v(\hat{Y}) + \sum' N_h S_{hT}^2} \quad (2.06)$$

The optimum allocation of sample sizes to strata which are not over-sampled is made according to the following formula:

$$n_h = \frac{N_h S_{hT}}{\sum N_h S_{hT}} (n - \sum'' N_h) . \quad (2.07)$$

The size of sample in each oversampled stratum is equal to the number of sampling units in the stratum.

The sample size equation for the estimate of the total for proportional sampling when $n_h \propto M_{hh}$ is used, is as follows:

$$n = \frac{\sum'' N_h \left\{ v(\hat{Y}) + \sum' N_h S_{hT}^2 \right\} + M' \sum' \frac{N_h^2 S_{hT}^2}{N_h}}{v(\hat{Y}) + \sum' N_h S_{hT}^2} , \quad (2.08)$$

where M' is the number of elements in the strata which are not oversampled. Stratum sample size is computed by the formula

$$n_h = \frac{M_h}{M'} n , \quad (2.09)$$

and in each oversampled strata the same size is equal to the number of units in the stratum.

Table 14 indicates that sample sizes computed by the conventional formulas for proportional sampling when $n_h \propto M_{hh}$ and optimum sampling do not always apply, especially when

$d_T = 5$ percent of the total and $\alpha = 0.05$. Correct sample sizes have been computed by the methods just discussed.

Sum of the Total Costs of Improvements for the Separate Populations

Variance of the Estimate of Total Costs for the Separate Populations

The variance of the sum of the estimates of highway costs, bridge costs and railroad crossing costs is equal to the sum of the variances of the separate estimates. Table 15 compares the sum of the variances obtained for a given order of accuracy in the separate populations with the variance obtained for the same order of accuracy in the composite population. A comparison of variances reveals that the variance of the sum of the estimates of total costs, $V(\hat{Y})'$, using the separate populations is less than the variance of the estimate total cost $V(\hat{Y})$ (all highway, bridge and railroad crossing improvements) using the composite population.

Discussion of Results

Comparison of Sampling Rates

For a given population and a specified order of accuracy, sample sizes required to estimate various population characteristics varied considerably. For each separate population and for the composite population the characteristic which required minimum sample size was total cost.

TABLE 15. VARIANCES FOR THE ESTIMATE OF TOTAL COST FOR THE SUM OF THE RURAL SEPARATE POPULATIONS AND THE ESTIMATE OF TOTAL COST FOR THE RURAL COMPOSITE POPULATIONS

Population	Margin of Error and α Risk for the Separate Highway, Bridge, and Railroad Crossing Populations, and Composite Population					
	$d_T = 20$	$d_T = 10$	$d_T = 10$	$d_T = 5$	$d_T = 5$	
	Percent of the Total $\alpha = 0.10$	Percent of the Total $\alpha = 0.10$	Percent of the Total $\alpha = 0.05$	Percent of the Total $\alpha = 0.10$	Percent of the Total $\alpha = 0.05$	
Michigan Data						
Separate: Variance, $V(Y)$	$4,321 \times 10^6$	$1,081 \times 10^6$	804	$x 10^6$	270	$x 10^6$
Composite: Variance, $V(Y)$	$5,384 \times 10^6$	$1,346 \times 10^6$	943.1×10^6	336.5×10^6	237.0	$x 10^6$
Minnesota Data						
Separate: Variance, $V(Y)$	$3,439 \times 10^6$	860×10^6	606	$x 10^6$	215	$x 10^6$
Composite: Variance, $V(Y)$	$4,256 \times 10^6$	$1,064 \times 10^6$	749.3×10^6	265.9×10^6	187.3	$x 10^6$

Tables 16-22 show the sampling rates required for estimating total cost using all forms of sampling using two combinations of margin of error and α risk for each population. Because the sizes of the respective populations varied, sampling rates of different populations cannot be compared. Sampling rates for the same population using various sampling methods, however, can be compared.

Table 16 indicates the sampling rates required for the separate rural populations for the Michigan data. Optimum stratified random sampling required minimum sampling rates for the respective populations. However, only a nominal difference occurred between this method and either simple random or proportional stratified random sampling. For example, when $d_T = 20$ percent of the total and $\alpha = 0.10$, the sampling rates for the highway population were 1.0, 0.9 and 1.0 percent, respectively, for simple random, optimum, and proportional stratified random sampling. When $d_T = 5$ percent of the total and $\alpha = 0.05$, the rates for these respective forms of sampling increase to 19.2, 16.7 and 18.3 percent.

The bridge population required sampling rates of 8.0, 7.1, and 7.9 percent, respectively, for simple random, optimum and proportional sampling when $d_T = 20$ percent of the total and $\alpha = 0.10$. These rates increase to 66.3, 59.2, and 66.3, respectively, when $d_T = 5$ percent of the total and $\alpha = 0.05$.

TABLE 16. SAMPLING RATES FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE SEPARATE POPULATIONS ON THE RURAL HIGHWAY SYSTEM-MICHIGAN DATA

Method of Sampling	Population	Sampling Rate in Percent, $\frac{n}{N} \times 100$	
		Margin of Error and α Risk	
		$d_T = 20$ Percent of the Total $\alpha = 0.10$	$d_T = 5$ Percent of the Total $\alpha = 0.05$
Simple Random Sampling	(a) Highways	1.0	19.2
	(b) Bridges*	8.0	66.3
	(c) Railroad Crossings	10.7	73.3
Optimum Stratified Random Sampling	(a) Highways	0.9	16.7
	(b) Bridges*	7.1	59.2
	(c) Railroad Crossings	9.8	69.1
Proportional Stratified Random Sampling	(a) Highways	1.0	19.3
	(b) Bridges*	7.9	66.3
	(c) Railroad Crossings	10.2	71.2
Simple Cluster Sampling	(a) Highways	34.9	91.5
	(b) Bridges	45.7	95.1
	(c) Railroad Crossings	77.0	98.7
Optimum Stratified Cluster Sampling	(a) Highways	14.4	61.3
	(b) Bridges	32.5	84.2
	(c) Railroad Crossings	47.0	75.8
Proportional Stratified Cluster Sampling ($n_h \propto N_h$)	(a) Highways	22.9	86.6
	(b) Bridges	45.8	93.8
	(c) Railroad Crossings	73.5	100.0
Proportional Stratified Cluster Sampling ($n_h \propto M_{11h}$)	(a) Highways	18.1	69.8
	(b) Bridges	32.5	84.3
	(c) Railroad Crossings	57.8	75.8

* Includes Approach Costs

TABLE 17. SAMPLING RATES FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE SEPARATE POPULATIONS ON THE RURAL HIGHWAY SYSTEM-MINNESOTA DATA

Method of Sampling	Population	Sampling Rate in Percent, $\frac{n}{N} \times 100$	
		Margin of Error and α Risk	
		$d_T = 20$ Percent of the Total $\alpha = 0.10$	$d_T = 5$ Percent of the Total $\alpha = 0.05$
Simple Random Sampling	(a) Highways	0.7	14.2
	(b) Bridges	6.3	60.4
	(c) Railroad Crossings	32.9	91.6
Optimum Stratified Random Sampling	(a) Highways	0.6	12.2
	(b) Bridges	5.1	49.3
	(c) Railroad Crossings	25.1	72.1
Proportional Stratified Random Sampling	(a) Highways	0.7	13.1
	(b) Bridges	5.3	60.2
	(c) Railroad Crossings	31.9	91.2
Simple Cluster Sampling	(a) Highways	19.5	34.0
	(b) Bridges	40.2	93.1
	(c) Railroad Crossings	74.7	97.7
Optimum Stratified Cluster Sampling	(a) Highways	11.6	70.3
	(b) Bridges	32.5	83.6
	(c) Railroad Crossings	63.3	96.2
Proportional Stratified Cluster Sampling ($n_h \propto N_h$)	(a) Highways	14.0	77.9
	(b) Bridges	38.4	93.0
	(c) Railroad Crossings	75.5	100.0
Proportional Stratified Cluster Sampling ($n_h \propto N_{Hh}$)	(a) Highways	12.3	70.3
	(b) Bridges	33.7	84.8
	(c) Railroad Crossings	72.1	96.5

TABLE 18. SAMPLING RATES FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE SEPARATE POPULATIONS ON THE URBAN HIGHWAY SYSTEM-MICHIGAN DATA

Method of Sampling	Population	Sampling Rate in Percent, $\frac{n}{N} \times 100$		Margin of Error and α Risk
		$d_T = 20$ Percent of the Total $\alpha = 0.10$	$d_T = 5$ Percent of the Total $\alpha = 0.05$	
Simple Random Sampling	(a) Highways	42.0	94.0	
	(b) Bridges*	81.8	97.3	
	(c) Railroad Crossings	Inadequate Data		
Optimum Stratified Random Sampling	(a) Highways	30.1	75.7	
	(b) Bridges*	46.5	61.4	
	(c) Railroad Crossings	Inadequate Data		
Proportional Stratified Random Sampling	(a) Highways	37.0	93.2	
	(b) Bridges*	79.5	97.7	
	(c) Railroad Crossings	Inadequate Data		

* Includes Approach Costs

TABLE 19. SAMPLING RATES FOR THE ESTIMATES OF TOTAL COST OF IMPROVEMENT FOR THE SEPARATE POPULATIONS ON THE URBAN HIGHWAY SYSTEM-MINNESOTA DATA

Sampling Rate in
Percent, $\frac{n}{N} \times 100$

Margin of Error and
 α Risk

<u>Method of Sampling</u>	<u>Population</u>	<u>$d_T = 20$ Percent of the Total $\alpha = 0.10$</u>	<u>$d_T = 5$ Percent of the Total $\alpha = 0.05$</u>
Simple Random Sampling	(a) Highways	6.0	59.2
	(b) Bridges	61.8	97.2
	(c) Railroad	22.0	86.5
	Crossings		
Optimum Stratified Random Sampling	(a) Highways	5.1	52.9
	(b) Bridges	40.2	64.3
	(c) Railroad	21.8	85.9
	Crossings		
Proportional Stratified Random Sampling	(a) Highways	5.5	57.3
	(b) Bridges	60.8	97.2
	(c) Railroad	21.8	86.4
	Crossings		

TABLE 20. SAMPLING RATES FOR THE ESTIMATES OF TOTAL COST HIGHWAY COST, BRIDGE COST, RAILROAD CROSSING COST FOR THE COMPOSITE POPULATIONS ON THE RURAL HIGHWAY SYSTEM-MICHIGAN DATA

Method of Sampling		Desired Estimated Value		Sampling Rate in Percent, $\frac{n}{N} \times 100$	
				Margin of Error and α Risk	
				$d_T = 20$	$d_T = 5$
				Percent of the	Percent of the
				Total	Total
				$\alpha = 0.10$	$\alpha = 0.05$
Simple Random Sampling		(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)		1.1	19.9
		(b) Highway Cost	Same as Table 16		
		(c) Bridge Cost	11.3		74.3
		(d) Railroad Crossing Cost	19.4		84.4
Optimum Stratified Random Sampling		(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)		0.9	16.9
		(b) Highway Cost			
		(c) Bridge Cost	Same as Table 16		
		(d) Railroad Crossings Cost	10.0		67.4
Proportional Stratified Random Sampling		(a) Total Cost: (All Highway, Bridge) and Railroad Crossing Improvements)		1.0	19.0
		(b) Highway Cost			
		(c) Bridge Cost	Same as Table 16		
		(d) Railroad Crossing Cost	14.9		69.8
Simple Cluster Sampling		(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)			
		(b) Highway Cost			
		(c) Bridge Cost	Same as Table 16		
		(d) Railroad Crossing Cost	11.2		74.0
Optimum Stratified Cluster Sampling		(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)		14.4	61.3
		(b) Highway Cost			
		(c) Bridge Cost	Same as Table 16		
		(d) Railroad Crossing Cost	18.7		82.6
Proportional Stratified Cluster Sampling ($n_h \propto N_h$)		(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)		32.5	91.5
		(b) Highway Cost			
		(c) Bridge Cost	Same as Table 16		
		(d) Railroad Crossing Cost	14.4		61.3
Proportional Stratified Cluster Sampling ($n_h \propto N_h$)		(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)		22.9	65.5
		(b) Highway Cost			
		(c) Bridge Cost	Same as Table 16		
		(d) Railroad Crossing Cost	18.1		68.6

TABLE 21. SAMPLING RATES FOR THE ESTIMATES OF TOTAL COST HIGHWAY COST, BRIDGE COST, RAILROAD CROSSING COST FOR THE COMPOSITE POPULATIONS ON THE RURAL HIGHWAY SYSTEM-MINNESOTA DATA

Method of Sampling	Desired Estimated Value	Sampling Rate in Percent, $\frac{n}{N} \times 100$	
		Margin of Error and α Risk	$d_T = 20$ Percent of the Total $\alpha = 0.10$
Simple Random Sampling	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	0.7	14.5
	(b) Highway Cost	Same as Table 17	17
	(c) Bridge Cost	8.7	68.3
	(d) Railroad Crossing Cost	38.7	93.2
Optimum Stratified Random Sampling	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	0.6	12.5
	(b) Highway Cost	Same as Table 17	17
	(c) Bridge Cost	7.4	58.2
	(d) Railroad Crossing Cost	27.9	82.9
Proportional Stratified Random Sampling	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	0.7	13.5
	(b) Highway Cost	Same as Table 17	17
	(c) Bridge Cost	8.7	68.4
	(d) Railroad Crossing Cost	38.4	93.2
Simple Cluster Sampling	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	19.5	84.0
	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	12.8	69.7
	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	14.0	79.0
	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	12.8	70.8
Optimum Stratified Cluster Sampling	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	19.5	84.0
	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	12.8	69.7
	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	14.0	79.0
	(a) Total Cost: (All Highway, Bridge, and Railroad Crossing Improvements)	12.8	70.8

TABLE 22. SAMPLING RATES FOR THE ESTIMATE OF TOTAL COST HIGHWAY COST, BRIDGE COST, RAILROAD CROSSING COST FOR THE COMPOSITE POPULATIONS ON THE URBAN HIGHWAY SYSTEM-MINNESOTA DATA

Sampling Rates in
Percent, $\frac{n}{N} \times 100$

Margin of Error and
 α Risk

$d_T = 20$ $d_T = 5$
Percent Percent
of the of the
Total Total
 $\alpha = 0.10$ $\alpha = 0.05$

Method of Sampling	Desired Estimated Value
Simple Random Sampling	(a) Total Cost (All Highway, Bridge, and Railroad Crossing Improvements) (b) Highway Cost (c) Bridge Cost (d) Railroad Crossing Cost
Optimum Stratified Random Sampling	(a) Total Cost (All Highway, Bridge, and Railroad Crossing Improvements) (b) Highway Cost (c) Bridge Cost (d) Railroad Crossing Cost
Proportional Stratified Random Sampling	(a) Total Cost (All Highway, Bridge, and Railroad Crossing Improvements) (b) Highway Cost (c) Bridge Cost (d) Railroad Crossing Cost

4.3 32.8
Same as Table 19
15.2 38.8
12.6 35.0

3.1 22.4
Same as Table 19
13.0 36.7
12.7 38.0

4.1 29.7
Same as Table 19
14.9 38.7
13.3 38.0

A large increase in sampling rates can be noted for all forms of cluster sampling when compared to simple and stratified random sampling. For example, when $d_T = 20$ percent of the total and $\alpha = 0.10$, the rates for the highway population using simple, optimum, proportional when $n_h \propto N_h$, and proportional when $n_h \propto M_{hi}$, cluster sampling were 34.9, 14.4, 22.9, and 18.1 percent, respectively. These rates increase to 91.5, 61.3, 86.6, and 69.3 percent, respectively, when $d_T = 5$ percent of the total and $\alpha = 0.05$. These sampling rates indicate that optimum stratified cluster sampling requires a much smaller sampling rate than that required by simple cluster sampling for specific margin of error and α risk.

Large sampling rates are required for the bridge populations using cluster sampling. The railroad crossing populations also requires large sampling rates. When $d_T = 5$ percent of the total and $\alpha = 0.05$, almost every unit in each population must be sampled.

Table 17 gives sampling rates computed for the separate populations in Minnesota. Optimum stratified random sampling gives minimum rates for each population. All forms of cluster sampling require much larger sampling rates than those required by simple and stratified random sampling.

Table 18 indicates the rates required using the separate urban populations for the Michigan data. Large sampling rates are required for populations for the combination

of margins of error and α risks shown and also for all other combinations used in this study.

Table 19 contains rates required using the Minnesota data using the separate urban populations. When $d_T = 20$ percent of the total highway cost and $\alpha = 0.10$, sampling rates of 6.0, 5.1, and 5.5 percent, respectively, are required using simple, optimum and proportional stratified random sampling. When $d_T = 5$ percent of the total and $\alpha = 0.05$, the rates increased to 59.2, 52.9, and 57.3 percent, respectively.

Comparatively large sampling rates are required for the estimates of total costs of the bridge and railroad crossing improvements. For example, when $d_T = 20$ percent of the total and $\alpha = 0.10$, a sampling rate of 40.2 percent is required using optimum stratified sampling. For the railroad crossing population when $d_T = 20$ percent of the total cost and $\alpha = 0.10$, the sampling rate using optimum stratified random sampling was 21.8 percent.

Tables 20 and 21 contain sampling rates required for the rural composite populations in Michigan and Minnesota respectively. Table 22 contains the sampling rates required for urban composite population in Minnesota. For a given order of accuracy and a given method of sampling, the sampling rates required for the estimate of total cost (all highway, bridge, and railroad crossing improvements) for the Michigan data are only slightly higher than or equal to

the corresponding rates required for the separate highway populations. A similar statement can be made for the rural and urban Minnesota data.

CHAPTER III

ESTIMATED TOTAL COST OF SAMPLING METHODS

General Discussion

Using the cost functions developed in Chapter I and sample sizes computed for the various sampling methods, total sample survey costs were computed. Unit and total cost computations were made only for rural highway system surveys. The cost functions, however, are also applicable for an urban system survey.

Data for the development of unit costs were obtained from cost experience of previous highway need studies in Indiana, general information on the cost of travel and expenses of survey crews, and judgment as to reasonable costs for various operations. Specific cost data were lacking for the needs studies made in Michigan and Minnesota because much of the cost of data collection and evaluation was borne by the individual county highway organizations. The state highway departments in these states provided over-all planning and supervision for the surveys, reviewed results, and wrote the final reports. Furthermore, the studies in Michigan and Minnesota were not made by sampling but were made by a complete evaluation of the population. All costs

in this study have been considered without distinction as to whether they were incurred by the county or state highway agencies. All data were assumed to be collected by a survey party operating from a central headquarters or office.

Salary schedules for professional engineers, technicians, clerks, and other necessary employees were based primarily upon pay rates of the Michigan State Highway Department for the year 1957. Rate schedules for expenses of travel, subsistence, office and computing equipment, and other supplies were also based on the costs found in this state. The cost level of labor and other necessary expenses involved in the survey, however, are approximately the same in Minnesota.

Using separate populations, the estimated cost of a sample survey includes the cost of the estimation of needs for the highways, bridges and railroad crossings, respectively. An estimate of the total cost of highway needs (highways, bridges and railroad crossings) for the composite population was obtained directly.

Wage Rates and Other Basic Data

Survey Party. The survey party was assumed to be composed of three persons - one engineer and two technicians - and were paid at the following rates for a forty-hour week

<u>Job Classification</u>	<u>Hourly Rate per Person</u>
1. Engineer	\$ 3.50
2. Technicians	\$ 2.25

Subsistence expense of \$10 per day per person for an average of three nights stay per week away from headquarters was assumed. The average distance of the survey party from headquarters to the job and return was assumed to be 200 miles and the party was paid for travel time for this trip one time per week.

Area of Michigan and Minnesota. The areas of Michigan and Minnesota were as follows (39):

	<u>Michigan</u>	<u>Minnesota</u>
A_s	58,216 square miles*	84,068 square miles*
$\sqrt{A_s}$	241.3 miles	290.0 miles

Stratified Sampling. The unit costs of data collection and data analysis were assumed to be constant in all strata in all forms of stratified random and stratified cluster sampling investigated for both the separate and composite populations. Adequate cost data for sampling the various strata were not available.

Unit Cost of Listing. The listing of sampling units was assumed to be done by an engineer familiar with the highway problems in a given county so that proper limits could be assigned to each road section. All information, including bridge and railroad identification, was placed on punch cards. If the composite population was used only one card was required for each highway section; however, the use

* Includes land and water area except area of Great Lakes.

of separate populations required one card for each highway section, bridge and railroad crossing.

Identification information was only required for each sampling unit in simple random sampling. Stratified random sampling, however, required additional topography and traffic data. Only those counties which were sampled required complete listing of the elements when simple and stratified cluster sampling were used.

The unit costs of listing for the respective separate populations for simple random sampling were equal to the unit costs of listing for all other forms of sampling except stratified random sampling and proportional stratified cluster sampling when $n_{11} \propto M_{111}$. Because strata sample sizes in this latter method of cluster sampling were proportional to the number of highway sections in each stratum, a knowledge of the number of these sections was required. However, complete listing of the highway sections was only essential for the units included in the sample and those sections which were not listed required only counting.

The listing unit cost for the separate highway populations for the Michigan and Minnesota data using simple random sampling was developed as follows:

<u>Item</u>	<u>Cost per Unit</u>
(a) Locating road sections on	
base maps	\$ 0.06

<u>Item</u>	<u>Cost per Unit</u>
(b) Placing road section	
identification on coding	
forms, punching and check-	
ing cards	
1. Placing information on	
coding forms	\$ 0.07
2. Punching and checking	
cards	<u>\$ 0.03</u>
Cost per unit	<u>\$ 0.10</u>
Total listing unit	
cost, $L_H =$	\$ 0.16

The unit costs of listing highway sections for the other methods of sampling and for the separate bridge and railroad crossing populations for all sampling methods were similarly developed.

Listing unit costs for the composite populations using simple random sampling were the same in all forms of sampling except stratified random sampling and proportional stratified cluster sampling when $n_h \propto M_{Hh}$. The value of this unit cost for the composite population was developed differently than for the separate populations because its value was dependent upon the number of bridges and railroad crossings located in a highway section. This additional cost was obtained by computing the expected unit cost for

locating bridges and railroad crossings which were located in a highway section on a base map and was

Bridges:
$$c_{BL} = \frac{N_B}{N_H} c_B , \tag{3.00}$$

Railroad Crossings:
$$c_{RL} = \frac{N_R}{N_H} c_R . \tag{3.01}$$

The symbols c_B and c_R are the unit costs used for locating information on the base maps for the separate bridge and railroad crossing populations. The symbols c_{BL} and c_{RL} are the cost per highway section for locating bridges and railroad crossings on base maps.

The unit cost of listing the Michigan data for simple random sampling was developed as follows:

<u>Item</u>	<u>Cost per Unit</u>
(a) Locating road sections on base maps	
1. Highway sections	\$0.06
2. Bridges: Using formula (3.00), this rate is:	
$\frac{1985}{6321} \times \0.04	\$0.01
3. Railroad Crossings: Using formula (3.01), this cost is:	
$\frac{521}{6321} \times \0.04	<u>\$0.01</u>
Cost per Unit	\$0.08

<u>Item</u>	<u>Cost per Unit</u>
(b) Placing information on code forms, punching and checking cards	
1. Placing information on code forms	\$0.08
2. Punching and checking cards	<u>\$0.03</u>
Cost per Unit	<u>\$0.11</u>
Total unit cost of listing, L_C	\$0.19

This value for the Michigan data was developed for stratified random sampling and proportional stratified cluster sampling when $n_{hi} \propto M_{hi}$. Similar procedures also were used for all forms of sampling studied for the Minnesota data.

Travel Unit Cost. A charge of seven cents per mile was used to compute the cost of an automobile to transport the survey crew while traveling between sampling units and traveling to the job from headquarters and return. The travel rates were assumed to be 30 and 50 miles per hour, respectively.

The following is a summary of the costs involved in the development of the unit cost of travel per mile that was used for all forms of sampling for the Michigan and Minnesota data for the separate and composite populations.

<u>Item</u>	<u>Cost per Hour</u> *
Salaries (For Travel between Sampling Units)	\$ 8.00
Subsistence (Part of the Cost of Overnight Stay Away from Headquarters)	2.25
Headquarters to Work and Return (Travel Cost and Salaries)	1.05
Travel between Sampling Units	<u>2.10</u>
Total	\$13.40

When the travel speed between sampling units is 30 miles per hour, the total unit cost of travel

$$C_{IH} = C_{IC} = C_{PH} = C_{PC} = \frac{13.40}{30} = \$0.447 \text{ per mile}$$

Data Collection Unit Cost. The travel rate of the automobile while collecting data within a highway section was assumed to be 20 miles per hour. Time required to take field measurements and fill out inventory forms was 17 minutes for a highway section, 12 minutes for a bridge and 7 minutes for a railroad crossing. The average length of each road section for each state was 3.3 miles.

* Based on a 40-hour work week.

The unit costs of data collection for the respective separate populations for all sampling methods were assumed equal. The unit cost for the separate highway population for the Michigan and Minnesota data was developed as follows:

<u>Item</u>	<u>Cost per Unit</u>
(a) Unit cost of travel within the highway section	
1. Automobile: $3.3 \times \$0.07$	\$0.23
2. Salaries: $\frac{2.2}{60} \times (\$8.00 + 2.25)$	<u>\$1.69</u>
Total travel cost	\$1.92
(b) Measurement and recording data	
1. Salaries $\frac{17}{60} \times \$8.00$	\$2.27
2. Miscellaneous expense such as field supervision, telephone calls, training of inventory crews, etc.	<u>\$0.11</u>
Total measurement and recording	<u>\$2.38</u>
Total unit data collection cost, C _{2H}	\$4.30

Similar reasoning was used to develop the unit costs for bridge and railroad crossing data collection. Travel within the sampling unit was not required to collect data

* Includes part of subsistence cost.

for these facilities and all costs were caused by the measurement and recording of data.

Development of unit costs for the composite population required an evaluation of the expected increase in the data collection unit cost caused by the bridges and railroad crossings being included with highway sections. This additional unit cost is:

$$\text{Bridges:} \quad c_{BC} = \frac{N_B}{N_H} C_{2B} \quad (3.02)$$

$$\text{Railroad Crossings:} \quad c_{RC} = \frac{N_R}{N_H} C_{2R} \quad (3.03)$$

The total unit cost, therefore, was developed as follows for the composite population for the Michigan data:

<u>Item</u>	<u>Cost per Unit</u>
(a) Highways:	\$4.30
(b) Bridges: $\frac{1985}{6321} \times \2.05	
(Formula (3.02))	0.65
(c) Railroad Crossings:	
$\frac{521}{6321} \times \1.19 (Formula (3.03))	<u>0.09</u>
Total Unit Cost, C_{2C}	\$5.04

Similar procedures were used for the Minnesota data to develop unit costs for data collection.

Data Analysis Unit Cost. The data analysis unit cost varied with the type of sampling being investigated for the

separate populations but was the same for a specific method of sampling for both states. The unit costs for the composite population, however, generally varied with the type of sampling and the state being used.

The evaluation for the required improvements, and the calculation and checking of their cost for the separate populations was assumed to require 15 minutes for a highway section, 7 1/2 minutes for a bridge and 5 minutes for a railroad crossing. The following calculations were required to develop the data analysis unit costs for Michigan and Minnesota data for the separate highway population for simple random sampling:

<u>Item</u>	<u>Cost per Unit</u>
(a) Drawing of sample	\$0.10
(b) Evaluation of needs, computing costs and checking data $15/60 \times \$3.50$	0.88
(c) Statistical analysis of data	
1. Coding and punching costs into cards	\$0.13
2. Statistical computations	0.60
3. Additional computing and checking results	<u>0.15</u>
Total statistical analysis cost	\$0.88

<u>Item</u>	<u>Cost per Unit</u>
(d) Reporting, editing and re-	
vising results	<u>\$0.20</u>
Total data analysis unit costs, C_{3H}	\$2.06

Similar calculations were made for other forms of sampling for the separate and composite populations.

Tables 23-25 contain values computed for the unit costs of listing, travel, data collection and data analysis for all forms of sampling used. Table 23 contains unit costs obtained for the separate populations in Michigan and Minnesota data. The values contained in these tables were substituted in the appropriate cost functions developed in Chapter I. Estimated total sample survey costs were computed for five combinations of margin of error and a risk used for the separate and composite populations for each sampling method.

Discussion of Total Cost of Sampling Survey Methods

Estimated total sample survey costs for simple random, optimum stratified and proportional stratified random, simple cluster, and optimum and proportional stratified cluster sampling are compared in Figures 17 and 18 for the Michigan and Minnesota data for the separate populations. Optimum stratified random sampling gives minimum total costs for both groups of data. The difference in cost for simple random and proportional stratified random sampling, however,

ESTIMATED TOTAL COST OF SAMPLE SURVEYS FOR SEPARATE POPULATIONS USING SIMPLE AND STRATIFIED RANDOM SAMPLING AND SIMPLE AND STRATIFIED CLUSTER SAMPLING (MICHIGAN DATA)

FIGURE 17

ESTIMATED TOTAL COST OF SAMPLE SURVEYS FOR SEPARATE POPULATIONS USING SIMPLE AND STRATIFIED RANDOM SAMPLING AND SIMPLE AND STRATIFIED CLUSTER SAMPLING (MINNESOTA DATA)

FIGURE 18

TABLE 23. UNIT COSTS OF DATA LISTING, TRAVEL, DATA COLLECTION, AND DATA ANALYSIS FOR ESTIMATION OF TOTAL SAMPLE SURVEY COSTS FOR THE RURAL SEPARATE POPULATIONS WHEN ESTIMATING TOTAL COST OF IMPROVEMENTS

Michigan and Minnesota Data

Method of Sampling	Population	Listing Unit Cost	Travel Unit Cost	Data	
				Collection Unit Cost	Analysis Unit Cost
1. Simple Random Sampling	(a) Highways	\$0.16	\$0.447	\$4.30	\$2.06
	(b) Bridges	0.14	0.447	2.05	1.81
	(c) Railroad Crossings	0.14	0.447	1.19	1.22
2. Optimum Stratified Random Sampling	(a) Highways	0.21	0.447	4.30	3.13
	(b) Bridges	0.19	0.447	2.05	2.59
	(c) Railroad Crossings	0.19	0.447	1.19	1.74
3. Proportional Stratified Random Sampling	(a) Highways	0.21	0.447	4.30	2.73
	(b) Bridges	0.19	0.447	2.05	2.19
	(c) Railroad Crossings	0.19	0.447	1.19	1.44
4. Simple Cluster Sampling	(a) Highways	0.16	0.447	4.30	1.75
	(b) Bridges	0.14	0.447	2.05	1.50
	(c) Railroad Crossings	0.14	0.447	1.19	1.00
5. Optimum Stratified Cluster Sampling	(a) Highways	0.16	0.447	4.30	2.80
	(b) Bridges	0.14	0.447	2.05	2.20
	(c) Railroad Crossings	0.14	0.447	1.19	1.50
6. Proportional Stratified Cluster Sampling $n_h \propto N_h$	(a) Highways	0.16	0.447	4.30	2.50
	(b) Bridges	0.14	0.447	2.05	1.90
	(c) Railroad Crossings	0.14	0.447	1.19	1.20
7. Proportional Stratified Cluster Sampling $n_h \propto N_h^{1/3}$	(a) Highways	0.45	0.447	4.30	2.52
	(b) Bridges	0.14	0.447	2.05	1.92
	(c) Railroad Crossings	0.14	0.447	1.19	1.22

TABLE 24. UNIT COSTS OF DATA LISTING, TRAVEL, DATA COLLECTION, AND DATA ANALYSIS
FOR ESTIMATION OF TOTAL SAMPLE SURVEY COSTS FOR RURAL COMPOSITE
POPULATIONS WHEN ESTIMATING TOTAL COST OF IMPROVEMENTS

Method of Sampling	Michigan Data			
	Listings Unit Cost	Travel Unit Cost	Data Collection Unit Cost	Data Analysis Unit Cost
1. Simple Random Sampling	\$0.19	\$0.447	\$5.04	\$2.35
2. Optimum Stratified Sampling	0.26	0.447	5.04	3.54
3. Proportional Stratified Random Sampling	0.26	0.447	5.04	3.19
4. Simple Cluster Sampling	0.19	0.447	5.04	2.36
5. Optimum Stratified Cluster Sampling	0.19	0.447	5.04	3.20
6. Proportional Stratified Cluster Sampling (Method 1, $n_h \propto N_h$)	0.19	0.447	5.04	2.90
7. Proportional Stratified Cluster Sampling (Method 2, $n_h \propto M_{ih}$)	0.50	0.447	5.04	2.92

TABLE 25. UNIT COSTS OF DATA LISTING, TRAVEL, DATA COLLECTION, AND DATA ANALYSIS
FOR ESTIMATED TOTAL SAMPLE SURVEY COSTS FOR THE RURAL COMPOSITE
POPULATION WHEN ESTIMATING TOTAL COST OF IMPROVEMENTS

Minnesota Data					
Method of Sampling	Listing Unit Cost	Travel Unit Cost	Data Collection		Data Analysis Unit Cost
			Unit	Cost	
1. Simple Random Sampling	\$0.19	\$0.447		\$5.11	\$2.36
2. Optimum Stratified Random Sampling	0.26	0.447		5.11	3.55
3. Proportional Stratified Random Sampling	0.26	0.447		5.11	3.20
4. Simple Cluster Sampling	0.19	0.447		5.11	2.36
5. Optimum Stratified Cluster Sampling	0.19	0.447		5.11	3.20
6. Proportional Stratified Cluster Sampling (Method 1, $n_h \propto N_h$)	0.19	0.447		5.11	2.90
7. Proportional Stratified Cluster Sampling (Method 2, $n_h \propto N_{mh}$)	0.50	0.447		5.11	2.92

is small. Any one of three methods can be used without great increases in cost. From the standpoint of ease of understanding the method and ease of selecting the sample, simple random sampling is, without doubt, the most feasible. All forms of cluster sampling require much larger expenditures for comparable degrees of precision.

For comparable orders of accuracy, the Minnesota data required higher expenditures than the Michigan data. When $d_T = 20$ percent of the total and $\alpha = 0.10$, the total cost for simple random and stratified random sampling of the Michigan data was approximately \$5,400 and of the Minnesota data was \$7,800. These costs increased to \$24,000 for the Michigan data and \$23,700 for the Minnesota data when $d_T = 5$ percent of the total and $\alpha = 0.05$.

Figures 19 and 20 illustrate the total sample survey costs obtained for the various orders of accuracy and sampling methods using the composite populations for the Michigan and Minnesota data. For both groups of data simple random sampling generally gives minimum cost, although optimum stratified random sampling for the Michigan data gives a slightly smaller value when $d_T = 5$ percent of the total, $\alpha = 0.10$ and $d_T = 5$ percent of the total, $\alpha = 0.05$. However, only slight differences in total cost are apparent for simple random, optimum, and proportional stratified random sampling in the Michigan and Minnesota data. Any one of these three sampling methods could be used without any substantial difference in expended funds.

ESTIMATED TOTAL COST OF SAMPLE SURVEYS FOR COMPOSITE POPULATIONS USING SIMPLE AND STRATIFIED RANDOM SAMPLING AND SIMPLE AND STRATIFIED CLUSTER SAMPLING (MICHIGAN DATA)

FIGURE 19

ESTIMATED TOTAL COST OF SAMPLE SURVEYS FOR COMPOSITE POPULATIONS USING SIMPLE AND STRATIFIED RANDOM SAMPLING AND SIMPLE AND STRATIFIED CLUSTER SAMPLING (MINNESOTA DATA)

FIGURE 20

All forms of cluster sampling exhibit much greater costs than simple and stratified random sampling. These large costs indicate the impracticality of the county as a sampling unit. A much smaller unit is needed to provide a large number of sampling units and moderate variance so that small sample sizes can give reliable estimates. Optimum stratified cluster sampling gives the smallest total costs for cluster sampling for both groups of data.

The Minnesota data again required larger expenditures for sample surveys than the Michigan data. When $d_T = 20$ percent, $\alpha = 0.10$, the total cost of the sample survey using simple random sampling was \$2,600 for the Michigan data and \$2,900 for the Minnesota data. These values increased to \$14,300 and \$14,400 respectively when $d_T = 5$ percent of the total, $\alpha = 0.05$.

Comparison of sample survey costs of the separate populations and the composite populations for similar orders of accuracy show that the total cost using the separate populations were much higher than the cost when using the corresponding composite population. The separate populations required a 70-150 percent increase in expenditures for estimating the total cost of improvements compared to the sample survey costs required for the composite populations. The sum of the total cost of the needs has a higher degree of precision than is indicated in Figures 17 and 18, however,

for the separate populations so that an exact comparison between the two figures cannot be made. The information which can be obtained from the composite population may be limited. Furthermore, if estimates for bridge and railroad crossing improvement costs are desired, much larger sample sizes are required for comparable orders of accuracy with the separate populations when simple and stratified random sampling are used.

CHAPTER IV

SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

Summary of Results

Sample Sizes and Sampling Rates

The following are the results obtained for the four methods of sampling investigated in this study.

1. For a given population and specified order of accuracy, the sample size required to estimate various population characteristics varied considerably.
2. For each population, separate and composite, and for a specified order of accuracy, the characteristic which required minimum sample size was total cost. Optimum stratified random sampling required the smallest sample sizes when compared to the sizes required for proportional stratified random sampling and for simple random sampling.
3. Sample sizes required using proportional sampling were only slightly larger than sample sizes required using optimum sampling for a specified margin of error and a risk for each separate and composite population. Sample sizes required for simple random sampling were only moderately larger than those required for proportional sampling.

4. The respective urban separate populations for the Michigan data required a large proportion of the populations to be sampled for the estimate of total cost for all orders of accuracy for the sampling methods studied i.e., simple and stratified random sampling.

5. The urban separate highway population for the Minnesota data required a small sampling rate for the estimates of total cost for the lower orders of accuracy. However, large sampling rates were required for the estimate of bridge and railroad crossing costs for all orders of accuracy.

6. For a specified order of accuracy for all types of sampling studied, the rural and urban composite populations required much larger sample sizes for the estimation of bridge and railroad crossing costs than those required for the respective separate populations. Sample sizes required for the estimate of highway cost in the separate population were equal to the sizes required for the composite highway.

7. The cost total and variance of the separate highway population in Minnesota were equal, respectively, to highway cost total and variance for the composite population. For the Michigan data, the highway cost total and variance for the separate population did not exactly equal the highway cost total and variance, respectively, of the composite population because the bridge costs contained approach costs (road costs). However, this caused a negligible change in required sample size for a specified margin of error and

a risk. Furthermore, the sample sizes required for estimate of highway cost using the composite population for the various sampling methods studied were only slightly less than or equal to the sample sizes required for the estimate of total cost (all highway, bridge, and railroad crossing improvements) using the composite population.

8. For a given order of accuracy, optimum stratified cluster sampling for the rural separate highway and bridge populations using the Minnesota data required approximately the same sample sizes for the estimate of total cost as the Michigan data. The Minnesota railroad crossing population, however, required much larger samples than those required for the corresponding Michigan population.

9. For a given margin of error and a risk, all forms of cluster sampling for the respective populations required substantially larger sampling rates for the estimates of total cost than those required for simple random or stratified random sampling. Optimum stratified random sampling required the smallest rates and simple cluster sampling required the largest. For the various forms of cluster sampling, optimum stratified cluster sampling required the lowest rates, and proportional sampling when $n_{hh} \propto M_{hh}$ required sampling rates somewhat larger than optimum.

Estimated Total Cost of Sample Survey Methods

The following results for the estimated sample survey costs required for the estimate of total cost of the rural

highway, bridge, and railroad crossing improvements for various populations and orders of accuracy were obtained.

1. For all sample survey methods investigated and using the separate populations, minimum total sample survey cost for the five orders of accuracy investigated was given by optimum stratified random sampling for both the Michigan and Minnesota data.

2. For the separate populations, simple random and proportional stratified random sample survey costs were only slightly larger than the costs required for optimum stratified random sampling for each order of accuracy studied.

3. Maximum estimated sample survey costs for the separate populations usually occurred using simple cluster sampling. Stratified cluster sampling required the largest expenditures in all other cases.

4. For the three lowest orders of accuracy, minimum sample survey costs in the Michigan composite population were obtained using simple random sampling. However, when $d_T = 5$ percent of the total, $\alpha = 0.10$, and when $d_T = 5$ percent of the total, $\alpha = 0.05$, optimum stratified random sampling requires minimum costs. For each order of accuracy studied using the Minnesota composite population, simple random sampling required minimum total survey costs.

5. For each order of accuracy studied for the Michigan and Minnesota data, only a nominal difference between

estimated sample survey costs for simple and stratified random sampling occurred.

6. For all types of cluster sampling investigated, optimum stratified cluster sampling required minimum total cost. These costs, however, were much higher than simple or stratified random sampling costs for a given order of accuracy.

Conclusions

1. Sample survey techniques were found feasible for the estimation of the costs of improvements on the rural two-lane and urban county primary highways in Michigan and Minnesota. Magnitudes of sample size similar to those found in this study may be expected for the two-lane county primary highways in other states, especially those which have a well-developed county primary highway system.

2. For the estimate of total cost (all highway, bridge, and railroad crossing improvements) for each order of accuracy, the sample survey cost of the composite sample was less than the sum of the sample survey costs of the separate highway, bridge, and railroad crossing population samples. The information which can be obtained from the composite sample is more limited, however, than that which can be obtained from the separate samples. Generally, a 70 to 150 percent larger in estimated sample survey cost occurred for the separate samples than for the composite samples.

3. The apparent differences in total survey costs for simple, random, optimum, and proportional stratified random sampling for all orders of accuracy were small. Any one of these sampling methods could be used without an appreciable change in total cost.

4. Sample survey techniques were not feasible for the estimation of highway, bridge, and railroad crossing improvements on multi-lane highways such as rural and urban expressways and freeways on the county primary road system.

5. The county is too large a sampling unit for the estimation of the total cost of improvements for the rural county primary systems. Large sampling rates were required even for the lowest order of accuracy studied.

Recommendations

1. Sample survey techniques should be applied to future highway needs studies. The use of these methods for the estimation of local road and city street needs should be investigated.

2. Sample survey methods should be used to maintain highway needs studies in a current status.

3. Investigation of cluster sampling methods should be extended to include the use of smaller sampling units for the estimation of county primary highway needs. Perhaps the township might be a convenient sampling unit. These investigations also should include a study of the needs on

the local or township road systems. The use of area sampling (5) may also be applicable to this problem.

4. Research is required to determine the feasibility of using cluster sampling for the estimation of municipal street needs especially in small and intermediate size cities.

5. The feasibility of using two-stage sampling for the estimate of total cost of highway, bridge, and railroad crossing improvements for municipal, county, and township highway systems should be investigated. Area sampling (5) also may be conveniently used for this sampling method.

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APPENDIX A

GLOSSARY OF SYMBOLS

APPENDIX A

Glossary of Symbols

<u>Symbol</u>	<u>Definition</u>
A_s	= Area of the state in square miles.
C_B	= Estimated total bridge survey cost for the separate population.
C'_B	= Estimated cost of the survey for bridges which are "forced" into the highway sections.
C''_B	= Estimated cost of the survey for bridges which must be sampled separately.
C_H	= Estimated total highway survey cost for the separate population.
C_{pB}	= Unit cost for travel per mile between units for the separate bridge population.
C_{pc}	= Unit cost of travel per mile between units in the composite population.
C_{pH}	= Unit cost for travel per mile between the units for the separate highway population.
C_{pR}	= Unit cost for travel per mile between the units for the separate railroad crossing population.
C_R	= Estimated total railroad crossing survey cost.
C_T	= Estimated total cost of the sample survey.
C_{TR}	= Estimated total travel cost.

Glossary of Symbols (Continued)

<u>Symbol</u>	<u>Definition</u>
C_{1B}	= Unit cost of travel per mile for the separate bridge population.
C_{1C}	= Composite unit cost of travel per mile.
C_{1H}	= Unit cost of travel per mile for the separate highway population.
C_{1R}	= Unit cost of travel per mile for the separate railroad crossing population.
C_{2B}	= Unit cost of data collection for the separate bridge population.
C_{2Bh}	= Unit cost of data collection for the separate bridge population in the hth stratum.
C_{2c}	= Composite unit cost of data collection.
C_{2ch}	= Composite unit cost of data collection in the hth stratum.
C_{2H}	= Unit cost of data collection for the separate highway population.
C_{2Hh}	= Unit cost of data collection for the separate highway population in the hth stratum.
C_{2R}	= Unit cost of data collection for the separate railroad crossing population.
C_{2Rh}	= Unit cost of data collection for the separate railroad crossing population in the hth stratum.
C_{3B}	= Unit cost of data analysis for the separate bridge population.

Glossary of Symbols (Continued)

<u>Symbol</u>	<u>Definition</u>
C_{3Bh}	= Unit cost of data analysis for the separate bridge population in the hth stratum.
C_{3c}	= Composite unit cost of data analysis.
C_{3ch}	= Composite unit cost of data analysis in the hth stratum.
C_{3H}	= Unit cost of data analysis for the separate highway population.
C_{3Hh}	= Unit cost of data analysis for the separate highway population in the hth stratum.
C_{3R}	= Unit cost of data analysis for the separate railroad crossing population.
C_{3Rh}	= Unit cost of data analysis for the separate railroad crossing population in the hth stratum.
c_{BC}	= Expected cost per highway section for data collection of a bridge for the composite sample.
c_{BL}	= Expected cost per highway section for locating a bridge on base map for the composite sample.
c_{hi}	= Cost of the ith unit in the hth stratum.
c_{hij}	= Cost of the ith unit in the jth category in the hth stratum.
c_{RC}	= Expected cost per highway section for data collection of a railroad crossing for the composite sample.

Glossary of Symbols (Continued)

<u>Symbol</u>	<u>Definition</u>
c_{RL}	= Expected cost per highway section for locating a railroad crossing on base map for the composite sample.
d_T	= Margin of error for the total being estimated.
L_B	= Unit cost of listing data for the separate bridge population.
L_C	= Composite unit cost of listing data.
L_H	= Unit cost of listing data for the separate highway population.
L_R	= Unit cost of listing data for the separate railroad crossing population.
M	= Number of elements in the population.
M_i	= Number of elements in the population for the i th unit.
M'	= Number of elements in the strata which are not oversampled.
$\bar{M}$	= Average number of elements in the population for each primary unit = M/N .
$\bar{M}_B$	= Average number of elements in each unit for the separate bridge population.
$\bar{M}_{Bh}$	= Average number of elements in each unit for the separate bridge population in the h th stratum.
$\bar{M}_H$	= Average number of elements in each unit for the separate highway population.

Glossary of Symbols (Continued)

<u>Symbol</u>	<u>Definition</u>
$\bar{M}_{Hh}$	= Average number of elements in each unit for the separate highway population in the hth stratum.
M_h	= Number of elements in the hth stratum.
M_{Hh}	= Number of elements in the hth stratum for the separate highway population.
M_{hi}	= Number of elements in the ith unit in the hth stratum.
$\bar{M}_R$	= Average number of elements in each unit for the separate railroad crossing population.
$\bar{M}_{Rh}$	= Average number of elements in each unit for the separate railroad crossing population in the hth stratum.
m_{hij}	= Mileage of ith unit in the jth category in the hth stratum.
N	= Total number of units in the population.
N_H	= Total number of sampling units in highway population.
N_h	= Total number of units in the hth stratum.
N'_h	= Number of sampling units in the respective populations for simple random sampling and the number of sampling units in the respective strata for stratified random sampling which are used to compute the variance of the estimate of the total for the sum of the separate populations.
N_R	= Total number of units in the separate railroad crossing population.

Glossary of Symbols (Continued)

<u>Symbol</u>	<u>Definition</u>
n	= Sample size.
n'_B	= Estimated number of bridges "forced" into the sample.
n''_B	= Number of bridges which must be sampled separately.
n_{Bh}	= Number of units sampled for the separate bridge population in the hth stratum.
n_c	= Composite sample size.
n_{ch}	= Composite sample size in the hth stratum.
n_h	= Number of units in the sample in the hth stratum.
n'_h	= Number of units sampled in the respective populations for simple random sampling and the number of units sampled in the respective strata for stratified random sampling which are used to compute the variance of the estimate of the total for the sum separate populations.
n_{Hh}	= Number of units sampled for the separate highway population in the hth stratum.
n_o	= Computed sample size ignoring the effect of the finite population correction.
n_R	= Number of units sampled for the separate railroad crossing population.
n'_R	= Estimated number of sampled units for the separate railroad crossing population which are "forced" into the sample.

Glossary of Symbols (Continued)

<u>Symbol</u>	<u>Definition</u>
n_{Rh}	= Number of units sampled for the separate rail-road crossing population in the hth stratum.
P	= Proportion of units in a certain class in the population.
p	= Estimate of the proportion in a certain class in the population.
Q	= $1 - P$.
S^2	= Population variance used for simple random sampling.
$S_b'^2$	= Between unit population variance.
S_h^2	= Stratum variance used for stratified random sampling.
S_{hT}^2	= Variance of the respective populations for simple random sampling or the variance of the respective strata for stratified random sampling which are used to compute the variance of the estimate of the total for the sum of the separate populations.
S_{hb}^2	= Between unit variance in the hth stratum.
S_{hj}^2	= Stratum variance of the ith units in the jth category in the hth stratum.
S_{hT}^2	= Stratum variance for stratified cluster sampling.
S_{hT}^2	= Variance of the respective populations for simple cluster sampling or the variance in the respective strata for stratified cluster sampling which are

Glossary of Symbols (Continued)

<u>Symbol</u>	<u>Definition</u>
	used to compute the variance of the estimate of the total for the sum of the separate populations.
S_T^2	= Population variance for simple cluster sampling.
$V(\bar{Y})=S^2$	= Variance of the population mean.
$V(\hat{Y})$	= Variance of the estimate of the population total.
$V(\hat{Y})'$	= Variance of the estimate of the total for the sum of the separate populations.
$V(\bar{y})$	= Variance of the sample mean.
$V(\bar{y}_{st})$	= Variance of the estimate of the mean for stratified random sampling.
$V(\bar{\bar{y}})$	= Variance of the sample mean per element.
w_h	= The ratio of stratum sample size to sample size = n_{h1}/n
Y	= Population total.
Y_i	= Total value of the population characteristic for the i th unit in simple cluster sampling.
y_i	= Value of the population characteristic for the i th unit in simple random sampling.
Y_{hi}	= Total value for the population characteristic for the i th unit in the h th stratum.
y_{hi}	= Value of the population characteristics obtained for the i th unit in the h th stratum.
$\bar{Y}$	= Population mean.
$\bar{y}$	= Sample mean.
$\bar{\bar{y}}$	= Population mean per element.

Glossary of Symbols (Continued)

<u>Symbol</u>	<u>Definition</u>
$\bar{y}$	= Sample mean per element.
$\hat{Y}$	= Estimate of the population total.
$Z_{(1-\alpha)}$	= Value obtained from Z distribution or normal distribution for specified confidence coefficient or α risk.
α	= Probability risk or confidence coefficient.
λ	= Lagrange multiplier.

APPENDIX B
SAMPLE SURVEY
FORMULAS

APPENDIX B

SAMPLE SURVEY FORMULAS

General Discussion

The following are the sample survey formulas which were used in the various forms of sampling investigated. Most of these formulas and an appropriate discussions of sample survey theory can be found in Sampling Techniques by William G. Cochran (reference 9) or Sampling Theory of Surveys With Applications by Pandurang V. Sukhatme (reference 47). All symbols have the same meaning as is found in the former text; however, the glossary of symbols in Appendix A can be consulted for a definition of symbols.

The variance formulas for the estimate of the mean and total are not specifically cited in the indicated references for simple and stratified cluster sampling. These equations are easily derived however from these cited formulas. The formulas used for the computation of sample sizes for simple and stratified cluster sampling were also derived by the author from the basic equations cited in the references. An abbreviated derivation of these formulas is shown where they occur.

Simple Random Sampling

Mean, Total and Variance

Population Mean: $\bar{Y} = \frac{Y}{N}$ (B.00)
(Reference 9, page 12)

Sample Mean: $\bar{y} = \frac{Y}{n}$ (B.01)
(Reference 9, page 12)

Estimate of Population Total: $\hat{Y} = N\bar{y}$ (B.02)
(Reference 9, page 13)

Population Variance: $S^2 = \frac{\sum_{i=1}^N (y_i - \bar{Y})^2}{N - 1} =$
(Reference 9, page 15)

$$\frac{N \sum_{i=1}^N y_i^2 - \left(\sum_{i=1}^N y_i \right)^2}{N(N - 1)} \quad (\text{B.03})$$

Variance of the Estimate of the Total: $V(\hat{Y}) = N^2 \left(\frac{N - n}{N} \right) \frac{S^2}{n}$ (B.04)
(Reference 9, page 16)

Proportions and Percentages

Population Proportion: $P = \frac{A}{N}$ (B.05)
(Reference 9, page 31)

Sample Proportion: $p = \frac{a}{n}$ (B.06)
(Reference 9, page 31)

Estimate of Total Number: $\hat{A} = Np$ (B.07)
(Reference 9, page 31)

Variance of $\hat{A}$: $V(\hat{A}) = \frac{N^2 PQ}{n} \left(\frac{N - n}{N - 1} \right)$ (B.08)
(Reference 9, page 33)

Sample Size

For Estimate of the Total: $n = \frac{\frac{N^2 S^2}{V(\hat{Y})}}{1 + \frac{1}{N} \frac{N^2 S^2}{V(\hat{Y})}}$ (B.09)
(Reference 9, page 55)

$$n_o = \frac{N^2 S^2}{V(\hat{Y})} \quad (\text{B.10})$$

$$n = \frac{n_o}{1 + \frac{n_o}{N}} \quad (\text{B.11})$$

Estimate of the
Number in C Class:

(Reference 9, page 54)

$$n = \frac{\frac{N^2 PQ}{V(\hat{A})}}{1 + \frac{1}{N} \frac{N^2 PQ}{V(\hat{A})}} \quad (\text{B.12})$$

Stratified Random Sampling

Mean, Total, and Variance

Stratum Variance:

(Reference 9, page 66)

$$S_h^2 = \frac{\sum_i^{N_h} (y_{hi} - \bar{Y}_h)^2}{N_h - 1} = \quad (\text{B.13})$$

$$\frac{N_h \sum_i^{N_h} y_{hi}^2 - \left(\sum_i^{N_h} y_{hi} \right)^2}{N_h (N_h - 1)}$$

Population Mean:

(Reference 9, page 67)

$$\bar{Y} = \frac{\sum_h^L N_h \bar{Y}_h}{N} \quad (\text{B.14})$$

Sample Stratified Mean:

(Reference 9, page 66)

$$\bar{y}_{st} = \frac{\sum_h^L N_h \bar{y}_h}{N} \quad (\text{B.15})$$

Estimate of the Total:

(Reference 9, page 66)

$$\hat{Y} = N \bar{y}_{st} \quad (\text{B.16})$$

Variance of the Estimate
of the Total:
(Reference 9, page 70)

$$V(\hat{Y}) = \sum_h^L N_h (N_h - n_h) \frac{S_h^2}{n_h} \quad (B.17)$$

Optimum and Proportional Allocation of Sample Size

Optimum Allocation:
(Reference 9, page 74)

$$n_h = \frac{N_h S_h}{\sum_h^L N_h S_h} n \quad (B.18)$$

Proportional Allocation:
(Reference 9, page 67)

$$n_h = \frac{N_h}{N} n \quad (B.19)$$

Sample Size

For the Estimate
of Total:

1. General Equation:

$$n = \frac{\sum_h^L \frac{N_h^2 S_h^2}{w_h}}{V(\hat{Y}) + \sum_h^L N_h S_h^2} \quad (B.20)$$

2. Optimum:
(Reference 9, page 88)

$$n = \frac{\left(\sum_h^L N_h S_h \right)^2}{V(\hat{Y}) + \sum_h^L N_h S_h^2} \quad (B.21)$$

3. Proportional:
(Reference 9, page 88)

$$n_o = \frac{N}{V(\hat{Y})} \sum_h^L N_h S_h^2 : \quad (B.22)$$

$$n' = \frac{n_o}{1 + \frac{n_o}{N}}$$

Simple Cluster Sampling

Mean, Total and Variance Formulas*

Population Mean:
(Reference 9, page 235)

$$\bar{\bar{Y}} = \frac{\sum_{i=1}^N M_i \bar{Y}}{M} = \frac{Y}{N} \quad (\text{B.23})$$

Sample Mean:
(Reference 9, page 247)

$$\bar{y} = \frac{N}{nM} \sum_{i=1}^n M_i \bar{Y}_i = \quad (\text{B.24})$$

$$\frac{N}{nM} \sum_{i=1}^n Y_i$$

Estimate of Population Total:
(Reference 9, page 247)

$$\hat{Y} = \left(\frac{N}{nM} \sum_{i=1}^n M_i \bar{Y}_i \right) M = \quad (\text{B.25})$$

$$\frac{N}{n} \sum_{i=1}^n Y_i$$

Between Unit Population Variance:
(Reference 47, page 323)

$$S_b'^2 = \frac{\sum_{i=1}^N \left(\frac{M_i}{M} Y_i - \bar{Y} \right)^2}{N - 1} \quad (\text{B.26})$$

$$S_b'^2 = \frac{N^2}{M^2} \frac{\sum_{i=1}^N (Y_i - \bar{Y})^2}{N - 1} \quad (\text{B.27})$$

$$S_b'^2 = \frac{N^2}{M^2} S_T^2 \quad (\text{B.28})$$

* These formulas have been derived from simple two-stage sampling by assuming that every element within the second stage is sampled.

$$\text{where } S_T^2 = \frac{\sum_{i=1}^N (Y_i - \bar{Y})^2}{N - 1} \quad (\text{B.29})$$

Variance of the Estimate
of the Total:
(Reference 47, page 323)

$$V(\hat{Y}) = M^2 V(\bar{y}) \quad (\text{B.30})$$

$$V(\hat{Y}) = N^2 \left(\frac{N - n}{N} \right) \frac{S_T^2}{n} \quad (\text{B.31})$$

Sample Size

Solving equation (B.31), one obtains the following formula for sample size for the estimate of the total:

$$n = \frac{\frac{N^2 S_T^2}{V(\hat{Y})}}{1 + \frac{1}{N} \left(\frac{N^2 S_T^2}{V(\hat{Y})} \right)} \quad (\text{B.32})$$

$$\text{Letting } n_o = \frac{N^2 S_T^2}{V(\hat{Y})} \quad (\text{B.33})$$

$$n = \frac{n_o}{1 + \frac{n_o}{N}} \quad (\text{B.34})$$

Stratified Cluster Sampling

Mean, Total and Variance Formulas*

* These formulas have been derived from simple two-stage sampling by assuming every element within the second stage is sampled and by making the following substitution:

$$\bar{y}_{st} = \sum_h^L \frac{M_h}{M} \bar{y}_h; \quad V(\bar{y}_{st}) = \sum_h^L \frac{M_h^2}{M^2} V(\bar{y}_h); \quad \text{and } V(\hat{Y}) = N^2 V(\bar{y}_{st})$$

Stratum Variance:
(Reference 47, page 323)

$$S_{hb}^2 = \frac{\sum_1^{N_h} \left(\frac{M_{h1}}{M_h} Y_{h1} - \bar{Y}_h \right)^2}{N_h - 1} \quad (B.35)$$

$$= \frac{N_h^2 \sum_1^{N_h} (Y_{h1} - \bar{Y}_h)^2}{M_h^2 N_h - 1} \quad (B.36)$$

$$= \frac{N_h^2}{M_h^2} S_{hT}^2 \quad (B.37)$$

Population Mean:
(Reference 9, page 235)

$$\bar{Y} = \frac{\sum_h^L Y_h}{M} \quad (B.38)$$

Stratified Sample
Mean:
(Reference 9, page 263)

$$\bar{y}_{st} = \frac{1}{M} \sum_h^L \frac{N_h}{n_h} \sum_i^{n_h} M_h \bar{Y}_h \quad (B.39)$$

$$= \frac{1}{M} \sum_h^L \frac{N_h}{n_h} \sum_i^{n_h} Y_h \quad (B.40)$$

Estimate of the Total:
(Reference 9, page 263)

$$\hat{Y} = M \bar{y}_{st} = \sum_h^L \frac{N_h}{n_h} \sum_i^{n_h} Y_h \quad (B.41)$$

Variance of the Estimate
of the Total:
(Reference 47, page 323)

$$V(\hat{Y}) = M^2 \sum_h^L \frac{M_h^2}{M^2} V(\bar{y}_h) =$$

$$\sum_h^L M_h^2 \left(\frac{N_h - n_h}{N_h} \right) \frac{S_{hb}^2}{n_h}$$

(B.42)

$$= \sum_h^L N_h^2 \left(\frac{N_h - n_h}{N_h} \right) \frac{S_{hT}^2}{n_h}$$

(B.43)

Optimum and Proportional Allocation of Sample Size

Optimum: Using a method of derivation similar to the procedure used in reference 9, page 74, for stratified random sampling, optimum allocation for stratified cluster sampling is:

$$n_h = \frac{N_{h1} S_{hT}}{\sum_h^L N_h S_{hT}}$$

(B.44)

Proportional:

Formulas for Proportional Allocation are:

Proportional, Method 1,
 $n_h \propto N_h$:

$$n_h = \frac{N_h}{N} n$$

(B.45)

Proportional, Method 2,
 $n_h \propto M_h$:

$$n_h = \frac{M_h}{M} n$$

(B.46)

Sample Size

Solving formula (B.43) for sample size, the following general formula is obtained

For Estimate of
the Total:

$$1. \text{ General Equation: } n = \frac{\sum_{h=1}^L \frac{N_h^2 S_{hT}^2}{w_h}}{V(\hat{Y}) + \sum_{h=1}^L N_h S_{hT}^2} \quad (\text{B.47})$$

where $w_h = n_h/n$

$$2. \text{ Optimum } n_h \propto N_h S_{hT} \quad n = \frac{\left(\sum_{h=1}^L N_h S_{hT} \right)^2}{V(\hat{Y}) + \sum_{h=1}^L N_h S_{hT}^2} \quad (\text{B.48})$$

$$3. \text{ Proportional, Method 1, } n_h \propto N_h: \quad n = \frac{N \sum_{h=1}^L N_h S_{hT}^2}{V(\hat{Y}) + \sum_{h=1}^L N_h S_{hT}^2} \quad (\text{B.49})$$

$$4. \text{ Proportional, Method 2, } n_h \propto M_h: \quad n = \frac{M \sum_{h=1}^L \frac{N_h^2 S_{hT}^2}{M_h}}{V(\hat{Y}) + \sum_{h=1}^L N_h S_{hT}^2} \quad (\text{B.50})$$

General Formulas

Variance for the estimate of total in terms of margin of error and $Z_{(1-\alpha)}$ value is

$$v(\hat{Y}) \approx \frac{d_T^2}{Z_{(1-\alpha)}^2} . \quad (E.51)*$$

* Assumes a normal distribution of $\hat{Y}$.

APPENDIX C

HISTOGRAMS REPRESENTING THE SEPARATE AND COMPOSITE

POPULATIONS AND STRATA

MICHIGAN AND MINNESOTA DATA

APPENDIX C (Continued)

Histograms Representing the Separate Populations and Strata

Million Tons

FLAT TOPOGRAPHY

0-100 V.P.D.

1975 TRAFFIC

NUMBER OF HIGHWAY SECTIONS

400

300

200

100

0

800
720
640
560
480
400
320
240
160
80
0

COST OF IMPROVEMENT IN THOUSANDS OF DOLLARS

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
(MICHIGAN DATA)

FIGURE C1

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
(MICHIGAN DATA)

FIGURE C2

FLAT TOPOGRAPHY

400-1000 V.P.D.

1975 TRAFFIC

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
(MICHIGAN DATA)

FIGURE C3

FLAT TOPOGRAPHY

OVER 1000 V.P.D.

1975 TRAFFIC

NUMBER OF HIGHWAY SECTIONS

400

300

200

100

0

COST OF IMPROVEMENT IN THOUSANDS OF DOLLARS

HISTOGRAM REPRESENTING COST-OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
(MICHIGAN DATA)

FIGURE C4

800

720

640

560

480

400

320

240

160

80

0

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
(MICHIGAN DATA)

FIGURE C5

ROLLING TOPOGRAPHY

100-400 V.P.D.

1975 TRAFFIC

400

NUMBER OF HIGHWAY SECTIONS

300

200

100

0

800

720

640

560

480

400

320

240

160

80

COST OF IMPROVEMENT IN THOUSANDS OF DOLLARS

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
(MICHIGAN DATA)

FIGURE C6

ROLLING TOPOGRAPHY

400-1000 V.P. D.

1975 TRAFFIC

NUMBER OF HIGHWAY SECTIONS

COST OF IMPROVEMENT IN THOUSANDS OF DOLLARS

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
(MICHIGAN DATA)

FIGURE C7

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
(MICHIGAN DATA)

FIGURE C8

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
(MICHIGAN DATA)

FIGURE C9

SUM OVER ALL TOPOGRAPHY AND TRAFFIC STRATA

COST OF IMPROVEMENT IN THOUSANDS OF DOLLARS

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
DURING FIRST FIVE YEARS (MICHIGAN DATA)

FIGURE C10

HISTOGRAM REPRESENTING COST OF IMPROVEMENT FOR RECONSTRUCTION OF RURAL HIGHWAY SECTIONS
(MICHIGAN DATA)

FIGURE CII

HISTOGRAM REPRESENTING COST OF IMPROVEMENT FOR RURAL BRIDGES PLUS APPROACHES
(MICHIGAN DATA)

FIGURE C12

HISTOGRAM REPRESENTING COST OF IMPROVEMENT FOR RURAL BRIDGES
(MICHIGAN DATA)

FIGURE C13

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF APPROACHES TO RURAL BRIDGES
(MICHIGAN DATA)

FIGURE C14

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF RURAL BRIDGES PLUS APPROACHES
DURING FIRST FIVE YEARS (MICHIGAN DATA)

FIGURE C15

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF RURAL RAILROAD CROSSINGS
(MICHIGAN DATA)

FIGURE C16

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF RURAL RAILROAD CROSSINGS
DURING FIRST FIVE YEARS (MICHIGAN DATA)

FIGURE C17

SUM OF ALL POPULATION STRATA

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE URBAN HIGHWAY SECTIONS
(MICHIGAN DATA)

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE URBAN HIGHWAY SECTIONS
DURING FIRST FIVE YEARS (MICHIGAN DATA)

FIGURE C19

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE URBAN HIGHWAY SECTIONS
POPULATION LESS THAN 5000 (MICHIGAN DATA)

FIGURE C20

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE URBAN HIGHWAY SECTIONS
DURING FIRST FIVE YEARS - POPULATION LESS THAN 5000 (MICHIGAN DATA)

FIGURE C 21

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF RESURFACING AND WIDENING
OF URBAN HIGHWAY SECTIONS - POPULATION LESS THAN 5000 (MICHIGAN DATA)

FIGURE C22

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF URBAN BRIDGES PLUS APPROACHES
POPULATION LESS THAN 5000 (MICHIGAN DATA)

FIGURE C23

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF URBAN BRIDGES PLUS APPROACHES
DURING FIRST FIVE YEARS - POPULATION LESS THAN 5000 (MICHIGAN DATA)

FIGURE C24

FIGURE C25

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF URBAN BRIDGES
POPULATION MORE THAN 5000 (MICHIGAN DATA)

FIGURE C 26

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE URBAN HIGHWAY SECTIONS
POPULATION MORE THAN 5000 (MICHIGAN DATA)

FIGURE C27

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF URBAN BRIDGES PLUS APPROACHES
DURING FIRST FIVE YEARS - POPULATION MORE THAN 5000 (MICHIGAN DATA)

FIGURE C28

APPENDIX C (Continued)

Michigan: Representing the Composite Formations and StrataMichigan Data

HISTOGRAM REPRESENTING COST OF IMPROVEMENT FOR RURAL COMPOSITE POPULATION
(ALL HIGHWAY BRIDGE AND RAILROAD CROSSING IMPROVEMENTS)
(MICHIGAN DATA)

APPENDIX C (Continued)

Histograms Representing the Separate Populations and Strata

Minnesota Data

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE RURAL HIGHWAY SECTIONS
(MINNESOTA DATA)

FIGURE C 30

HISTOGRAM REPRESENTING COST OF IMPROVEMENT FOR RURAL BRIDGES
(MINNESOTA DATA)

FIGURE C 31

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF RURAL RAILROAD CROSSINGS
(MINNESOTA DATA)

FIGURE C 32

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF THE URBAN HIGHWAY SECTIONS
(MINNESOTA DATA)

FIGURE C 33

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF URBAN BRIDGES
(MINNESOTA DATA)

FIGURE C 34

SUM OVER ALL POPULATION STRATA

HISTOGRAM REPRESENTING COST OF IMPROVEMENT OF URBAN RAILROAD CROSSINGS
(MINNESOTA DATA)

FIGURE C 35

APPENDIX C (Continued)

Histograms Representing the Composite Populations and Strata

Minnesota Data

HISTOGRAM REPRESENTING COST OF IMPROVEMENT FOR RURAL COMPOSITE POPULATION
(ALL HIGHWAY BRIDGE AND RAILROAD CROSSING IMPROVEMENTS)

(MINNESOTA DATA)

APPENDIX D

POPULATION AND STRATA TOTALS

AND VARIANCES FOR THE SEPARATE AND COMPOSITE POPULATIONS

FOR

MICHIGAN AND MINNESOTA DATA USED IN

SIMPLE AND STRATIFIED RANDOM SAMPLING AND

SIMPLE AND STRATIFIED CLUSTER SAMPLING

APPENDIX D (Continued)

Populations and Strata Cost Totals and Variances

See Use 1.

Simple and Stratified Random Sampling

Michigan Data

TABLE D1. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR RURAL HIGHWAYS-TOPOGRAPHY, TRAFFIC AND LENGTH STRATIFICATION-MICHIGAN DATA

1975 Traffic	Length Miles	Total Cost (\$1000)	Number of Cards Containing Costs- N_h	Total Number of Cards N_h	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{(N_h - 1)N_h}$
<u>Flat Topography</u>					
Under 100	0-5.99	15,080	228	228	2,306
V.P.D.	6.00-Max.	4,792	36	36	1,401
100- 400	0-5.99	90,138	1,512	1,513	1,751
V.P.D.	6.00-Max.	27,243	214	214	5,178
100- 600	0-5.99	60,086	1,032	1,032	2,582
V.P.D.	6.00-Max.	30,336	168	169	11,447
Over 600	0-5.99	88,309	790	794	14,256
V.P.D.	6.00-Max.	22,200	87	87	23,622
<u>Subtotal</u>		357,374	4,067	4,073	
<u>Rolling Topography</u>					
Under 100	0-5.99	8,435	167	157	914
V.P.D.	6.00-Max.	3,495	21	21	1,677
100- 400	0-5.99	51,927	891	892	1,296
V.P.D.	6.00-Max.	19,341	111	111	5,076
100- 600	0-5.99	31,656	555	555	1,367
V.P.D.	6.00-Max.	10,299	65	65	1,549
Over 600	0-5.99	40,893	395	397	7,228
V.P.D.	6.00-Max.	13,302	40	40	61,431
<u>Subtotal</u>		179,348	2,245	2,248	
<u>Total</u> (Flat & Rolling)		536,722	6,312	6,321	7,073

TABLE D2. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR RURAL HIGHWAYS-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MICHIGAN DATA

<u>1975 Traffic</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards Containing Costs-N_h</u>	<u>Total Number of Cards N_h</u>	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{(N_h - 1)N_h}$
<u>Flat Topography</u>				
Under 100 V.P.D.	19,872	264	264	3,571
100-400 V.P.D.	127,481	1,726	1,727	3,607
400-1000 V.P.D.	99,422	1,200	1,201	5,788
Over 1000 V.P.D.	110,599	877	881	17,089
<u>Subtotal</u>	357,374	4,067	4,073	
<u>Rolling Topography</u>				
Under 100 V.P.D.	11,930	188	188	2,652
100-400 V.P.D.	71,268	1,002	1,003	3,174
400-1000 V.P.D.	41,955	620	620	2,660
Over 1000 V.P.D.	54,195	435	437	17,067
<u>Subtotal</u>	179,348	2,245	2,248	
<u>Total</u>	536,722	6,312	6,321	7,073

TABLE D3. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR COSTS OCCURRING DURING DIFFERENT TIME PERIODS FOR RURAL HIGHWAYS-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MICHIGAN DATA

<u>Flat Topography</u>				
<u>1975 Traffic</u>	<u>Timing of Costs (Years)</u>	<u>Costs (\$1000)</u>	<u>Number of Cards</u> N_{hi}	$\frac{N_h \sum_i c_{hij}^2 - (\sum_i c_{hij})^2}{(N_h - 1)N_h}$
Under 100 V.P.D.	0-5	2,126	29	961
	5-10	6,117	71	2,394
	10-15	7,417	101	2,614
	15-20	4,212	63	1,633
	Over 20	0	0	--
	<u>Total</u>	19,872	264	
100-400 V.P.D.	0-5	51,075	653	2,767
	5-10	42,515	603	2,096
	10-15	22,708	362	1,261
	15-20	4,183	108	158
	Over 20	0	1	--
	<u>Total</u>	127,481	1,727	
400-1000 V.P.D.	0-5	55,303	607	1,408
	5-10	29,143	339	4,216
	10-15	9,117	151	764
	15-20	5,859	102	465
	Over 20	0	1	--
	<u>Total</u>	99,422	1,201	
Over 1000 V.P.D.	0-5	46,013	284	8,390
	5-10	29,845	229	7,122
	10-15	10,041	158	1,551
	15-20	15,700	106	7,538
	Over 20	0	4	--
	<u>Total</u>	110,599	881	
<u>Subtotal</u>		357,374	4,073	

TABLE D3 (Continued). SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR COSTS OCCURRING DURING DIFFERENT TIME PERIODS FOR RURAL HIGHWAYS- TOPOGRAPHY AND TRAFFIC STRATIFICATION- MICHIGAN DATA

<u>Rolling Topography</u>				
<u>1975 Traffic</u>	<u>Timing of Costs (Years)</u>	<u>Costs (\$1000)</u>	<u>Number of Cards</u> N_{hi}	$\frac{S_{hj}^2}{N_h} = \frac{\sum_i N_{hi} \sum_j c_{hij}^2 - (\sum_i \sum_j c_{hij})^2}{(N_h - 1)N_h}$
Under 100 V.P.D.	0-5	1,500	27	518
	5-10	1,219	62	1,811
	10-15	1,561	70	2,023
	15-20	1,650	28	1,075
	Over 20	0	0	--
	<u>Total</u>	11,930	188	
100-400 V.P.D.	0-5	27,156	365	2,352
	5-10	28,502	270	2,626
	10-15	11,784	197	1,115
	15-20	3,826	70	390
	Over 20	0	1	--
	<u>Total</u>	71,268	1,003	
400-1000 V.P.D.	0-5	21,811	200	2,818
	5-10	12,424	186	1,634
	10-15	6,884	120	965
	15-20	836	24	62
	Over 20	0	0	--
	<u>Total</u>	41,955	620	
Over 1000 V.P.D.	0-5	29,650	218	11,165
	5-10	13,808	120	6,028
	10-15	8,425	73	5,005
	15-20	2,312	24	1,288
	Over 20	0	2	--
	<u>Total</u>	54,195	437	
<u>Subtotal</u>		179,348	2,248	
<u>Total</u> (Flat & Rolling)		536,722	6,321	7,073

Flat Topography

1975 Traffic	Type of Construction	Number of Cards N_{hi}	Mileage	$S_{hj}^2 = \frac{N_h \sum_i m_{hij}^2 - (\sum_i m_{hij})^2}{(N_h - 1)N_h}$	Cost (\$1000)	$S_{hj}^2 = \frac{N_h \sum_i m_{hij}^2 - (\sum_i m_{hij})^2}{(N_h - 1)N_h}$
Under 100 V.P.D.	Resurf. & Widen	29	70.95	9,340	733	136
	Base & Surf.	35	129.05	28,300	1,856	658
	Reconstruction	190	743.62	81,803	15,968	3,834
	New Const.	10	67.28	22,221	1,315	876
	None	0	0		0	
	<u>Total</u>	264	1,010.90		19,872	
100- 100 V.P.D.	Resurf. & Widen	374	1,109.48	27,121	12,615	399
	Base & Surf.	212	702.46	18,412	12,074	592
	Reconstruction	1,107	3,990.23	87,020	100,258	1,382
	New Const.	33	92.23	2,624	2,534	202
	None	1	5.82	196	0	
	<u>Total</u>	1,727	5,900.32		127,181	
100- 100 V.P.D.	Resurf. & Widen	423	1,377.58	45,056	19,227	878
	Base & Surf.	165	614.32	23,558	11,930	912
	Reconstruction	604	2,160.60	73,170	67,200	723
	New Const.	8	25.99	983	1,055	139
	None	1	6.00	300	0	
	<u>Total</u>	1,201	4,184.49		99,122	
Over 100 V.P.D.	Resurf. & Widen	410	1,172.20	41,144	38,084	5,714
	Base & Surf.	109	337.30	16,093	9,292	1,338
	Reconstruction	345	1,096.39	44,658	58,298	16,744
	New Const.	13	35.26	1,289	1,925	2,574
	None	4	9.94	354	0	
	<u>Total</u>	881	2,651.09		110,599	
	<u>Subtotal</u>	4,073	13,717.80		377,374	

Rolling Topography

1975 Traffic	Type of Construction	Number of Cards N_{hi}	Mileage	$S_{hj}^2 = \frac{N_{hi} \sum m_{hij}^2}{(N_h - 1)N_h}$	Cost (\$1000)	$S_{hj}^2 = \frac{N_{hi} \sum c_{hij}^2}{(N_h - 1)N_h}$
Under 100 V.F.D.	Resurf. & Widen	24	73.39	17,215	647	173
	Base & Surf.	29	70.67	10,815	1,006	239
	Reconstruction	130	459.86	69,569	9,835	3,275
	New Const.	5	18.81	3,952	442	216
	None	0	0	--	0	--
	Total	188	622.73		11,930	
100- 400 V.F.D.	Resurf. & Widen	221	656.34	26,209	7,574	476
	Base & Surf.	105	376.74	18,303	5,006	556
	Reconstruction	657	2,319.47	82,911	56,026	364
	New Const.	19	70.73	14,872	1,762	285
	None	1	1.30	17	0	--
	Total	1,003	3,424.08		72,268	
400- 1000 V.P.D.	Resurf. & Widen	267	848.30	40,198	11,047	784
	Base & Surf.	59	181.89	10,650	2,195	1,25
	Reconstruction	286	980.71	19,589	26,275	3,510
	New Const.	8	49.21	7,571	1,138	376
	None	0	0	--	0	--
	Total	620	2,060.11		41,955	
Over 1000 V.P.L.	Resurf. & Widen	212	647.55	53,285	19,925	6,375
	Base & Surf.	52	112.82	12,116	6,097	2,550
	Reconstruction	169	553.28	17,299	27,912	16,771
	New Const.	2	8.19	861	231	69
	None	2	2.75	143	0	--
	Total	437	1,355.59		54,195	
Subtotal		2,248	7,162.51		179,248	
Total		6,321	21,210.31		536,722	7,073

TABLE D5. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR RURAL BRIDGES (PLUS APPROACHES)-TRAFFIC STRATIFICATION-MICHIGAN DATA

1975 Traffic	Total Costs Bridges and Approaches (\$1000)	Number of Cards Containing Costs N'_h	Total Number of Cards N_h	$S_h^2 = \frac{N_h \sum_i c_{hi}^2 - (\sum_i c_{hi})^2}{(N_h - 1)N_h}$
Under 100 P.D.	3,112	85	105	840
100-400 P.D.	25,156	624	788	1,263
400-1000 P.D.	18,074	423	614	2,116
Over 1000 P.D.	17,515	272	478	5,935
Total	63,957	1,404	1,985	2,634

TABLE D6. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE OF DIFFERENT TYPES OF CONSTRUCTION FOR RURAL BRIDGES (PLUS APPROACHES)-TRAFFIC STRATIFICATION-MICHIGAN DATA

1975 Traffic	Type of Construction	Number of Cards N_{hi}	Cost (Bridges Only) (\$1000)	$S_{hj}^2 = \frac{N_h \sum c_{hij}^2 - (\sum c_{hij})^2}{N_h(N_h - 1)}$
Under 100 V.P.D.	Reflooring	3	59	23.12
	Rebuild or Rec.	8	202	89.22
	Replace S. Loc.	66	2,115	759.2
	Replace N. Loc.	8	229	117.9
	New Sep. or Str.	0	0	
	None	20	0	
	<u>Total</u>	<u>105</u>	<u>2,705</u>	
100- 400 V.P.D.	Reflooring	16	111	20.78
	Rebuild or Rec.	73	1,186	118.01
	Replace S. Loc.	179	18,756	966.6
	Replace N. Loc.	56	2,173	1116.1
	New Sep. or Str.	0	0	
	None	161	0	
	<u>Total</u>	<u>788</u>	<u>23,826</u>	
400- 1000 V.P.D.	Reflooring	7	138	7.930
	Rebuild or Rec.	54	782	25.62
	Replace S. Loc.	317	12,821	1,180
	Replace N. Loc.	44	2,215	980.5
	New Sep. or Str.	1	280	127.5
	None	191	0	
	<u>Total</u>	<u>611</u>	<u>17,746</u>	
Over 1000 V.P.D.	Reflooring	3	28	.9690
	Rebuild or Rec.	62	1,899	352.2
	Replace S. Loc.	176	10,287	2,139
	Replace N. Loc.	18	1,453	117.6
	New Sep. or Str.	12	3,330	2,222
	None	206	0	
	<u>Total</u>	<u>478</u>	<u>17,097</u>	
<u>Totals</u>		<u>1,985</u>	<u>61,174</u>	<u>2,634</u>

TABLE D7. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR RURAL BRIDGES
(AND APPROACHES)-TRAFFIC STRATIFICATION-MICHIGAN DATA

1975 Traffic	Total Approach Cost (\$1000)	Number of Cards Containing Costs N_h'	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{N_h(N_h - 1)}$	Total Bridges Costs (\$1000)	Number of Cards Containing Costs N_h'	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{N_h(N_h - 1)}$
Under 100 V.P.D.	207	45	23.12	2,905	85	759.3
100-400 V.P.D.	1,330	223	33.07	23,826	622	1,155
400-1000 V.P.D.	728	128	12.83	17,346	423	1,295
Over 1000 V.P.D.	518	72	32.86	17,097	271	5,396
<u>Total</u>	<u>2,783</u>	<u>468</u>	<u>26.28</u>	<u>61,174</u>	<u>1,401</u>	<u>2,412</u>

TABLE D8. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR COSTS OCCURRING AT DIFFERENT TIME PERIODS FOR RURAL BRIDGE PLUS APPROACHES-TRAFFIC STRATIFICATION-MICHIGAN DATA

1975 Traffic	Timing of Cost (Years)	Total Cost Bridges and Approaches (\$1000)	Number of Cards N_{hi}	$\frac{N_h \sum_{hi}^2 c_{hij}^2 - (\sum_{hi}^2 c_{hij})^2}{N_h(N_h - 1)}$
Under 100 V.P.D.	0-5	479	18	141.0
	5-10	982	29	292.2
	10-15	968	21	552.2
	15-20	682	17	296.6
	Over 20	0	20	
	<u>Total</u>	<u>3,112</u>	<u>105</u>	
100-400 V.P.D.	0-5	9,826	219	722.4
	5-10	7,065	172	571.1
	10-15	5,458	151	287.8
	15-20	2,807	81	228.6
	Over 20	0	164	
	<u>Total</u>	<u>25,156</u>	<u>788</u>	
400-1000 V.P.D.	0-5	8,064	168	1,234
	5-10	4,249	99	804.9
	10-15	4,041	93	529.5
	15-20	1,720	62	132.7
	Over 20	0	191	
	<u>Total</u>	<u>18,074</u>	<u>614</u>	
Over 1000 V.P.D.	0-5	6,437	95	1,988
	5-10	4,466	59	2,328
	10-15	3,323	73	1,374
	15-20	2,889	45	1,236
	Over 20	0	206	
	<u>Total</u>	<u>17,615</u>	<u>478</u>	
<u>Total</u>		<u>63,957</u>	<u>1,985</u>	<u>2,634</u>

TABLE D9. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR TYPE OF SERVICE OF THE STRUCTURE, RURAL BRIDGES ONLY-TRAFFIC STRATIFICATION-MICHIGAN DATA

1975 Traffic	Type of Service	Number of Cards N_h	Total Cost (Bridges Only) (\$1000)	$\frac{N_h \sum_{ij} c_{hij}^2 - (\sum_{ij} c_{hij})^2}{N_h(N_h - 1)}$
Under 100 V.P.D.	Stream Crossing	85	2,905	759.3
	Highway Sep.	0	0	--
	R.R. Under Hwy.	0	0	--
	R.R. Over Hwy.	0	0	--
	Adequate	20	0	--
	<u>Total</u>	<u>105</u>	<u>2,905</u>	
100- 400 V.P.D.	Stream Crossing	616	23,497	1,159
	Highway Sep.	2	49	1.520
	R.R. Under Hwy.	4	181	12.32
	R.R. Over Hwy.	2	99	6.610
	Adequate	164	0	--
	<u>Total</u>	<u>788</u>	<u>23,826</u>	
400- 1000 V.P.D.	Stream Crossing	418	17,156	1,094
	Highway Sep.	2	20	.3250
	R.R. Under Hwy.	2	107	11.11
	R.R. Over Hwy.	1	63	6.160
	Adequate	191	0	--
	<u>Total</u>	<u>614</u>	<u>17,346</u>	
Over 1000 V.P.D.	Stream Crossing	257	11,547	3,480
	Highway Sep.	3	530	222.2
	R.R. Under Hwy.	6	470	96.52
	R.R. Over Hwy.	6	1,550	1,231
	Adequate	206	0	--
	<u>Total</u>	<u>478</u>	<u>17,097</u>	
<u>Totals</u>		1,985	61,174	2,412

TABLE D10. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR RURAL RAILROAD CROSSINGS-TRAFFIC STRATIFICATION-MICHIGAN DATA

<u>1975 Traffic</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards Containing Costs N_h</u>	<u>Total Number of Cards J_h</u>	$s_h^2 = \frac{N_h \sum_{i=1}^{N_h} c_{hi}^2 - (\sum_{i=1}^{N_h} c_{hi})^2}{N_h(N_h - 1)}$
Under 100 V.P.D.	25	5	9	0.91
100-400 V.P.D.	472	74	150	15.72
400-1000 V.P.D.	757	106	150	19.25
Over 1000 V.P.D.	1,503	196	212	32.35
<u>Total</u>	2,757	281	521	20.03

TABLE D11. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR COSTS OCCURRING DURING DIFFERENT TIME PERIODS FOR RURAL RAILROAD CROSSINGS-TRAFFIC STRATIFICATION-MICHIGAN DATA

<u>1975 Traffic</u>	<u>Timing of Cost (Years)</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards N_{hi}</u>	$\frac{N_h \sum c_{hij}^2 - (\sum_i c_{hij})^2}{N_h(N_h - 1)}$
Under 100 V.P.D.	C-5	15	3	6.25
	5-10	5	1	2.75
	10-15	0	0	--
	15-20	5	1	2.75
	Over 20	0	1	--
	<u>Total</u>	<u>25</u>	<u>9</u>	
100- 400 V.P.D.	C-5	234	26	10.21
	5-10	112	18	5.29
	10-15	86	12	5.51
	15-20	40	8	1.27
	Over 20	0	76	--
	<u>Total</u>	<u>472</u>	<u>150</u>	
400- 1000 V.P.D.	C-5	567	73	21.1
	5-10	78	15	2.16
	10-15	66	11	3.20
	15-20	46	7	2.63
	Over 20	0	144	--
	<u>Total</u>	<u>757</u>	<u>150</u>	
Over 1000 V.P.D.	C-5	1,112	113	21.52
	5-10	224	24	25.73
	10-15	85	12	3.00
	15-20	82	14	2.32
	Over 20	0	10	--
	<u>Total</u>	<u>1,503</u>	<u>212</u>	
<u>Totals</u>		<u>2,757</u>	<u>521</u>	<u>26.03</u>

TABLE D12. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE OF DIFFERENT TYPES OF RAILROAD CROSSING PROTECTION FOR RURAL RAILROAD CROSSINGS-TRAFFIC STRATIFICATION-MICHIGAN DATA

1975 Traffic	Type of Construction	Number of Cards N_{hi}	Total Costs (\$1000) $\sum c_{hij}$	$S_{hj}^2 = \frac{N_h \sum c_{hij}^2 - (\sum c_{hij})^2}{N_h(N_h - 1)}$
Over	Signals	5	25	6.94
100	Signals & Gates	0	0	--
V.P.D.	None	1	0	--
	<u>Total</u>	<u>9</u>	<u>25</u>	
100-	Signals	56	282	6.12
400	Signals & Gates	18	190	11.38
V.P.D.	None	76	0	--
	<u>Total</u>	<u>150</u>	<u>472</u>	
400-	Signals	80	1149	9.86
1000	Signals & Gates	26	308	21.76
V.P.D.	None	44	0	--
	<u>Total</u>	<u>150</u>	<u>757</u>	
Over	Signals	126	669	7.42
1000	Signals & Gates	67	834	59.82
V.P.D.	None	19	0	--
	<u>Total</u>	<u>212</u>	<u>1,503</u>	
<u>Totals</u>		521	2,757	26.03

TABLE D13. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR URBAN HIGHWAYS-POPULATION GROUP STRATIFICATION-MICHIGAN DATA

Population Group	Total Cost (\$1000)	Number of Cards Containing Costs- N_h	Total Number of Cards N_h	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{(N_h - 1)N_h}$
Population Less than 5000	5,970	74	74	9,271
Population Over 5000	84,545	202	202	398,201
<u>Total</u>	90,515	276	276	315,991

TABLE D14. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR COSTS OCCURRING DURING DIFFERENT TIME PERIODS FOR URBAN HIGHWAYS-POPULATION GROUP STRATIFICATION-MICHIGAN DATA

Population Group	Timing of Costs (Years)	Costs (\$1000)	Number of Cards N_{hi}	$S_{hj}^2 = \frac{N_h \sum c_{hij}^2 - (\sum c_{hij})^2}{N_h(N_h - 1)}$
Population Less than 5000	0-5	1,818	33	1,590
	5-10	1,469	18	2,770
	10-15	2,335	20	9,017
	15-20	348	3	597
	Over 20	0	0	—
	<u>Total</u>	5,970	74	9,271
Population Over 5000	0-5	30,803	92	112,566
	5-10	32,280	54	3,100,367
	10-15	12,848	32	607,329
	15-20	8,614	24	269,361
	Over 20	0	0	—
	<u>Total</u>	84,545	202	398,201
<u>Totals</u>		90,515	276	315,991

TABLE D15. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE OF DIFFERENT TYPES OF CONSTRUCTION FOR URBAN HIGHWAYS-POPULATION GROUP STRATIFICATION-MICHIGAN DATA

Population Group	Type of Construction	Number of Cards N_{hi}	Mileage	$\frac{N_h \sum_{hi}^2 m_{hij}^2 - (\sum_{i} m_{hij})^2}{N_h(N_h - 1)}$	Costs (\$1000)	$\frac{N_h \sum_{hi}^2 c_{hij}^2 - (\sum_{i} c_{hij})^2}{N_h(N_h - 1)}$
Population Less than 5000	Resurf. & Widen	42	40.83	.7496	2,976	5,953
	Reconstruction	21	46.67	1.9293	2,919	6,622
	New Street	1	0.50	.0034	75	760
	None	0	0	—	0	—
	Total	74	88.00	—	5,970	9,271
Population Over 5000	Resurf. & Widen	118	160.72	1.1783	24,749	29,958
	Reconstruction	75	133.38	1.7139	53,124	410,625
	New Street	9	20.07	.2835	6,672	37,375
	None	0	0	—	0	—
	Total	202	314.17	—	84,545	398,201
Totals		276	402.17		90,515	315,091

Population Group	Total Cost Bridge and Approaches (\$1000)	Number of Cards Containing Costs N'_h	Total Number of Cards N_h	$\frac{N_h \sum_i c_{hi}^2 - (\sum_i c_{hi})^2}{N_h(N_h - 1)}$
Population Less than 5000	293	5	20	1,066
Population Over 5000	13,968	24	24	459,697
<u>Total</u>	14,261	29	44	328,000

TABLE D16 (Continued)

Population Group	Total Approach Cost (\$1000)	Number of Cards Containing Costs N'_h	$\frac{N_h \sum_i c_{hi}^2 - (\sum_i c_{hi})^2}{(N_h - 1)N_h}$	Total Bridge Cost (\$1000)	Number of Cards Containing Costs N'_h	$\frac{N_h \sum_i c_{hi}^2 - (\sum_i c_{hi})^2}{N_h(N_h - 1)}$
Population Less than 5000	6	1	1.80	287	5	1,055
Population Over 5000	0	0	-	13,968	24	459,697
<u>Total</u>	6	1	0.82	14,255	29	328,100

TABLE D17. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR COSTS OCCURRING DURING DIFFERENT TIME PERIODS FOR URBAN BRIDGES (PLUS APPROACHES) - POPULATION GROUP STRATIFICATION-NICHIGAN DATA

<u>Population Group</u>	<u>Timing of Cost (Years)</u>	<u>Total Cost Structures and Approaches (\$1000)</u>	<u>Number of Cards N_{hi}</u>	$S_{hj}^2 = \frac{N_h \sum_1 c_{hij}^2 - (\sum_1 c_{hij})^2}{N_h (N_h - 1)}$
Population Less than 5000	0-5	275	4	1,076
	5-10	0	0	--
	10-15	0	0	--
	15-20	13	1	16.20
	Over 20	0	15	--
	<u>Total</u>	<u>293</u>	<u>20</u>	
Population Over 5000	0-5	1,445	6	41,653
	5-10	7,429	12	271,824
	10-15	3,950	3	345,756
	15-20	1,144	3	19,509
	Over 20	0	0	--
	<u>Total</u>	<u>13,968</u>	<u>24</u>	
<u>Totals</u>		<u>14,261</u>	<u>44</u>	<u>328,000</u>

TABLE D18. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE OF DIFFERENT TYPES OF CONSTRUCTION FOR URBAN BRIDGES ONLY-POPULATION GROUP STRATIFICATION-MICHIGAN DATA

Population Group	Type of Construction	Number of Cards N_h	Cost Structures Only (\$1000)	$\frac{N_h \sum_i c_{hi}^2}{N_h(N_h - 1)} = \frac{\sum_{hj} N_h c_{hi}^2}{N_h(N_h - 1)}$
Population Less than 5000	Reflooring	0	0	--
	Rebuild or Rec.	1	13	16.20
	Replace S Loc.	4	269	1,065
	Replace N Loc.	0	0	--
	New Sep. or Str.	0	0	--
	None	15	0	--
	Total	20	287	
Population Over 5000	Reflooring	2	2,894	314,533
	Rebuild or Rec.	12	4,643	193,049
	Replace S Loc.	1	60	150
	Replace N Loc.	1	103	442
	New Sep. or Str.	8	6,268	179,549
	None	0	0	--
	Total	24	13,968	
Total		44	14,255	328,100

TABLE D19.

SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR
DIFFERENT TYPES OF SERVICE OF THE STRUCTURE FOR UREAN BRIDGES
ONLY-POPULATION GROUP STRATIFICATION-MICHIGAN DATA

Population Group	Type of Service	Number of Cards N_h	Total Cost Structures Only (\$1000)	$\frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{N_h(N_h - 1)}$
Population Less than 5000	Stream Crossing	5	287	1,055
	Highway Sep.	0	0	--
	R.R. Under Hwy.	0	0	--
	R.R. Over Hwy.	0	0	--
	Adequate Total	$\frac{15}{20}$	$\frac{0}{287}$	
Population Over 5000	Stream Crossing	12	3,830	503,234
	Highway Sep.	8	5,244	146,410
	R.R. Under Hwy.	4	4,894	41,775
	R.R. Over Hwy.	0	0	--
	Adequate Total	$\frac{0}{24}$	$\frac{0}{13,968}$	--
<u>Totals</u>		44		328,100

TABLE D20. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR URBAN RAILROAD CROSSINGS-POPULATION GROUP STRATIFICATION-MICHIGAN DATA

<u>Population Group</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards Containing Costs</u> N'_h	<u>Total Number of Cards</u> N_h	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{N_h(N_h - 1)}$
Population Less than 5000	47	6	6	10.16
Population Over 5000	Incomplete Data			
<u>Total</u>	--	-	-	--

TABLE D21. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR COSTS OCCURRING DURING DIFFERENT TIME PERIODS FOR URBAN RAILROAD CROSSINGS-POPULATION GROUP STRATIFICATION-MICHIGAN DATA

<u>Population Group</u>	<u>Timing of Cost (Years)</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards</u> N_{hi}	$S_{hj}^2 = \frac{N_h \sum c_{hij}^2 - (\sum c_{hij})^2}{N_h(N_h - 1)}$
Population Less than 5000	0-5	47	6	10.16
	5-10	0	0	-
	10-15	0	0	-
	15-20	0	0	-
	Over 20	0	0	-
	<u>Total</u>	47	6	
Population Over 5000	0-5	Incomplete Data		
	5-10			
	10-15			
	15-20			
	Over 20			
<u>Total</u>				
<u>Total</u>				

TABLE D22.

SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE OF
DIFFERENT TYPE OF RAILROAD CROSSING PROTECTION FOR URBAN
RAILROAD CROSSINGS-POPULATION GROUP STRATIFICATION-MICHIGAN
DATA

<u>Population Group</u>	<u>Type of Construction</u>	<u>Number of Cards N_{hi}</u>	<u>Total Costs (\$1000)</u>	$S_{hj}^2 = \frac{N_h \sum_i c_{hij}^2 - (\sum_i c_{hij})^2}{N_h(N_h - 1)}$
Population Less than 5000	Signals Signals & Gates None <u>Total</u>	3 3 0 6	15 32 0 47	7.50 34.66 - -
Population Over 5000	Signals Signals & Gates None <u>Total</u>			
<u>Total</u>				

Incomplete Data

TABLE D23. COMPOSITE POPULATION AND STRATUM COST
TOTAL AND VARIANCE (ALL RURAL HIGHWAY,
BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-
TOPOGRAPHY AND TRAFFIC STRATIFICATION-
MICHIGAN DATA

<u>1975 Traffic</u>	Total Cost: (Highways, Bridges, & Railroad Crossings) (\$1000)	Total Number of Cards <u>N_h</u>	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{N_h (N_h - 1)}$
<u>Flat Topography</u>			
Under 100 V.P.D.	22,165	264	5,066
100-400 V.P.D.	145,459	1,727	5,170
400-1000 V.P.D.	114,614	1,201	2,016
Over 1000 V.P.D.	124,916	881	22,803
<u>Total</u>	<u>407,154</u>	<u>4,073</u>	
<u>Rolling Topography</u>			
Under 100 V.P.D.	12,886	188	3,933
100-400 V.P.D.	79,167	1,003	4,406
400-1000 V.P.D.	46,011	620	3,019
Over 1000 V.P.D.	58,257	437	18,227
<u>Total</u>	<u>196,321</u>	<u>2,248</u>	
<u>Total</u> (Flat & Rolling)	603,475		9,316

TABLE D24. COMPOSITE POPULATION AND STRATUM COST
TOTAL AND VARIANCE FOR COSTS OCCURRING
DURING DIFFERENT TIME PERIODS (ALL RURAL
HIGHWAY, BRIDGE, AND RAILROAD CROSSING
IMPROVEMENTS)-TOPOGRAPHY AND TRAFFIC
STRATIFICATION-MICHIGAN DATA

<u>Flat Topography</u>				
<u>1975</u> <u>Traffic</u>	<u>Timing</u> <u>of Costs</u> <u>(Years)</u>	<u>Total</u> <u>Cost</u> <u>(\$1000)</u>	<u>Number</u> <u>of Cards</u> <u>N_{hi}</u>	$S_{hj}^2 = \frac{N_h \sum c_{hij}^2}{N_h(N_h - 1)} - \left(\frac{\sum c_{hij}}{N_h} \right)^2$
Under 100 V.P.D.	0-5	2,217	29	1,075
	5-10	6,963	71	3,375
	10-15	7,981	101	3,292
	15-20	5,004	63	2,353
	Over 20	-	-	-
	<u>Total</u>	<u>22,165</u>	<u>264</u>	
100-400 V.P.D.	0-5	57,370	653	3,602
	5-10	56,599	603	3,242
	10-15	25,915	362	1,915
	15-20	5,075	108	317
	Over 20	-	1	
	<u>Total</u>	<u>145,459</u>	<u>1,727</u>	
400-1000 V.P.D.	0-5	64,565	607	6,390
	5-10	33,654	339	5,459
	10-15	9,981	151	967
	15-20	6,414	103	540
	Over 20	-	1	
	<u>Total</u>	<u>114,614</u>	<u>1,201</u>	
Over 1000 V.P.D.	0-5	52,827	384	12,300
	5-10	33,156	299	9,720
	10-15	21,912	158	6,467
	15-20	17,021	106	5,416
	Over 20	-	4	
	<u>Total</u>	<u>124,916</u>	<u>851</u>	
<u>Subtotal</u>		<u>407,154</u>	<u>4,073</u>	

TABLE D24 (Continued). COMPOSITE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR COSTS OCCURRING DURING DIFFERENT TIME PERIODS (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MICHIGAN DATA

Rolling Topography				
<u>1975 Traffic</u>	<u>Timing of Costs (Years)</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards N_{hi}</u>	$\frac{S_{hj}^2 = N_h \sum c_{hij}^2 - (\sum c_{hij})^2}{N_h(N_h - 1)}$
Under 100 V.P.D.	0-5	1,591	27	643
	5-10	4,574	63	2,528
	10-15	5,019	70	2,832
	15-20	1,702	28	1,237
	Over 20	-	-	
	<u>Total</u>	<u>12,886</u>	<u>188</u>	
100-400 V.P.D.	0-5	30,331	365	3,054
	5-10	31,629	370	3,327
	10-15	13,174	197	1,602
	15-20	4,033	70	497
	Over 20	-	1	
	<u>Total</u>	<u>79,167</u>	<u>1,003</u>	
400-1000 V.P.D.	0-5	24,173	290	4,064
	5-10	13,287	186	1,873
	10-15	7,678	120	1,189
	15-20	873	24	70.32
	Over 20	-	0	
	<u>Total</u>	<u>46,011</u>	<u>620</u>	
Over 1000 V.P.D.	0-5	31,846	218	15,355
	5-10	14,970	120	6,557
	10-15	9,038	73	5,556
	15-20	2,403	24	1,614
	Over 20	-	2	
	<u>Total</u>	<u>58,257</u>	<u>437</u>	
<u>Subtotal</u>		196,321	2,248	
<u>Total</u>				
(Flat & Rolling)		603,475	6,321	9,316

Flat Topography

1975 Traffic	Type of Construction	Number of Cards N_{hi}	Mileage	$N_h \sum_i m_{hij}^2$ $N_h \sum_i m_{hij} - (\sum_i m_{hij})^2$	$S_{hj}^2 = N_h$	Total Costs (\$1000)	$N_h \sum_i c_{hij}^2$ $N_h \sum_i c_{hij} - (\sum_i c_{hij})^2$	$S_{hj}^2 = N_h$
				$N_h (N_h - 1)$			$N_h (N_h - 1)$	
Under 100 V.P.D.	Resurf. & Widen	29	70.95			374	219.5	
	Base & Surface	35	129.05			2,428	1,599	
	Reconstruction	190	743.62			17,480	4,845	
	New Construction	10	67.28			1,333	993.9	
	None	-	0			--	--	
	<u>Total</u>	<u>264</u>	<u>1,010.90</u>			<u>22,165</u>		
100- 400 V.P.D.	Resurf. & Widen	374	1,109.48			15,133	735.5	
	Base & Surface	212	702.46			13,747	841.6	
	Reconstruction	1,107	3,990.33			113,523	5,961	
	New Construction	33	92.23			3,006	267.0	
	None	1	5.82			--	--	
	<u>Total</u>	<u>1,727</u>	<u>5,900.32</u>		SAME AS	<u>145,459</u>		
400- 1000 V.P.D.	Resurf. & Widen	423	1,377.58		TABLE D4	22,993	1,535	
	Base & Surface	165	614.32			14,038	1,357	
	Reconstruction	604	2,160.60			76,393	9,493	
	New Construction	8	25.99			1,135	181.0	
	None	1	6.00			--	--	
	<u>Total</u>	<u>1,201</u>	<u>4,134.49</u>			<u>114,614</u>		
Over 1000 V.P.D.	Resurf. & Widen	410	1,172.20			44,390	3,113	
	Base & Surface	109	337.30			9,709	1,471	
	Reconstruction	345	1,096.39			62,984	19,970	
	New Construction	13	35.26			7,833	6,513	
	None	4	9.94			--	--	
	<u>Total</u>	<u>881</u>	<u>2,651.09</u>			<u>124,916</u>		
<u>Subtotal</u>		<u>4,073</u>	<u>13,746.80</u>			<u>407,154</u>		

TABLE D-3 (Continued) 7. COMPARISON OF PLANNED AND ACTUAL COSTS, TOTAL AND VARIANCE OF DIFFERENT TYPES OF CONSTRUCTION (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)- TOPOGRAPHY AND TRAFFIC STRATIFICATION-MICHIGAN DATA

Rolling Topography

1975 Traffic	Type of Construction	Number of Cards N_{hi}	Mileage	$N_h \sum_{i=1}^m c_{hij}^2$ $N_h \sum_{i=1}^m m_{hij}^2$	$S_{hj}^2 =$ $\sum_{i=1}^m c_{hij}^2$ $N_h(N_h - 1)$	Total Costs (\$1000) $N_h \sum_{i=1}^m c_{hij}^2$ $S_{hj}^2 =$ $\sum_{i=1}^m c_{hij}^2$ $N_h(N_h - 1)$
Under 100 V.P.D.	Resurf. & Widen	24	73.39		172.7	647
	Base & Surface	29	70.67		316.4	1,081
	Reconstruction	130	459.86		4,657	10,666
	New Construction	5	18.81		271.5	492
	None	-	0		--	--
	<u>Total</u>	<u>188</u>	<u>622.73</u>			<u>12,836</u>
100- 400 V.P.D.	Resurf. & Widen	221	656.34		676.8	8,470
	Base & Surface	105	376.74		787.8	7,003
	Reconstruction	657	2,319.47		4,938	61,787
	New Construction	19	70.23		317.2	1,907
	None	1	1.30		--	--
	<u>Total</u>	<u>1,003</u>	<u>3,424.08</u>			<u>79,167</u>
SAME AS TABLE D4						
400- 1000 V.P.D.	Resurf. & Widen	267	248.30		1,730	12,960
	Base & Surface	59	181.89		474.0	3,684
	Reconstruction	286	980.71		4,150	28,086
	New Construction	8	49.21		447.8	1,281
	None	-	0		--	--
	<u>Total</u>	<u>620</u>	<u>2,060.11</u>			<u>46,011</u>
Over 1000 V.P.D.	Resurf. & Widen	212	647.55		7,319	21,915
	Base & Surface	52	143.92		3,197	6,864
	Reconstruction	169	553.28		17,697	29,247
	New Construction	2	8.19		69.80	231
	None	2	2.75		--	--
	<u>Total</u>	<u>437</u>	<u>1,355.59</u>			<u>38,257</u>
Subtotal						
		2,242	7,469.51			136,321
<u>Total (Flat & Rolling)</u>		6,391	21,269.71			653,475

1975 Traffic	Total Bridge Cost (\$1000)	$\frac{N_h^2 \sum c_{hi}^2}{N_h(N_h - 1)}$	Total Railroad Crossing Costs (\$1000)	$\frac{S_h^2 N_h}{N_h^2 \sum c_{hi}^2 - (\sum c_{hi})^2}$
<u>Flat Topography</u>				
Under 100 V.P.D.	2,084	527.0	10	0.3788
100-400 V.P.D.	16,950	729.0	270	1.178
400-1000 V.P.D.	13,766	1,007	524	3.733
Over 1000 V.P.D.	12,788	3,248	1,164	11.50
<u>Subtotal</u>	45,588		1,968	
<u>Rolling Topography</u>				
Under 100 V.P.D.	851	350.0	15	0.3947
100-400 V.P.D.	7,173	575.1	202	1.758
400-1000 V.P.D.	3,892	973.3	186	3.008
Over 1000 V.P.D.	3,663	674.1	350	12.51
<u>Subtotal</u>	15,579		753	
<u>Total</u> (Flat & Rolling)	61,167	1,115	2,721	4.265

APPENDIX D (Continued)

Populations and Strata Cost Totals and Variances
for Use in
Simple and Stratified Cluster Sampling
Michigan Data

TABLE D27. COMPOSITE POPULATION AND STRATUM COST TOTAL AND VARIANCE (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-MILEAGE STRATIFICATION-MICHIGAN DATA

Total County Primary Mileage	Total Cost (\$1000)	Number of Primary Units (Counties) N_h	Number of Elements (Highway Sections) N_h	$S_{hT}^2 = \frac{N_h \sum Y_{hi}^2 - (\sum Y_{hi})^2}{N_h(N_h - 1)}$
0-249.99	153,316	41	1,908	$17,369 \times 10^2$
250-349.99	281,176	30	2,738	$40,465 \times 10^3$
350-Max.	162,994	12	1,675	$15,099 \times 10^3$
<u>Total</u>	603,486	83	6,321	$31,823 \times 10^3$

TABLE D28. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR THE RURAL HIGHWAYS-MILEAGE STRATIFICATION-MICHIGAN DATA

Total County Primary Mileage	Total Cost (\$1000)	Number of Primary Units (Counties) N_h	Number of Elements (Highway Sections) N_h	$S_{hT}^2 = \frac{N_h \sum Y_{hi}^2 - (\sum Y_{hi})^2}{N_h(N_h - 1)}$
0-249.99	139,784	41	1,908	$13,890 \times 10^2$
250-349.99	246,755	30	2,378	$32,303 \times 10^3$
350-Max.	153,008	12	1,675	$13,280 \times 10^3$
<u>Total</u>	539,547	83	6,321	$25,461 \times 10^3$

TABLE D29. SEPARATE POPULATION AND STRATUM COST TOTAL
AND VARIANCE FOR RURAL BRIDGES-MILEAGE
STRATIFICATION-MICHIGAN DATA

<u>Total County Primary Mileage</u>	<u>Total Cost (\$1000)</u>	Number of Primary Units (Counties) N_h	Number of Elements (Highway Sections) N_{hi}	$S_{hT}^2 = \frac{N_h \sum_i Y_{hi}^2 - (\sum_i Y_{hi})^2}{N_h (N_h - 1)}$
0-249.99	13,277	41	1,908	125,273
250-349.99	33,001	30	2,378	733,613
350-Max.	14,836	12	1,675	607,966
<u>Total</u>	61,164	83	6,321	572,914

TABLE D30. SEPARATE POPULATION AND STRATUM COST TOTAL
AND VARIANCE FOR THE RURAL RAILROAD CROSSINGS-
MILEAGE STRATIFICATION-MICHIGAN DATA

<u>Total County Primary Mileage</u>	<u>Total Cost (\$1000)</u>	Number of Primary Units (Counties) N_h	Number of Elements (Highway Sections) N_{hi}	$S_{hT}^2 = \frac{N_h \sum_i Y_{hi}^2 - (\sum_i Y_{hi})^2}{N_h (N_h - 1)}$
0-249.99	213	41	1,908	129
250-349.99	1,409	30	2,378	7,722
350-Max.	1,099	12	1,675	4,207
<u>Total</u>	2,721	83	6,321	4,318

APPENDIX D (Continued)

Populations and Strata Cost Totals and Variances

for Use in

Simple and Stratified Random Sampling

Minnesota Data

TABLE D31. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR RURAL HIGHWAYS-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MINNESOTA DATA

<u>1975 Traffic</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards Containing Costs-N_{hi}</u>	<u>Total Number of Cards N_h</u>	$S_{hi}^2 = \frac{N_h \sum_{hi} c_{hi}^2 - (\sum_{hi} c_{hi})^2}{(N_h - 1)N_h}$
<u>Flat Topography</u>				
Under 100 V.P.D.	19,470	731	735	438
100-400 V.P.D.	94,909	1,443	1,443	2,286
400-1000 V.P.D.	16,962	295	296	4,135
Over 1000 V.P.D.	2,449	53	53	2,184
<u>Subtotal</u>	133,790	2,522	2,527	
<u>Rolling Topography</u>				
Under 100 V.P.D.	35,213	1,061	1,062	999
100-400 V.P.D.	243,615	3,429	3,430	3,246
400-1000 V.P.D.	55,996	762	762	4,565
Over 1000 V.P.D.	10,466	124	124	7,016
<u>Subtotal</u>	345,290	5,376	5,378	
<u>Total</u>	479,080	7,893	7,905	3,133

TABLE D32. SEPARATE POPULATION AND STRATUM COST TOTAL
AND VARIANCE FOR RURAL BRIDGES-TRAFFIC
STRATIFICATION-MINNESOTA DATA

<u>1975 Traffic</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards Containing Costs-N'_h</u>	<u>Total Number of Cards N_h</u>	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{N_h (N_h - 1)}$
<u>Flat and Rolling Topography</u>				
Under 100 V.P.D.	2,954	467	612	474
100-400 V.P.D.	34,036	1,242	1,740	638
400-1000 V.P.D.	10,278	231	360	4,390
Over 1000 V.P.D.	1,456	30	49	1,721
<u>Total</u>	55,724	1,977	2,761	1,122

TABLE D33. SEPARATE POPULATION AND STRATUM COST TOTAL
AND VARIANCE FOR RURAL RAILROAD CROSSINGS-
TRAFFIC STRATIFICATION-MINNESOTA DATA

<u>1975 Traffic</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards Containing Costs-N'_h</u>	<u>Total Number of Cards N_h</u>	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{N_h (N_h - 1)}$
<u>Flat and Rolling Topography</u>				
Under 100 V.P.D.	128	16	134	7.91
100-400 V.P.D.	905	98	386	17.51
400-1000 V.P.D.	561	50	111	115.1
Over 1000 V.P.D.	168	17	31	26.85
<u>Total</u>	1,762	181	662	34.12

TABLE D34. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR URBAN HIGHWAYS-POPULATION GROUP STRATIFICATION-MINNESOTA DATA

<u>Population Group</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards Containing Costs-N'_h</u>	<u>Total Number of Cards N_h</u>	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{(N_h - 1)N_h}$
Population Less than 5000	54,898	2,572	2,584	1,635
Population Over 5000	41,436	713	723	5,237
<u>Total</u>	96,334	3,290	3,307	2,654

TABLE D35. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR URBAN BRIDGES-POPULATION GROUP STRATIFICATION-MINNESOTA DATA

<u>Population Group</u>	<u>Total Cost (\$1000)</u>	<u>Number of Cards Containing Costs-N'_h</u>	<u>Total Number of Cards N_h</u>	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{(N_h - 1)N_h}$
Population Less than 5000	9,316	172	258	6,045
Population Over 5000	13,991	80	115	95,466
<u>Total</u>	23,307	252	373	35,003

TABLE D36. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR URBAN RAILROAD CROSSINGS-POPULATION GROUP STRATIFICATION-MINNESOTA DATA

Population Group	Total Cost (\$1000)	Number of Cards Containing Costs- N'_h	Total Number of Cards N_h	$S_h^2 = \frac{N_h \sum_i c_{hi}^2 - (\sum_i c_{hi})^2}{N_h (N_h - 1)}$
Population Less than 5000	1,807	184	392	48.41
Population Over 5000	476	45	75	34.42
<u>Total</u>	2,283	229	467	46.49

TABLE 237. COMPOSITE POPULATION AND STRATUM COST
TOTAL AND VARIANCE (ALL RURAL HIGHWAY,
BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-
TOPOGRAPHY AND TRAFFIC STRATIFICATION-
MINNESOTA DATA

<u>1975 Traffic</u>	<u>Total Cost Highways, Bridges, & Railroad Crossings (\$1000)</u>	<u>Number of Cards Containing Costs-N' h</u>	<u>Total Number of Cards N h</u>	$S_h^2 = \frac{N_h \sum c_{hi}^2 - (\sum c_{hi})^2}{(N_h - 1)N_h}$
<u>Flat Topography</u>				
Under 100 V.P.D.	23,492	730	734	774
100-400 V.P.D.	105,008	1,444	1,444	3,580
400-1000 V.P.D.	20,660	296	296	8,407
Over 1000 V.P.D.	2,765	53	53	2,639
<u>Subtotal</u>	151,931	2,522	2,527	
<u>Rolling Topography</u>				
Under 100 V.P.D.	41,252	1,061	1,062	1,433
100-400 V.P.D.	260,457	3,429	3,430	3,991
400-1000 V.P.D.	63,030	761	762	5,940
Over 1000 V.P.D.	11,774	124	124	8,918
<u>Subtotal</u>	584,563	5,375	5,378	
<u>Total</u> (Flat & Rolling)	536,494	7,897	7,905	4,011

TABLE D32. COMPOSITE POPULATION AND STRATUM COST TOTAL AND VARIANCE (ALL URBAN HIGHWAY, BRIDGE, AND AND RAILROAD CROSSING IMPROVEMENTS)-POPULATION GROUP STRATIFICATION-MINNESOTA DATA

Population Group	Total Cost (Highways, Bridges & Railroad Crossings) (\$1000)	Number of Cards Containing Cost N'_h	Total Number of Cards N_h	$S_h^2 = \frac{N_h \sum c_{hi}^2}{N_h} - \frac{(\sum c_{hi})^2}{N_h(N_h - 1)}$
Population Less than 5000	66,021	2,573	2,584	2,640
Population Greater than 5000	55,903	721	726	23,150
<u>Total</u>	121,924	3,294	3,310	7,584

APPENDIX D (Continued)

Populations and Strata Cost Totals and Variances

for Use in

Simple and Stratified Cluster Sampling

Minnesota Data

TABLE D39. COMPOSITE POPULATION AND STRATUM COST TOTAL AND VARIANCE (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-MILEAGE STRATIFICATION-MINNESOTA DATA

Rural County Primary Mileage	Total Cost (\$1000)	Number of Primary Units (Counties) N_h	Number of Elements (Highway Sections) M_h	$\frac{N_h \sum Y_{hi}^2 - (\sum Y_{hi})^2}{(N_h - 1)N_h} = S_{hT}^2$
0-249.99 Miles	138,032	34	2,173	$21,458 \times 10^2$
250-349.99 Miles	187,367	29	3,028	$12,931 \times 10^3$
350-Max. Miles	211,095	23	2,704	$11,355 \times 10^3$
<u>Total</u>	536,494	86	7,905	$12,230 \times 10^3$

TABLE D40. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR RURAL HIGHWAYS-MILEAGE STRATIFICATION-MINNESOTA DATA

Rural County Primary Mileage	Total Cost (\$1000)	Number of Primary Units (Counties) N_h	Number of Elements (Highway Sections) M_h	$\frac{N_h \sum Y_{hi}^2 - (\sum Y_{hi})^2}{N_h(N_h - 1)} = S_{hT}^2$
0-249.99 Miles	124,237	34	2,173	$13,293 \times 10^2$
250-349.99 Miles	165,025	29	3,028	$33,679 \times 10^2$
350-Max. Miles	189,696	23	2,704	$10,030 \times 10^3$
<u>Total</u>	479,008	86	7,905	$94,865 \times 10^2$

TABLE D41. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR RURAL BRIDGES-MILEAGE STRATIFICATION-MINNESOTA DATA

Rural County Primary Mileage	Total Cost (\$1000)	Number of Primary Units (Counties) N_h	Number of Elements (Highway Sections) N_h	$S_{hT}^2 = \frac{N_h \sum_{i=1}^N Y_{hi}^2 - (\sum_{i=1}^N Y_{hi})^2}{N_h (N_h - 1)}$
0-249.99 Miles	13,276	34	2,173	98,786
250-349.99 Miles	21,405	29	3,028	617,596
350-Max. Miles	21,403	23	2,704	310,571
<u>Total</u>	55,724	86	7,905	366,872

TABLE D42. SEPARATE POPULATION AND STRATUM COST TOTAL AND VARIANCE FOR RURAL RAILROAD CROSSINGS-MILEAGE STRATIFICATION-MINNESOTA DATA

Rural County Primary Mileage	Total Cost (\$1000)	Number of Primary Units (Counties) N_h	Number of Elements (Highway Sections) N_h	$S_{hT}^2 = \frac{N_h \sum_{i=1}^N Y_{hi}^2 - (\sum_{i=1}^N Y_{hi})^2}{N_h (N_h - 1)}$
0-249.99 Miles	469	34	2,173	709
250-349.99 Miles	937	29	3,028	3,462
350-Max. Miles	356	23	2,704	603
<u>Total</u>	1,762	86	7,905	1,544

APPENDIX E

SAMPLE SIZES FOR THE

SEPARATE AND COMPOSITE POPULATIONS

USING

SIMPLE AND STRATIFIED RANDOM SAMPLING

AND

SIMPLE AND STRATIFIED CLUSTER SAMPLING

FOR

MICHIGAN AND MINNESOTA DATA

APPENDIX E (Continued)

Sample Size
for the
Separate Populations
Using
Simple and Stratified
Random Sampling
Michigan Data

ESTIMATE OF TOTAL COST OF RURAL AND URBAN HIGHWAYS, BRIDGES AND RAILROAD CROSSINGS-MICHIGAN DATA

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Population	Total Sampling Units N	S^2	$d_T = 20$				$d_T = 10$				$d_T = 5$			
			Per Cent of the Total				Per Cent of the Total				Per Cent of the Total			
			$\alpha = 0.10$				$\alpha = 0.10$				$\alpha = 0.10$			
			Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size
Rural Highways	6,321	7,073	66**	265**	356**	909	1,218							
Rural Bridges & Approaches	1,985	2,634	153	510	653	1,152	1,315							
Rural Bridge Approaches	1,985	26.28	621	1,281	1,432	1,745	1,810							
Rural Bridge Only	1,985	2,412	159	512	656	1,154	1,318							
Rural Railroad Crossings	521	26.03	56	169	211	343	382							
Urban Highways	276	315,291	116	205	222	254	260							
Urban Bridge & Approaches	44	328,000	36	42	42	43	43							
Urban Bridge Approaches	44	0.82	43	44	44	44	44							
Urban Bridges	44	328,100	36	42	42	43	43							
Urban Railroad* Crossings	--	--	-	-	-	-	-							

* Incomplete Data

** Finite Population Correction Ignored

Total Sampling Units N	Desired Estimated Values	dT = 20		dT = 10		dT = 10		dT = 5		dT = 5	
		Per Cent of the Total	Sample Size	Per Cent of the Total	Sample Size	Per Cent of the Total	Sample Size	Per Cent of the Total	Sample Size	Per Cent of the Total	Sample Size
		$\alpha = 0.10$	$\alpha = 0.10$	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$	$\alpha = 0.05$
Total Cost		66*	265*	356*	909	1,210					
Timing of	1st 5 Years	232*	210	1,092	2,337	2,876					
	2nd 5 Years	329	1,108	1,466	2,905	3,457					
	3rd 5 Years	595	1,856	2,346	4,053	4,613					
	4th 5 Years	1,875	3,964	4,673	5,504	5,723					
6,321	Res. & Widen	400	1,343	1,751	3,281	3,826					
	Base & Surface	771	2,258	2,737	4,359	4,800					
	Reconstruction New	150*	549	752	1,741	2,216					
	Construction	3,682	5,360	5,613	6,050	6,128					
Mileage of	Res. & Widen	272*	929	1,242	2,578	3,126					
	Base & Surface	660	2,029	2,539	4,135	4,606					
	Reconstruction New	110*	410	567	1,374	1,763					
	Construction	3,402	5,205	5,491	5,999	6,091					

* Finite Population Correction Ignored

Total Sampling Units N	Desired Estimated Values	d _T = 20		d _T = 10		d _T = 10		d _T = 5		d _T = 5	
		Per Cent of the Total	α = 0.10	Per Cent of the Total	α = 0.10	Per Cent of the Total	α = 0.05	Per Cent of the Total	α = 0.10	Per Cent of the Total	α = 0.05
		Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size
Total Cost (Bridge + Approaches)											
	1st 5 Years	157	510	653	1,152	1,315					
1,985	2nd 5 Years	403	1,010	1,182	1,599	1,697					
	3rd 5 Years	666	1,327	1,471	1,766	1,826					
	4th 5 Years	974	1,576	1,679	1,864	1,898					

TABLE E4. SIMPLE RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES ONLY-MICHIGAN DATA

Total Sampling Units N	Desired Estimated Value	$d_T = 20$ Per Cent of the Total		$d_T = 10$ Per Cent of the Total		$d_T = 10$ Per Cent of the Total		$d_T = 5$ Per Cent of the Total		$d_T = 5$ Per Cent of the Total	
		$\alpha = 0.10$		$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$		$\alpha = 0.05$	
		Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size
Total Cost (Bridges Only)											
1,985	Reflooring	1,594	1,370	1,903	1,955	1,318					
	Rebuild of										
	Recondition	970	1,574	1,677	1,363	1,898					
	Replace Same										
	Location	163	521	665	1,165	1,328					
	Replace New										
	Location	1,040	1,617	1,711	1,878	1,909					
	New Separation										
	or Structure	1,776	1,928	1,945	1,970	1,975					
	Stream										
1,985	Crossing	143	471	608	1,100	1,267					
	Highway										
	Separation	1,894	1,962	1,968	1,979	1,981					
	Railroad										
1,985	Separation	1,332	1,941	1,954	1,974	1,977					
	Number Inadequate Structures	20*	106	146	365	480					

* Finite Population Correction Ignored

Total Sampling Units N	Desired Estimated Value	d _T = 20 Per Cent of the Total α = 0.10		d _T = 10 Per Cent of the Total α = 0.10		d _T = 10 Per Cent of the Total α = 0.05		d _T = 5 Per Cent of the Total α = 0.10		d _T = 5 Per Cent of the Total α = 0.05	
		Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size	
Total Cost											
Type of Imp. No. Cost	1st 5 Years	56	169	211	343	382					
	2nd 5 Years	85	227	273	394	424					
	3rd 5 Years	375	475	487	509	512					
	4th 5 Years	375	475	487	509	512					
Total Inadequate Railroad Crossings											
Type of Imp. No. Cost	Signals	63	136	230	359	396					
	Signal & Gates	203	274	408	474	487					
Total Inadequate Railroad Crossings											
Type of Imp. No. Cost	Signals	57	172	214	229	275					
	Signals & Gate	217	387	418	430	491					

TABLE E6. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL HIGHWAYS-TOPOGRAPHY, TRAFFIC, AND LENGTH STRATIFICATION-MICHIGAN DATA*

Topo- graphy	1975 Traffic	Length	Total Stratum Sampling Units $\bar{n}_h$	Sample Sizes, n_h				
				Optimum Sampling				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
				S_h^2				
Flat	Under	0.00-5.99 Mi.	228	3,306	1	5	7	17
	100 V.P.D.	6.00-Max.	36	1,401	1	1	1	2
	100 To	0.00-5.99 Mi.	1,513	1,751	6	23	22	83
	400 V.P.D.	6.00-Max.	214	5,178	1	6	5	28
	400 To	0.00-5.99 Mi.	1,032	2,582	5	19	26	69
	1000 V.P.D.	6.00-Max.	169	14,547	2	7	10	27
	Over	0.00-5.99 Mi.	794	14,356	9	35	48	125
Rolling	1000 V.P.D.	6.00-Max.	87	23,622	1	5	7	10
	Under	0.00-5.99 Mi.	167	914	1	2	3	7
	100 V.P.D.	6.00-Max.	21	4,677	1	1	1	2
	100 To	0.00-5.99 Mi.	292	1,296	3	12	10	42
	400 V.P.D.	6.00-Max.	111	5,976	1	3	4	11
	400 To	0.00-5.99 Mi.	555	1,367	2	6	10	27
	1000 V.P.D.	6.00-Max.	65	4,549	1	2	2	6
Totals	Over	0.00-5.99 Mi.	327	7,222	3	13	18	46
	1000 V.P.D.	6.00-Max.	40	61,431	1	4	5	13
			6,321	7,073	41**	146**	190**	514
								599

* This Method of Stratification was not Chosen and is Only Shown to Illustrate the Effect of Stratification by Topography, Traffic, and Length on Sample Size

** Finite Population Correction Ignored

TABLE E6 (Continued). STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL HIGHWAYS- TOPOGRAPHY, TRAFFIC, AND LENGTH STRATIFICATION-MICHIGAN DATA*

Topo- graphy	1975 Traffic	Length	Total Stratum Sampling Unit N _h	S _h ²	Sample Sizes, n _h				
					Proportional Sampling				
					d _T = 20 Per Cent of the Total α = 0.10	d _T = 10 Per Cent of the Total α = 0.10	d _T = 10 Per Cent of the Total α = 0.05	d _T = 5 Per Cent of the Total α = 0.10	d _T = 5 Per Cent of the Total α = 0.05
Flat	Under	0.00-5.99 Mi.	228	3,306	2	7	10	24	33
	100 V.P.D.	6.00-Max.	36	1,401	1	1	2	4	5
	100 To	0.00-5.99 Mi.	1,513	1,751	10	45	64	162	220
	400 V.P.D.	6.00-Max.	214	5,178	1	6	9	23	31
	400 To	0.00-5.99 Mi.	1,032	2,582	7	31	43	110	152
	1000 V.P.D.	6.00-Max.	169	14,547	1	5	7	18	25
	Over	0.00-5.99 Mi.	794	14,356	5	24	33	85	116
Rolling	1000 V.P.D.	6.00-Max.	57	23,622	1	3	4	9	13
	Under	0.00-5.99 Mi.	167	914	1	5	7	18	24
	100 V.P.D.	6.00-Max.	21	4,677	1	1	1	2	3
	100 To	0.00-5.99 Mi.	292	1,296	6	27	38	95	130
	400 V.P.D.	6.00-Max.	111	5,876	1	3	5	12	16
	400 To	0.00-5.99 Mi.	555	1,367	4	17	23	59	81
	1000 V.P.D.	6.00-Max.	65	4,549	1	2	3	7	9
Totals	Over	0.00-5.99 Mi.	397	7,923	3	12	17	42	58
	1000 V.P.D.	6.00-Max.	40	61,431	1	1	2	4	6
			6,321	7,073	46**	190**	268**	674	922

* This Method of Stratification was not Chosen and is Only Shown to Illustrate the Effect of Stratification by Topography, Traffic, and Length on Sample Size

** Finite Population Correction Ignored

TABLE E7. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL HIGHWAYS-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MICHIGAN DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h							
				Optimum Sampling							
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$			
Flat	Under 100 V.P.D.	264	3,571	2	7	9	24	33			
	100 to 400 V.P.D.	1,727	3,607	12	47	63	162	217			
	400 to 1000 V.P.D.	1,201	5,788	10	41	56	142	191			
	Over 1000 V.P.D.	881	17,089	13	52	70	179	241			
Rolling	Under 100 V.P.D.	188	2,652	1	4	6	15	20			
	100 to 400 V.P.D.	1,003	3,124	6	25	34	87	117			
	400 to 1000 V.P.D.	620	2,660	4	14	19	50	67			
	Over 1000 V.P.D.	437	17,087	6	26	35	89	120			
<u>Totals</u>		6,321	7,073	54*	216*	292*	748	1,006			

* Finite Population Correction Ignored

TABLE E7 (Continued). SUGGESTED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL HIGHWAYS-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MICHIGAN DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	Sample Sizes, n_h				
			<u>Proportional Sampling</u>				
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Flat	Under 100 V.F.D.	264	3	10	14	36	48
	100 to 400 V.P.D.	1,727	17	68	91	235	316
	400 to 1000 V.F.D.	1,201	12	47	63	163	220
	Over 1000 V.P.D.	301	9	35	47	120	161
Rolling	Under 100 V.F.D.	183	2	7	10	26	34
	100 to 400 V.P.D.	1,003	10	40	53	137	183
	400 to 1000 V.P.D.	620	6	24	33	84	113
	Over 1000 V.P.D.	437	4	17	23	59	80
<u>Totals</u>		6,321	63*	243*	334*	860	1,155

* Finite Population Correction Ignored

TABLE EC. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES PLUS APPROACHES-TOPOGRAPHY AND TRAFFIC STRATIFICATION*-NICHIGAN DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h				
				Optimum Sampling				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Flat	Under 100 V.P.D.	30	837	3	11	14	24	31
	100 to 400 V.P.D.	546	1,157	27	37	110	194	241
	400 to 1000 V.P.D.	472	1,722	23	90	115	206	257
	Over 1000 V.P.D.	336	7,520	42	137	175	310	336
Rolling	Under 100 V.P.D.	25	698	1	3	4	7	9
	100 to 400 V.P.D.	242	1,507	13	43	56	93	121
	400 to 1000 V.P.D.	142	3,442	12	30	49	37	106
	Over 1000 V.P.D.	142	1,352	7	24	31	55	67
<u>Totals</u>		1,985	7,073	133	432	554	981	1,169**

* This Method of Stratification was not Used, but is Shown to Illustrate the Effect of Stratification by Topography and Traffic on Sample Size

** Total Sample Size Computed by Formula (2.04)

TABLE EC (Continued). STRATIFIED RANDOM SAMPLING--SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES PLUS APPROACHES--TOPOGRAPHY AND TRAFFIC STRATIFICATION*-MICHIGAN DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	Sample Sizes, n_h					
			Proportional Sampling					
			$d_T = 20$		$d_T = 10$		$d_T = 10$	
			Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.05$
			S_h^2					
Flat	Under 100 V.P.D.	80	837	6	20	26	46	53
	100 to 400 V.P.D.	546	1,157	43	140	179	316	361
	400 to 1000 V.P.D.	472	1,722	37	121	155	273	312
	Over 1000 V.P.D.	336	7,320	27	86	110	195	222
Rolling	Under 100 V.P.D.	25	698	2	6	3	14	16
	100 to 400 V.P.D.	242	1,507	19	62	79	140	160
	400 to 1000 V.P.D.	142	3,442	11	36	47	82	94
	Over 1000 V.P.D.	142	1,352	11	36	47	82	94
<u>Totals</u>		1,925	7,073	156	507	651	1,148	1,312

* This Method of Stratification was not Used, but is Shown to Illustrate the Effect of Stratification by Topography and Traffic on Sample Size

TABLE E9. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES PLUS APPROACHES-TRAFFIC STRATIFICATION-MICHIGAN DATA

1975 Stratum	Sample Size, n_h				
	Optimum Sampling				
	S_h^2	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Total Strata Sampling Units					
Under 100 V.P.D.	105	4	14	18	37
100 to 400 V.P.D.	788	41	132	170	299
400 to 1000 V.P.D.	614	41	133	171	302
Over 1000 V.P.D.	478	54	174	223	393
Totals	1,985	140	453	582	1,027
					1,172

TABLE E9 (Continued). STRATIFIED RANDOM SAMPLING--SEPARATE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES PLUS APPROACHES--
 TRAFFIC STRATIFICATION-MICHIGAN DATA

1975 Stratum	Sample Size, n_h					
	Total Strata Sampling Units	S_h^2	Proportional Sampling			
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Under						
100 V.P.D.	105	840	27	35	61	70
100 to						
400 V.P.D.	788	1,263	202	259	457	522
400 to						
1000 V.P.D.	614	2,116	157	202	356	407
Over						
1000 V.P.D.	478	5,935	123	157	277	317
Totals	1,985	2,634	509	653	1,151	1,316

TABLE E10. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES ONLY-TRAFFIC STRATIFICATION-MICHIGAN DATA

1975 Traffic	Total Strata Sampling Units	S_h^2	Sample Size, n_h					
			Optimum Sampling					
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	
Under								
100 V.P.D.	105	759	4	14	18	32	37	
100 to								
400 V.P.D.	786	1,155	41	133	170	299	342	
400 to								
1000 V.P.D.	614	1,994	42	136	174	306	350	
Over								
1000 V.P.D.	473	5,398	54	174	223	392	443	
Totals	1,985	2,412	141	457	535	1,029	1,177	

TABLE E10 (Continued). STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES ONLY-TRAFFIC
 STRATIFICATION-MICHIGAN DATA

1975 Traffic	Total Strata Sampling Units	S_h^2	Sample Size, n_h					$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
			Proportional Sampling							
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$			
Under										
100 V.P.D.	105	759	8	27	35	61	70			
100 to										
400 V.P.D.	788	1,155	63	203	260	458	522			
400 to										
1000 V.P.D.	614	1,994	49	158	203	357	407			
Over 1000										
V.P.D.	478	5,398	30	123	150	278	317			
Totals	1,985	2,412	158	511	656	1,154	1,316			

TABLE E11. STRATIFIED RANDOM SAMPLING--SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL RAILROAD CROSSINGS--TRAFFIC STRATIFICATION--MICHIGAN DATA

1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h					
			Optimum Sampling					
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	
Under 100 V.P.D.	9	6.94	1	1	2	3	3	
100 to 400 V.P.D.	150	15.72	12	37	46	77	36	
400 to 1000 V.P.D.	150	19.25	13	41	51	85	95	
Over 1000 V.P.D.	212	32.35	24	74	94	156	175	
Totals	521	26.03	50	153	193	321	360	

TABLE E11 (Continued). STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL RAILROAD CROSSINGS-TRAFFIC
 STRATIFICATION-MICHIGAN DATA

1975 Traffic	Sample Sizes, n_h					
	Total Stratum Sampling Units N_h	S_h^2	Proportional Sampling			
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Under						
100 V.P.D.	9	6.94	3	3	6	6
100 to						
400 V.P.D.	150	15.72	45	57	95	107
400 to						
1000 V.P.D.	150	19.25	45	57	95	107
Over						
1000 V.P.D.	212	32.35	64	81	134	151
Totals	521	26.03	157	190	330	371

TABLE E12. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN HIGHWAYS-TOPOGRAPHY AND POPULATION GROUP STRATIFICATION*-MICHIGAN DATA

Topo- graphy	Population Group	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h					
				Optimum Sampling					
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	
Flat	Less than 5000	53	6,263	3	5	6	6	7	
	Over 5000	178	451,411	76	138	151	174	178	
Rolling	Less than 5000	21	15,781	2	3	3	4	4	
	Over 5000	24	11,995	2	3	3	4	4	
<u>Totals</u>		276	315,991	83	199	163	189	193	

* This Method of Stratification was not Chosen, but was Used to Investigate its Effect on Sample Size. A Negligible Difference in Sample Size was Found for this Stratification when Compared to Stratification by Population Group Only.

TABLE E12 (Continued). STRATIFIED RANDOM SAMPLING--SEPARATE POPULATION SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN HIGHWAYS-- TOPOGRAPHY AND
POPULATION GROUP STRATIFICATION--MICHIGAN DATA

Topo- graphy	Population Group	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h							
				Proportional Sampling							
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$			
Flat	Less than 5000	53	6,863	21	39	42	48	50			
	Over 5000	178	451,411	72	130	141	163	167			
Rolling	Less than 5000	21	15,781	8	15	17	19	20			
	Over 5000	24	11,995	10	17	19	22	23			
Totals		276	315,991	111	201	219	252	260			

* This method of stratification was not chosen, but was used to investigate its effect on sample size. A negligible difference in sample size was found for this stratification when compared to stratification by population group only.

TABLE E13. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN HIGHWAYS-POPULATION GROUP STRATIFICATION-MICHIGAN DATA

Population Group	Total Strata Sampling Units N_h	S_h^2	Optimum Sampling					Sample Sizes, n_h
			$d_T = 20$	$d_T = 10$	$d_T = 10$	$d_T = 5$	$d_T = 5$	
			Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	
Less than 5000	74	9,271	5	9	10	11	12	
Over 5000	202	348,450	78	148	163	192	197	
Totals	276	315,991	83	157	173	203	209	

TABLE E13 (Continued). STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN HIGHWAYS-POPULATION GROUP
 STRATIFICATION-MICHIGAN DATA

Population Group	Sample Sizes, n_h				
	Total Strata Sampling Units N_h	S_h^2	Proportional Sampling		
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Less than 5000	74	9,271	52	57	69
Over 5000	202	348,450	141	155	183
<u>Totals</u>	276	315,991	193	212	257

TABLE E14. STRATIFIED RANDOM SAMPLING--SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN BRIDGES AND APPROACHES-POPULATION GROUP STRATIFICATION-MICHIGAN DATA

Population Group	Sample Sizes, n_h				
	Total Strata Sampling Units N_h	S_h^2	Optimum Sampling		
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$
Less than 5000	20	1,066	1	1	3
Over 5000	24	459,697	19	24	24
<u>Totals</u>	44	323,017	20	25	27*

* Total Sample Size Computed by Formula (2.04)

TABLE E14 (Continued). STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN BRIDGES AND APPROACHES-
 POPULATION GROUP STRATIFICATION-MICHIGAN DATA

Population Group	Sample Sizes, n_h				
	Total Strata Sampling Units N_h	S_h^2	Proportional Sampling		
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$
Less than 5000	20	1,066	19	19	20
Over 5000	24	459,697	19	23	23
<u>Totals</u>	44	328,017	41	42	43

Total
Sampling
Units
N

Desired
Estimated
Value

$d_T = 20$
Per Cent
of the
Total
 $\alpha = 0.10$
Sample
Size

$d_T = 10$
Per Cent
of the
Total
 $\alpha = 0.10$
Sample
Size

$d_T = 10$
Per Cent
of the
Total
 $\alpha = 0.05$
Sample
Size

$d_T = 5$
Per Cent
of the
Total
 $\alpha = 0.10$
Sample
Size

$d_T = 5$
Per Cent
of the
Total
 $\alpha = 0.05$
Sample
Size

Total Cost	55**	216**	292**	748	1,006
1st 5 Years	198**	690	933	2,015	2,485
2nd 5 Years	302	1,049	1,390	2,756	3,283
3rd 5 Years	519	1,623	2,039	3,479	3,920*
4th 5 Years	1,057	2,261*	2,617*	3,751*	4,113*
Res. & Widen	312	791	1,014	1,727	2,055
Base & Surface	714	2,083	2,576	4,043*	4,474*
Reconstruction	83**	309	425	1,032	1,341
New Construction	2,559*	4,196*	4,630*	5,469*	5,659*
Res. & Widen	255	376	1,174	2,455	2,986
Base & Surface	657	2,016	2,497	4,067	4,251
Reconstruction	104	396	547	1,330	1,735
New Construction	2,759*	4,459*	4,791*	5,512*	5,690*

6,321

* Total Sample Size Computed by Formula (2.04)

** Finite Population Correction Ignored

TABLE E16. PROPORTIONAL STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES. REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL ROADS-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MICHIGAN DATA

Total Sampling Units N	Desired Estimated Value	d _T = 20 Per Cent of the Total			d _T = 10 Per Cent of the Total			d _T = 5 Per Cent of the Total			d _T = 5 Per Cent of the Total					
		α = 0.10			α = 0.10			α = 0.05			α = 0.10			α = 0.05		
		Sample Size			Sample Size			Sample Size			Sample Size			Sample Size		
Total Cost		63*			242*			334*			860			1,155		
Mileage of Construction	1st 5 Years	222*			701			1,052			2,275			2,800		
	2nd 5 Years	316			1,104			1,462			2,098			2,453		
	3rd 5 Years	529			1,937			2,325			3,926			4,422		
	4th 5 Years	1,048			3,933			4,432			5,490			5,713		
Total Cost of Construction	Res. & Widen	494			1,601			2,053			3,630			4,161		
	Base & Surface	767			2,248			2,779			4,351			4,748		
	Reconstruction	112*			416			574			1,394			1,009		
	New Construction	3,679			5,350			5,610			6,049			6,120		
Mileage of Construction	Res. & Widen	264			900			1,204			2,522			3,063		
	Base & Surface	746			2,027			2,530			3,995			4,604		
	Reconstruction	106			398			550			1,337			1,746		
	New Construction	3,406			5,207			5,490			5,999			6,091		

6,321

* Finite Population Correction Ignored

APPENDIX E (Continued)

Sample Sizesforthe Composite PopulationUsingSimple and Stratified Random SamplingMichigan Data

TABLE E17. SIMPLE RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS) HIGHWAY COST, BRIDGE COST, AND RAILROAD CROSSING COST-MICHIGAN DATA

Total Number of Sampling Units	Type of Cost	S^2	Sample Sizes, n				
			$d_T = 20$	$d_T = 10$	$d_T = 10$	$d_T = 5$	$d_T = 5$
			Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$
6,321	Total (Highways, Bridges and Railroad Crossings)	9,316	69	277	370	941	1,253
	Highway*	7,073	66	265	356	909	1,215
	Bridge	1,115	714	2,133	2,655	4,240	4,698
	Railroad Crossing	4.265	1,223	3,095	3,645	5,015	5,341

* This is the same as sample sizes required for the estimate of highway cost using the separate population. See Table E1

TABLE E15. SIMPLE RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-MICHIGAN DATA

Sample Sizes, n

Total Sampling Units N	Desired Estimated Values	d _T = 20 Per Cent of the Total α = 0.10				d _T = 10 Per Cent of the Total α = 0.05				d _T = 5 Per Cent of the Total α = 0.10				d _T = 5 Per Cent of the Total α = 0.05			
		α = 0.10				α = 0.05				α = 0.10				α = 0.05			
	Total Cost	69				277				941				1,258			
Planning Cost	1st 5 Years	238				827				2,390				2,910			
	2nd 5 Years	329				1,138				2,956				3,509			
	3rd 5 Years	629				1,939				4,039				4,522			
	4th 5 Years	1,834				3,923				5,340				5,706			
Total Cost or Construction	Res. & Widen	423				1,407				3,375				3,914			
	Base & Surface	801				2,322				4,418				4,850			
	Reconstruction	150				547				1,736				2,211			
	New Construction	3,960				5,501				6,094				6,159			

6,321

Mileage of
Construction
Res. & Widen
Base & Surface
Reconstruction
New
Construction

See Table E2

TABLE E19. STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE AND RAILROAD CROSSING IMPROVEMENTS)-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MICHIGAN DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Size, n_h				
				Optimum Sampling				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Flat	Under 100 V.P.D.	264	5,066	2	8	10	25	36
	100 to 400 V.P.D.	1,727	5,178	13	52	69	168	238
	400 to 1000 V.P.D.	1,201	8,016	11	45	60	145	206
	Over 1000 V.P.D.	881	22,805	14	55	74	180	255
Rolling	Under 100 V.P.D.	138	3,983	2	5	7	16	23
	100 to 400 V.P.D.	1,003	4,406	7	28	37	90	127
	400 to 1000 V.P.D.	620	3,819	4	16	21	52	73
	Over 1000 V.P.D.	437	18,227	6	23	33	80	113
<u>Totals</u>		6,321	9,316	59*	232*	211	756	1,071

* Finite Population Correction Ignored

TABLE E19 (Continued). STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE AND
 RAILROAD CROSSING IMPROVEMENTS)-TOPOGRAPHY AND TRAFFIC STRATIFICATION-
 MICHIGAN DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h				
				Proportional Sampling				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Flat	Under 100 V.P.D.	264	5,066	3	11	15	41	50
	100 to 400 V.P.D.	1,727	5,178	18	71	95	268	328
	400 to 1000 V.P.D.	1,201	8,016	12	49	66	186	229
	Over 1000 V.P.D.	881	22,805	9	36	49	137	167
Rolling	Under 100 V.P.D.	188	3,983	2	8	10	29	36
	100 to 400 V.P.D.	1,003	4,406	10	41	55	155	190
	400 to 1000 V.P.D.	620	3,819	6	26	34	96	118
	Over 1000 V.P.D.	437	18,227	4	18	24	68	83
Totals		6,321	9,316	64*	260*	348	980	1,201

* Finite Population Correction Ignored

TABLE E20. STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MICHIGAN DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	Sample Sizes, n_h				
			Optimum Sampling				
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Flat	Under 100 V.P.D.	264	527	58	72	119	137
	100 to 400 V.P.D.	1,727	729	446	555	914	1,055
	400 to 1000 V.P.D.	1,201	1,007	364	453	745	863
	Over 1000 V.P.D.	381	3,248	430	597	821	831
Rolling	Under 100 V.P.D.	188	350	34	42	69	80
	100 to 400 V.P.D.	1,003	575	230	286	471	545
	400 to 1000 V.P.D.	620	973	185	230	379	43
	Over 1000 V.P.D.	437	674	108	135	222	257
<u>Totals</u>		6,321	636	1,205	2,370	3,800*	4,256*

* Sample Size Computed by Formula (2.04)

TABLE E2C (Continued). STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES-TOPOGRAPHY AND
 TRAFFIC STRATIFICATION-MICHIGAN DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h					
				Proportional Sampling					
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	
Flat	Under 100 V.P.D.	264	527	30	59	110	177	196	
	100 to 400 V.P.D.	1,727	729	194	381	722	1,156	1,232	
	400 to 1000 V.P.D.	1,201	1,007	135	404	502	804	891	
	Over 1000 V.P.D.	331	3,243	99	296	369	590	653	
Rolling	Under 100 V.P.D.	193	350	21	63	79	126	139	
	100 to 400 V.P.D.	1,003	575	113	337	419	671	744	
	400 to 1000 V.P.D.	620	973	70	209	259	415	460	
	Over 1000 V.P.D.	437	674	49	147	183	293	324	
Totals		6,321		711	2,126	2,642	4,232	4,689	

TABLE E21. STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL RAILROAD CROSSINGS-TOPOGRAPHY AND TRAFFIC STRATIFICATION-NICHIGAN DATA

		Sample Sizes, n_h									
		Optimum Sampling									
Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	$d_T = 20$		$d_T = 10$		$d_T = 10$		$d_T = 5$	
				Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$		
Flat	Under 100 V.P.D.	264	.3788	13	35	41	65	73			
	100 to 400 V.P.D.	1,727	1.178	155	396	468	743	845			
	400 to 1000 V.P.D.	1,201	3.733	192	490	579	920	1,046			
	Over 1000 V.P.D.	881	11.53	247	632	747	881	881			
Rolling	Under 100 V.P.D.	138	.3947	10	25	29	47	53			
	100 to 400 V.P.D.	1,003	1.753	110	281	332	528	599			
	400 to 1000 V.P.D.	620	3.003	39	227	263	426	484			
	Over 1000 V.P.D.	437	12.51	128	327	386	437	437			
Totals		6,321		944	2,413	2,550	4,047*	4,418*			

* Sample Size Computed by Formula (2.04)

TABLE E21 (Continued). STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL RAILROAD CROSSINGS-
TOPOGRAPHY AND TRAFFIC STRATIFICATION-MICHIGAN DATA

		Sample Sizes, n_h						
		Proportional Sampling						
Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	$d_T = 20$	$d_T = 10$	$d_T = 10$	$d_T = 5$	$d_T = 5$
				Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$
Flat	Under 100 V.P.D.	264	.3788	50	123	150	203	219
	100 to 400 V.P.D.	1,727	1.178	324	834	930	1,359	1,433
	400 to 1000 V.P.D.	1,201	3.733	225	530	631	945	996
	Over 1000 V.P.D.	881	11.53	165	426	500	693	731
Rolling	Under 100 V.P.D.	138	.3947	35	91	107	148	156
	100 to 400 V.P.D.	1,003	1.758	188	485	569	789	832
	400 to 1000 V.P.D.	620	3.008	116	299	352	488	514
	Over 1000 V.P.D.	437	12.51	82	211	248	344	362
Totals		6,321		1,135	3,054	3,587	4,974	5,243

APPENDIX E (Continued)

Sample Sizesfor theSeparate PopulationsUsingSimple and Stratified Random SamplingMinnesota Data

TABLE E22. SIMPLE RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL AND URBAN HIGHWAYS, BRIDGES AND RAILROAD CROSSINGS-MINNESOTA DATA

Population	Total Sampling Units N	S^2	Sample Sizes, n			
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Rural Highways	7,905	3,133	50	231	326	827
Rural Bridges	2,761	1,122	174	507	765	1,433
Rural Railroad Crossings	662	34.12	213	439	407	507
Urban Highways	3,307	2,654	199	674	381	1,673
Urban Bridges	373	35,003	231	323	337	359
Urban Railroad Crossings	467	46.49	103	248	287	302
						404

TABLE E23. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL HIGHWAYS-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MINNESOTA DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h					Optimum Sampling				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$					
				Total	Total	Total	Total	Total					
Flat	Under 100 V.P.D.	735	438	2	7	10	27	36					
	100 to 400 V.P.D.	1,443	2,956	10	33	54	137	187					
	400 to 1000 V.P.D.	296	4,135	2	9	13	33	45					
	Over 1000 V.P.D.	53	2,164	1	1	2	4	6					
Rolling	Under 100 V.P.D.	1,062	999	4	16	23	53	79					
	100 to 400 V.P.D.	3,430	3,246	24	94	133	339	462					
	400 to 1000 V.P.D.	762	4,565	6	25	35	99	122					
	Over 1000 V.P.D.	124	7,016	1	5	7	18	25					
Totals		7,905	3,133	50*	195*	277*	705	962					

* Finite Population Correction Ignored

TABLE E23 (Continued). STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL HIGHWAYS-TOPOGRAPHY AND
 TRAFFIC STRATIFICATION-MINNESOTA DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_{h1}^2	Sample Sizes, n_h					
				Proportional Sampling					
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	
Flat	Under 100 V.P.D.	735	438	5	20	28	71	96	
	100 to 400 V.P.D.	1,443	2,936	9	38	54	139	189	
	400 to 1000 V.P.D.	296	4,135	2	8	11	28	39	
	Over 1000 V.P.D.	53	2,184	1	1	2	5	7	
Rolling	Under 100 V.P.D.	1,062	999	7	28	40	102	139	
	100 to 400 V.P.D.	3,430	3,246	23	91	129	329	449	
	400 to 1000 V.P.D.	762	4,565	5	20	28	73	100	
	Over 1000 V.P.D.	124	7,016	1	3	5	13	16	
<u>Totals</u>		7,905	3,133	53*	209*	298*	759	1,035	

* Finite Population Correction Ignored

TABLE E24. STRATIFIED RANDOM SAMPLING--SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES--TRAFFIC STRATIFICATION--MINNESOTA DATA

1975 Traffic	Sample Sizes, n_h					
	Total Stratum Sampling Units N_h	S_h^2	Optimum Sampling			
			$dT = 20$ Per Cent of the Total $\alpha = 0.10$	$dT = 10$ Per Cent of the Total $\alpha = 0.05$	$dT = 5$ Per Cent of the Total $\alpha = 0.10$	$dT = 5$ Per Cent of the Total $\alpha = 0.05$
Under						
100 V.P.D.	612	474	23	99	187	225
100 to						
400 V.P.D.	1,740	638	75	328	616	743
400 to						
1000 V.P.D.	360	4,390	40	137	334	360
Over						
1000 V.P.D.	49	1,721	3	15	28	34
Totals	2,761	1,122	141	620	1,165	1,362*

* Sample Size Computed by Formula (2.04)

TABLE E24 (Continued). STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES-TRAFFIC
 STRATIFICATION-MINNESOTA DATA

1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h				
			Proportional Sampling				
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Under							
100 V.P.D.	612	474	38	129	168	316	369
100 to							
400 V.P.D.	1,740	638	109	367	478	899	1,049
400 to							
1000 V.P.D.	360	4,390	23	76	99	186	217
Over 1000 V.P.D.	49	1,721	3	10	13	25	29
<u>Totals</u>	2,761	1,122	173	582	758	1,426	1,664

TABLE E25. STRATIFIED RANDOM SAMPLING--SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL RAILROAD CROSSINGS--TRAFFIC STRATIFICATION-MINNESOTA DATA

1975 Traffic	Sample Sizes, n_h					
	Total Stratum Sampling Units N_h	S_h^2	Optimum Sampling			
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Under 100 V.P.D.	134	7.91	40	49	70	76
100 to 400 V.P.D.	386	17.51	173	208	301	327
400 to 1000 V.P.D.	111	115.05	111	111	111	111
Over 1000 V.P.D.	31	26.85	17	21	30	31
<u>Totals</u>	662	34.12	341*	389*	512*	545*

* Sample Size Computed by Formula (2.04)

TABLE E25 (Continued). STRATIFIED RANDOM SAMPLING--SEPARATE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL RAILROAD CROSSINGS--
 TRAFFIC STRATIFICATION-MINNESOTA DATA

1975 Traffic	Sample Sizes, n_h				
	Proportional Sampling				
	Total Stratum Sampling Units N_h	S_h^2	$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$
Under					
100 V.P.D.	134	7.91	43	97	118
100 to					
400 V.P.D.	386	17.51	123	280	341
400 to					
1000 V.P.D.	111	115.05	35	81	98
Over					
1000 V.P.D.	31	26.85	10	23	27
Totals	662	34.12	211	481	584

TABLE E26. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN HIGHWAYS-POPULATION GROUP STRATIFICATION-MINNESOTA DATA

Population Group	Total Strata Sampling Units N_h	S_h^2	Sample Sizes, n_h			
			Optimum Sampling			
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Less than 5000	2,534	1,635	113	327	510	937
Over 5000	723	5,287	57	195	256	497
Totals	3,307	2,654	170	522	766	1,434
						1,751

TABLE E26 (Continued). STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN HIGHWAYS-POPULATION GROUP
STRATIFICATION-MINNESOTA DATA

Population Group	Total Strata Sampling Units N_h	S_{h1}^2	Sample Sizes, n_h			
			Proportional Sampling			
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Less than 5000	2,584	1,635	492	646	1,251	1,476
Over 5000	723	5,237	137	181	350	413
<u>Totals</u>	3,307	2,654	629	827	1,601	1,889

TABLE E27. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL CCST OF URBAN BRIDGES-POPULATION GROUP STRATIFICATION-MINNESOTA DATA

Population Group	Total Strata Sampling Units N_h	S_h^2	Sample Sizes, n_h			
			Optimum Sampling			
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Less than 5000	253	6,045	54	113	195	210
Over 5000	115	95,486	96	115	115	115
<u>Totals</u>	373	35,003	150	228*	310*	325*

* Sample Size Computed by Formula (2.04)

TABLE E27 (Continued). STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN BRIDGES-POPULATION GROUP
STRATIFICATION-MINNESOTA DATA

Population Group	Total Strata Sampling Units N_h	S_h^2	Sample Sizes, n_h			
			Proportional Sampling			
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Less than 5000	258	6,045	223	232	248	251
Over 5000	115	95,486	99	103	111	112
<u>Totals</u>	373	35,003	322	335	359	363

TABLE E2E. STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN RAILROAD CROSSINGS-POPULATION GROUP STRATIFICATION-MINNESOTA DATA

Population Group	Sample Sizes, n_h				
	Total Strata Sampling Units N_h	S_h^2	Optimum Sampling		
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$
Less than 5000	392	43.41	212	246	328
Over 5000	75	34.42	34	40	53
Totals	467	46.49	246	286	381
					402

TABLE E23 (Continued). STRATIFIED RANDOM SAMPLING-SEPARATE POPULATION SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN RAILROAD CROSSINGS--
POPULATION GROUP STRATIFICATION-MINNESOTA DATA

Population Group	Total Strata Sampling Units N_h	S_h^2	Sample Sizes, n_h							
			Proportional Sampling							
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Less than 5000	392	48.41	36	207	241	321	339			
Over 5000	75	34.42	16	40	46	61	65			
<u>Totals</u>	467	46.49	102	247	287	382	404			

APPENDIX E (Continued)

Sample Sizesfor theComposite PopulationUsingSimple and Stratified Random SamplingMinnesota Data

TABLE E29. SIMPLE RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS) HIGHWAY COST, BRIDGE COST, AND RAILROAD CROSSING COST-MINNESOTA DATA

Total Number of Sampling Units	Type of Cost	S^2	Sample Sizes, n			
			$d_T = 20$	$d_T = 10$	$d_T = 10$	$d_T = 5$
			Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$
7,905	Total (Highways, Bridges and Railroad Crossings)	4,611	59	236	334	843
	Highways					1,144
	Bridges	555	689	2,185	2,731	4,778
	Railroad Crossings	3.66	3,056	5,660	6,179	7,192
						7,389

See Table E22

TABLE E30. STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MINNESOTA DATA

		Sample Sizes, n_h									
Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Optimum Sampling							
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Flat	Under 100 V.P.D.	734	774	2	9	13	32	44			
	100 to 400 V.P.D.	1,444	3,580	10	38	53	136	185			
	400 to 1000 V.P.D.	296	8,407	3	12	17	43	58			
	Over 1000 V.P.D.	53	2,642	1	2	2	4	6			
Rolling	Under 100 V.P.D.	1,062	1,433	4	18	25	63	86			
	100 to 400 V.P.D.	3,430	3,992	24	94	134	341	465			
	400 to 1000 V.P.D.	762	5,940	6	26	36	92	126			
	Over 1000 V.P.D.	124	8,919	1	5	7	18	25			
<u>Totals</u>		7,905	4,011	51*	204*	287*	729	995			

* Finite Population Correction Ignored

TABLE E30 (Continued). STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MINNESOTA DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h							
				Proportional Sampling							
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$			
Flat	Under 100 V.P.D.	734	774	5	20	29	73	99			
	100 to 400 V.P.D.	1,444	3,530	10	40	56	143	195			
	400 to 1000 V.P.D.	296	8,407	2	3	12	29	40			
	Over 1000 V.P.D.	53	2,642	1	1	2	5	7			
Rolling	Under 100 V.P.D.	1,062	1,439	7	29	41	105	143			
	100 to 400 V.P.D.	3,430	3,992	23	94	134	339	463			
	400 to 1000 V.P.D.	762	5,940	5	21	30	75	103			
	Over 1000 V.P.D.	124	8,919	1	3	5	12	17			
<u>Totals</u>		7,905	4,011	54*	216*	309*	781	1,067			

* Finite Population Correction Ignored

TABLE E31. STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MINNESOTA DATA

		Sample Sizes, n_h							
Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Optimum Sampling					$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$		
Flat	Under 100 V.P.D.	734	240	39	123	157	236	332	
	100 to 400 V.P.D.	1,444	322	99	281	357	652	758	
	400 to 1000 V.P.D.	296	3,924	63	201	256	296	296	
	Over 1000 V.P.D.	53	462	4	12	16	29	33	
Rolling	Under 100 V.P.D.	1,062	279	61	192	244	446	510	
	100 to 400 V.P.D.	2,430	521	240	762	970	1,772	2,059	
	400 to 1000 V.P.D.	762	940	80	253	322	538	634	
	Over 1000 V.P.D.	124	747	12	37	47	85	99	
Totals		7,905	555	588	1,861	2,362	4,073*	4,610*	

* Sample Size Computed by Formula (2.04)

TABLE E31 (Continued). STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF RURAL BRIDGES-TOPOGRAPHY AND
 TRAFFIC STRATIFICATION-MINNESOTA DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h				
				Proportional Sampling				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Flat	Under 100 V.P.D.	734	240	64	203	250	443	502
	100 to 400 V.P.D.	1,444	322	126	390	507	372	983
	400 to 1000 V.P.D.	296	3,924	26	82	104	179	202
	Over 1000 V.P.D.	53	462	4	14	18	31	35
Rolling	Under 100 V.P.D.	1,062	278	92	293	373	641	726
	100 to 400 V.P.D.	3,430	421	298	946	1,205	2,071	2,346
	400 to 1000 V.P.D.	762	940	66	210	268	460	521
	Over 1000 V.P.D.	124	747	11	34	44	75	85
<u>Totals</u>		7,905	555	687	2,180	2,777	4,772	5,405

TABLE E32. STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR RURAL RAILROAD CROSSINGS FOR THE ESTIMATE OF TOTAL COST-TOPOGRAPHY AND TRAFFIC STRATIFICATION-MINNESOTA DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h					
				Optimum Sampling					
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$	
Flat	Under 100 V.P.D.	734	.728	108	235	273	376	410	
	100 to 400 V.P.D.	1,444	2.747	412	899	1,044	1,435	1,444	
	400 to 1000 V.P.D.	296	5.137	115	252	293	296	296	
	Over 1000 V.P.D.	53	30.30	50	53	53	53	53	
Rolling	Under 100 V.P.D.	1,062	.595	141	308	353	491	537	
	100 to 400 V.P.D.	3,430	1.709	771	1,686	1,957	2,691	2,937	
	400 to 1000 V.P.D.	762	18.14	558	762	762	762	762	
	Over 1000 V.P.D.	124	5.308	52	112	124	124	124	
<u>Totals</u>		7,905	3.66	2,207	4,307*	4,864*	6,228	6,563*	

* Sample Size Computed by Formula (2.04)

TABLE E32 (Continued). STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES
REQUIRED FOR RURAL RAILROAD CROSSINGS FOR THE ESTIMATE OF TOTAL COST-
TOPOGRAPHY AND TRAFFIC STRATIFICATION-MINNESOTA DATA

Topo- graphy	1975 Traffic	Total Stratum Sampling Units N_h	S_h^2	Sample Sizes, n_h				
				Proportional Sampling				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Flat	Under 100 V.P.D.	734	.723	262	524	573	667	636
	100 to 400 V.P.D.	1,444	2.747	555	1,031	1,127	1,313	1,349
	400 to 1000 V.P.D.	296	5.137	114	211	231	269	276
	Over 1000 V.P.D.	53	30.30	19	36	39	46	47
Rolling	Under 100 V.P.D.	1,062	.595	403	759	828	965	992
	100 to 400 V.P.D.	3,430	1.709	1,313	2,449	2,675	3,116	3,204
	400 to 1000 V.P.D.	762	18.14	293	544	594	693	712
	Over 1000 V.P.D.	124	5.308	48	89	97	113	116
Totals		7,905	3.66	3,037	5,643	6,164	7,184	7,382

TABLE E33. SIMPLE RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED
FOR THE ESTIMATE OF TOTAL COST, HIGHWAY COST, BRIDGE COST AND
RAILROAD CROSSING COST FOR THE URBAN SYSTEM-MINNESOTA DATA

Total Number of Sampling Units	Type of Cost	S^2	Sample Sizes, n							
			$d_T = 20$		$d_T = 10$		$d_T = 10$		$d_T = 5$	
			Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$
3,310	Total (Highways, Bridges and Railroad Crossings)	7,584	339	1,039	1,302	2,141			2,595	
	Highways						See Table E22			
	Bridges	1,384	1,202	2,301	2,529	2,983			3,072	
	Railroad Crossings	1,028	1,014	2,113	2,366	2,900			3,010	

TABLE E34.

STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL URBAN HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-POPULATION GROUP STRATIFICATION-MINNESOTA DATA

Population Group	Sample Sizes, n_h				
	Optimum Sampling				
	Total Strata Sampling Units N_h	S_h^2	$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Less than 5000	2,584	2,640	133	411	518
Over 5000	726	23,150	110	341	630
Totals	3,310	7,584	243	752	948
					1,581
					1,794*

* Sample Size Computed by Formula (2.04)

TABLE E34 (Continued). STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL URBAN HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-POPULATION GROUP STRATIFICATION-MINNESOTA DATA

Population Group	Total Strata Sampling Units N_h	S_h^2	Sample Sizes, n_h			
			Proportional Sampling			
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Less than 5000	2,584	2,640	251	777	977	1,634
Over 5000	726	23,150	70	218	275	459
<u>Totals</u>	3,310	7,584	321	995	1,252	2,093
						2,346

TABLE E35. STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN BRIDGES-POPULATION GROUP STRATIFICATION-MINNESOTA DATA

Population Group	Sample Sizes, n_h				
	<u>Optimum Sampling</u>				
	S_h^2	$dT = 20$ Per Cent of the Total $\alpha = 0.10$	$dT = 10$ Per Cent of the Total $\alpha = 0.05$	$dT = 5$ Per Cent of the Total $\alpha = 0.10$	$dT = 5$ Per Cent of the Total $\alpha = 0.05$
Total Strata Sampling Units N_h					
Less than 5000	2,584	737	1,258	1,483	2,045
Over 5000	726	389	726	726	726
<u>Totals</u>	3,310	1,384	1,984*	2,209*	2,771*
* Sample Size Computed by Formula (2.04)					

TABLE E35 (Continued). STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN BRIDGES-POPULATION GROUP
STRATIFICATION-MINNESOTA DATA

Population Group	Total Strata Sampling Units N_{h1}	S_h^2	Sample Sizes, n_{h1}			
			Proportional Sampling			
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Less than 5000	2,534	737	1,755	1,960	2,322	2,394
Over 5000	726	3,499	493	551	652	672
<u>Totals</u>	3,310	1,384	2,248	2,511	2,974	3,066

TABLE E36.

STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR
THE ESTIMATE OF TOTAL COST OF URBAN RAILROAD CROSSINGS-POPULATION GROUP
STRATIFICATION-MINNESOTA DATA

Population Group	Total Strata Sampling Units N_h	S_h^2	Sample Sizes, n_h			
			Optimum Sampling			
			$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Less than 5000	2,584	10.73	1,684	1,885	2,309	2,397
Over 5000	726	8.703	426	477	535	607
<u>Totals</u>	3,310	10.28	2,110	2,362	2,894	3,004

TABLE E36 (Continued). STRATIFIED RANDOM SAMPLING-COMPOSITE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST OF URBAN RAILROAD CROSSINGS-
 POPULATION GROUP STRATIFICATION-MINNESOTA DATA

<u>Population Group</u>	<u>Total Strata Sampling Units N_h</u>	<u>S_h^2</u>	<u>Sample Sizes, n_h</u>			
			<u>Proportional Sampling</u>			
			<u>$d_T = 20$ Per Cent of the Total $\alpha = 0.10$</u>	<u>$d_T = 10$ Per Cent of the Total $\alpha = 0.10$</u>	<u>$d_T = 10$ Per Cent of the Total $\alpha = 0.05$</u>	<u>$d_T = 5$ Per Cent of the Total $\alpha = 0.10$</u>
Less than 5000	2,584	10.73	792	1,650	1,847	2,264
Over 5000	726	8.703	222	463	519	636
<u>Totals</u>	3,310	10.28	1,014	2,113	2,366	2,900
						3,010
						2,350

APPENDIX E (Continued)

Sample Sizesfor theSeparate and Composite PopulationUsingSimple and Stratified Cluster SamplingMichigan Data

TABLE E37.

SIMPLE CLUSTER SAMPLING-SEPARATE AND COMPOSITE POPULATION-SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE,
 AND RAILROAD CROSSING IMPROVEMENTS) HIGHWAY COST, BRIDGE COST, AND
 RAILROAD CROSSING COST-MICHIGAN DATA

Total Number of Primary Sampling Units and Elements	Type of Cost	S_T^2 (1000)	Sample Sizes				
			$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
N = 83 M = 6,321	Total*	31,820	27	55	61	74	76
	Highways**	25,460	29	55	61	74	76
	Bridges**	572.9	38	64	69	77	79
	Railroad Crossings**	4,318	64	77	79	81	82

* Composite Population Only

** Separate Populations

TABLE E38. OPTIMUM-STRATIFIED CLUSTER SAMPLING COMPOSITE POPULATION-SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)--MICHIGAN DATA

Rural County Primary Mileage	Number Primary Units N_h	Number of Elements M_h	S_{ht}^2 (1000)	Sample Sizes				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
0-249.99 Miles	41	1,908	1,736	2	6	6	9	11
250-349.99 Miles	30	2,738	40,470	8	20	23	30	30
350-Max. Miles	12	1,675	14,860	2	5	6	7	10
<u>Totals</u>	83	6,321	31,820	12	31	35	46	51*

* Sample Size Computed by Formula (2.06)

TABLE E39. OPTIMUM STRATIFIED CLUSTER SAMPLING SEPARATE POPULATIONS-SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL RURAL HIGHWAY COST-MICHIGAN DATA

Rural County Primary Mileage	Number Primary Units N_h	Number of Elements M_h	S_{ht}^2 (1000)	Sample Sizes				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
C-249.99 Miles	41	1,908	1,389	2	6	6	9	11
250-349.99 Miles	30	2,738	32,300	8	19	23	30	30
350-Max. Miles	12	1,675	13,280	2	5	6	8	10
Totals	83	6,321	25,460	12	30	35	47	51*

* Sample Size Computed by Formula (2.06)

TABLE E40. OPTIMUM STRATIFIED CLUSTER SAMPLING SEPARATE POPULATION-SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL RURAL BRIDGE COST-MICHIGAN DATA

Rural County Primary Mileage	Number Primary Units N_h	Number of Elements M_h	S_{hT}^2 (1000)	Sample Sizes				
				$d_T = 20$	$d_T = 10$	$d_T = 10$	$d_T = 5$	$d_T = 5$
				Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$
0-249.99 Miles	41	1,903	126.0	8	15	16	25	28
250-349.99 Miles	30	2,738	733.0	14	26	29	30	30
350-Max. Miles	12	1,675	607.9	5	10	11	12	12
<u>Totals</u>	33	6,321	572.9	27	51	56	67	70*

* Sample Size Computed by Formula (2.06)

TABLE E41. OPTIMUM STRATIFIED CLUSTER SAMPLING-SEPARATE POPULATION SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL RURAL RAILROAD CROSSING COST-
MICHIGAN DATA

Rural County Primary Mileage	Number Primary Units N_h	Number of Elements M_h	S_{ht}^2 (1000)	Sample Sizes				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
0-249.99 Miles	41	1,908	.1287	5	7	9	18	21
250-349.99 Miles	30	2,738	7.722	26	30	30	30	30
350-Max. Miles	12	1,675	4.207	8	12	12	12	12
<u>Totals</u>	83	6,321	4.318	39	49*	51*	60*	63*

* Sample Size Computed by Formula (2.06)

TABLE E42. PROPORTIONAL STRATIFIED CLUSTER SAMPLING-COMPOSITE POPULATION-(METHOD 1, $n_h \propto N_h$ AND METHOD 2, $n_h \propto M_{ht}$) SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-MICHIGAN DATA

Stratum	Number Primary Units N_{hi}	Number of Elements M_h	S_{ht}^2 (1000)	Sample Sizes											
				$d_T = 20$			$d_T = 10$			$d_T = 10$			$d_T = 5$		
				Per Cent of the Total			Per Cent of the Total			Per Cent of the Total			Per Cent of the Total		
				$\alpha = 0.10$			$\alpha = 0.10$			$\alpha = 0.05$			$\alpha = 0.10$		
				Method	1	2	Method	1	2	Method	1	2	Method	1	2
0-249.99 Miles	41	1,908	1,736	9	5	21	11	25	13	33	17	35	13		
250-349.99 Miles	30	2,738	40,470	7	6	16	16	18	18	24	25	26	27		
350-Max. Miles	12	1,675	14,860	3	4	6	10	7	11	10	12	10	12		
<u>Totals</u>	83	6,321	31,820	19	15	43	37	50	42	67	54*	71	57*		

* Sample Size Computed by Formula (2.08)

TABLE E43. PROPORTIONAL STRATIFIED CLUSTER SAMPLING-SEPARATE POPULATION (METHOD 1,
 $n \propto N_h$ AND METHOD 2, $n_h \propto M_{hh}$) SAMPLE SIZES REQUIRED FOR THE ESTIMATE
 OF TOTAL RURAL HIGHWAY COST-NICHIGAN DATA

Stratum	Number Primary Units N_h	Number of Elements M_h	S_{ht}^2 (1000)	Sample Sizes							
				$d_T = 20$		$d_T = 10$		$d_T = 10$		$d_T = 5$	
				Per Cent of the Total		Per Cent of the Total		Per Cent of the Total		Per Cent of the Total	
				$\alpha = 0.10$		$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$	
				Method		Method		Method		Method	
				1	2	1	2	1	2	1	2
0-249.99 Miles	41	1,908	1,389	9	5	22	11	25	13	34	17
250-349.99 Miles	30	2,738	32,300	7	6	16	16	18	18	25	25
350-Max. Miles	12	1,675	13,280	3	4	6	10	7	11	10	12
Totals	83	6,321	25,460	19	15	44	37	50	42	69	54*

* Sample Size Computed by Formula (2.03)

TABLE E44. PROPORTIONAL STRATIFIED CLUSTER SAMPLING-SEPARATE POPULATION-(METHOD 1, $n_h \propto N_h$, AND METHOD 2, $n_h \propto M_{h1}$). SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL RURAL BRIDGE COST-MICHIGAN DATA

Stratum	Number Primary Units N_h	Number of Elements M_{h1}	S_{hT}^2 (1000)	Sample Sizes									
				$d_T = 20$		$d_T = 10$		$d_T = 10$		$d_T = 5$		$d_T = 5$	
				Per Cent of the Total		Per Cent of the Total		Per Cent of the Total		Per Cent of the Total		Per Cent of the Total	
				$\alpha = 0.10$		$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$		$\alpha = 0.05$	
Rural County Primary Highway Mileage				Method		Method		Method		Method		Method	
				1	2	1	2	1	2	1	2	1	2
0-249.99 Miles	41	1,903	126.0	16	3	29	16	32	13	37	25	39	28
250-349.99 Miles	30	2,733	733.0	12	12	21	24	23	26	27	30	28	30
350-Max. Miles	12	1,675	607.9	5	7	9	12	9	12	11	12	11	12
Totals	83	6,321	572.9	38	27	59	52*	64	57*	75	67*	78	70*

* Sample Size Computed by Formula (2.03)

TABLE E45. PROPORTIONAL STRATIFIED CLUSTER SAMPLING-SEPARATE POPULATION (METHOD 1, $n_h \propto N_h$ AND METHOD 2, $n_h \propto M_h$). SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL RURAL RAILROAD CROSSING COST-MICHIGAN DATA

Stratum Rural County Primary Highway Mileage	Number Primary Units N_h	Number of Elements M_h	S_{ht}^2 (1000)	Sample Sizes											
				$d_T = 20$			$d_T = 10$			$d_T = 10$			$d_T = 5$		
				Per Cent of the			Per Cent of the			Per Cent of the			Per Cent of the		
				Total			Total			Total			Total		
				$\alpha = 0.10$			$\alpha = 0.10$			$\alpha = 0.05$			$\alpha = 0.10$		
				Method		Method		Method		Method		Method		Method	
				1	2	1	2	1	2	1	2	1	2	1	2
0-249.99 Miles	41	1,908	.1237	30	15	38	19	39	20	40	21	41	21		
250-349.99 Miles	30	2,738	7.722	22	21	27	28	28	28	29	30	30	30		
350-Max. Miles	12	1,675	4.207	9	12	11	12	11	12	12	12	12	12		
Totals	83	6,321	4.318	61	48*	76	59*	78	60*	81	63*	83	63*		

* Sample Size Computed by Formula (2.08)

APPENDIX E (Continued)

Sample Sizes
for the
Separate and Composite Population
Using
Simple and Stratified Cluster Sampling
Minnesota Data

TABLE E46. SIMPLE CLUSTER SAMPLING-COMPOSITE POPULATION-SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL HIGHWAY, BRIDGE AND RAILROAD CROSSING IMPROVEMENTS) HIGHWAY COST, BRIDGE COST, AND RAILROAD CROSSING COST FOR THE RURAL SYSTEM-MINNESOTA DATA

Total Number of Primary Sampling Units and Elements	Type of Cost	$S^2_{\bar{y}}$ (1000)	Sample Sizes			
			$d_T = 20$	$d_T = 10$	$d_T = 5$	$d_T = 5$
			Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$
N = 87 M = 7,905	Total*	12,280	17	43	50	69
	Highway**	9,436	17	42	50	68
	Bridge**	367.4	35	63	69	79
	Railroad Crossing**	1.644	65	80	81	85

* Composite Population

** Separate Population

TABLE E47.

OPTIMUM STRATIFIED CLUSTER SAMPLING-COMPOSITE POPULATION SAMPLE SIZES
 REQUIRED FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE,
 AND RAILROAD CROSSING IMPROVEMENTS)-MINNESOTA DATA

Rural County Primary Mileage	Number Primary Units N_h	Number of Elements M_h	S_{ht}^2 (1000)	Sample Sizes							
				$d_T = 20$		$d_T = 10$		$d_T = 10$		$d_T = 5$	
				Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$
0-249.99 Miles	34	2,173	2,145	2	6	3	12	13			
250-349.99 Miles	29	3,028	12,930	5	14	17	25	27			
350-Max. Miles	23	2,704	11,350	4	10	12	18	20			
<u>Totals</u>	86	7,905	12,280	11	30	37	55	60			

TABLE E48. OPTIMUM STRATIFIED CLUSTER SAMPLING-COMPOSITE POPULATION SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL RURAL HIGHWAY COST-MINNESOTA DATA

Rural County Primary Mileage	Number Primary Units N_h	Number of Elements M_h	S_{hT}^2 (1000)	Sample Sizes				
				$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
0-249.99 Miles	34	2,173	1,829	2	7	8	12	14
250-349.99 Miles	29	3,028	8,368	4	12	15	23	25
350-Max. Miles	23	2,704	10,020	4	11	13	20	22
Totals	86	7,905	9,486	10	30	36	55	61

TABLE E49. OPTIMUM STRATIFIED CLUSTER SAMPLING-SEPARATE POPULATION SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL RURAL BRIDGE COST-MINNESOTA DATA

Rural County Primary Mileage	Number Primary Units N_h	Number of Elements M_h	S_{ht}^2 (1000)	Sample Sizes				
				$d_T = 20$	$d_T = 10$	$d_T = 10$	$d_T = 5$	$d_T = 5$
				Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$
0-249.99 Miles	34	2,173	88.79	6	12	13	18	20
250-349.99 Miles	29	3,028	617.6	14	26	29	29	29
350-Max. Miles	23	2,704	310.6	8	15	16	22	23
<u>Totals</u>	86	7,905	366.9	28	53	58	69*	72*

* Sample Size Computed by Formula (2.08)

TABLE E50. OPTIMUM STRATIFIED CLUSTER SAMPLING--SEPARATE POPULATION SAMPLE SIZES
REQUIRED FOR THE ESTIMATE OF TOTAL RURAL RAILROAD CROSSING COST--
MINNESOTA DATA

Rural County Primary Mileage	Number Primary Units N_h	Number of Elements M_h	S_{ht}^2 (1000)	Sample Sizes				
				$d_T = 20$	$d_T = 10$	$d_T = 10$	$d_T = 5$	$d_T = 5$
				Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$	Per Cent of the Total $\alpha = 0.10$	Per Cent of the Total $\alpha = 0.05$
0-249.99 Miles	34	2,173	.7090	16	27	29	33	33
250-349.99 Miles	29	3,028	3.462	29	29	29	29	29
350-Max. Miles	23	2,704	.6030	10	17	18	20	21
Totals	86	7,905	1.644	55*	73*	76*	82*	83*

* Sample Size Computed by Formula (2.03)

TABLE E51. PROPORTIONAL STRATIFIED CLUSTER SAMPLING-COMPOSITE POPULATION (METHOD 1, $n_h \propto N_h$ AND METHOD 2, $n_h \propto M_{h1}$). SAMPLE SIZES FOR THE ESTIMATE OF TOTAL COST (ALL RURAL HIGHWAY, BRIDGE, AND RAILROAD CROSSING IMPROVEMENTS)-MINNESOTA DATA

Stratum Rural County Primary Highway Mileage	Number Primary Units N_h	Number of Elements M_h	S^2_{ht} (1000)	Sample Sizes											
				$d_T = 20$			$d_T = 10$			$d_T = 10$			$d_T = 5$		
				Per Cent of the Total			Per Cent of the Total			Per Cent of the Total			Per Cent of the Total		
				$\alpha = 0.10$			$\alpha = 0.10$			$\alpha = 0.05$			$\alpha = 0.10$		
				Method			Method			Method			Method		
	1	2	1	2	1	2	1	2	1	2	1	2			
0-249.99 Miles	34	2,173	2,145	5	3	13	9	17	10	25	15	27	17		
250-349.99 Miles	29	3,028	12,930	4	4	11	12	14	15	21	21	23	23		
350-Max. Miles	23	2,704	11,350	3	4	9	11	11	13	17	19	18	21		
Totals	86	7,905	12,280	12	11	33	32	42	38	63	55	68	61		

TABLE E52. PROPORTIONAL STRATIFIED CLUSTER SAMPLING-SEPARATE POPULATION (METHOD 1, $n_h \propto N_h$ AND METHOD 2, $n_h \propto M_{hh}$). SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL RURAL HIGHWAY COST-MINNESOTA DATA

Stratum Rural County Primary Highway Mileage	Number Primary Units N_h	Number of Elements M_h	S_{hT}^2 (1000)	Sample Sizes									
				$d_T = 20$		$d_T = 10$		$d_T = 10$		$d_T = 5$		$d_T = 5$	
				Per Cent of the Total		Per Cent of the Total		Per Cent of the Total		Per Cent of the Total		Per Cent of the Total	
				$\alpha = 0.10$		$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$		$\alpha = 0.05$	
				Method		Method		Method		Method		Method	
				1	2	1	2	1	2	1	2	1	2
0-249.99 Miles	34	2,173	1,329	5	3	13	8	16	10	25	15	26	17
250-349.99 Miles	29	3,023	3,363	4	4	11	11	14	14	21	21	23	23
350-Max. Miles	23	2,704	10,030	3	4	9	10	11	13	17	19	18	21
<u>Totals</u>	86	7,905	9,486	12	11	33	29	41	37	63	55	67	61

TABLE E53. PROPORTIONAL STRATIFIED CLUSTER SAMPLING-SEPARATE POPULATION (METHOD 1, $n_h \propto N_h$ AND METHOD 2, $n_h \propto M_h$). SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL RURAL BRIDGE COST-MINNESOTA DATA

Stratum Rural County Primary Highway Mileage	Number Primary Units N_h	Number of Elements M_h	S_{ht}^2 (1000)	Sample Sizes											
				$d_T = 20$		$d_T = 10$		$d_T = 10$		$d_T = 5$		$d_T = 5$			
				Per Cent of the		Per Cent of the		Per Cent of the		Per Cent of the		Per Cent of the			
				Total		Total		Total		Total		Total			
				$\alpha = 0.10$		$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$		$\alpha = 0.05$			
				Method		Method		Method		Method		Method			
				1	2	1	2	1	2	1	2	1	2		
0-249.99 Miles	34	2,173	28.79	13	8	24	15	26	17	31	20	32	21		
250-349.99 Miles	29	3,023	617.6	11	11	21	21	23	23	26	23	27	29		
350-Max. Miles	23	2,704	310.6	9	10	16	19	18	21	21	23	21	23		
Totals	86	7,905	366.9	33	29	61	55	67	61	78	71*	80	73*		

* Total Sample Size Computed by Formula (2.08)

TABLE E54. PROPORTIONAL STRATIFIED CLUSTER SAMPLING-SEPARATE POPULATION (METHOD 1, $n_h \propto N_h$ AND METHOD 2, $n_h \propto M_{ht}$). SAMPLE SIZES REQUIRED FOR THE ESTIMATE OF TOTAL RURAL RAILROAD CROSSINGS COST-MINNESOTA DATA

Stratum Rural County Primary Highway Mileage	Number Primary Units N_h	Number of Elements M_{ht}	S_{ht}^2 (1000)	Sample Sizes									
				$d_T = 20$		$d_T = 10$		$d_T = 10$		$d_T = 5$		$d_T = 5$	
				Per Cent		Per Cent		Per Cent		Per Cent		Per Cent	
				of the		of the		of the		of the		of the	
				Total	Total	Total	Total	Total	Total	Total	Total	Total	Total
				$\alpha = 0.10$		$\alpha = 0.10$		$\alpha = 0.05$		$\alpha = 0.10$		$\alpha = 0.05$	
				Method	Method	Method	Method	Method	Method	Method	Method	Method	Method
				1	2	1	2	1	2	1	2	1	2
0-249.99 Miles	34	2,173	0.7090	26	17	31	23	32	25	33	30	34	31
250-349.99 Miles	29	3,028	3.462	22	24	27	29	27	29	28	29	29	29
350-Max. Miles	23	2,704	0.6030	17	21	21	23	22	23	22	23	23	23
Totals	86	7,905	1.644	65	62	79	75*	81	77*	83	82*	86	83*

* Total Sample Size Computed by Formula (2.08)

APPENDIX F
VARIANCES FOR THE ESTIMATES
OF THE TOTALS FOR THE SEPARATE
AND COMPOSITE POPULATIONS
MICHIGAN AND MINNESOTA DATA

APPENDIX F (Continued)

Variances for the Estimate
of the
Totals for the Separate
and Composite Populations
Michigan Data

TABLE F1. VARIANCES FOR THE ESTIMATES OF THE TOTALS FOR THE RURAL SEPARATE AND COMPOSITE POPULATIONS-MICHIGAN DATA

Population Characteristics		Sample Variance $V(\hat{Y}) = \frac{d_T^2}{Z^2}$			
		$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Highway Total Cost*		4,259x10 ⁶	1,068x10 ⁶	749.9x10 ⁶	266.5x10 ⁶
Highway Total Cost**		4,304x10 ⁶	1,076x10 ⁶	75.79x10 ⁶	269.0x10 ⁶
Timing of Highway Cost*	1st 5 Years	814.0x10 ⁶	203.5x10 ⁶	143.3x10 ⁶	50.87x10 ⁶
	2nd 5 Years	445.4x10 ⁶	111.4x10 ⁶	78.43x10 ⁶	27.84x10 ⁶
	3rd 5 Years	119.6x10 ⁶	29.90x10 ⁶	21.06x10 ⁶	7.475x10 ⁶
	4th 5 Years	22.00x10 ⁶	5.501x10 ⁶	3.874x10 ⁶	1.375x10 ⁶
Cost of Highway Construction*	Res. & Widen Base & Surface	172.5x10 ⁶	44.61x10 ⁶	31.42x10 ⁶	11.15x10 ⁶
	Reconst.	39.45x10 ⁶	9.862x10 ⁶	6.945x10 ⁶	2.466x10 ⁶
	New Const.	1,935x10 ⁶	4,238x10 ⁶	3,407x10 ⁶	121x10 ⁶
		2.654x10 ⁶	0.6637x10 ⁶	0.4674x10 ⁶	0.1659x10 ⁶
Mileage of Highway Construction	Res. & Widen Base & Surface	524.4x10 ³	1,311x10 ³	92.35x10 ³	32.78x10 ³
	Reconst.	96.59x10 ³	24.15x10 ³	17.01x10 ³	6.036x10 ³
	New Const.	2.238x10 ⁶	0.5596x10 ⁶	0.3941x10 ⁶	0.1398x10 ⁶
		1,920	495	349	124

* Does not Include Bridge Approach Cost
** Includes Bridge Approach Cost

TABLE F2. VARIANCES FOR THE ESTIMATES OF THE TOTALS FOR THE RURAL COMPOSITE
POPULATION-MICHIGAN DATA

$$\text{Sample Variance } V(\hat{Y}) = \frac{d_T^2}{Y^2}$$

Population Characteristics	$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.10$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Total Cost (Highways, Bridges & Railroad Crossings)	5,384x10 ⁶	1,346x10 ⁶	948.1x10 ⁶	336.5x10 ⁶	237.0x10 ⁶
Timing of Cost	1st 5 Years 1,042x10 ⁶ 2nd 5 Years 561.1x10 ⁶ 3rd 5 Years 149.9x10 ⁶ 4th 5 Years 26.73x10 ⁶	260.4x10 ⁶ 140.3x10 ⁶ 37.48x10 ⁶ 6.684x10 ⁶	183.4x10 ⁶ 98.79x10 ⁶ 26.40x10 ⁶ 4.708x10 ⁶	65.10x10 ⁶ 35.07x10 ⁶ 9.370x10 ⁶ 1.671x10 ⁶	45.85x10 ⁶ 24.69x10 ⁶ 6.599x10 ⁶ 1.177x10 ⁶
Cost of Construction	Res. & Widen 240.1x10 ⁶ Base & Surface 50.78x10 ⁶ Reconst. 2,368x10 ⁶ New Const. 4.409x10 ⁶	60.028x10 ⁶ 12.69x10 ⁶ 591.9x10 ⁶ 1.102x10 ⁶	42.27x10 ⁶ 8.941x10 ⁶ 416.9x10 ⁶ 0.7763x10 ⁶	15.01x10 ⁶ 3.174x10 ⁶ 147.9x10 ⁶ 0.2755x10 ⁶	10.57x10 ⁶ 2.235x10 ⁶ 104.2x10 ⁶ 0.1941x10 ⁶
Mileage of Highway Construction	Res. & Widen Base & Surface Reconst. New Const.	See Table F1			

TABLE F3. VARIANCES FOR THE ESTIMATES OF THE TOTALS FOR THE RURAL SEPARATE AND COMPOSITE POPULATIONS-MICHIGAN DATA

Population Characteristics		Sample Variance $V(\hat{Y}) = \frac{d_T^2}{L^2}$			
		$d_T = 20$	$d_T = 10$	$d_T = 5$	$d_T = 5$
		Per Cent	Per Cent	Per Cent	Per Cent
		of the	of the	of the	of the
		Total	Total	Total	Total
		$\alpha = 0.10$	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.10$
Total Dridge Plus					
Approache Cost		60.52x10 ⁶	15.12x10 ⁶	3.779x10 ⁶	2.662x10 ⁶
Timing of	1st 5 Years	9.100x10 ⁶	2.270x10 ⁶	0.5690x10 ⁶	0.4000x10 ⁶
	2nd 5 Years	4.150x10 ⁶	1.040x10 ⁶	0.2600x10 ⁶	0.1830x10 ⁶
	3rd 5 Years	3.020x10 ⁶	0.7550x10 ⁶	0.1890x10 ⁶	0.1330x10 ⁶
	4th 5 Years	93.10x10 ⁴	23.30x10 ⁴	5.820x10 ⁴	4.100x10 ⁴
Total Approach (Only) Cost		114.5x10 ³	28.62x10 ³	7.156x10 ³	5.041x10 ³
Total Bridge (Only) Cost		56.21x10 ⁶	13.82x10 ⁶	3.456x10 ⁶	2.435x10 ⁶
Cost of Type of Bridge Construction	Reflooring	5.930x10 ³	1.500x10 ³	.3740x10 ³	.2630x10 ³
	Rebuild or				
	Reconst.	2,450x10 ²	612.0x10 ²	153.0x10 ²	108.0x10 ²
	Replace Same				
	Location	29.10x10 ⁶	7.280x10 ⁶	1.320x10 ⁶	1.280x10 ⁶
	Replace New				
Location	1,000x10 ³	265.0x10 ³	187.0x10 ³	46.70x10 ³	
Now Seperation or Structure					
	Seperation or Structure	192.0x10 ³	47.90x10 ³	12.00x10 ³	3.430x10 ³

TABLE F3 (Continued). VARIANCES FOR THE ESTIMATES OF THE TOTALS FOR THE RURAL SEPARATE AND COMPOSITE POPULATIONS-MICHIGAN DATA

		Sample Variance $V(\hat{Y}) = \frac{d_T^2}{Z^2}$			
<u>Population Characteristics</u>		$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Cost of Type of Bridge Services	Stream	49.90×10^6	12.50×10^6	3.790×10^6	2.200×10^6
	Crossing				
	Highway	53.20×10^2	13.30×10^2	9.37×10^2	2.34×10^2
	Separation	90.20×10^3	22.55×10^3	15.90×10^3	4.000×10^3
Number of Inadequate Structures (Bridges)	Railroad				
	Separation	29.19×10^3	7.296×10^3	5.139×10^3	1.235×10^3

TABLE F4. VARIANCES FOR THE ESTIMATES OF THE TOTALS FOR THE RURAL SEPARATE AND COMPOSITE POPULATIONS-MICHIGAN DATA

$$\text{Sample Variance } V(\hat{t}) = \frac{d_T^2}{Z^2}$$

Population Characteristics		d _T = 20 Per Cent of the Total α = 0.10	d _T = 10 Per Cent of the Total α = 0.10	d _T = 10 Per Cent of the Total α = 0.05	d _T = 5 Per Cent of the Total α = 0.10	d _T = 5 Per Cent of the Total α = 0.05
Total Railroad Crossing Cost		112.4x10 ³	26.11x10 ³	19.75x10 ³	7.021x10 ³	4.946x10 ³
Timing of Railroad Total Cost	1st 5 Years	54.96x10 ³	13.74x10 ³	9.677x10 ³	5.455x10 ³	2.419x10 ³
	2nd 5 Years	2.596x10 ³	0.649x10 ³	0.457x10 ³	0.162x10 ³	0.114x10 ³
	3rd 5 Years	330.6	207.7	146.3	51.93	36.57
	4th 5 Years	442.4	110.6	77.91	27.66	19.48
Cost of Railroad Construction	Signals	30x10 ³	7.500x10 ³	5.286x10 ³	1.376x10 ³	1.321x10 ³
	Signals & Gates	26.23x10 ³	6.558x10 ³	4.619x10 ³	1.640x10 ³	1.155x10 ³
Total Inadequate Railroad Crossings		2,112	528.2	372.0	132.0	92.99
Type Imp. (Number)	Signals	1,054	263.5	185.6	65.79	46.34
Railroad	Signals & Gates	102.2	45.46	32.02	11.38	8.013

TABLE F5. VARIANCES FOR THE ESTIMATES OF THE TOTALS FOR THE URBAN SEPARATE AND COMPOSITE POPULATIONS-MICHIGAN DATA

Population Characteristics	Sample Variance $V(\hat{Y}) = \frac{d_T^2}{Z^2}$			
	$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Total Cost (Highways, Bridges and Railroad Crossings)			Inadequate Data	
Total Highway Cost	121.3×10^6	30.31×10^6	21.33×10^6	5.332×10^6
Total Bridge & Approach Cost	$3,008 \times 10^3$	751.7×10^3	529.5×10^3	132.3×10^3
Total Bridge (Only) Cost	$3,004 \times 10^3$	751.1×10^3	529.0×10^3	132.2×10^3
Total Approach (Only) Cost	0.5322	0.1331	0.0937	0.0244
Total Railroad Crossing Cost			Inadequate Data	

APPENDIX F (Continued)

Variances for the Estimates
of the Totals for the
Separate and Composite Populations
Minnesota Data

TABLE F6. VARIANCES FOR THE ESTIMATES OF THE TOTALS FOR THE RURAL SEPARATE AND COMPOSITE POPULATIONS-MINNESOTA DATA

Population Characteristics	Sample Variance $V(\hat{Y}) = \frac{d_T^2}{Z^2}$			
	$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Total Cost (Highways, Bridges & Railroad Crossings)	4,256x10 ⁶	1,064x10 ⁶	749.3x10 ⁶	265.9x10 ⁶ 197.3x10 ⁶
Total Highway Cost	3,393x10 ⁶	848.1x10 ⁶	597.3x10 ⁶	212.0x10 ⁶ 149.3x10 ⁶
Total Bridge Cost	45.91x10 ⁶	11.47x10 ⁶	8.03x10 ⁶	2.869x10 ⁶ 2.021x10 ⁶
Total Railroad Crossing Cost	45.90x10 ³	11.47x10 ⁶	8.032x10 ³	2.869x10 ³ 2.021x10 ³

TABLE F7. VARIANCES FOR THE ESTIMATE OF THE TOTALS FOR THE URBAN SEPARATE AND COMPOSITE POPULATIONS-MINNESOTA DATA

$$\text{Sample Variance } V(\hat{Y}) = \frac{d_T^2}{Z^2}$$

Population Characteristics	Sample Variance $V(\hat{Y}) = \frac{d_T^2}{Z^2}$			
	$d_T = 20$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.10$	$d_T = 10$ Per Cent of the Total $\alpha = 0.05$	$d_T = 5$ Per Cent of the Total $\alpha = 0.05$
Total Cost (Highways, Bridges & Railroad Crossings)	219.8x10 ⁶	54.94x10 ⁶	38.70x10 ⁶	13.74x10 ⁶
Total Highway Cost	137.2x10 ⁶	34.30x10 ⁶	24.16x10 ⁶	8.576x10 ⁶
Total Bridge Cost	3,031x10 ³	2,003x10 ³	1,414x10 ³	501.9x10 ³
Total Railroad Crossing Cost	770.6x10 ²	192.7x10 ²	135.6x10 ²	48.16x10 ²
				33.92x10 ²

VITA

Donald Orville Covault was born in Fort Wayne, Indiana on April 19, 1926. Mr. Covault received his education in the Fort Wayne school system where he graduated from Central High School in June 1944. He entered Purdue University in November 1944 where he received the degree of Bachelor of Science in Civil Engineering in June 1948. Mr. Covault continued his education at Purdue University and was awarded the degree of Master of Science in Civil Engineering in June 1950. While studying for the master's degree, Mr. Covault held the rank of Instructor in Civil Engineering.

In September 1950, Mr. Covault accepted the position of Instructor in Civil Engineering at the University of Colorado. In June 1951, Mr. Covault resigned his position at the University of Colorado and accepted a position with the Wisconsin Highway Commission as a highway engineer. Mr. Covault was actively engaged in the design and construction of highways while employed by the Wisconsin Highway Department. In September 1955 Mr. Covault accepted a position as research engineer with Purdue University while he continued his education for the Ph.D. degree. His research work at Purdue University was primarily concerned with the conduct

development of a state-wide highway needs study for the Indiana Highway System. Mr. Covault is the author of a paper concerning the Indiana Highway Needs Study and has co-authored two other publications concerning this subject.

Mr. Covault is now employed by the Georgia Institute of Technology in Atlanta, Georgia, as a Research Associate and Associate Professor of Civil Engineering where he is teaching and conducting research in transportation.

The professional organizations and honorary societies of which Mr. Covault is a member are as follows:

American Society of Civil Engineers

National Society of Professional Engineers

Highway Research Board

Tau Beta Pi

Chi Epsilon

Sigma Xi