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Report 03169-I

ACQUISITION OF INFORMATION ON EXPOSURE AND ON NON-FATAL CRASHES

Volume I - Exposure Survey Considerations

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May 12, 1971

Final Report

Prepared under contract FH-11-7293 for

National Highway Traffic Safety Administration
Department of Transportation
Washington, D.C. 20591

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
03169-I		

4. Title and Subtitle	5. Report Date
Acquisition of Information on Exposure and on Non-Fatal Crashes Volume I - Exposure Survey Considerations	May 12, 1971
	6. Performing Organization Code
7. Author(s) P.S. Carroll, W.L. Carlson, T.L. McDole, D.W. Smith	8. Performing Organization Report No.
9. Performing Organization Name and Address Highway Safety Research Institute The University of Michigan Ann Arbor, Michigan 48104	10. Work Unit No.
	11. Contract or Grant No. FH-11-7293
12. Sponsoring Agency Name and Address National Highway Traffic Safety Admin. Washington, D.C. 20591	13. Type of Report and Period Covered Final Report June 1969 - March, 1971
	14. Sponsoring Agency Code FH-11

15. Supplementary Notes

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

16. Abstract

This volume presents an analysis of the considerations involved in the design of driving-exposure surveys. Exposure is defined as the frequency of traffic events which create a risk of accident, measured in vehicle miles of travel. Exposure data obtained in a survey may be combined with accident data to derive accident rates, for use in evaluating highway safety countermeasures. Exposure estimates from a random sample of 8000 drivers in 18 representative states were analyzed, and six variables were chosen as best predictors of exposure (driver sex, driver age, vehicle type, model year, day/night, and road type); 26 unique classes of these variables were defined. Small auxiliary surveys were performed to test the effectiveness of various survey methods. The mail questionnaire method (using one-day trip records) was selected as the best, based on cost and accuracy. Interview methods were also considered, including techniques such as odometer readings and driver estimations of mileage. Indirect methods of collecting exposure data (e.g., gasoline sales) were considered, but their cost-effectiveness was poor. Final recommendations include the implementation of a national exposure survey field test in 1972 at a cost of about $250,000, and continuing operational surveys on an annual basis.

17. Key Words	18. Distribution Statement
	NTIS For public distribution

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
none	none	131	

Form DOT F 1700.7 (8-69)

Preface

This is Volume I of the final report on Contract FH-11-7293, "Acquisition of Information on Exposure and on Non-Fatal Crashes." It covers Phase I of the contract (Exposure Information).

Requirements, approaches, and findings are presented for each of the six tasks in Phase I. Final conclusions and recommendations are presented with regard to content and procedure of future exposure surveys.

This volume is probably the first comprehensive attempt to analyze the needs for collection of exposure data on a large scale. Its breadth and depth of detail should be sufficient to support policy decisions regarding the implementation of exposure data collection programs.

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SECTION 1

INTRODUCTION

This volume explores the meaning of driving-exposure data and its relationship to highway safety. The research findings are intended to answer two basic questions:

1. What are the unique classes of drivers, vehicles, roadways, and environments in the highway transportation system for which exposure data should be collected?

2. What are the methods by which exposure data for these unique classes should be collected and analyzed?

A systematic study approach produced results which answer these questions comprehensively for the first time. Subsequent recommendations are presented as guidelines for policy decisions to implement future exposure-survey programs.

VEHICLE MILES AS A MEASURE OF EXPOSURE

Exposure in the highway transportation system is the frequency of traffic events which create a risk of accident. It is a cumulative quantity which increases continually with increased driving. It may be used to characterize individual drivers or vehicles, or--in aggregate--to characterize certain classes of drivers or vehicles. Further details of driving-exposure concepts are presented in Section 3.

The most commonly used measure of exposure is driving distance expressed in vehicle miles of travel. Other measures proposed and used occasionally include driving time, traffic volume, number of registered vehicles, number of licensed drivers, and gasoline consumption.[1] Among all of the proposed exposure measures, driving distance (vehicle miles) is the one that relates most directly to the processes of highway travel, and hence to the risk of accident. It is also the one most amenable to detailed classification. Therefore, it is logical for the contract to specify that vehicle miles is the measure of exposure to be used in this study.

MOTIVATIONS FOR STUDYING EXPOSURE

Research in highway safety requires the use of data pertaining to measures of effectiveness, i.e. quantities which tell something pertinent about the actual performance of the highway transportation system and its various elements, especially with regard to the accident process. Both accident data and exposure data serve this purpose.

When measures of effectiveness in highway safety are narrowed sufficiently to apply to specific segments of the system, the corresponding data may be used in two ways. One is to identify problems of safety in certain parts of the system; the other is to evaluate changes in safety brought about by the introduction of safety countermeasures in certain parts of the system.

In the past, the only measure of effectiveness used in a comprehensive way in highway safety research has been frequency of accident occurrence within various parts of the system. But accident data alone has proven to be inadequate for the identification of problem areas and evaluation of changes.

Exposure data (vehicle miles) has been derived in a gross manner for many years in all of the states, but it has been classified only by road type. It has not proven useful as a measure of effectiveness for comprehensive identification and evaluation in highway safety. A small number of research projects have derived well-classified exposure data, but their limited scope and longevity have curtailed their potential value.

Fortunately, the idea of combining accident data and exposure data in an improved measure of effectiveness (accident rate) has gained tremendous strength in recent years. This kind of accident rate is derived by dividing the number of reported accidents (in a certain area, time, and system classification) by the corresponding estimate of vehicle miles. Its advantage as a measure of effectiveness in assessing highway safety trends is its relative insensitivity to changes in "the population at risk."[2] Recognition of this fact is spurring an irresistible movement in highway safety research toward the use of exposure-derived accident rates in preference to accident frequency data alone.

The basic motivation for this study is to satisfy the demand for exposure data. Further, given the near certainty that comprehensive exposure surveys will begin to be implemented in the near future, another motivation is to standardize the content and procedures of exposure data collection.

The study contract clarifies its motivation in the very first technical paragraph, entitled Background:

> "Inadequate or non-existent information on certain aspects of highway safety has hampered the development of effective countermeasures. In particular, knowledge of the amount and nature of drivers' and vehicles' use of various highway types, i.e., their exposure to the crashes toward which these countermeasures are directed, has been fragmentary. Information on motor vehicle crashes which result in property damage only or in non-fatal injuries is unreliable. Some of this information may be obtainable by better exploitation of existing information sources. However, additional sources and methods, such as sample surveys, must be used in order to satisfy the Bureau's needs."

OBJECTIVES OF THE EXPOSURE STUDY

In its second technical paragraph, the study contract states Objectives, as follows:

1. To formulate a logical structure and methodology to aid in the orderly acquisition of exposure data.
2. To develop sampling techniques and procedures for obtaining mileage of travel on different classes of highways, with differing traffic characteristics, for significant driver-vehicle combinations.
3. To develop procedures for obtaining reliable estimates of numbers and types of property damage and personal injury crashes and the associated damage and injuries.

The first two objectives deal with "acquisition of exposure data"---the subject of this volume. The third objective deals with the reliability of accident data--the subject of the next volume. As seen in the preceding section, these two subject areas are intimately related in the context of accident-rate derivations. Thus, an implicit objective in both areas is to formulate relationships between corresponding sets of exposure data and accident data.

The details of the contract Work Statement are presented in Appendix A. A key guideline therein is particularly relevant to the relationship among the objectives, namely that the work "should ensure that the classes for which exposure data is collected and the classes for which crash experience is collected will correspond and permit appropriate rates to be calculated."

ORGANIZATION OF VOLUME I

This volume covers Phase I of the contract (Exposure Information). The six tasks of Phase I are presented in six consecutive sections, preceded by a summary section and a section on exposure concepts. The final section compiles conclusions and recommendations of the total volume.

Section 2 - Summary - contains a brief discussion of requirements, approach, and findings in each of the six tasks. For many readers, it will include sufficient information for consideration of future exposure programs, and for others it will serve as a convenient review of the entire volume.

The main text - Sections 3 through 9 - may be considered in four parts:

- Exposure Concepts - Section 3: Explanations of exposure, its uses, needs, and classifications.
- Exposure Classes - Section 4: Task 1/Determination of exposure classifications that should be used in the future.

• Data Collection Procedures	- Section 5:	Task 2/Analysis of alternate procedures for exposure data collection.
	Section 6:	Task 3/Analysis of exposure survey costs; recommended procedures.
	Section 7:	Task 4/Analysis of field tests of recommended collection procedures
	Section 8:	Task 5/Analysis of indirect measures of exposure as inexpensive alternatives
• Future Programs	- Section 9:	Task 6/Recommendations for future exposure programs

Separately bound volumes of Appendices A through I provide further details pertaining to the tasks of Volume I.

SECTION 2
SUMMARY

This volume presents the requirements, approaches, and findings pertaining to each of the six tasks of Phase I - Exposure Information (see contract work statement, Appendix A). Summaries of each of the tasks are given under the headings below.

EXPOSURE CLASSIFICATIONS (TASK 1)

The requirement of this task is to "determine the principal classes of drivers and vehicles and environments for which exposure measurements are needed." The classes may be characterized by variables such as driver age, vehicle type and road type, and combinations thereof. The classes are required to be "relatively homogeneous with respect to relevant exposure factors," amenable to sampling procedures, and "useful for studying the impact of safety countermeasures."

This task is the key task in the exposure study. Its results define the required content of future exposure data records, and they determine feasible alternatives for data collection in later tasks.

The approach was to perform two consecutive exposure surveys, and to analyze their data in terms of the variables which are best predictors of exposure. The first survey had a small sample (448), but it had a large number of potential "predictor" variables as candidates for the definition of unique exposure classes. The second survey had a very large sample size (8000), but it had a greatly reduced number of potential predictor variables. (Many of the variables of the first survey were eliminated because analysis showed they were not good predictors of exposure).

Both surveys were conducted by personal interviews of licensed drivers in licensing offices. The first was done in one office, and the second was done in 37 offices distributed throughout the country. Drivers were asked for estimates of mileage driven in the last 30 days, and for information on themselves, their vehicle, and their driving patterns.

Data analysis was performed by means of a computer program (AID - Automatic Interaction Detector) which divides data samples into smaller groups by picking the best predictor variable on the basis of minimum variance. Successive analyses of the smaller groups leads to a hierarchy of best predictor variables, as illustrated in Figure 1.

This figure identifies four variables which determine best splitting of sample groups: Drive on Job?, Driver Sex, Type of Vehicle Driven, and Percent Driving on Local Streets. The boxes indicate group size N, mean miles $\overline{Y}$, and variable levels which define one part of a two-way group split.

The first variable, Drive on Job?, does not correspond to any item of data on most accident reports. Therefore, it cannot be used to determine accident rates in the near future. However, Type of Vehicle Driven serves as a good substitute for Drive on Job? because of their strong correlation. But in the future, a Drive on Job? variable should be considered for inclusion in accident reports.

Further AID runs using logarithm of miles and number of accidents as dependent variables produced three more recommended predictor variables: Driver Age, Model Year of Vehicle, and Percent Driving at Night.

Other variables not selected after the second survey were: number of vehicles driven, vehicle use, driver's knowledge of engine, education, income, car size and make, urbanization index, socio-economic index, area population, and percentages of driving on freeways, rural roads, and wet roads.

Figure 2 presents a chart of 26 unique exposure classes based on the six selected variables:

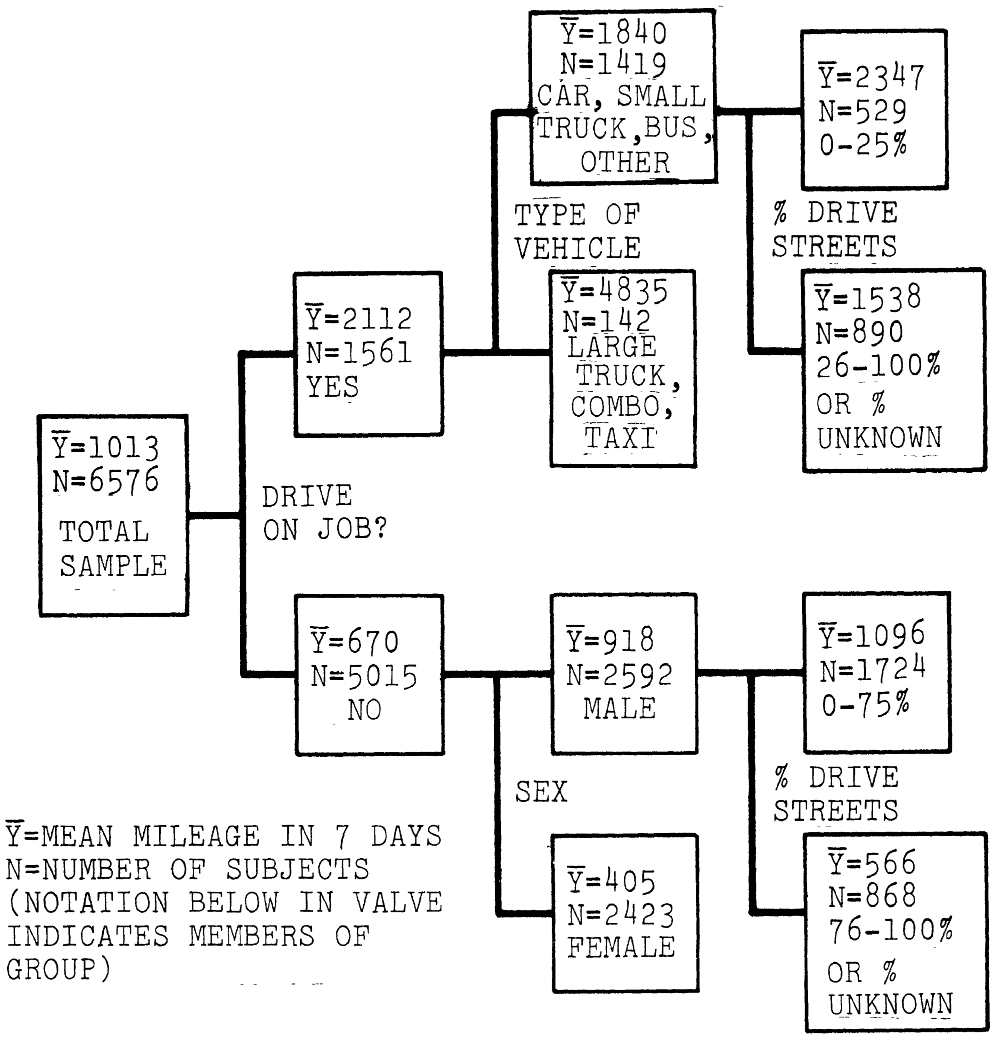


FIGURE 1 Basic AID Chart from Pilot Survey

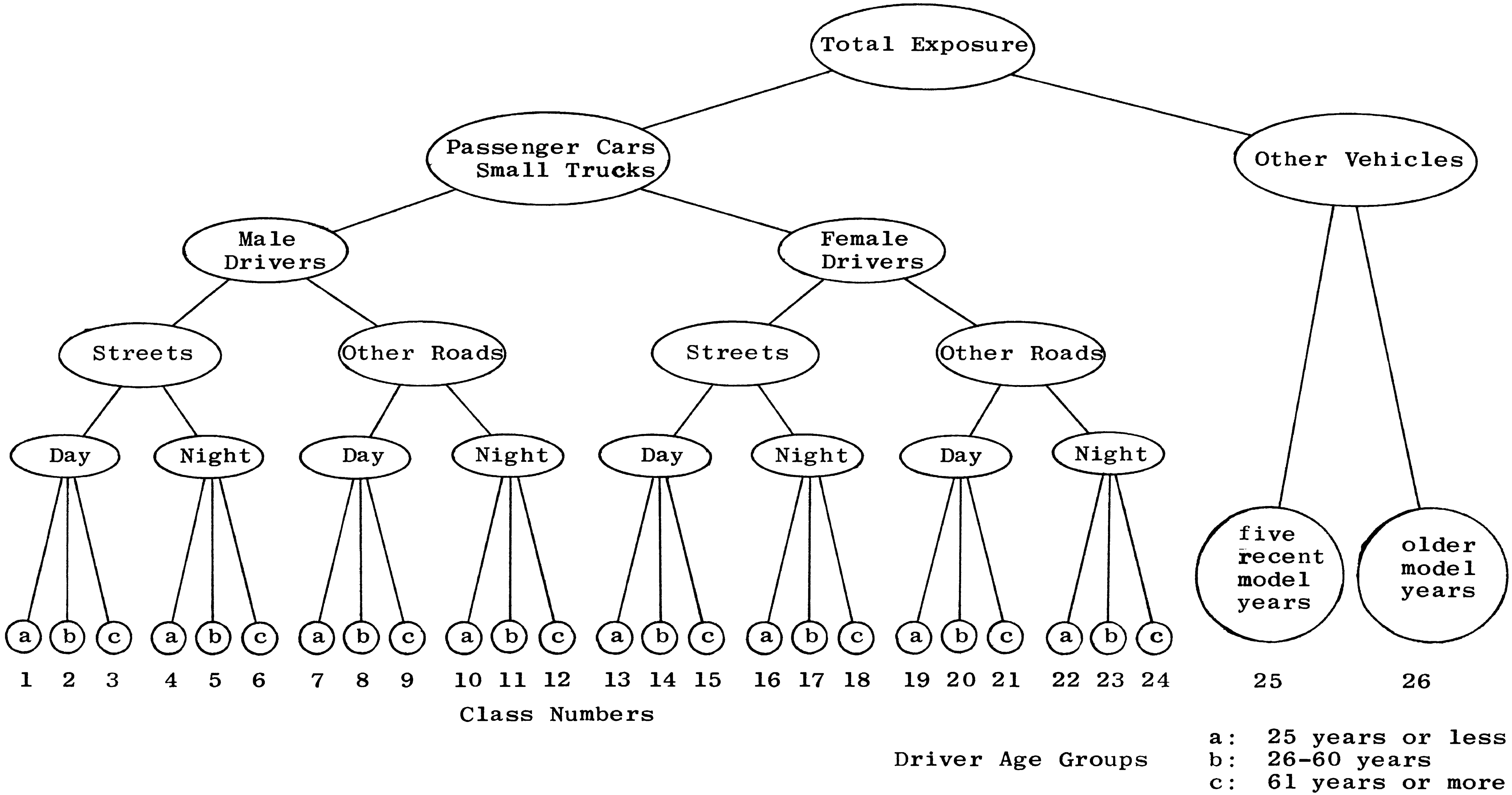


FIGURE 2

Chart of Unique Exposure Classes

Vehicle Type (Passenger Cars and Small Trucks vs. Other Vehicle Types)
Driver Sex (Male vs. Female)
Road Type (Local Streets vs. Other Road Types)
Light Condition (Day vs. Night)
Driver Age (Three groups: up to 25, 26-60, over 60)
Vehicle Model Year (five recent years vs. older years)

It is recommended that the six variables be included in future exposure surveys, and that the 26 classes be used to determine total exposure and accident rates.

EXPOSURE SURVEY PROCEDURES (TASK 2)

The requirement of this task is to "determine and analyze procedures for exposure sample surveys to provide estimates of vehicle-mileage" for the driver-vehicle-road-environment classifications determined in Task 1.

The approach was to systematically derive a set of feasible alternatives, i.e., basic procedural plans for potential exposure surveys, and to compare the alternatives for accuracy and response rate by means of brief test surveys.

Initial analysis of federal highway safety research needs concluded that operational exposure surveys should be officially sponsored, national in scope, and annual in frequency. Analysis of a scenario of exposure as a travel process among elements of the highway transportation system led to a conclusion that drivers are the only feasible source of accurate, well-classified exposure estimates. Further, the potential magnitudes of driver surveys made it clear that small samples of drivers must be used.

Potential methods of data collection from drivers were structured as follows:

Mode of Collection	Mileage Estimation Method
1. Office interview	a. Estimate of gross mileage
2. Office questionnaire	b. Estimates of mileages in several categories of driving or components
3. Mail questionnaire	
4. Telephone interview	
5. Home interview	c. Estimates of trip mileages after reconstruction of recent trips

d. Recording of mileages in a trip log

e. Recording of cumulative odometer readings

Of the 25 possible mode/estimation combinations, 14 were compared by small specialized surveys with a total sample of about 900. Of the remaining 11 combinations, six were not feasible and the others — home interviews — were rejected because of high cost.

In one survey, odometer readings of the sample were compared with gross estimates by the same drivers in office interviews. Odometer-reading responses were received by mail from about 50% of the sample, and mean mileage results were in error by only 4 percent.

In the other surveys, independent driver samples were taken in the same county. Response rates of about 90% were achieved for all office interview methods and office questionnaire methods, except those requiring a mailed trip log following the interview. Most of the mailed questionnaires and mailed trip logs had response rates of about 50% of less. The telephone response rate was 58%. In most cases, the rates could be raised to an acceptable 80% level by means of one or two follow-up contacts.

Accuracy comparisons were made with the mean value of trip log responses as a reference (because of intrinsic accuracy in one-trip odometer readings). Mean values were within 15% by all methods except the total of component estimates, which reflected the compounding of overestimation.

Although the results are not statistically significant, they do show that gross estimates are probably closest to the more accurate trip log method.

SURVEY COSTS AND RECOMMENDED PROCEDURES (TASK 3)

The requirements of this task are to determine comparative costs of alternative survey methods, and then, in conjunction with accuracy findings of Task 2, to "recommend procedures that will best fulfill Bureau requirements."

Cost estimates were made for 19 of the alternative survey methods, borken down into about 20 cost elements under categories of planning, preparation, data collection, and analysis. Based on a sample of 5000, cost per data case ranged from about $4.50 to $11.00. Mailed questionnaires were cheapest (up to $4.70); office interviews, office questionnaires and telephone interviews were in the $6 - $7 range; and home interviews were most expensive (nearly $11.00).

At the present time, the office interview and office questionnaire methods are not feasible because many of the states do not require drivers to appear in person at a licensing office when they apply for renewal. Home interviews and telephone interviews are eliminated because of high costs and sampling difficulties. Thus, the mailed-questionnaire type survey is recommended, with attached trip logs as the mileage estimation method.

FIELD TEST PROCEDURES (TASK 4)

The requirement in this task is to "recommend field tests to evaluate procedures developed" in the preceding tasks.

A field test of an exposure-survey plan would require real-world implementation of all aspects of the plan, but it would be limited in time and geographic scope. Its purpose would be to validate cost and accuracy estimates of the plan, to discover operational problems, and to evaluate overall performance.

An outline of field-test procedures for a national, mailed-questionnaire exposure survey was generated, including scheduling, questionnaire development, liaison, sample design, clerical preparation, data handling, and analysis. In each part, subtasks for auxiliary procedure evaluations were included.

Procedure evaluations in all parts of the field-test plan appear to be straight-forward, and capable of solid verification of the operational survey plan.

INDIRECT EXPOSURE MEASURES (TASK 5)

The requirement in this task is to develop indirect measures of exposure (i.e. substitutes for vehicle-miles data) in situations where it is impossible or uneconomical to obtain vehicle-mile data.

The following indirect exposure measures were analyzed: gasoline sales, one-time-only odometer readings, population, vehicle registrations, roadway right-of-way mileage, and auto insurance premiums. All of these measures are strongly related to vehicle miles, in aggregate. However, they are <u>all incapable of being broken down into classifications</u> according to the six recommended variables of Task 1.

Other problems include gasoline losses (leaks, nontravel uses, etc.), imprecise miles per gallon data, gasoline transfer between states and year to year, vehicle age biases in samples of odometer readings, and time lags and other biases in insurance premiums.

Costs of obtaining indirect exposure data in recommended classifications would not be less than costs of direct exposure surveys; accuracies would not be better. Thus, <u>indirect measures do not provide cost-effective alternatives to direct exposure measures</u>.

RECOMMENDED EXPOSURE SURVEY PROGRAMS (TASK 6)

The requirement of this task is to synthesize the findings of the preceding tasks -- i.e., the needs for exposure surveys and the efforts required -- and to make "recommendations for future exposure data collection programs."

The basic findings were as follows:

1. Comprehensive exposure data is needed in highway safety research to permit calculation of accident rates as the key measure of effectiveness.
2. On the basis of need, official exposure surveys should be conducted.

3. Future exposure surveys should use estimates of vehicle miles of travel as the measure of exposure.
4. Independent variables should include vehicle type, driver sex, road type, light condition (day, night), driver age, and vehicle model year.
5. The six independent variables should be used to define 26 unique classifications of exposure, i.e. driver-vehicle-road-environment combinations.
6. Future exposure surveys should be national in scope, on an annual basis.
7. Drivers should be the source of exposure estimates.
8. Small random samples of drivers are adequate for exposure surveys, and necessary economically.
9. The basic mode of exposure data collection should be by means of mailed questionnaires, which have the lowest relative cost.
10. The basic method of drivers' vehicle-mile estimation should be by means of trip logs of one-day duration, which have the highest relative accuracy.
11. Field tests of a recommended exposure survey plan are feasible and desirable prior to full-scale operational implementation.
12. There are no available indirect measures of exposure which are preferrable, on a cost-effective basis, to direct measure of vehicle miles.

In the process of synthesizing these findings, the following conclusions were reached:

1. Eventually, national exposure survey programs should be conducted on a state-by-state basis, so that each state may apply measures of effectiveness to its own unique set of highway safety countermeasures.
2. Official sponsorship authority of future exposure survey programs should be held by the National Highway Traffic Safety Administration.
3. Implementation responsibility of future exposure survey programs should be held by the National Highway Traffic Safety Administration.

Five future exposure programs are recommended:

1. Field Test Program - A nationwide mail survey of driving exposure in the calendar year 1972. Quarterly mailings

would be sent to randomly selected drivers in all states, distributed by random selection of each of the seven types of day of the week. State subsamples would be proportional to driving population. Total sample size would be limited for economy to about 25,000 such that statistically significant results would be obtained in the 26 unique exposure classes, nationally but not for each state.

Auxiliary survey methods could be tested simultaneously to provide data on possible evolution of survey method to home interview or office interview procedures.

A first year mail survey program would cost about $250,000, and additional testing of alternatives could cost up to $125,000 more.

2. Operational Exposure Survey Program - Annual surveys, starting in 1973, including modifications derived from the field test program. State subsample sizes would be increased to provide significant results for the unclassified aggregates in each state and for many of the 26 unique classes within each state. Survey designs would continue to evolve as new insights were obtained from yearly re-evaluations.

   Costs of an operational exposure survey would be about the same as the first-year field test ($250,000 annually) if sample size remained at 25,000. A maximum annual cost of about $500,000 is estimated for eventual samples of 100,000 (0.1% of all drivers).

3. Continuing Survey-Evaluation Program - Data from the field test and operational programs should be analyzed continually to determine new variables and exposure classes. This program would involve continuing research, in conjunction with analysis phases of the operational programs, at modest additional cost.

4. Auxiliary Indirect-Exposure Program - Although the potential in the indirect-exposure area is not highly promising, it is likely that gasoline sales data and odometer data will continue to be collected. Also, induced exposure data, derived solely from improved accident data, is still considered worthy of further investigation. Therefore, it is recommended that indirect-exposure research programs be pursued independently at appropriate times, and that the results be compared with results of operational exposure surveys.

5. Other Exposure Sources - Direct and semi-direct exposure data may be obtained opportunistically by means of driver estimates or odometer readings at the time of

licensing, vehicle registration and inspection, and accident reporting. Though these exposure sources may not be capable of driver-vehicle cross-classification they may serve as partial checks on direct vehicle-mile surveys. It is recommended that they be considered for inclusion in future revisions of highway safety program standards.

SECTION 3
CONCEPTS OF EXPOSURE

The purpose of this section is to provide a conceptual basis for thorough understanding of the detailed exposure analysis in this volume. The discussion includes basic definitions, rationale of exposure classifications, and uses and needs of exposure data.

BASIC DEFINITIONS OF EXPOSURE

Even though the concept of exposure is widely discussed in the highway safety research community, there is no generally accepted definition of exposure to be found in the literature. In fact, many of the authors who introduce the problem of exposure data, do so by means of reference, rather than direct definition.

However, two things are commonly inferred about exposure:

1. It tells something about the risk of driving.
2. It is usually measured in terms of vehicle miles.

These conform to the implied definition of exposure in the contract, namely: "the amount and nature of drivers' and vehicles' use of various highway types."

The amount of highway use (driving) is readily measured in units of vehicle-miles (though other units may be equally valid). On the other hand, the nature of highway use cannot be measured in vehicle miles, or any other convenient units. Thus, a problem arises when we attempt to define exposure as a compound quantity involving both amount and nature of highway use.

The dilemma can be solved by the adoption of vehicle miles as the sole measure of exposure, as specified in the contract. Thus, the "nature" of driving can be removed as a defining attribute of exposure quantities, and "amount" of driving becomes their only attribute. This does not preclude the establishment of meaningful relationships between exposure data and data on some other independent variable which characterizes the "nature" of driving.

The following definition of exposure is proposed for use in this study, and for adoption within the highway safety research community until such time as more investigations are performed on measures--other than vehicle miles--which can deal more directly with "nature" of driving, in addition to "amount".

EXPOSURE is the frequency of traffic events which create a risk of accident.

This definition is very flexible, because it admits vehicles miles as an average measure of the occurrence of "traffic events," and yet it allows for future development of a scale of intensity of "traffic events which create a risk of accident." Hence, "intensity variables" such as speed or traffic volume could be added later in order to characterize the risk of each vehicle mile travelled.

When we apply units of vehicle miles as the measure of exposure in this study, we assume that all driving is equally susceptible to the "risk of accident." Every increment of distance travelled is viewed as part of a uniform stream of driving; chains of traffic events merge into a continuous flow, and the relative danger of various traffic events are submerged in importance. Thus, the "frequency of traffic events which create a risk of accident" is conceptualized mathematically as a continuous, linear function of distance travelled (vehicle miles).

Obviously, the traffic events of any trip are closely linked and continually interrelated. Even a seemingly uneventful trip segment of straight and level driving is a unique traffic event in itself. However, many common traffic events are clearly identifiable as discrete events--e.g. conflicts and near misses--with readily observable boundaries in time and space. The depth of analysis in such considerations is beyond the scope of this report.

BACKGROUND

As mentioned earlier, many authors have discussed the problem of exposure without attempting a direct definition. In 1953, Dunlap and Associates[3] implied that exposure is a measure of "the frequency of the existence of...a situation which may or may not involve an accident." Mathewson and Brenner,[4] in 1957, recommended a "unit of risk in motor vehicle accident rates." In "The Federal Role in Highway Safety"[1] (1959), the discussion referred to "exposure to hazard" and the "chances of being involved in an accident." In 1960, Stewart[5] indicated that driving exposure requires information on total driving experience, kinds of experience, and the distribution of the kinds of experience, in a given time period. In 1961, Jacobs[6] asked how one measures exposure, i.e., "the frequency of occurrence of risk situations (and) circumstances associated with risk situations." In 1964, Thorpe[7] defined exposure to accident of particular groups of driver-vehicle combinations as "total vehicle miles," and assumed it to be proportional to twice the number of two-car accidents of the group minus the number of one-car accidents of the group. (Thus, he added precision to the description of the term exposure, but avoided further clarification of its meaning.) In 1967, Little[8] said that "exposure is intended to indicate something about the relative risk of a certain vehicle-driver combination to the occurrence of some undesirable event." In 1968, Goeller[9] called exposure over a given driving distance "the number of times that danger occurs," and he related it to vulnerability (by juxtaposition) and hence to confrontation. In 1969, Carr[10] suggested in place of exposure, a relative risk function that characterizes driver-vehicle combinations in <u>all</u> environmental conditions (especially with respect to roadway location). In 1970, Klein and Waller[2] discussed exposure as the "population at risk (in terms of passenger or vehicle miles)," used as a denominator in calculation of an accident or injury rate.

Other authors (Hall, Platt, Pelz, Foldvary, Burg, Coppin, Witheford, Haight) have variously referred to:

exposure to accident
exposure to accident hazards
exposure to the risk of accident
exposure to accident susceptibility
exposure to crash-producing situations

In all of these cases, the implied definitions of exposure are consistent with the one proposed for this study.

One of the very few cases where the author makes it explicitly clear that he is attempting a definition of exposure is the book by DeSilva[11], where exposure is defined as "the number and relative danger of external hazards encountered while driving." Here, the number of external hazards is analogous to our "frequency of traffic events." The relative danger of external hazards is analogous to the "nature of driving", as previously discussed, and it is subsumed in a "scale of intensity" which may be developed in the future.

On the basis of this historical perspective, it is clear that the basic definition of exposure offered in this study serves to clarify the concept for current usage, and to simplify the application for various measures of exposure. A flexible framework is provided for future research into the ways that the nature of driving may be incorporated with the amount of driving in more complex definitions.

CLASSIFICATIONS OF EXPOSURE DATA

When appropriate measurement techniques are available, exposure data may be collected over a selected time period for almost any driver or vehicle, or specified groups of drivers or vehicles. On the broadest scale, it is theoretically possible to obtain exposure data for all drivers or all vehicles in a given area, such as the United States. If this were done for a period of one year, we could sum the results and produce a national, annual total of exposure in vehicle miles. A mean yearly exposure value could then be calculated for the entire population of drivers or vehicles.

The same results can be achieved, with negligible error, by the use of small random samples of drivers or vehicles. The mean exposure of the sample can be extrapolated to an accurate estimate of total exposure by multiplying by the total driving population, i.e., numbers of drivers or vehicles.

If samples are collected in each state, total exposure in each state may be estimated and summed in a national estimate. In this case, national exposure is classified by state. The mean values of exposure for the states will be similar in magnitude, but the slight differences will be statistically significant. At the present time in fact, national exposure is determined for the Federal Highway Administration (FHWA) by means of gasoline sales data in each state, and hence it is classified by state. Unfortunately, the accuracy of this data is unknown. However, it does provide an excellent example of the value of the classification of exposure data, e.g., comparisons of exposure among different classes of drivers or vehicles. For example, the FHWA national estimate of mean exposure per driver in 1967 was 9162 vehicle miles, ranging from 6923 for Hawaii to 11,683 for Wyoming.[12] Analysis of the exposure differences among classes often provides a correlation with certain variables which may suggest highway safety countermeasures; in this case, it appears that densely populated states tend to have lower mean exposure per driver, and less densely populated states tend to have higher mean exposure per driver. The only other classification of FHWA exposure data is by highway type.

In order to provide more comprehensive classifications of exposure data (beyond state and highway type) it would be desirable to obtain exposure data with relation to many other variables of the highway transportation system. Many of these variables—characteristics of system elements—are excellent predictors of exposure.

The highway transportation system is usually categorized by four basic elements: the driver, the vehicle, the roadway, and the environment. Hence, the following types of variables should be considered for classification of exposure data:

Variables which characterize drivers operating in the system
Variables which characterize vehicles operating in the system
Variables which characterize roadways existing in the system
Variables which characterize environments influencing the other elements.

In each category there are several variables which have a significant correlation with exposure, and many others which have little effect.

When data on a variable such as driver age is collected in conjunction with each individual exposure estimate, the total exposure obtained may be classified according to that single variable, and a unique driver age distribution of exposure is obtained. The result is a wide variation in mean exposure among many of the age groups, and a definite trend of increasing exposure per driver is observed in early age groups, followed by decreasing exposure in older age groups. But the distribution of exposure for some other variables, such as vehicle manufacturer may be relatively uniform. The variables which show more pronounced variations in exposure distributions are the better predictors of exposure, and they are the ones which should be used in classifying exposure.

Every increment of exposure (e.g. one vehicle mile or fraction thereof) can be classified according to unique characteristics of the elements involved. Thus, a certain trip will have associated with it certain driver variables (age, sex, occupation, etc.), certain vehicle characteristics (make, model, year, etc.), certain rowadway characteristics (road type, number of lanes, etc.), and a certain environment (time, weather, etc.). In this case, ten variables were mentioned parenthetically as examples, and the specific trip would have fixed values for each variable, e.g., 25 years old, male, student, Ford, 2-door, 1968, city street, 4 lanes, daytime, raining. In any exposure survey, there will be many other trips of the precisely same class. There will also be many others which differ only by the value of one variable, e.g., female instead of male. The number of unique classes will depend not only on the number of variables but also on the number of levels in each variable. If each variable in this example has just two levels (e.g., under 30 years vs. over 30 years, male vs. female, employed vs. unemployed, etc.) then there will be 2^{10} or 1024 different exposure classifications. In other words, we could cross-classify all exposure in the survey area according to all the levels of the selected variables.

In the example above, the 1024 classifications would be unmanageable and largely without value, even though the ten selected variables might be the best predictors of exposure. The mean values of exposure in many of the classes would be nearly identical. However, by establishing a hierarchy of the same ten variables with a limited number of cross classifications, it would be possible to drastically reduce the number of unique classes. The objective should be a manageable set of driver-vehicle-road-environment combinations which exhibit homogeneity of their own exposure distribution. The final classifications might use only four variables, but all of the classes might use different combinations of four variables. Uniqueness of the final classifications should be evident in a wide range of mean values for their exposure distributions, and by relatively homogeneous distributions, i.e. minimum possible statistical variance.

In order to be of most usefulness, the classifications selected for an exposure survey must be useful for studying the impact of safety countermeasures, i.e., they should define situations to which major countermeasures may be applied. Clearly, a great many system variables are relevant to major safety countermeasures.

The problem, then, in selecting variables for exposure classifications, is to balance the desire for many variables which are relevant to countermeasures against the need for a limited number of variables in terms of effective data management.

FURTHER CONCEPTS OF EXPOSURE

1. Exposure values may be viewed either from the perspective of a desirable process to be encouraged (increasing use of a travel service offered by the system) or from the perspective of an undesirable concomitant phenomenon to be discouraged (increasing risk of accident experienced reluctantly in the face of potential breakdown of the system). The driving public appears to accept the risk at the present level because it demands the service at its present level. A risk-service tradeoff continues in the public mind.

In the future, exposure data may be used to determine optimum points in the risk-service tradeoff. However in this study the emphasis is focussed only on the risk perspective in the use of exposure data.

2. The terms "exposure" and "driving exposure" are often used interchangeably. They both imply the risk of accident, and they could in fact be called accident exposure, referring to the exposure of a driver (or vehicle) to an accident. The risks of the driver are considered independently of the number of passengers he may be carrying. If passengers are involved in non-injury accidents, their presence, after the fact, appears to have no bearing on the *a priori* risk of accident.

As more is learned about exposure, it will be desirable to consider carefully a broader "riding exposure" or injury exposure. Here, the risk of injury replaces risk of accident in the exposure definition, and the number of passengers involved in every vehicle mile of travel has critical importance. A new measure—passenger miles—may replace vehicle miles in studies of injury exposure. Another approach may be to consider the chain of events--accident/injury--and to define injury exposure (exposure to injury, given an accident). This approach provides a rational separation between countermeasures in the system to prevent accidents, and countermeasures in the vehicle to prevent injuries.

3. A direct measure of exposure is one that may be obtained directly from a source in the highway transportation system (driver estimate, odometer reading), and that may be directly related to the driving process. Included are driving distance (vehicle miles), driving time (vehicle hours), and traffic volume (vehicles per hours).

An indirect measure of exposure is one that is obtained from a source that is not part of the highway transportation system, or that is not directly related to the driving process. The best examples are gasoline sales and auto insurance premiums, which are determined outside the system and which do not relate directly to driving. Others, which could be considered "semi-direct" include unpaired odometer readings (i.e. not intended to compute a difference between readings over time), miles of roadway, population, and vehicle registrations.

4. Exposure is a cumulative quantity. Over a given time period of interest (e.g., one year), the exposure of an individual driver or vehicle increases continually, though sometimes sporadically. Likewise, the exposure of a group of drivers increases continually during a year; in this case the aggregation effect causes the increase to be relatively uniform as a function of time. However, rates of accumulation do vary slightly over time, especially as a function of season of the year. Similarly, rates of exposure accumulation in one day are low in early hours, high during daylight (especially at rush hours), and low again in the evening.

For purposes of future analysis, it may be useful to consider the concept of instantaneous exposure. For an individual driver, this is most simply expressed as his driving speed. However, there are many other factors which influence an instantaneous risk of accident. Obviously, the exposure to accident of a driver travelling at 30 mph is much greater in heavy traffic or on a curving road than it is when he is driving alone on a straight road. Thus, risk profiles of constant-speed trips may very both positively and negatively from the nominal speed. At this microscopic level of exposure analysis, it may be possible to generate meaningful relationships between cumulative exposure and incidence of discrete traffic events such as conflicts or near misses.

ALTERNATIVE MEASURES OF EXPOSURE

The primary measure of exposure used in this study is the quantity "vehicle-miles travelled" by various driver-vehicle combinations in various roadway-environment combinations. Vehicle miles is the most commonly used measure of exposure in highway safety research, but there are several other measures that similarly provide a direct indication of the quantity and/or intensity of highway driving patterns, e.g., driving time, traffic volume, speed, and square of vehicle miles.[1] Very little has been done to analyze the potential of these as exposure measures. A notable exception was the study by Solomon[13] (1964) in which speed on rural highway was considered as an exposure measure. There continues in the highway safety research community a feeling that an exposure measure may be found that is superior to vehicle miles for some purposes.

Research is needed to resolve the question of an optimum exposure measure and it should be pursued. On the other hand, such research requires a solid basis in experience with present methods, i.e., use of vehicle mileage as the exposure measure.

The present study fulfills this need, and therefore, limiting its exposure measures to just one (vehicle miles) is a wise decision.

USES AND NEEDS OF EXPOSURE DATA

At present, exposure data is used in many states to determine gross accident rates (aggregate numbers of accidents or fatalities per 100 million miles travelled). However, there are very few attempts to determine official accident rates for the various classes of drivers, vehicles or roads. Such attempts would be dependent on exposure data classified by the characteristics of the drivers, vehicles or roads. Data of this kind is not currently being collected by the states on a comprehensive basis, and there do not appear to be any plans in existence to collect such data at the state level. Instead, the states continue to collect aggregate exposure data (total miles travelled per year) for purposes of highway construction planning. The yearly exposure totals are used to compute gross accident rates only as an incidental use.

Exposure data of limited scope has been used effectively in a number of research projects concerned with specific problems of highway safety. Burg[14] surveyed 17,000 California drivers for exposure and visual acuity, and found a positive correlation between good driving records and good visual acuity. In Australia, Foldvary[15] surveyed 23,000 vehicle owners for exposure, and found decreasing accident rates with driver age. The California Department of Motor Vehicles[16] surveyed 10,000 teen-aged drivers for exposure and driving record, and found no reason to raise the minimum age for driver licensing. Many smaller research surveys of driver's exposure have been conducted in recent years, but most have been applied to a specific sub-population rather than a general population. In most cases, the research determined accident rates for only a few driver or vehicle classes appropriate to the specific research question.

Generally, the purpose of research surveys of driving exposure has been to evaluate the performance of certain classes in the highway transportation system, and generally the evaluation measure is accident rate derived with exposure as the denominator. Clearly, there is a movement in highway safety research toward the use of accident rates rather than accident occurrence frequency as an evaluation measure. Thus, it appears that the primary future use of exposure data will be for the derivation of accident rates.

When accident rates are used to evaluate classes in the system, it is necessary to make comparisons of related accident rates--either comparisons among classes or comparisons over time for a selected class. Such comparisons may be used not only to evaluate the performance of classes, but also to evaluate safety countermeasures that are applied to some classes but not others. For example, a certain countermeasure may be applied to just one class, and hence the accident rate for that class may be compared with the rates for similar classes to indicate the efficacy of the countermeasure. Or, a countermeasure may be applied to several classes,starting in a given year, and the accident rates for that year may be compared with the rates for previous years to indicate the immediate changes brought about by the countermeasure. Thus, if accident rates (and hence exposure data) are to be valuable for a wide range of evaluations, they must cover all of the defined classes of the system, and must be derived continually, e.g., year by year.

In addition to the evaluation use described above, exposure data may be used in the identification of driver-vehicle-road-environment classes for which new countermeasures may be applicable. As inter-class accident rates are compared, and as accident rate trends for single groups are observed over time, it is possible to note quantitatively those classes for which the greatest need exists to reduce accidents and injuries.

Identification of the classes with priority needs may then lead to an emphasis on development of appropriate countermeasures. As the selected countermeasures are implemented for certain classes, there will then be a natural and logical emphasis on subsequent evaluation of the classes with respect to the new countermeasures. Thus, exposure-based accident rates should eventually be used for a sequence of identification of need and evaluation of performance in unique driver-vehicle-road-environment classes.

The needs for nationwide exposure data are inherent in the needs for problem identification and solution evaluation in the entire realm of national highway safety programs. Many of the problems have been identified independently and subjectively, and workable highway safety countermeasures have been implemented to ameliorate their effects. Evaluations have been performed on many of these countermeasures, often on a cost-effectiveness basis, and more complex evaluation methodologies are being considered. Exposure data is an essential part of many of these methodologies with respect to the evaluation of countermeasure effectiveness, i.e., the capability of countermeasures to reduce highway accidents and injury. Exposure data, in and of itself, can be used as a measure of countermeasure effectiveness. But exposure data can also serve as part of other derived measures, notably accident rate, and it is for this purpose that exposure data needs are greatest. Thus, the needs for exposure data are based on the needs for accident rate data as a measure of countermeasure effectiveness.

In the current state of the art of highway safety analysis, accident rate data based on mileage (e.g., accidents per mile) is uniquely suited as the primary measure of effectiveness. It provides a simple and meaningful relationship between the basic process of the highway transportation system (viz. travel, or the accrual of mileage) and the most obvious dangers of the system (accidents and injuries). No other measure has been proposed to represent this relationship consistently for all of the phenomena in the system. Therefore, the need for accident rate data is urgent if we intend to pursue a rational course of identifying and evaluating highway safety countermeasures with proper priorities.

In the long term, there will be continuing needs for measures of effectiveness in highway safety such as exposure and accident rate data. It is not likely that they will be superseded in the forseeable future. Thus, the need for exposure data appears to be a permanent need.

SECTION 4

EXPOSURE CLASSIFICATIONS (TASK 1)

The requirement of this task is to "determine the principal classes of drivers and vehicles and environments for which exposure measurements are needed." The classes may be characterized by variables such as driver age, vehicle type and road type, and combinations thereof. The classes are required to be "relatively homogeneous with respect to relevant exposure factors," amenable to sampling procedures, and "useful for studying the impact of safety countermeasures."

This task is the key task in the exposure study. Its results define the required content of future exposure data records, and they determine feasible alternatives for data collection in later tasks.

METHODOLOGY

The methodology for the selection of exposure classifications is based on the premise that the classifications should be defined by a set of variables—characteristics of drivers, vehicles, roadways, and environments in the highway transportation system—which are the best predictors of exposure. The basic steps involved are identification of candidate variables, collection of data relating these variables to individual exposure estimates, and statistical analysis of the data to determine which variables are the best predictors of exposure. The methodology sequence is shown in Figure 3.

The Data Collection Surveys

As indicated in Figure 3, the collection of exposure data for this study was performed in a sequence of two surveys: a preliminary survey and a pilot survey. The rationale of this approach was to permit initial consideration of a large number of

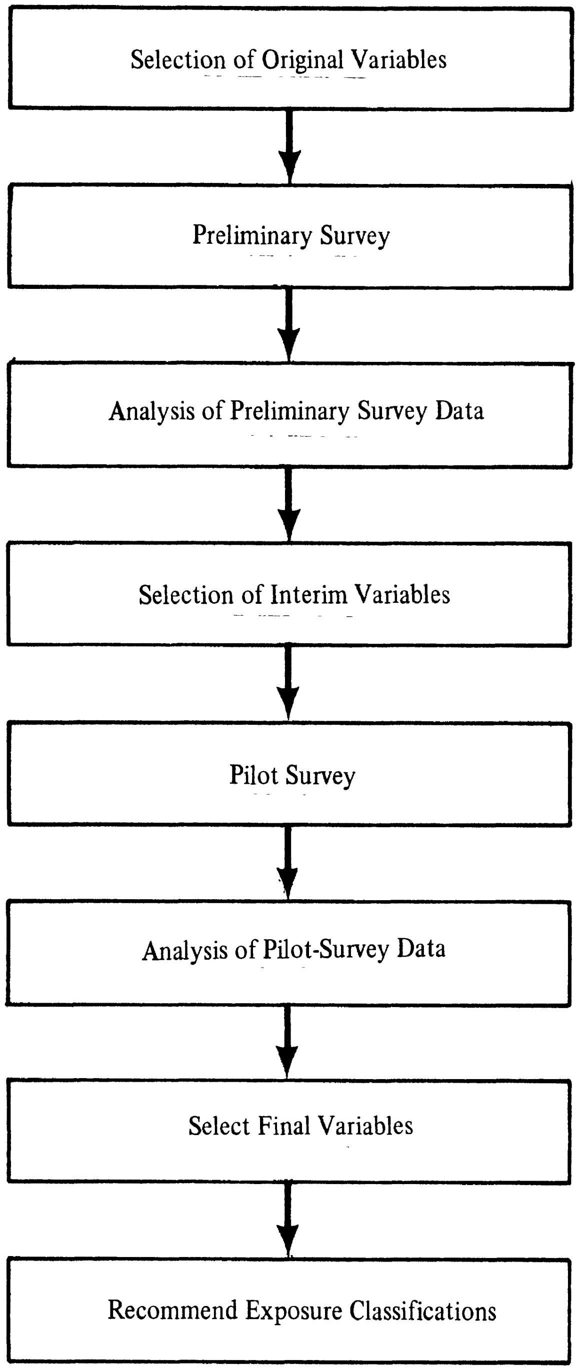


Figure 3 Methodology

potential predictor variables at relatively low cost in the preliminary survey, and then, after eliminating poor predictors, to permit a very thorough analysis of a small number of good predictors in the pilot survey.

Both surveys were conducted by personal interviews of licensed drivers in licensing offices. This survey method was chosen because of its ease of sampling, relative ease of immediate implementation, and low cost. All of the other methods considered (home interviews, mail questionnaires, telephone interviews) would have required lengthy and costly sampling procedures with state license records or state registration records. The selection of the "office interview method" for short-reaction-time experimental research does not imply its superiority for operational implementation of exposure surveys in the long run.

The preliminary survey was conducted in the state-operated driver licensing branch office in Washtenaw County, Michigan, August 18-29, 1969. A total of 448 drivers were interviewed after renewing their licenses. The interview questionnaire for the preliminary survey is shown in Appendix B.

The pilot survey was conducted in 37 licensing offices throughout the country during the first six months of 1970. The total sample size was 7145, representing 89% of the 8014 interview requests. Random sampling was applied in three stages. First, 32 sampling areas (large counties or county groups) were selected (by population-weighted probability sampling) from the 24 states which require personal appearance of drivers for license renewal. (The 24 states are well distributed throughout the country, as seen in Figure 4, and are considered fairly representative.) Second, in those sampling areas with more than one licensing office, a specific office was selected for interviewing; in five of the largest cities there are two offices selected, making a total of 37 interviewing locations. Third, for each office an interviewing interval was defined on the basis of

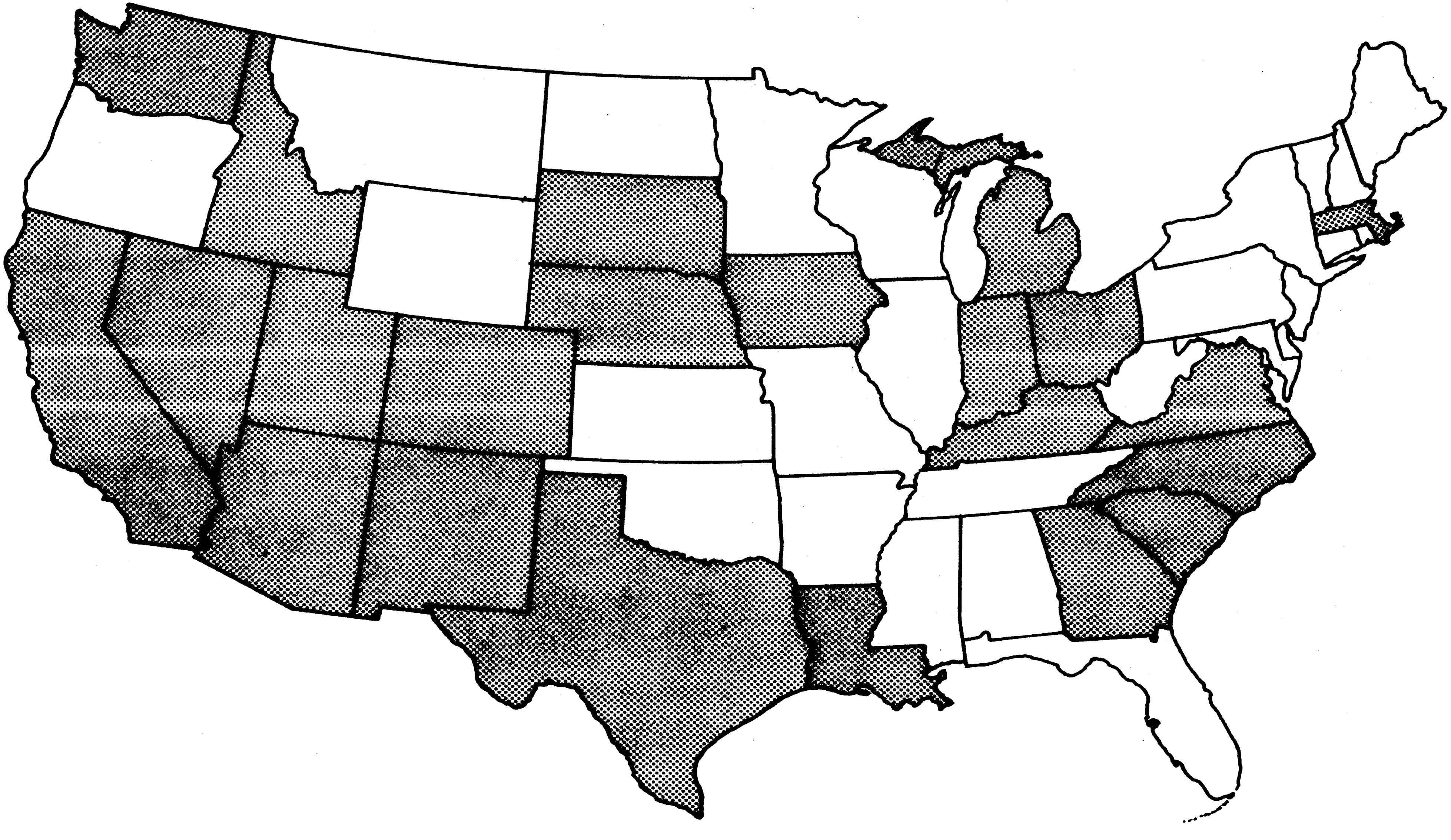


Figure 4 - Sample States of Pilot Survey

volume of renewal applications. Thus, the sample subjects were randomly selected and self-weighting. The interview questionnaire for the pilot survey is shown in Appendix B. Further details of pilot survey implementation are presented in Appendix C.

Application of the Aid Analysis Program

The purpose of the basic statistical data analysis for each survey is to determine a set of the independent variables which interactively provide the best prediction of exposure, the dependent variable. By means of separate one-way analysis of variance studies for each candidate variable, it is possible to determine which variables are best predictors individually, and to rank them on that basis. However, that basis does not provide insights into the interaction among variables. Thus, it would be possible that the second best individual predictor, because of a very high correlation with the first, would not provide a useful second-level prediction capability. Therefore, a next logical step would be to perform two-way analysis of variance studies for all combinations of the first ranked predictor with all other candidate variables. Ultimately, multi-variable analysis of variance studies could be performed for all combinations of variables, resulting in a complex hierarchy of interacting exposure-prediction variables.

Obviously, the number of multi-variable analysis required for a large set of candidate variables is unmanageable. An efficient solution to the problem is offered by an algorithm known as AID (Automatic Interaction Detector).[17]

The AID computer program divides a data sample into two groups by picking the best predictor variable for the whole sample, and identifying the two sets of value levels (of the selected variable) which produce a minimum remaining unexplained variability in the dependent variable. The program continues by repeating the process for each of the groups identified in the preceding stage of analysis. Results of an AID run may be conveniently represented as shown in the generalized AID chart of Figure 5.

The AID program is capable of handling thousands of data cases in each run. The required input format for each data case includes a single dependent variable defined on an interval scale, and a set of independent predictor variables (40 maximum) defined at a maximum of ten discrete levels. A program option allows the user to restrict any independent variable to a monotonic predictor. At each stage, the algorithm performs a binary comparison between all possible groups defined by the levels of a particular independent variable. The comparison determines the two groups of data which would maximize explained variability (minimize error variance) if the particular variable were chosen as a predictor of the dependent variable. Thus, a best grouping or split of the sample is defined for the particular variable. The ratio of explained to total variability is the comparison criterion. The process is performed for each of the independent variables considered as candidates in the analysis, and the variable with the maximum ratio is chosen as a predictor. The chosen variable is divided into the two groups with maximum explained variability. In addition, a detailed printout indicates the step by step analysis performed. This detail is often useful for determining the relative predictability in a set of predictor variables. In addition, it helps to indicate what variable would have defined a split if the "best" predictor had not been included in the analysis.

The program could theoretically proceed until subgroups of size one were produced. This would be inefficient, and the smaller groups produced at the end of the sequence would not be statistically significant. The program has been provided with several stopping rules, which provide flexibility in examining the data. These rules are: 1) a minimum acceptable ratio of

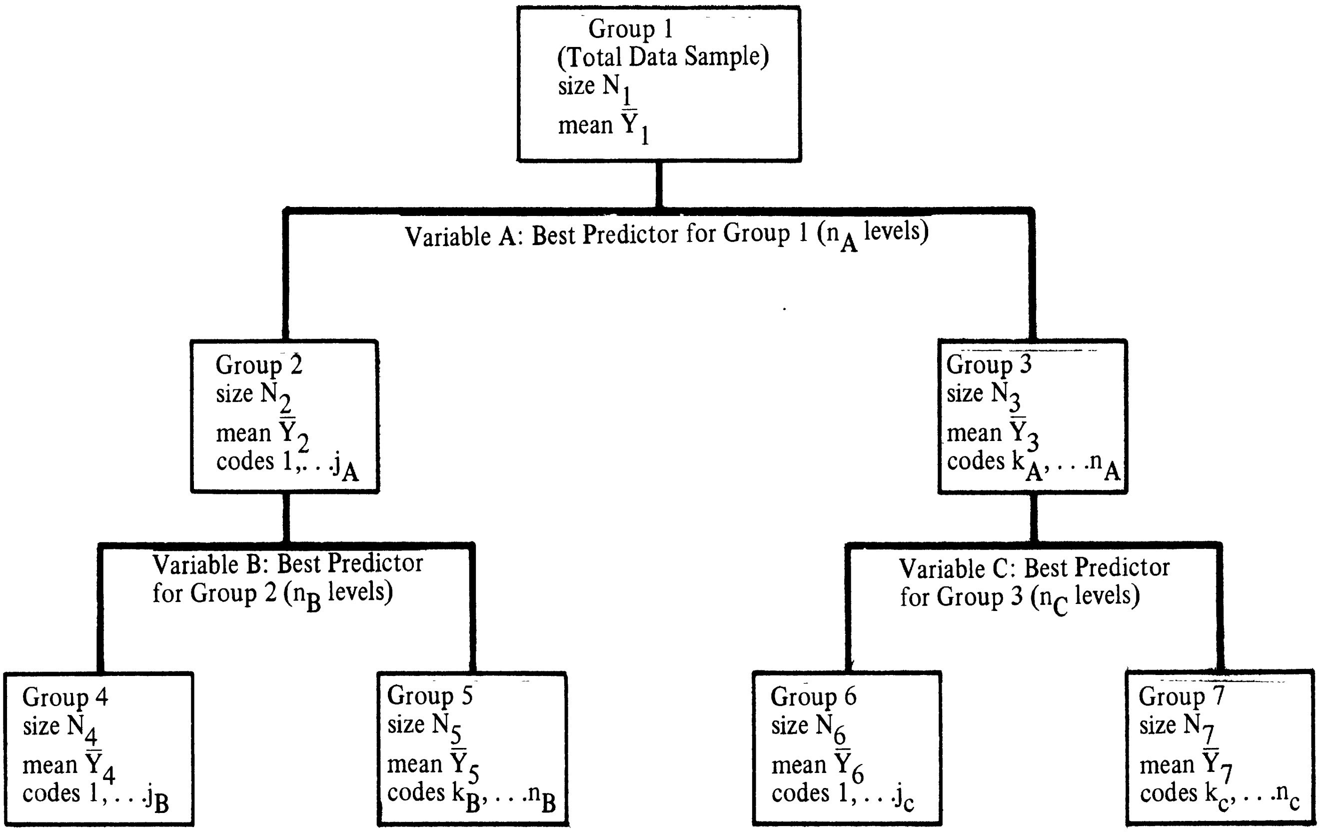


Figure 5 Generalized AID Chart, Two Splitting Levels

explained variability to total variability, 2) a minimum variability within a group in order that a group be a candidate for further analysis, and 3) a minimum number of observations within a group. The choice of the levels for these stopping rules is dependent upon the problem. The normal strategy is to begin with low levels on the first analysis (yielding many groups) followed by a tightening of these rules as the data structure becomes better understood. Tighter restrictions result in an output that is easier to analyze since it has fewer groups.

CANDIDATE VARIABLES

Variables in the Preliminary Survey

The primary dependent variable in the preliminary survey was:

Total number of vehicle miles driven in the last seven days.

Data was collected on the two most frequently driven vehicles for each interview, and therefore, two auxiliary dependent variables were also used:

Number of vehicle miles in the most frequently driven vehicle (Vehicle 1) in the last seven days.

Number of vehicle miles in the second most frequently driven vehicle (Vehicle 2) in the last seven days.

There were 90 independent variables in the preliminary-survey interview questionnaire (see Appendix B) as listed in Table 1. After the initial screening analysis, 31 additional independent variables were added by derivation from the original set, as seen in Table 2. Most of the additional variables were derived by transforming certain of the original variables into "percent driving" variables (one new "percent driving" variable for each level of the original variable). Definitions of the new socio-economic scale and knowledge of engine variables are given in Appendix D.

TABLE 1

ORIGINAL INDEPENDENT VARIABLES IN THE PRELIMINARY SURVEY

Driver Age	Vehicle Use #1
Driver Sex	Vehicle Use #2
Dwelling Type	Commuting Miles #1
Dwelling Ownership	Commuting Miles #2
Area Population	Town Miles #1
Marital Status	Town Miles #2
Children at Home?	Vacation Miles #1
Employment Status	Vacation Miles #2
Occupation	Long Trip Miles #1
Drive on Job?	Long Trip Miles #2
Income	Other Trip Miles #1
Education Level	Other Trip Miles #2
Driver Education?	Percent Driving on City Streets #1
Use Seat Belts?	Percent Driving on City Streets #2
Number of Vehicles Driven	Percent Driving on Suburban Streets #1
Vehicle Type #1	Percent Driving on Suburban Streets #2
Vehicle Type #2	Percent Driving on Rural Highways #1
Vehicle Size #1	Percent Driving on Rural Highways #2
Vehicle Size #2	Percent Driving on Rural Roads #1
Body Style #1	Percent Driving on Rural Roads #2
Body Style #2	Percent Driving on Urban Freeways #1
Manufacturer #1	Percent Driving on Urban Freeways #2
Manufacturer #2	Percent Driving on Rural Freeways #1
Model #1	Percent Driving on Rural Freeways #2
Model #2	Percent Driving at Day
Year #1	Percent Driving at Night
Year #2	Percent Driving in Fog
Power Steering ? #1	Percent Driving in Rain
Power Steering ? #2	Percent Driving on Wet Pavement
Power Brakes ? #1	Percent Driving on Dry Pavement
Power Brakes ? #2	Percent Driving with No Passengers
Seat Belts ? #1	Percent Driving with One Passenger
Seat Belts ? #2	Percent Driving with Two Passengers
Vehicle Weight #1	Percent Driving with Three or More Passengers
Vehicle Weight #2	Adherance to Speed Limit
No. Cylinders #1	Number of Accidents in Three Years
No. Cylinders #2	Dollar Damage in Three Years
Engine Size #1	Number Injured in Three Years
Engine Size #2	Number Killed in Three Years
Horsepower #1	Number of Violations in Three Years
Horsepower #2	Number of Points in Three Years
Own Vehicle? #1	Violations in Accidents in Three Years
Own Vehicle? #2	Driver After Drinking?
Principal Operator? #1	Percent Driving #1
Principal Operator? #2	Percent Driving #2

TABLE 2

DERIVED INDEPENDENT VARIABLES FROM THE PRELIMINARY SURVEY

Total Percent Driving in Standard Size Car
Total Percent Driving in Intermediate Car
Total Percent Driving in Compact Car
Total Percent Driving in Four-door Sedan
Total Percent Driving in Two-door Sedan
Total Percent Driving in Convertible
Total Percent Driving in Sports Car
Total Percent Driving in Station Wagon
Total Percent Driving with Power Steering
Total Percent Driving with Power Brakes
Total Percent Driving with Seat Belts
Total Percent Driving in Four-cylinder Vehicle
Total Percent Driving in Six-cylinder Vehicle
Total Percent Driving in Eight-cylinder Vehicle
Total Percent Driving on City Streets
Total Percent Driving on Surburban Streets
Total Percent Driving on Rural Highways
Total Percent Driving on Rural Roads
Total Percent Driving on Urban Freeways
Total Percent Driving on Rural Freeways
Total Percent Driving Commuting
Total Percent Driving in Town
Total Percent Driving on Vacation
Total Percent Driving on Other Trips
Violations not Connected with Accident
Weight-Horsepower Ratio #1
Weight-Horsepower Ratio #2
Socio-economic Scale
Vehicle Model Class #1
Vehicle Model Class #2
Knowledge of Engine Index

Variables in the Pilot Survey

The primary dependent variable in the pilot survey was:

Total number of vehicle miles driven in the last 30 days.

Four auxiliary dependent variables were also used:

Total number of vehicle miles driven in the last 7 days.

Number of accidents in the last three years.

Derived accident rate (based on the two preceding dependent variables).

Logarithm of miles driven in the last 30 days.

There were 21 independent variables in the pilot-survey interview questionnaire (see Appendix B) as listed in Table 3. Mainly, these variables are the ones identified as "best" predictors of exposure in the analysis of the 121 independent variables of the preceding preliminary survey. However, an urbanization index was added as a possible substitute for population (see Appendix D); vehicle size and make were limited to passenger cars only; and road type classifications were changed slightly.

RESULTS OF AID ANALYSIS

Results from the Preliminary Survey

The candidate variables were screened in the AID program in groups of 40 or less, and the best predictors from the various runs were combined for a final screening. Variables pertaining to the second most frequently driven vehicle were among the first to be eliminated. The final AID chart is shown in Figure 6. The best predictor variable was "percent driving on vacation or long trip", an anomaly because the survey was conducted in a peak vacation season. The left-hand portion of the chart (less than 75% vacation driving) is fairly representative of typical driving patterns. In addition to the variables on the chart, several others were identified from the one-way analysis printouts as

TABLE 3

INDEPENDENT VARIABLES USED IN THE PILOT SURVEY

Driver Age
Driver Sex
Area Population
Drive on Job?
Income
Number of Vehicles Driven
Vehicle Type
Passenger Car Size
Passenger Car Manufacturer
Vehicle Year
Vehicle Use
Percent Driving on City Streets
Percent Driving on Urban Freeways
Percent Driving on Rural Freeways
Percent Driving on Rural Roads
Percent Driving at Night
Percent Driving on Wet Pavement
Number of Violations not Connected with Accidents
Socio-economic Scale
Knowledge of Engine Index
Urbanization Index

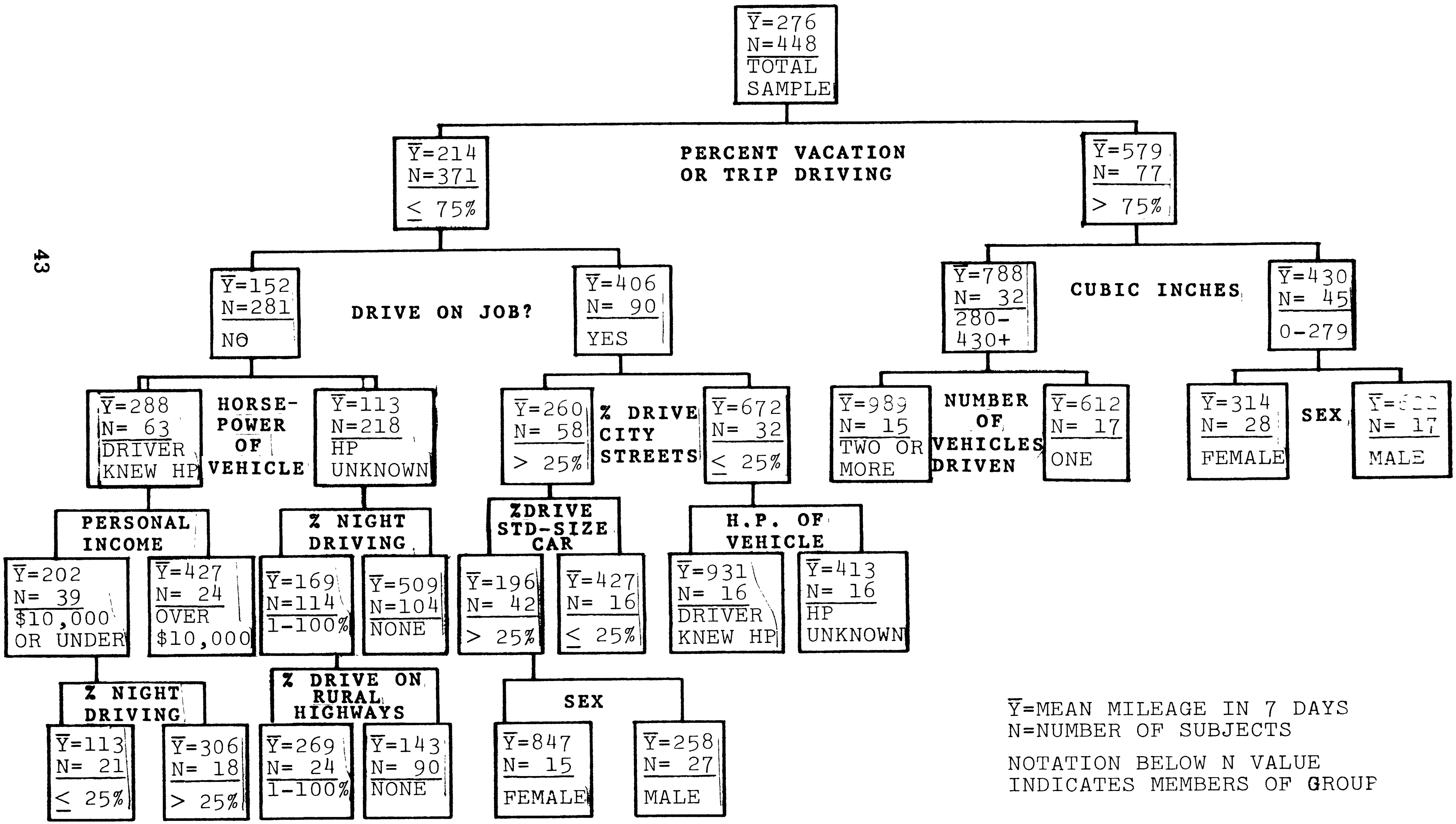


FIGURE 6--Basic AID Chart from Preliminary Survey

excellent predictors individually, and they were retained for further use in the pilot survey.

Results from the Pilot Survey

The basic AID chart from the data of the pilot survey is shown in Figure 7. The total sample consisted of 6576 subjects (N = 6576) who responded to the primary dependent-variable question (miles in last 30 days). Their mean mileage was 1013 miles ($\overline{Y}$ = 1013). The strongest predictor variable was: Drive on Job? (yes or no). The result of this first split was a subgroup of 1561 subjects who drove on the job and whose exposure averaged 2112 miles during the previous month. This compares with the subgroup of 5015 drivers who did not drive on the job and who reported an average monthly mileage of 670. The remaining splits used the predictor variables: type of vehicle, sex, and percent driving on city streets. Of particular interest is the interaction between the variables Drive on Job? and Vehicle Type. Comparison of the two subgroups under the group of 1561 (who did drive on the job) indicates that of those subjects who drove as a part of their job, the 142 who drove large trucks, tractor-trailer combinations and taxis or limousines drove many more miles, on the average, than any other subgroup. This conclusion is consistent with expectations.

Several other AID runs were performed on pilot survey data, using reduced sets of candidate variables and auxiliary dependent variables (see AID charts in Appendix E). The entire series of charts presents a fairly consistent exposure prediction pattern, especially at the first two splitting levels. From the entire set of AID analyses we conclude that the driving population can be divided into three major groups: 1) those persons who drive on the job, 2) males who do not drive on the job, and 3) females who do not drive on the job. It is further noted that the road and environment percent-driving variables, especially percent driving on city streets, are strong predictors within these major

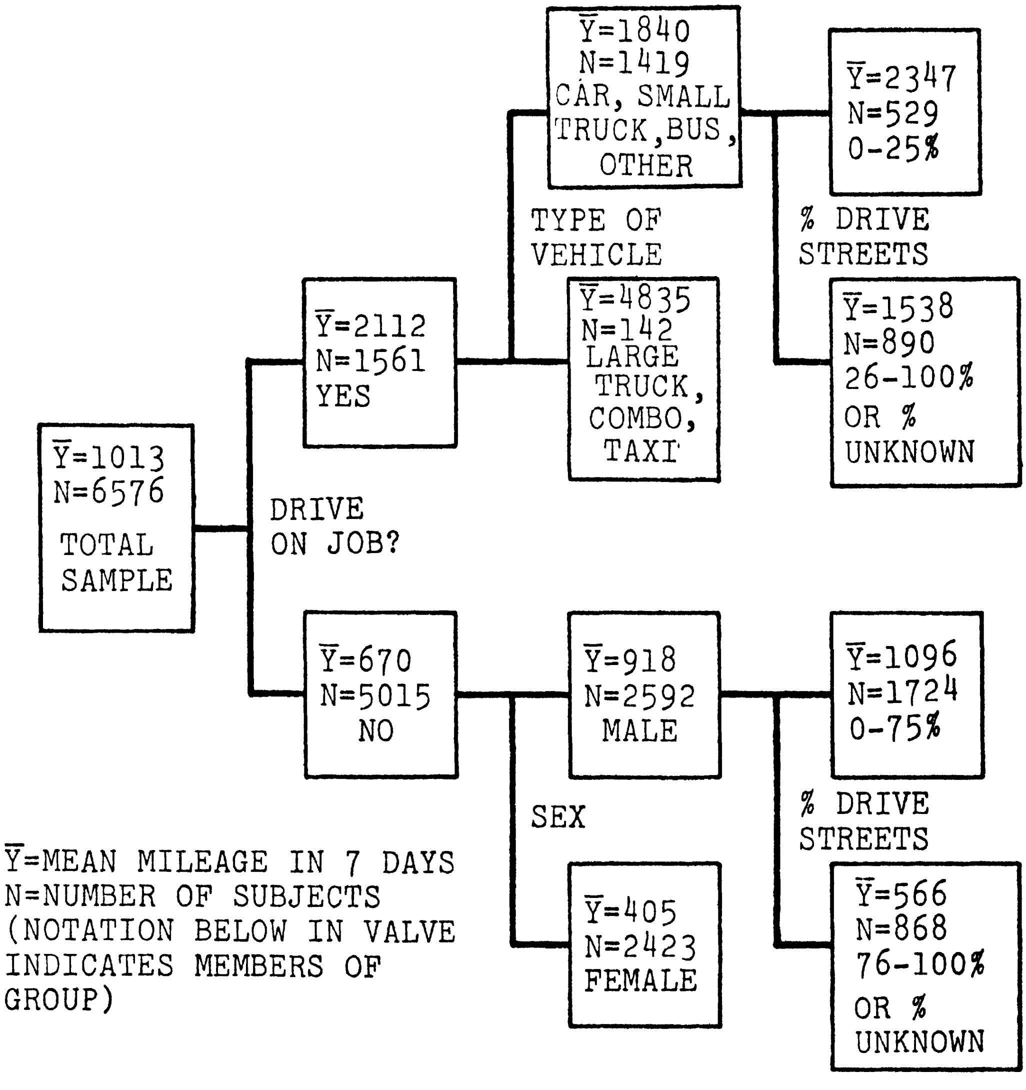


FIGURE 7 Basic AID Chart from Pilot Survey

groups. If the road and environment variables are removed, the strongest predictors are: drive on job, sex, age, type of vehicle, and model year of vehicle. The two best percent-driving predictors are percent driving on city streets and percent driving at night.

ANALYSIS OF STATISTICAL SIGNIFICANCE

The statistical analysis of this study deals with the problem of selecting variables which predict exposure and which enable one to divide a population of driver-vehicle-road-environment combinations into groups which are relatively homogeneous with respect to exposure. Expressing this in terms of standard statistical methodology, we begin with a mean value for the driving exposure for a sample from a population. Associated with this mean is a random error term or variance. Given that there are variables which are related to different quantities of exposure, it should be possible to partition the variability into an explained and an unexplained portion. By doing this we can obtain group estimates of exposure which have a smaller random error term and hence an improved reliability expressed in terms of narrower confidence intervals about the subgroup sample mean. Thus each observation of miles driven is assumed to be structured as follows:

$$\text{Subject Mileage Estimate} = \text{Basic Component} + \text{Sum of Individual Effects Due to Various Predictor Variables} \pm \text{Random Error}$$

where the sum of predictor effects is, e.g., effect due to sex + effect due to drive-on-job + effect due to age, etc.

This analysis problem is well suited for the application of analysis of variance procedures. Unfortunately a basic assumption required for their strict application--a normal distribution of the dependent variable--is violated. However it has been shown that significance tests between means are robust with respect to the assumption of normality.[18] In addition, the analysis of variance procedure assumes that the variances at each level of the predictor variable are the same, an assumption also violated by the mileage data. To overcome this problem the data was transformed by obtaining the natural logarithm of miles driven for each subject. This transformation provides a dependent variable with a uniform variance over the subgroups identified by the levels of the predictor variables. Thus, tests of statistical significance can be performed on the transformed variable as a screening procedure for the candidate predictor variables.

The results of the analysis of statistical significance of the 21 candidate variables in the pilot survey are presented in Appendix F. All but three of the 21 candidate variables (passenger car size, passenger car make, and number of violations not connected with accidents) were found to be significant (at the 0.05 level) in predicting total vehicle miles.

RECOMMENDED EXPOSURE CLASSIFICATIONS

As a result of the preceding analyses, we are now able to choose several independent variables for recommended use in future exposure surveys. The superiority of several of the variables has been shown with respect to significance and variance-minimization criteria. In addition, we must limit the choice of variables to those which appear on state accident-report forms.

Selection of Predictor Variables

In Table 4, the independent variables of the pilot survey are listed in an approximate order of importance with respect to their value as predictors of exposure (vehicle miles of travel). The variables near the top of the list are most capable of explaining variance in estimates of vehicle miles, while the variables near the bottom are least capable of explaining variance. By defining groups with minimum variance in vehicle miles, the best

TABLE 4

ASSESSMENT OF VARIABLES FOR FUTURE EXPOSURE SURVEYS

Variable	Correspondence to Variables on Accident Reports		Substitute Variables on Accident Reports	Eliminated
	Direct	Indirect		
Drive on Job?			Vehicle Type*	
Driver Sex	x			
Vehicle Type	x		*	
% Driving, City Streets		x	Road Type**	
% Driving, Night		x	Light Condition	
Driver Age	x			
Vehicle Year	x			
Number of Vehicles Driven			-----	x
% Driving, Urban Freeways		x	Road Type**	
% Driving, Rural Freeways		x	Road Type**	
Vehicle Use			Vehicle Type*	
% Driving, Rural Roads		x	Road Type**	
% Driving, Wet Pavement		x	Road Condition	x
Knowledge of Engine Index			-----	x
Income			-----	x
Passenger Car Size	x			x
Urbanization Index			-----	x
Socio-economic Scale			-----	x
Area Population			Kind of Locality	x
Passenger Car Make	x			x
Violations not in Accidents			-----	x

* The original variable "Vehicle Type" correlates with and substitutes for two other original variables.

** Four original variables have indirect correspondence to this substitute variable (Road Type).

predictors also define groups with best relative homogeneity in the distribution of vehicle miles estimates.

If we were to select all the variables in Table 4 for future exposure surveys, there would probably result an unmanageable number of classes for computation of accident rates. Thus, there is good reason for arbitrarily eliminating some of the variables near the bottom of the list. In addition, some of the variables need to be redefined so that they have a direct correspondence to variables on existing accident records; some of the variables which do not have even an indirect correspondence to variables on accident forms need to be replaced by correlated variables. Table 4 indicates which variables have a direct coorespondence to variables on accident forms, which have an indirect correspondence, and which variables should be substituted.

The last nine variables in Table 4 are eliminated because they are relatively poor predictors and/or have no substitute variables. Also, the variable Number of Vehicles Driven is eliminated because it has no substitute, even though it is a reasonably good predictor.

Of the 11 remaining predictors, four are recommended for use in future exposure surveys as presently defined:

Driver Sex
Vehicle Type
Driver Age
Vehicle Year

Also, two redefined predictors are recommended:

Road Type
Light Condition

The "road type" variable, when defined in four road-type categories, includes all four of the "percent driving" variables for the various road types. The "light conditions", when defined in time-of-day categories, includes not only the "percent driving at night" variable but also "percent driving in day."

The next best predictor after the six recommended above would be "percent driving on wet pavement" or a substitute, "road condition". A subjective tradeoff between minimizing the number of predictors and adding information led to the elimination of this variable.

The six recommended predictor variables are listed in Table 5, along with the variable levels into which they should be divided.

Unique Exposure Classes

The variable levels listed for a potential questionnaire are typical of the options on accident reports. Though the age and model year questions are open-ended on accident forms, it is typical for states to define about 10 brackets each. Thus, the number of unique classes that might be defined is 11,200 (7x2x4x2x10x10). If instead, we use the variable levels listed for defining unique classes, there might be 96 classes (2^5x3). Even the reduced number of 96 classes is unnecessary in terms of unique countermeasures that might be proposed for certain classes.

By noting the relationship among the variables, as determined by AID charts and analyses of variance, the number of classes can be reduced to 26, as shown in Figure 8. These classes are listed in Table 6.

The six variables of Table 5 and the 26 classes of Table 6 are recommended as ones for which exposure data should be collected and accident rates computed. The accident rates should be useful in identifying classes for which countermeasures should be created, and in evaluating effectiveness after countermeasures are applied.

The sampling policy in exposure surveys may be random sampling of all drivers or it may make use of certain selected predictors for pre-stratification of a random sample.

TABLE 5

DEFINITION LEVELS FOR SELECTED VARIABLES

Selected Variables	Levels on a Questionnaire	Levels for Defining Unique Classes
Vehicle Type	7:Car, Small Truck, Large Truck, Tractor Trailer, Bus, Taxi, Other	2:Cars and Small Trucks, Other
Driver Sex	2:Male, Female	2:Male, Female
Road Type	4:City Streets, Urban Freeways, Rural Freeways, Rural Roads	2:City Streets, Other
Light Condition	2:Day, Night	2:Day, Night
Driver Age	open	3:Under 26 Years, 26-60, Over 60 Years
Model Year	open	2:5 Most Recent Years, Older

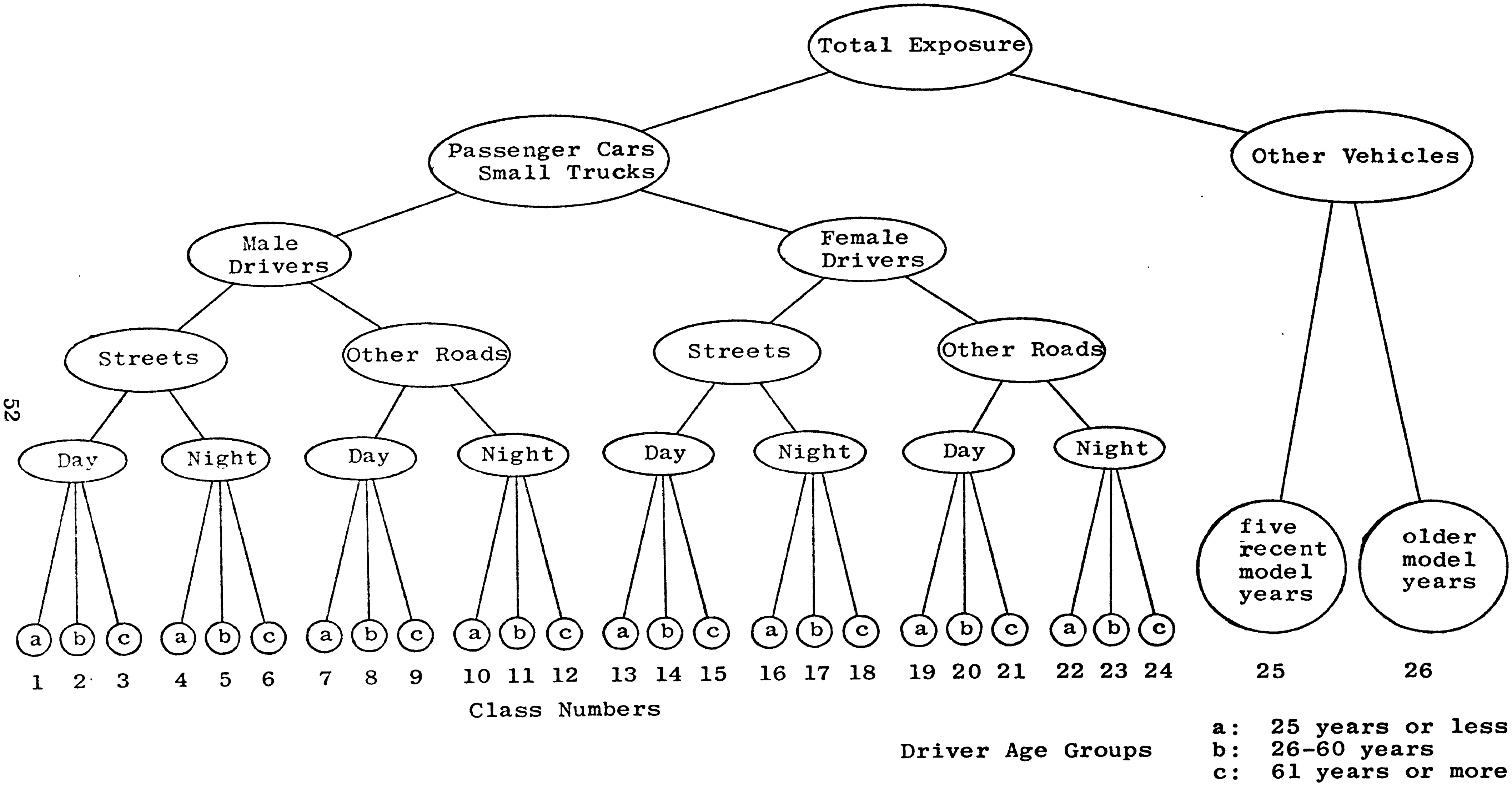


FIGURE 8

Chart of Unique Exposure Classes

TABLE 6

RECOMMENDED EXPOSURE CLASSES

Classes 1-12: Cars or Small Trucks Driven by Males

Class	Road Type	Light Condition	Age
1	Street	Day	Under 26
2	Street	Day	26-60
3	Street	Day	over 60
4	Street	Night	Under 26
5	Street	Night	26-60
6	Street	Night	over 60
7	Other Road	Day	Under 26
8	Other Road	Day	26-60
9	Other Road	Day	over 60
10	Other Road	Night	Under 26
11	Other Road	Night	26-60
12	Other Road	Night	over 60

Classes 13-24: Cars or Small Trucks Driven by Females

Class	Road Type	Light Condition	Age
13	Street	Day	Under 26
14	Street	Day	26-60
15	Street	Day	over 60
16	Street	Night	Under 26
17	Street	Night	26-60
18	Street	Night	over 60
19	Other Road	Day	Under 26
20	Other Road	Day	26-60
21	Other Road	Day	over 60
22	Other Road	Night	Under 26
23	Other Road	Night	26-60
24	Other Road	Night	over 60

Classes 25-26: Vehicles Other Than Cars or Small Trucks

Class	Model Year
25	5 most recent model years
26	older than 5 most recent model years

Every vehicle mile of travel in the highway transportation system may be classified explicitly in one of the 26 recommended classes. Thus, a natural method for estimating exposure would be by trip increments in which all travel is on one certain road type and either day or night. If gross estimates of mileage over long time periods are used instead, then they would have to be broken down into estimated components of total mileage by road type and light condition. In this case, it might be preferred to revert to the variables "percent driving on city streets" and "percent driving at night". However, the lack of independence between these two variables would decrease the estimation accuracy of the four road-type/light-condition groups.

Trip data may include "number of passengers" so that passenger miles may be computed as a dependent exposure variable in addition to vehicle miles. This would represent exposure to injury in addition to exposure to accident. Thus, computed rates would include both accident rate and injury rate.

Although the exposure values and accident rates of most interest will be those relating to the 26 classes, rates may be computed for any classes represented by any of the intermediate classes on Figure 8 or any other combination of variables. Care must be taken in computing some of the possible combinations because the subsample sizes may be too small. However, the analysis of other combinations will be important because subsequent survey data will provide useful research information for a wide variety of purposes, including possible future revisions of the definitions of the classes.

The variables Driver Age, Driver Sex and Vehicle Year present no problem of correspondence with accident form variables. However, in some states, Light Condition levels may include dawn or dusk, which will have to be assigned as either day or night. Also, with respect to Vehicle Type, it will be necessary to clarify the distinctions among trucks (small vs. large). Also, some states do not make it clear on accident forms whether a Road Type is a "street" or not, and this definition must be resolved.

In any exposure survey using the 26 recommended classes, it will be desirable for the distribution of total exposure to be relatively uniform across the 26 classes. In the pilot survey of this study, the distribution was not uniform, as seen in Table 7. Whereas the average percentage of total mileage in the 26 classes should be about 4%, it actually varied from less than 0.1% (older people at night) to 35.4% (a group of 26-60 year old men). It should be noted that the figures are approximations based on "percent driving on streets" as an indicator of all street-driving and "percent driving at night" as an indicator of all night driving.

TABLE 7

APPROXIMATED DISTRIBUTION OF PILOT SURVEY EXPOSURE

Cars and Small Trucks Driven by Males

Percent Street Driving	Percent Night Driving	Age	% Sample	% Miles
51-100	0-50	under 26	3.4	2.8
51-100	0-50	26-60	14.5	13.4
51-100	0-50	over 60	3.2	1.7
51-100	51-100	under 26	1.0	0.9
51-100	51-100	26-60	1.0	1.0
51-100	51-100	over 60	0.1	---
0-50	0-50	under 26	6.3	8.3
0-50	0-50	26-60	22.6	35.4
0-50	0-50	over 60	3.3.	3.3
0-50	51-100	under 26	1.3	1.6
0-50	51-100	26-60	1.7	2.4
0-50	51-100	over 60	0.1	0.1

Car and Small Trucks Driven by Females

Percent Street Driving	Percent Night Driving	Age	% Sample	% Miles
51-100	0-50	under 26	3.6	1.0
51-100	0-50	26-60	14.9	4.8
51-100	0-50	over 60	2.1	0.5
51-100	51-100	under 26	0.5	0.2
51-100	51-100	26-60	0.5	0.2
51-100	51-100	over 60	---	---
0-50	0-50	under 26	3.4	2.2
0-50	0-50	26-60	10.9	6.1
0-50	0-50	over 60	1.4	0.6
0-50	51-100	under 26	0.3	0.1
0-50	51-100	26-60	0.6	0.3
0-50	51-100	over 60	---	---

Vehicles Other Than Cars or Small Trucks

Vehicle Year	% Sample	% Miles
5 most recent model years	2.1	9.2
older than 5 most recent model years	1.2	3.9

SECTION 5
EXPOSURE SURVEY PROCEDURES (TASK 2)

This section contains a systematic derivation of alternative procedures for comprehensive exposure surveys, a description of the tradeoff studies in which the alternatives were compared, and a discussion of their evaluations.

ALTERNATIVE PROCEDURES

The alternative procedures for an exposure survey must all be designed to obtain data which relates measured or estimated values of vehicle miles to sets of values for driver-vehicle-road-environment characteristics, case by case. Ideally, the cases would include all exposure that occurs in the area and time period of interest. Practically, in terms of data collection, effort and cost, the cases must be limited in number. Thus, a comprehensive exposure survey must be conducted by means of sampling of individual cases, and the cases must be representative of the whole population of cases in the area and time period of interest.

In order to be relevant to the whole federal highway safety program, the scope of an exposure survey must be national, i.e. the geographic area of interest is the entire United States. This requirement does not preclude the stratification of sampling by sub-areas, nor the representation of lower jurisdictions as part of a national aggregate.

The basic time period for a national exposure survey should be one calendar year. This is compatible with the time period for which corresponding accident data are traditionally summarized and published by state agencies. Selection of a calendar year as the basic survey time period will not preclude the collection of exposure data by smaller time periods within a year (nor representation of shorter periods), so long as the data can be properly combined in annual aggregates.

Within the context of an annual, national exposure survey, there are many other factors to be considered such as sampling methods, timing, sources of data, and modes and settings of data collections. In order to consider all of the alternatives, a systematic structure of the various choices was established (Table 8).

The choice of an alternative under each category was a process of elimination based on logical rationale and comparative data. The first three categories--sample representation, implementation authority and implementation responsibility are discussed in Section 9, Recommended Exposure Survey Programs. The remainder of this section deals with all the other categories.

Sources of Exposure Data

Selection of a source of exposure data is probably the most fundamental choice in the structure of Table 8. By considering it first, we start with a consideration of exposure at the most detailed process level, and we can then go on to broader questions without neglecting hidden options. The result will be to minimize the number of options in later stages.

The processes of highway travel are movement in space and occurrence in time. Movement applies to the basic mobile elements of the highway transportation system: vehicles, drivers, and passengers. Occurrence applies to the basic fixed elements: roadway types and settings; and to the transitory elements: natural environment and traffic situations.

For simplicity, consideration of pedestrians is eliminated, and roadways and settings (urban vs. rural) may be combined.

With one exception, all units of travel involve interaction among at least one unit of each of the basic kinds of system elements. The exception is passengers, because some travel occurs with no passengers other than a driver.

Consider a single vehicle, single driver, single additional passenger, single road, single environment, single traffic

Table 8

Structure of Alternative Choices for An Exposure Survey

SAMPLE REPRESENTATION	1. National aggregate 2. State-by-State and national aggregates
IMPLEMENTATION AUTHORITY	1. Federal government 2. State governments
IMPLEMENTATION RESPONSIBILITY	1. Federal government 2. State governments 3. Private firms 4. Research institutions
PHASING WITHIN BASIC TIME PERIOD	1. Daily 2. Weekly 3. Monthly 4. Quarterly 5. Once per year

SAMPLING ENTITIES

1. Drivers	4. Driver-Vehicle Combinations
2. Vehicles	5. Driver-Vehicle-Road Combinations
3. Roadways	6. Trips

STRATIFICATION	1. Pre-sampling stratification by classes of drivers, vehicles and/or roads 2. No pre-sampling stratification

SOURCE OF SAMPLE IDENTIFICATION

1. Official records (driver records, vehicle registrations)
2. Population directories or telephone books
3. Residence distributions
4. Driver appearances at license offices
5. Vehicle appearances at inspection stations
6. Vehicles observed travelling on roads
7. Vehicles stopped on roadside for sample identification

Table 8 continued

SOURCE OF DATA	1. Observations external to the highway transportation system (researchers) 2. Responses internal to the highway transportation system (drivers, passengers, odometers) 3. Instrumentation auxiliary to the highway transportation system (counters, etc.)
SETTING OF DATA COLLECTION	1. Office 2. Home 3. Roadside
MODE OF DATA COLLECTION	1. Office interview 2. Office questionnaire 3. Mail questionnaire 4. Home interview 5. Telephone interview 6. Roadside interview
TIME PERIOD INVOLVED PER CASE	1. Time of one trip 2. Day - aggregate or by trip 3. Week - aggregate or by day 4. Month - aggregate or by week 5. Quarter - aggregate or by month 6. Year - aggregate or by quarter

situation, and single unit of travel. The driver-vehicle combination and associated passenger all move one mile along the road in a constant environment and constant traffic condition (fixed speed, no other vehicles). In overview, there has been one mile of exposure. But we can say also that 1) there has been one vehicle mile of exposure to the risk of accident and damage, 2) the driver has moved one mile and accrued one driver-mile of exposure to the risk of accident and injury, 3) the passenger has also moved one mile and has accrued one passenger mile of exposure to the risk of accident and injury, 4) the road has experienced the occurrence of one road-mile of exposure and the concomitant wear and risk of accident and damage to the road (including roadside objects), 5) the environment has experienced the occurrence of one "environment-mile" of exposure and the concomitant risk of accident <u>in</u> the given type of environment, and 6) the given type of traffic situation has accrued the occurrence of one "situation-mile" of exposure and the concomitant risk of accident <u>in</u> the given situation. Because of their similarity, the driver and passenger together, while each moving one mile, have accrued two "person-miles" of exposure to the risk of accident and injury.

In order to obtain data on exposure in the above situation, we must make use of one or more of the possible sources of data pertaining to it. These include:

1. External sources
    a) External observations during the situation
    b) External observations at the end points of the situation
    c) Existing records referenced from observations
    d) Existing records referenced by internal sources
2. Internal sources
    a) Driver
    b) Passenger

3. Instrumented measurement sources
   a) Road instrumentation
   b) Vehicle instrumentation
   c) Environment instrumentation

The choice of a data source in the above case depends critically on whether or not the driver is made aware of the experiment, and whether or not the researcher knows when and if the situation will take place. If a driver is pre-selected he can be made aware of the experiment; in that case the best data source may be a combination of external, internal, and instrumental sources: the driver, records referenced by the driver, and vehicle instrumentation (odometer) observed by the driver. If in addition, the researcher knows when the situation (trip) will occur, the best data source may still be the same combination. If the researcher selects a situation without pre-selecting or notifying a driver, the best data source may be a combination of existing records referenced from observations, and the driver (contacted later after being located from records, e.g. via license plate number). If the driver is not pre-selected and the researcher does not observe the situation, the best data source may be a randomly selected driver who is asked to recall a situation (trip) of the appropriate kind.

If only one specific case of the type described need be studied, then any one of the above data-source combinations would work. A selection would be made on the basis of ease of experimentation and expected accuracy.

However, if exposure data is to have great value, it must reflect the aggregation of many such situations (trips) as the one above, and many others of various types and complexities. It is not feasible to collect aggregate data on a large number of trips by means of direct observations because of the very large magnitude of effort logistically. Observations at thousands of fixed roadside locations would have to be made under all types of environmental conditions; high speeds of vehicles would make it too difficult to record driver-vehicle characteristics or license plate numbers. Similarly, observations by covert following of vehicles would be infeasible, and dangerous also. Finally, road and environment instrumentation are eliminated by logistic problems as above. Therefore, the feasible sources of exposure data are limited to drivers, passengers, and vehicle instrumentation (e.g., odometers). Since many trips are made without passengers, they must be eliminated for reasons of consistency.

If drivers are used as a data source, they can report on their own combinations with the various vehicles they drive over a period of time. However, if vehicles are used as a data source, it is necessary to rely additionally on the vehicle owners or other drivers of the vehicles in the sample to estimate all of the driver-vehicle combinations that occur for a given vehicle. Hence, it appears that driver involvement is necessary for estimates of exposure for either case, i.e., either drivers or vehicles as a sampling basis. Even if odometer readings are used, the driver is the basic source for reporting of exposure data.

Data Collection Alternatives

Given the selection of drivers as the basic source of information in an exposure survey, the next logical questions deal with mode and setting of data collection. In Table 8, certain choices in each category may be eliminated in view of the preceding discussion. Under "setting", the roadside is no longer appropriate, and hence under "mode", roadside interview is no longer appropriate. Thus, the remaining candidate modes of data collection are the following:

1. Office interview
2. Office questionnaire
3. Mail questionnaire
4. Telephone interview
5. Home interview

In the case of questionnaires, vehicle mileage values can be provided by driver estimation or odometer readings; the questionnaire would have to be taken to the vehicle by the driver for recording of odometer readings. In the case of interviews, odometer readings would not usually be provided during an interview; however, the driver could use an auxiliary form provided during the interview for subsequent recording and mailing of odometer readings.

The potential methods of mileage estimation by drivers are as follows:

1. Gross Estimate: A single "gross" estimate of total mileage driven by the driver over a specified time period (e.g. week, month).
2. Component Estimate: The sum of several estimates of mileage in several categories of trip purposes, encompassing all driving done by the driver over a specified time period (e.g., week, month).
3. Trip Reconstruction: The set of mileage estimates made by the driver for each of his recent trips, usually as recollected from the previous day.
4. Trip Log: The set of mileages calculated from odometer readings made by the driver for each of his trips in a certain time period, usually one day.
5. Odometer Readings: A single calculated mileage made by the driver from odometer readings before and after a specified time period (e.g., week, month).

The five modes of data collection and five methods of mileage estimation combine into 25 possibilities. The ease and practicability of each combination is assessed in Table 9.

Sixe of the 25 possibilities in Table 9 were judged impossible or low in feasibility, and were therefore eliminated from further consideration. Also, the five "home interview" methods

Table 9

Ease and Practicability of Data Collection Methods

Modes of Data Collection	Mileage Determination Methods: Gross Estimate	Component Estimate	Trip Reconstruction	Trip Log	Odometer Readings
Office Interviews	high	high	high	high*	high*
Office Question-naire	high	high	low	high*	high*
Mail Question-naire	high	high	low	high	high**
Telephone Inter-view	high	low	low	impossible	impossible
Home Interview	high	high	high	high*	high*

* Separate odometer recording forms must be taken by driver

** A separate form may be desirable if the time period between odometer readings is more than a few days.

were rejected because of high cost. Thus, 14 of the alternative combinations in Table 9 were retained for comparison of accuracy and response rate.

COMPARISON OF DATA COLLECTION METHODS

Special surveys were conducted to compare the various data collection methods. One survey compared the accuracy of odometer readings vs. gross estimates and the other surveys compared the remaining alternatives.

Odometer Reading Survey

The odometer-reading vs. gross estimate comparison was conducted in September 1969 in conjunction with the preliminary exposure survey in Washtenaw County. Of the 448 cases interviewed, 242 (54%) returned two odometer-reading postcards at about one week intervals following the interviews. Thus, odometer readings were for periods that were not exactly the same as the periods of interview estimates, i.e., they were one to two weeks following the week of the interview estimates.

In Table 10 the means and standard deviations of estimated and odometer data are compared. The smaller standard deviation for odometer readings indicate lesser random errors per case and hence a higher proportion of explained variability. Unfortunately, the odometer readings contain some mileage driven by drivers other than the one who gave the mileage estimate in an interview; also, the interviewed drivers undoubtedly drove some distances in vehicles other than the one or two covered by odometer readings. However, with a very large sample these two effects should nullify. The 4% error between the two methods is an acceptable error, and it is possible that most of it can be accounted for by the fact that estimates made in August were during vacation season while readings in September represent the usual downward exposure trend of autumn.

Table 10

Means and Standard Deviation of Estimation and Odometer Reading Methods

	Number of Cases	Mean Miles	St. Dev. of Miles
I Estimated Total Miles for Seven Days	242	297	456
II Estimated Miles for Seven days, By Vehicle	242	286	434
III Odometer Differential for Seven Days, by Vehicle (1 to 2 weeks after estimate)	242	276	261

The standard deviations of odometer readings and estimates (by vehicle) may be compared to determine the relative importance of errors due to estimation inaccuracy vs. the dispersion in the sample. The standard deviation of the odometer readings (261 miles) is presumably due to sample dispersion only, while the standard deviation of the estimates (434 miles) is due to both dispersion and inaccurate estimates. The variance due to inaccurate estimates may be computed as $434^2-261^2=347^2$. Thus, the standard deviation due to inaccuracy (347) is larger than that due to sample dispersion (261), which indicates that exposure distribution dispersion due to estimation errors for one week estimates is probably larger than the natural dispersion of real mileage in a random sample. A related analysis of estimate precision is given in Appendix G.

Other Special Surveys

The eleven remaining alternatives are indicated in Table 11. The table entries show the sample sizes of data collected for each of the special surveys.

Sampling for the special surveys was done at the Washtenaw County, Michigan driver licensing office in April 1970. Office interviews and office questionnaires of sampled drivers were conducted at the office following license renewal by the sampled drivers. Mail questionnaires were also distributed at the office for completion at home and return by mail. The telephone interview sample was obtained at the office, and calls were made the following week.

Table 12 presents the survey response rates for 18 alternative methods (including eleven of this section, the office interview/odometer method of the previous section, and six variations which were not tested). The response rate values represent responses to a single request to a driver to participate. All but the top five methods may have increased response rates

Table 11

Special Surveys-Sample Sizes

Data Collection Methods	Mileage Determination Methods: Gross Estimate	Component Estimate	Trip Reconstruction	Trip Log
Office Interview	149	30	65	39
Office Questionnaire	87	29	--	29
Mail Questionnaire (Office)*	47	20	--	134
Telephone Interview	51	--	--	--
	334	79	65	202

* Questionnaires distributed in office, but completed at home and returned by mail.

TABLE 12

RANKING OF ALTERNATIVE SURVEY METHODS BY RESPONSE RATE

	Method	Rate	
	Office Interview - Trip Reconstruction	.92	
	Office Interview - Component Estimate	.91	
	Office Interview - Gross Estimate	.88	
	Office Questionnaire - Gross Estimate	.88	
	Office Questionnaire - Component Estimate	.88	
	Mail Questionnaire (office) - Component Estimate	.70	
	Office Interview - Trip Log	.59	
	Telephone Interview - Gross Estimate	.58	
x	Mail Questionnaire - Component Estimate	.54	**
	Office Interview - Odometer Readings	.54	
	Mail Questionnaire (office) - Gross Estimate	.51	
	Office Questionnaire - Trip Log	.50	
x	Mail Questionnaire (office) - Trip Log	.45	
	Office Questionnaire - Odometer Readings	.44	**
x	Mail Questionnaire (office) - Odometer Readings	.40	**
x	Mail Questionnaire - Gross Estimate	.40	**
x	Mail Questionnaire - Trip Log	.35	*
x	Mail Questionnaire - Odometer Readings	.31	**

** - Calculated by ratio with analogous methods

* - Assumed value based on Australian survey by Foldvary.

X - Alternative not tested by special survey.

by appropriate follow-up. Twelve involve mailed responses which may be repeated, and one (telephone) may be improved by repeat calls.

The comparative accuracies and precisions of the eleven tested alternatives were based on statistical computations of means and confidence intervals of the exposure values. The differences among office interview, office questionnaire and mail questionnaire methods were not large, and therefore the data for these methods were grouped within gross estimate, component estimate and trip log categories. The telephone interview/gross estimate method and the office interview/trip reconstruction method were analyzed separately. Table 13 presents the mean values of vehicle mile estimates made in the special surveys by trip log, gross estimate, component estimate, telephone, and trip reconstruction methods. Since the trip log method is the only one that uses measurements instead of estimates, it is assumed to be more accurate and precise than the others. The mean values of gross estimates, trip reconstruction and telephone methods were within 15-20% of the trip log mean. The component estimate mean had a much larger error, probably because of the compounding of component overestimations. Table 13 also presents the 0.95 confidence intervals of the five categories, and relationships to the trip log confidence interval.

The "gross estimate" method is the closest of the alternatives to the more accurate trip log method. Both "gross estimate" and "trip reconstruction" methods have relatively small confidence intervals; their accuracies with respect to trip log results should be further considered in the evaluation of exposure survey programs.

TABLE 13

MEANS AND CONFIDENCE INTERVALS OF ALTERNATIVE SURVEY METHODS

A. Comparison of Trip Logs, Gross Estimates, Component Estimates: 7 day Period.

	Trip Log (veh.mi.)	Gross Est. (veh.mi.)	Component Est. (veh.mi.)	Gross Est. telephone (veh.mi.)
Mean	208	230	320	195
.95 Confidence Interval	±70	±40	±125	±75
Relation of Mean to Trip Log Confidence Interval	-	inside	outside	inside
Relation of Confidence Interval to Trip Log Confidence Interval	-	entirely inside	partially outside high end of scale	partially outside low end of scale

B. Comparison of Trip Logs and Trip Reconstruction: 4 day Period

	Trip Log (veh.mi.)	Trip Reconstruction (veh.mi.)
Mean	110	80
.95 Confidence Interval	±50	±35
Relation of Mean to Trip Log Confidence Interval	---	inside
Relation of Confidence Interval to Trip Log Confidence Interval	---	Partially outside low end of scale

SECTION 6

SURVEY COSTS AND RECOMMENDED PROCEDURES (TASK 3)

This section contains estimates of costs for various survey alternatives followed by recommendations--based both on costs and data quality information from the preceding section--of the types of procedures for future exposure surveys.

ESTIMATES OF COST COMPONENTS

Cost estimates were made for 19 alternative survey methods in four categories each: planning, preparation, data collection and analysis. The estimates were made for two sample sizes: 500 and 5000. An example of the components for the five Office Interview alternatives is shown in Table 14.

The standard situation assumed for all cases is a two week survey at a location 1000 miles from the central survey office. Manpower costs ranged from managerial to clerical ($12.00 to $2.50 per hour). Task times were estimated for each manpower level in each component. For the sample sizes of 5000, certain cost components were assumed to be constant with respect to the 500 sample (sample design and material design, guide book, programming, documentation, data analysis). All other components varied linearly with sample size.

COMPARISON OF TOTAL COSTS

The total cost estimates for the 19 survey methods are summarized in Table 15. It can be noted that several methods with higher relative costs for the 500 sample have lower relative costs for the 5000 sample, and vice versa. In particular, the mailed home questionnaire method achieves a great reduction in relative cost as sample size increases. Beyond sample sizes of 5000, it is felt that there will be few if any changes in the ranking of relative costs among the alternative methods.

Table 14

Cost Component Estimates for Office Interview Alternatives
(sample size of 500)

	Component	Gross Est.	Component Est.	Trip Recon.	Trip Log	Odom. Reading
			Method			
Survey Planning	Sample Design	$4608	$4608	$4608	$4608	$4608
	Material Design	230	230	230	230	230
	Liaison & Travel	298	298	298	298	298
Preparation	Recruiting & Training	312	312	324	324	324
	Materials	100	100	100	100	100
	Printing	100	100	100	100	100
	Collating	36	36	36	36	36
	Guide Book	1728	1728	1728	1728	1728
	Liaison	155	115	115	115	115
Collection	Mailing	----	----	----	30	75
	Office Rental	300	300	300	300	300
	Facilities	10	10	10	10	10
	Telephone	15	15	15	15	15
	Travel	50	50	50	50	50
	Personnel	720	720	860	860	860
Analysis	Coding	225	225	225	225	225
	Programming	576	576	576	576	576
	Keypunching	35	35	35	35	35
	Comp. Chgs.	250	250	250	250	250
	Documentation	576	576	576	576	576
	Data Analysis	1152	1152	1152	1152	1152
	Total	$11,436	$11,436	$ 11,588	$ 11,615	$ 11,663

Table 15

Total Cost Estimates of Alternative Survey Methods

	Sample Size 500	Sample Size 5000
Office Interview		
Gross Estimate	$11,436	$31,530
Component Estimate	$11,436	$31,530
Trip Reconstruction	$11,588	$33,050
Trip Log	$11,618	$33,050
Odometer	$11,663	$33,050
Office Questionnaire		
Gross Estimate	$11,441	$31,580
Component Estimate	$11,441	$31,580
Trip Log	$11,623	$33,400
Odometer	$11,678	$34,250
Mail Questionnaire		
Gross Estimate	$13,463	$22,918
Component Estimate	$13,463	$22,918
Trip Log	$13,463	$22,918
Odometer	$13,523	$23,518
Telephone Interview		
Gross Estimate	$14,393	$36,250
Home Interview		
Gross Estimate	$16,126	$55,370

In Table 16 the alternative methods are listed in order of increasing cost per case, i.e., cost per sampled driver from whom exposure data is obtained. The costs per case are very consistent with actual expenditures in a number of recent surveys of various types.[19] The mailed questionnaire methods are by far the least expensive, while home interviews are by far the most expensive.

RECOMMENDED PROCEDURES

The preceding results in Sections 5 and 6 present data which may be used in the selection of a recommended survey method. Although the response rates achieved show that all methods work, they do not reflect ultimate response rates achieved by follow-up procedures, i.e., two or more repeats of the survey for initial nonrespondents. Further, several of the tested methods, though potentially excellent, are not feasible on a national scale at present.

Therefore, a new set of guidelines was established (Table 17) to govern the selection of a survey plan for the immediate future, with the understanding that current limitations should not inhibit possible evolution of an official survey when the limitations are removed. Further, as an aid in subjectively considering the alternative modes of data collection, their advantages and disadvantages were listed comprehensively (see Appendix H).

The only primary survey methods that satisfy the guidelines for the first year are:

1. Mail Survey for random samples of drivers in all states,
2. Home Interviews of a national probability sample of households (not state by state).

Other alternatives are not satisfactory for the first year. Telephone interviews would not provide sufficient accuracy of mileage estimates because they do not allow for Trip Logs (which must be mailed), or Trip Reconstruction (which requires either personal contact for prodding or a longer time for introspective recall than is possible by telephone). Home interviews of samples

TABLE 16

RANKING OF ALTERNATIVE SURVEY METHODS BY COST PER CASE
Based on a sample of 5000

	$
Mail Questionnaire - Gross Estimate	4.58
Mail Questionnaire - Component Estimate	4.58
Mail Questionnaire - Trip Log Estimate	4.58
Mail Questionnaire - Odometer Readings	4.70
Office Interview - Gross Estimate	6.31
Office Interview - Component Estimate	6.32
Office Questionnaire - Gross Estimate	6.32
Office Questionnaire - Component Estimate	6.32
Office Interview - Trip Reconstruction	6.61
Office Interview - Trip Log	6.61
Office Interview - Odometer Readings	6.61
Office Questionnaire - Trip Log	6.68
Office Questionnaire - Odometer Readings	6.85
Telephone Interview - Gross Estimate	7.25
Home Interview	10.87

Table 17

GUIDELINES FOR SELECTION OF AN EXPOSURE SURVEY METHOD

1. Selected method for first year should provide an estimate of mileage for the nation as a whole.

2. Recommended method for the long term should provide mileage estimates for each state.

3. Acceptable response rates can be achieved for office interviews and home interviews in one-wave, and for mailed questionnaires and telephone <u>if</u> there are follow-ups.

4. Costs per case to achieve acceptable response rates are highest for home interviews, medium for telephone and office interviews, and lowest for mailed questionnaires.

5. Accuracies of mileage estimation are highest for Trip Logs, next highest for Gross Estimates and Trip Reconstruction, and lowest for Component Estimates.

6. There should be <u>some</u> provision in a long range plan for evolution of an initial method to an ultimate method over a period of years, but there should not be overemphasis on such provisions.

7. The first year should include one or more auxiliary surveys to permit verification of comparative accuracies of potential methods.

8. Potential sampling difficulties should be minimized the first year.

9. Potential sample biases should be minimized the first year.

10. Total cost for the first year should be as low as necessary, within the above guidelines, to be at a reasonable level for a new federal program in the light of the current budget restrictions.

diagonal entries become 2 in the case where only one driver drives a given vehicle. Typically, though, these processes become difficult because many more readings than 2 are necessary to keep other driver's mileage separated, especially for the longer involvement periods (e.g., over a week).

The entries one row below the major diagonal represent reasonable combinations of time periods and divisions for single-vehicle drivers. Here again though, the typical case will require many readings, especially for long involvement periods. However, in the case of one-day periods divided by trips, the number of measurements will be no more than twice the number of trips (typically 4-10), which is quite reasonable. The same combination (one day divided by trips) is both reasonable and accurate when done by estimation.

From the above discussion, the following possibilities are considered acceptable and tolerable to drivers who would be involved:

1. One year gross estimate of vehicle miles
2. One quarter gross estimate of vehicle miles
3. One month gross estimate of vehicle miles
4. One week gross estimate of vehicle miles
5. One week estimate of vehicle miles by day
6. One day gross estimate of vehicle miles
7. One day estimate by trip (trip reconstruction)
8. One day measurement by trip (trip log)

The final choice to be made is the phasing of the survey within the basic time period. For most efficient use of data, the phasing should equal the estimation time period. Thus, for a one-year estimate there should be one 1-year phase; for a one-quarter estimate there should be four 3-month phases; for a one-month estimate there should be twelve 1-month phases; for a one-week estimate there should be 52 one-week phases; and for a one-day estimate or trip log or reconstruction there should be 365 one-day phases.

in all states would require clustering of cases within states, and this requires probability sampling within states by county or other regional grouping; current forms of state driving records are not compatible with such sampling because they are not all on tape and in any case are too difficult to subdivide by county; even given the feasibility of county grouping, there would have to be many widespread clusters within each state, and thus the travel costs would be prohibitive for a modest program during the next year or next several years. Office interviews are simply not feasible in over a third of the states which do not require personal appearance at branch offices for license renewal; also, for state samples in the states where they are feasible, office interviews would be too expensive in the first year because of overhead inefficiencies in setting up, say 10 offices for only one week each; however, office interviews would be reasonable for a national sample (not state by state) if it were not for the 17 infeasible states.

Some of the methods eliminated above as potential primary methods for the first year or so might become feasible in the long term future as state systems of driver licensing and driver-record keeping are improved. Ultimately, it seems clear that administration of exposure surveys, though coordinated at the federal level, could be implemented by appropriate state agencies. This might be true because only the states will be capable of the efficiencies possible by decentralized integration of surveys into modifications of existing programs. Federal support of the integrated surveys must be assumed, however. In this context, the following survey methods appear to be feasible in the long-term:

1. Mail Survey for random samples of drivers in all states.
2. Office Interviews in probability samples of offices in all states.
3. Home Interviews for probability samples of drivers in all states.

The basic mileage estimation method for any of the above surveys, in the near future or the long term, probably should be Trip Logs. However, since the Trip Reconstruction method also shows promise of similar accuracy, it might be adopted. In addition, it appears useful for comparison purposes to ask for gross estimates of mileage over certain past time periods (year, month, or week). Odometer readings over long periods would be excellent if we were interested only in vehicle classifications; however, because most vehicles are driven by several drivers over long periods, odometer readings do not provide accurate cross classifications of the driver-vehicle combinations that we are primarily interested in.

Both of the methods identified above as satisfactory for the first year have the potential of evolving to a method satisfactory for the long term. The Mail Survey was chosen for the following reasons:

1. The Mail Survey plan would require only a minimal evolutionary process compared to the Home Interview plan (the latter must evolve from national-only to state-by-state and it would take a long time).
2. The Mail Survey plan satisfies the state-by-state criterion immediately.
3. The Mail Survey plan would be less expensive in the long run.
4. The Mail Survey plan is more compatible with customary state practices (official home interviews are rare at the state level).

The remaining choices to be made in the structure of Table 8 deal with sampling, phasing, and time periods. With drivers as a source of data on mailed questionnaires, the only possible sampling entities are the driver or the vehicle. Questionnaires could be sent to licensed drivers or owners of registered vehicles. In the latter case, the owner would have to identify all drivers of the registered vehicle over a certain time period, and this would be difficult in many cases. Thus, licensed drivers are recommended as the sampling entities. On this basis, the obvious choice for source of sample identification is official state driver records, i.e., lists of licensed drivers from which random samples may be drawn. The final sampling choice deals with stratification. In many state driver-license files, it is presently very difficult to stratify the entire population by driver characteristics. Therefore, exposure survey samples should be selected randomly without pre-stratification.

In choosing the time period over which each sampled driver should be involved in exposure measurement or estimation, we consider not only the total period but also the level of detail in dividing the time period (if at all). The various possibilities are charted in Table 18. The entries in the table indicate the number of distinct and separate exposure values that must be determined by drivers for the various possible time periods and time-period divisions of an individual driver's involvement. If a driver makes estimates of his vehicle miles travelled, the table entries indicate the exact number of estimates required. If a driver makes odometer readings at the end points of each time period division, then the number of odometer-readings recorded will be at least one more than the appropriate entry. If a driver is the only driver of a vehicle, then there will be required exactly one more reading than the entry indicates. In other words, most of the readings serve both as a beginning reading for one time division, and an end reading for the next division. However, if a driver is not the only driver of a vehicle, then he may have to make two readings per trip in order to keep his driving distances separated from the distances of the vehicle's other drivers, even though a longer time division is allowed.

The entries along the diagonal indicate a single estimate over the time period of a driver's involvement. These represent the easiest process of determining exposure for the individual driver. If odometer readings are used instead of estimates, the

Table 18

Number of Separate Exposure Estimates
for Various Time Periods

Total Time of Driver Involvement

Divisions of Total Period	Year	Quarter	Month	Week	Day	Trip
Year	1	-	-	-	-	-
Quarter	4	1	-	-	-	-
Month	12	3	1	-	-	-
Week	52	13	4	1	-	-
Day	365	91	31	7	1	-
Trip	**	**	**	**	2-5*	1

* Two to five trips per day is typical range

** Average number of trips: At least twice the number of days involved.

The tradeoff among possible phasings is governed somewhat by sample size (fewer cases required for shorter phasings) but primarily it is governed by the inherent accuracy in the recollections of vehicle types, road types, day-night distributions by the dirvers. The greatest accuracy for these classifications will occur in the one-day phasing.

In summary of Sections 5 and 6 the following choices have been made among survey alternatives from Table 8.

PHASING WITHIN TIME PERIOD - Daily
SAMPLING ENTITIES - Drivers
STRATIFICATION - No pre-sampling stratification
SOURCE OF SAMPLE IDENTIFICATION - State driver-license records
SOURCE OF DATA - Drivers, and perhaps odometers
SETTING AND MODE OF DATA COLLECTION - Home (mailed questionnaire)
TIME PERIOD PER CASE - One day, recorded by trip

SECTION 7
FIELD TEST PROCEDURES (TASK 4)

This section is a brief description of the field test procedures required to validate the feasibility of a nationwide mail survey of exposure data, as recommended in Section 6. Auxiliary surveys for comparison purposes may also be field tested simultaneously with the mail survey.

A field test of a detailed exposure survey plan is the first attempt to implement the plan on a large scale in the real world, including all the required operational procedures. Its purposes are:

1. To validate cost and accuracy estimates derived in the survey plan,
2. To evaluate the parts of the plan where insufficient data exists to make reasonable estimates of performance,
3. To determine and remove operational problems which arise in implementation.

Although the field test is conducted in the "field", i.e., in the real world where the operational survey will be conducted, its large scale does not necessarily imply that it will have as large a scope as the operational survey. Thus, a field test would not necessarily cover <u>all</u> states (though it should cover a large proportion of them), and it would not necessarily have a sample size as large as ultimately intended (though it should be a large percentage of the ultimate sample size).

A field test is unique from operational implementation in that the field test has, as incorporated auxiliary testing devices, means for collecting information on the effectiveness of the operational procedures. Thus, a field test may be slightly more complex than operational implementation. Whereas the major concern in an operational survey is the data results, in the case of a field test the major concern is on the effectiveness of its operational procedures.

A field test of the proposed mail-survey exposure program would involve random sampling of drivers from the driver lists in each state and D.C., and mailing of questionnaires and trip logs to each selected driver. Whereas a later operational program might involve mailing on a daily basis, the field test may be simplified by quarterly mailings. One fourth of the sample would be contacted in each quarter. The aggregate of daily trip logs would not represent driving exposure throughout the year because they would be concentrated in four periods. However, this lack could be accounted for simply by including a request for a gross estimate of mileage during the 3-month quarter. Follow-up reminders would be sent in two waves, with an expectation of achieving a cumulative response rate of 80-90%. Questions would include the selected variables from Section 4.

GENERAL FIELD TEST PLAN

A general outline of the mail survey field test plan is shown in Table 19. The first task, Procedure Evaluation Plans, is the one that is most noticeably unique from the tasks of an operational survey plan. All of the other major tasks in Table 19 are essentially ones that would be involved in an operational survey, with the exception that they all include a subtask for the evaluation of the procedures in their other subtasks. The distinguishing feature of the exposure field test, then, is its provision for evaluation of operational procedures.

EVALUATION OF OPERATIONAL PROCEDURES

The following sections present discussions of several categories for evaluation of proposed mail-survey procedures: Validity Evaluations (internal validity, external validity, and response rate); Time, Sequence and Schedule Evaluation; and Cost Evaluations. In addition, some of the possible special evaluations of alternative procedural details are presented.

TABLE 19

GENERAL FIELD TEST PLAN

Tasks	Sub-tasks
1. Procedure Evaluation Plans	a. Validity evaluations b. Sequence evaluations c. Schedule evaluations d. Cost evaluations
2. Scheduling	a. Operational procedures b. Evaluation scheduling
3. Questionnaire	a. Construction b. Pretesting c. Evaluation and revision
4. Liaison	a. Questionnaire approval b. State driver list access
5. Sample Design	a. Define target population b. Define sampling method c. Define sample size d. Draw sample e. Evaluate sampling problems
6. Clerical and/or Administrative Preparation	a. Mailing lists b. Printing c. Mailing d. Procedure evaluations
7. Data Collection	a. First mailing b. Identification of non-response c. Follow-up mailing d. Procedure evaluation
8. Data Preparation	a. Editing b. Coding c. Transcription d. File construction e. Data reduction f. Procedure evaluations
9. Data Analysis	a. Verifying predictor variables b. Computing exposure values by class and in aggregate c. Validity analysis and other evaluations

Internal Validity Evaluations

Quantitative Item Analysis

One of the prerequisites for obtaining valid survey information is the attainment of a high percentage of responses to all of the questionnaire items. If the questionnaires as a whole do not produce the proper quantity of suitable responses, then one might ask such qualitative questions as:

a) Is this due to ambiguity within the questions?

b) Is this due to a lack of respondent knowledge?

c) Is this due to lack of interest in the subject matter of the question?

In an operational survey there theoretically should be no major surprises regarding completeness of responses if the questionnaire had been adequately pretested and refined. This criterion should be handled by first defining what will be accepted as a complete or suitable response to each question. Also to be defined is the minimum level which will be acceptable for a satisfactory completeness percentage among all responses. Then the number of complete or suitable responses and the number of incomplete or unsuitable responses should be counted to see if the desired minimum completeness of response has been obtained.

Qualitative Item Analysis

The qualitative item analysis criterion flows from the quantitative. The individual questions which have a low completeness of response, as determined above, should be analyzed qualitatively as follows:

1. Examine each question for ambiguous words or ideas.
2. Examine each question to try to determine if it is a "leading" question or not.
3. Examine each question to try to determine if an "embarrassment factor" is present.

4. Examine each question to try to determine if there is a "socially desirable" response which may bias the results.
5. Examine each question to try to determine if the respondent is indeed capable of giving the desired information.
6. Examine each question to try to determine if the right type of question has been used, e.g., open vs. closed.

<u>Qualitative Content Analysis</u>

By leaving an open "Comments" section at the end of each questionnaire, information can be obtained for analysis in several ways, e.g., finding

1. The number of respondents to the "comments" section vs. the number of non-respondents to it.
2. The number of positive vs. the number of negative comments.
3. The number of positive and negative comments about certain frequently mentioned portions of the questionnaire, and
4. The major groups or categories of typical responses.

<u>External Validity Measures</u>

A second validation method is to compare survey-generated data with known facts. Some examples of comparisons that might be made are as follows:

1. When obtaining driver lists from the various states from which to draw samples, age and sex and any other variables which all of the states have in common can also be obtained. These data can be compared with the appropriate survey data for conformity. Another way to do this is to simply compare the appropriate survey data with the state averages and distributions on these very same variables. This latter method does not allow for identification of non-addressee respondents, however. Survey data might further be compared with national census data to see how typical the driving population is of the population-at-large, and how drivers compare with non-drivers.

2. Appropriate survey data can be compared to known distributions of vehicle models, years, and types.

3. Appropriate survey data can be compared with exposure and road type figures from other agencies or sources such as the highway departments, state police, AAA, or other research studies.

4. Appropriate exposure data from the mail survey can also be compared with results obtained in auxiliary surveys.

<u>Response Rate Measures</u>

A third validation category deals with response rates. Four examples of response rate measurements that can be made for the mail survey are as follows:

1. Non-respondents can be distinguished from non-recipients. For example, a certain percentage of people will have moved without leaving forwarding addresses. These letters, since they are going to be sent first class, will be returned and thus are not technically survey refusals.

2. If the survey includes respondent anonymity as a feature, then a non-anonymity technique can be tried in special tests in an attempt to discover if this factor has any significant influence on response rates. Or, if the survey does not provide for respondent anonymity, then an anonymity technique can be tried in special tests.

3. Non-addressee respondents can be discovered in an anonymous survey by comparing certain pre-selected demographic variables from the questionnaire returns for conformity with an original sample list with the same set of demographic variables. In a non-anonymous survey, signatures can also be compared with an original sample list.

4. A personal interview or telephone interview as a third follow-up with either all the mail non-respondents or a representative sample thereof would be a valuable aid in eliminating some of the non-response bias.

<u>Time, Sequence and Schedule Evaluations</u>

The following are examples of time measurements which could be obtained for comparisons with original estimates and for use in revising procedure sequences and schedules.

1. Average length of time for self-administration of the questionnaire.
2. Average length of time for completing the make-up of the entire mail package including:
   a. Ordering stamps and envelopes
   b. Obtaining address labels
   c. Obtaining forms from printers
   d. Applying labels to envelopes and/or forms
   e. Collating materials and placing them in envelopes
3. Average length of time for respondents to return questionnaires in each mail wave. This will improve the selection of an optimum cut-off time.
4. Average length of time for data preparation.
5. Average length of time for data analysis and reporting.
6. Unexpected time delays between steps in procedural sequences.
7. Unexpected time overlaps between steps and between sequences.

Cost Evaluation

The following are examples of cost measurements which could be obtained for comparison with original estimates.

1. Postage costs.
2. Printing costs.
3. Clerical costs.
4. Data reader and computer costs.
5. Professional staff costs.
6. Sampling costs.
7. Costs per questionnaire.

Special Evaluations

The following are examples of experimental comparisons which could be made:

1. Effect on response rate of different physical lay-outs of questionnaires such as

   a. Color,

   b. Length, or

   c. Aesthetic appearance (i.e., crowded vs. spacious lay-out; decorative vs. austere appearance; etc.)

2. Effect on response rate of different covering letter appeals such as

   a. Asking the potential respondents for his help, or

   b. Stressing the rewards of responding

3. Effect on response rate of

   a. Typewritten outgoing letters

   b. Machine plate addressing, or

   c. Computer printout labels

4. Effect on response rate of respondent anonymity vs. non-anonymity.

5. Effect on response rate of interest-arousal questions.

6. Effect on response rate of sending pencils along with the mailings.

7. Effect on response rate of pre-stamped return envelopes.

8. Effect on response rate of an air mail, special delivery mailing on the first wave. (The desired effect here is to increase the first wave returns to such an extent that the additional first-wave postage costs are more than balanced by the reduced number of follow-up questionnaires required.)

9. Effect on response rate of handwritten post-scripts in the covering letter.

10. Effect on response rates of reminder threats in the first wave covering letter.

11. Effect on response rates of certain "suspicious" questions.

12. Effect on response rate of

    a. Questionnaires without trip logs, or

    b. Questionnaires without trip reconstruction

13. Effect on response rate of different official sponsorships such as

    a. University,
    b. Private,
    c. Governmental, or
    d. Commercial.

SECTION 8

INDIRECT EXPOSURE MEASURES (TASK 5)

Indirect measures of exposure are characteristics of the highway transportation system or related systems that correlate well with measured, direct exposure. Operationally, indirect measures of exposure are thought to be inexpensive and readily obtainable denominators for the computation of accident rates. Items that are causally related to numbers of accidents are most often suggested. Miles of highway right-of-way is an obvious example that has all these properties.

A basic reason for considering indirect measures of exposure is the commonly held perception of the ease with which they may be obtained and used. This reason, plus the necessary ability of the user to quantify the error in the measure used, are basic to developing criteria for comparing measures of exposure, e.g.

1. Ease of collection - Primarily ready data availability, but also the cost of collecting original data.
2. Availability of information - We must be able to determine the total exposure for a population and the exposure for subgroups.
3. Ease of analysis - The cost of using the data collected to obtain the information needed. This includes determination of accuracy and the quantification of the error in the dependent variables.

The following alternatives of indirect exposure measures will be considered:

1. Gasoline consumption
2. Odometer readings
   (single, paired, successive samples)
3. Driving and non-driving population, by characteristic class (age, etc.)
4. Vehicle registrations

5. Roadway mileage (right-of-way)

6. Insurance premiums (total, by group)

Each of these is strongly related to exposure (vehicle-miles). Gasoline consumption is a direct function of vehicle miles. Odometer readings are, in some cases, a direct measure of vehicle travel and in others are indirectly related. Roadway mileage could be considered either a cause or an effect of vehicle travel. Increased driving populations and vehicle registrations both cause increased vehicle mileage. Insurance premiums are a function of increased risk, where the risk is a function of vehicle miles as well as other factors e.g., accident cost. Each of these measures of indirect exposure is one of a class of measures with similar relationships to the variable we are trying to measure, namely the mileage traveled by various subgroups of the population.

GASOLINE CONSUMPTION

Gasoline consumption is directly correlated with vehicle miles. Because of several intervening variables (or random processes) it is not possible to obtain a miles-driven figure from a gallons-consumed figure. The best we can do is obtain a confidence interval of miles driven. This leaves two courses of action available; we could just use gallons consumed as a denominator for accident rates, or we could try to determine the distribution function of vehicle miles.

We now have two questions to consider: one, what happens when we try to use gasoline consumption as a measure of exposure (denominator); two, what happens when we try to determine the distribution function of miles driven as a function of consumption.

The method used today by the various states to compute annual mileage on their highways (M) is to multiply total gasoline consumption per year (C) by a best guess of the average miles per gallon driven in the state (K). Thus,

$$M = KC$$

This is not significantly different from using the quantity of gasoline consumption (C) by itself as a measure of exposure.

The computed value of mileage, M, is better than C alone as a measure of exposure only if K is a good estimate of miles per gallon for the total population. If it is not a good estimate, then the computed value, M, is misleading. It represents itself as something it really isn't, that is, number of miles driven.

This means that the sources of error in number of gallons consumed are relevant both to current practice and to further considerations of indirect exposure.

There are two types of error sources: error arising from transfer of gasoline from one time-interval or area to another, and losses between the time of tax payment and the time of use. Let S_{it} be the gasoline sold in the i^{th} state in the t^{th} time interval and let C_{it} be the gasoline consumed. The total quantities of gasoline sold and consumed in all 50 states in time t are, respectively:

$$S_t = \sum_{i=1}^{50} S_{it} \text{ and } C_t = \sum_{i=1}^{50} C_{it}$$

If we let $B_{i(t-1)}$ denote the fraction of gasoline sold in a year that is not used until the following year, then our consumption figure adjusted for annual carry-over becomes:

$$C_t = S_t + B_{t-1} S_{t-1} - B_t S_t$$

$$C_t = (1-B_t) S_t + B_{t-1} S_{t-1}$$

If we let M_{it} denote the amount of gasoline imported into the i^{th} state during the t^{th} year, and let X_{it} be the amount exported, the equation becomes:

$$C_t = (1-B_t) S_t + B_{t-1} S_{t-1} + M_t - X_t$$

None of the estimates B_t, M_t, X_t are presently available. Some states do have estimates of the diversion of gasoline from highway uses. These estimates have usually been made for purposes of taxation or distribution of revenue. As an example, the State of Michigan is currently conducting a study to determine the consumption of gasoline by motorboats. The study is being made to determine the proper distribution of tax revenue to the state departments. Other sources of of loss are: use by farm vehicles, evaporation, power mowers, etc. Since the sources are not clear-cut, let alone the quantities, we lump these together under one variable, L_{it}, meaning the net losses to other forms of consumption. The equation becomes:

$$C_t = (1-B_t)\ S_t + B_{t-1}\ S_{t-1} + M_t - X_t - L_t$$

Although L_{it} would be very difficult to estimate for each state, discussions with the Michigan Highway Department indicate that it probably does not exceed 5% or 10% of total consumption.

The C_{it} provide, therefore, a rather accurate estimate of gasoline consumed. Quantifying the error will depend on quantifying each correction separately. Several of these may prove to be so small as to be inconsequential. The cost of quantifying the error regularly depends on past data. Some of this may have already been done, as in the motorboat example.

Therefore, it seems that in an area large enough, and a time interval long enough to make the error arising from these sources very small, that gasoline consumption would be a good measure of indirect exposure.

Vehicle miles of travel in time interval t may be represented as a function of gasoline consumption:

$$M_t = KC_t + E$$

where E is a random variable with mean zero and variance greater than zero, and K is the average miles per gallon driven by the population under study. This number can be estimated for any desired group in the population. This could be done by taking a random sample of the population, and determining M_t and C_t for each data point. This would be just as expensive as a direct exposure survey, and therefore does not seem to be justified.

ODOMETER READINGS

Sampling Problems

A sample of single (unpaired) odometer readings from randomly selected vehicles could be used to determine annual mileage in a state, if a survey were conducted annually. An opportunistic sample could be obtained from drivers when they purchase license plates or at vehicle inspection. Data collected this way would not be simple to analyze. Error would arise from several causes. The data would not cover a standard twelve month year. Older cars and cars involved in accidents would be less likely to come in for new plates. We would be measuring last year's mileage for next year's automobile and thus, population would under-represent non-registering groups. Mileage from cars visiting the state would not be included. Mileage of cars leaving the state would not be deducted. Given that we were prepared to expend a large amount of resources analyzing such data, and we recognized that it may be very expensive to fill in the above gaps in our knowledge, such as identifying vacationers, we might be very interested in an opportunistic type of sample.

We can construct a model of miles driven in each state in given year, as follows:

Let X_i = total annual mileage for state i for the first year.

Let Y_{ij_0} = total mileage travelled since last inspection by cars inspected in the jth month of the current year, and inspected in the jth month last year.

Similarly $Y_{ij_{-1}}$ = total mileage travelled since last inspection by cars inspected in the jth month of this year and in the j_{-1} month of last year (and similarly for $Y_{ij_{+1}}$).

For the sake of simplicity, assume that all cars being inspected in the jth month of the current year, were also inspected in the j-1, j, or j+1 month of the previous year. Then, the mileages travelled by each group in the current year, up to the date of inspection, are $b_{ij_{-1}} Y_{ij_{-1}}$, $b_{ij_0} Y_{ij_0}$, and $b_{ij_{+1}} Y_{ij_{+1}}$, where the sum of the b coefficients is 1.

For each month of the first year we accumulate a mileage figure that is part of the total for each year, namely:

$$b_{ij_{-1}} Y_{ij_{-1}} + b_{ij_0} Y_{ij_0} + b_{ij_1} Y_{ij_1} = \sum_{k=-1}^{1} b_{ij_k} Y_{ij_k}$$

Over the first year, the total is

$$\sum_{j=1}^{12} \sum_{k=-1}^{1} b_{ij_k} Y_{ij_k}$$

In addition, during each month of the second year, cars are being inspected that accumulated some of their mileage during the first year. Call these months the 13^{th} through 24^{th} of the first year. Since cars inspected in December of the second year may also have been inspected in January of the same year, there are only two terms for this month. Therefore the total is

$$\sum_{j=13}^{24} \sum_{k=-1}^{1} b_{ij_k} Y_{ij_k} \text{ where } Y_{i24_{+1}} = 0, \text{ i.e. } Y_{ij_k} =$$

$$0 \text{ for } j + k \geq 25$$

We must also include one term from the first month of the third year, namely

$$b_{i25_{-1}} Y_{i25_{-1}} = \sum_{k=-1}^{1} b_{i25_k} Y_{i25_k} \text{ where } Y_{ij_k} = 0 \text{ for } j+k \geq 25$$

Therefore we have a preliminary formula for miles travelled in year one by vehicles inspected in the i^{th} state.

$$X_i = \sum_{j=1}^{25} \sum_{k=-1}^{1} b_{ij_k} Y_{ij_k}; \text{ where } b_{ij_k} Y_{ij_k} = 0 \text{ for } j+k \geq 25$$

or

$$X_i = \sum_{m=1}^{75} b_{im} Y_{im} \quad \text{where } b_{im} = b_{ij_k},\ Y_{im} = Y_{ij_k},\ m=3j-1+k$$

For the United States:

$$X = BY = \begin{bmatrix} X_1 \\ \vdots \\ X_i \\ \vdots \\ X_{50} \end{bmatrix} = \begin{bmatrix} b_{1,1} & \cdots & b_{1,75} \\ \vdots & \cdots b_{i,m} \cdots & \vdots \\ b_{50,1} & \cdots & b_{50,75} \end{bmatrix} \begin{bmatrix} Y_{1,1} & \cdots & Y_{50,1} \\ \vdots & \cdots Y_{i,m} \cdots & \vdots \\ Y_{1,75} & \cdots & Y_{50,75} \end{bmatrix}$$

For each state we must introduce three variables:

V_i: mileage accumulated by cars visiting the state.

R_i: mileage accumulated by cars that did not come in for reinspection. This would include automobiles that have left the state (E_i) and abandoned automobiles (A_i).

O_i: mileage accumulated outside the state by vehicles undergoing inspection.

$$X = BY + V + R - O$$

$$X = BY + V + A + E - O$$

Of these vectors, B, V, A, E, O must all be estimated for a total of 3950 parameters for all states, for each year that the total mileage is calculated.

In the case where data is collected at a vehicle licensing office which sells renewal plates for about six months (September through February) there are at least 3800 parameters. This would also involve considerably more error than in the other case. All of these coefficients and their variation, both over time and in a given year, would need to be carefully estimated by an annual survey. All but one of the correction factors can be estimated by surveying the population of each state. There doesn't seem to be any good way of estimating the remaining parameter for each state, miles traveled by visitors to the state (V). Perhaps the only way is to stop a sample of vehicles leaving and entering the state.

The cost of these corrections are not simply costs incurred in measuring vehicle-miles; they are also costs incurred in quantifying the maximum or likely error in the estimate of the corrections. As such, this cost is essential to assessing the reliability of our estimate of the true value. Attempts to heuristically or intuitively assess such error face serious pitfalls. The only real alternative to quantification is to accept, and represent as such, a number that is an estimate not of vehicle miles, but of some other more or less closely related quantity. In this case, we might use vehicle miles travelled in a state, in year one, by vehicles registered in that state in years two and three. Even so, a random driver survey would be necessary each year for several years to quantify the error of our estimates of the coefficients, the b_{ij}.

The full expense of obtaining the odometer readings has not been considered. In a state that issues license plates by mail, and does not require vehicle inspection, this may be very large.

The quality of opportunistic data is unreliable. Odometer readings collected by untrained personnel of unknown motivation is of this type. Assuming that automobiles record accurate mileage, experiences with police accident reports indicates that reporting quality varies widely with location, workload, and reward to the collectors.

Comparison of Odometer-Reading Distributions

An analysis was performed on odometer readings collected. We examined odometer readings that were collected by the Michigan State Police in sporadic roadside checklanes in 1968.

The original police methodology attempted to randomly examine all vehicles passing a checklane location on the highway. When it was possible to choose between two vehicles, they usually chose the older, because it was likely to have more defects.

The odometer readings were coded in 1000 mile intervals (0 - 97). Vehicles with 98,000 or more miles were coded 98, and missing data was coded 99. We then plotted histograms of these mileage codes and their "moving means". The number of means for a single code in each moving mean varied from three to twenty-one. A k-unit moving mean computes the following number for the i^{th} interval:

$$A_i = \sum_{j=1-m}^{i+m} A\ j/k$$

where $i = m+1, \ldots, n-m$,

k = number of means for a single code in each moving mean

$m = \frac{k-1}{2}$, for k odd.

For k even, the formula would be slightly different. The values were plotted as a smoothed histogram. Figures 9, 10 and 11 present examples for k=5 for three successive model years.

This provides a good picture of mileage by year of manufacture. It would not be valid to interpret these histograms as showing change over time, though one may be tempted to do so. Also, this method, for large k, is not consistent with other assumptions we might like to make about the distribution of mileage by vehicle year.

Table 20 shows two distributions of single odometer readings. One population is from Michigan checklanes, the other is from

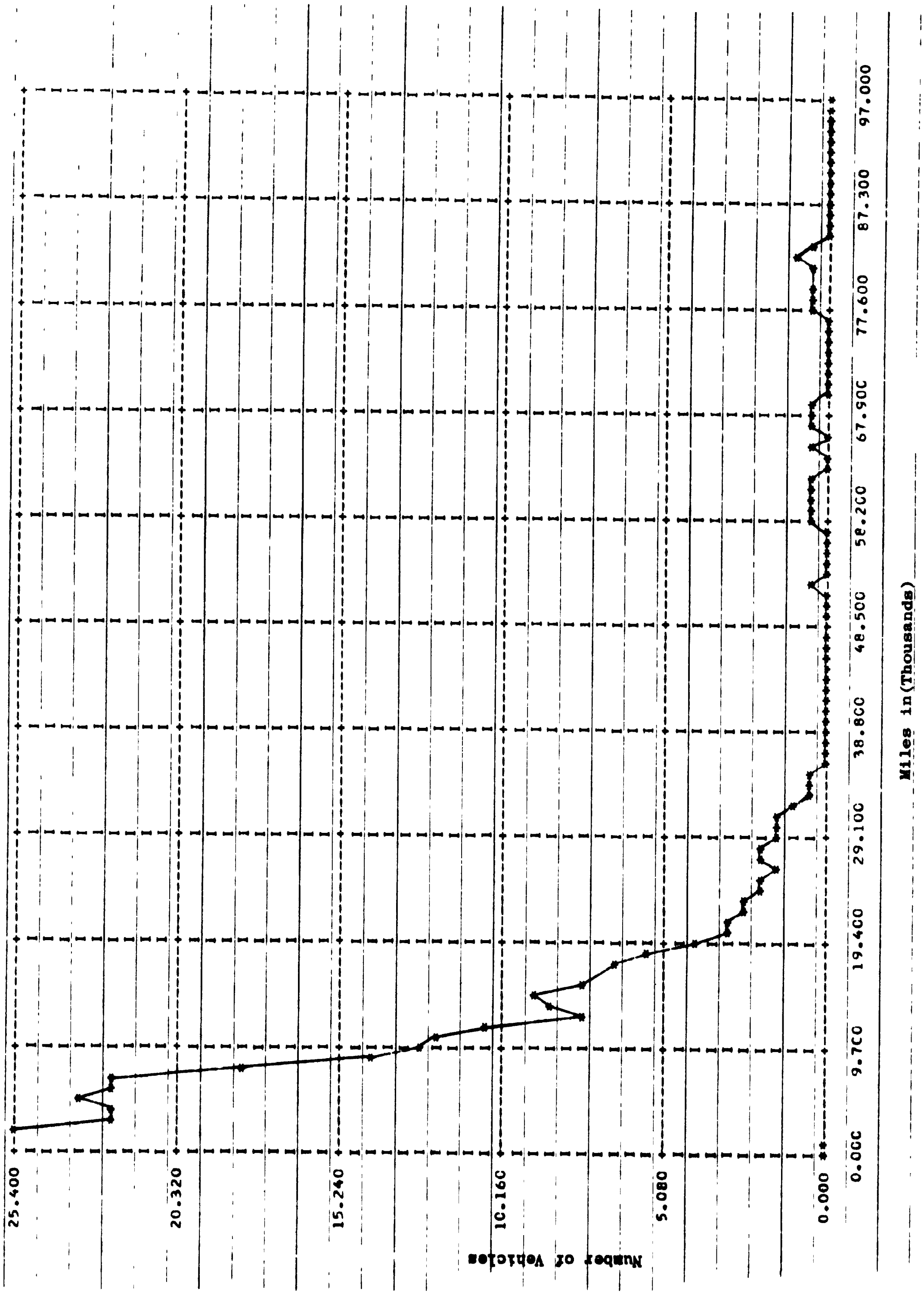


Figure 9 Five Unit Moving Mean of Odometer Readings of Current Model Year

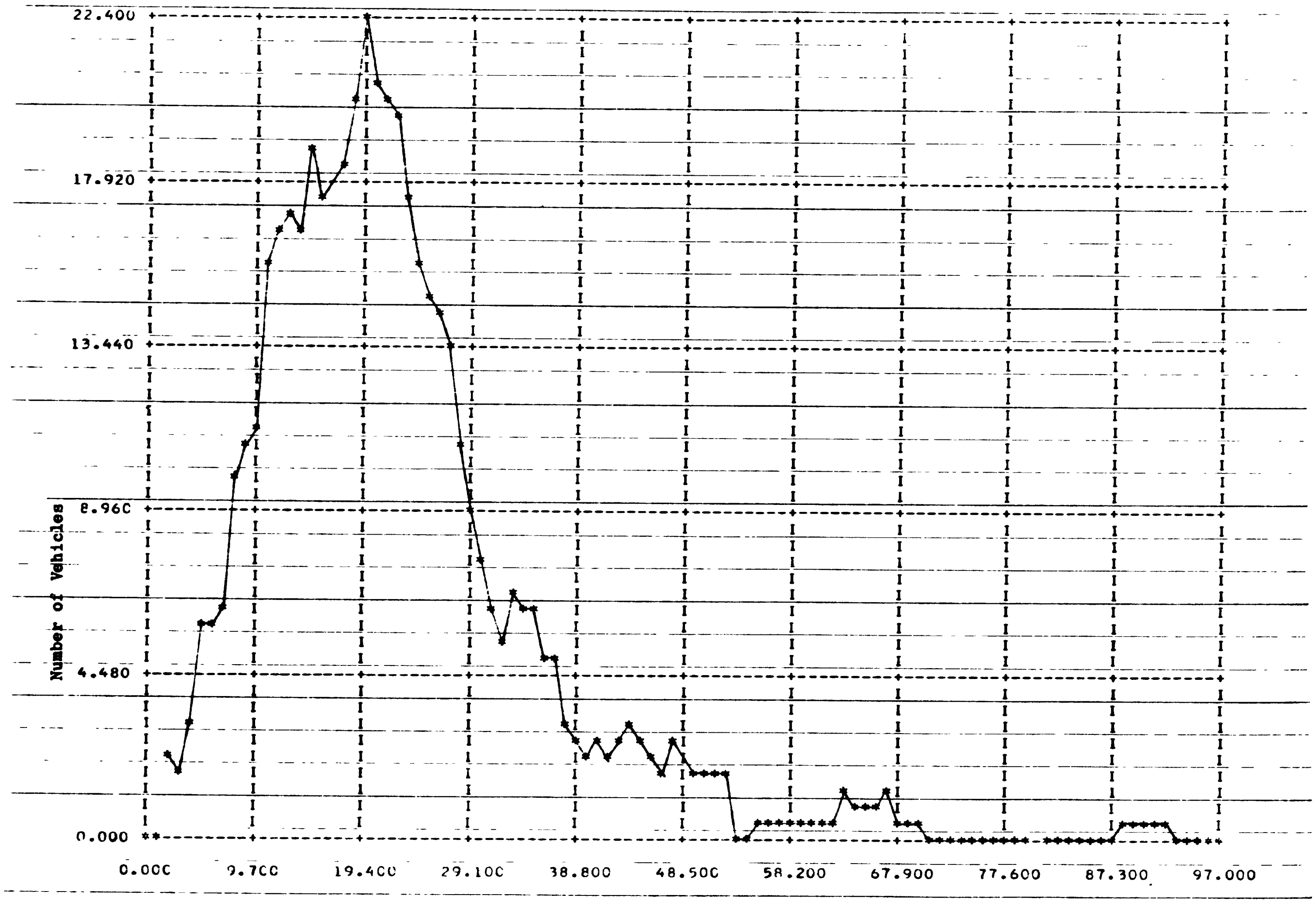
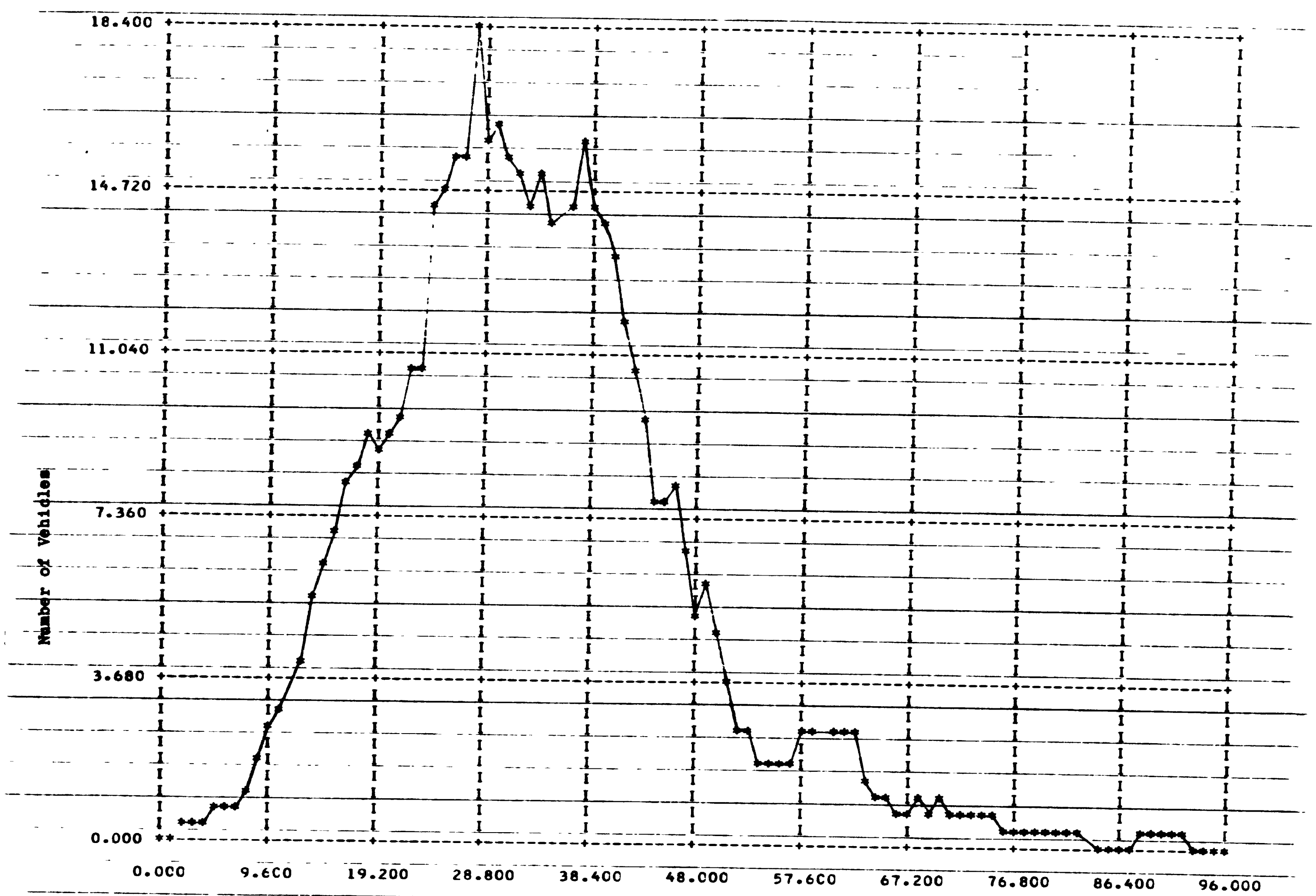


Figure 10 Five Unit Moving Mean of Odometer Readings of Previous Model Year



STOP 0
EXECUTION TERMINATED

Figure 11 Five Unit Moving Mean of Odometer Readings of Second Previous Model Year

Cornell ACIR accident investigations for July, 1964 to December, 1965.

TABLE 20

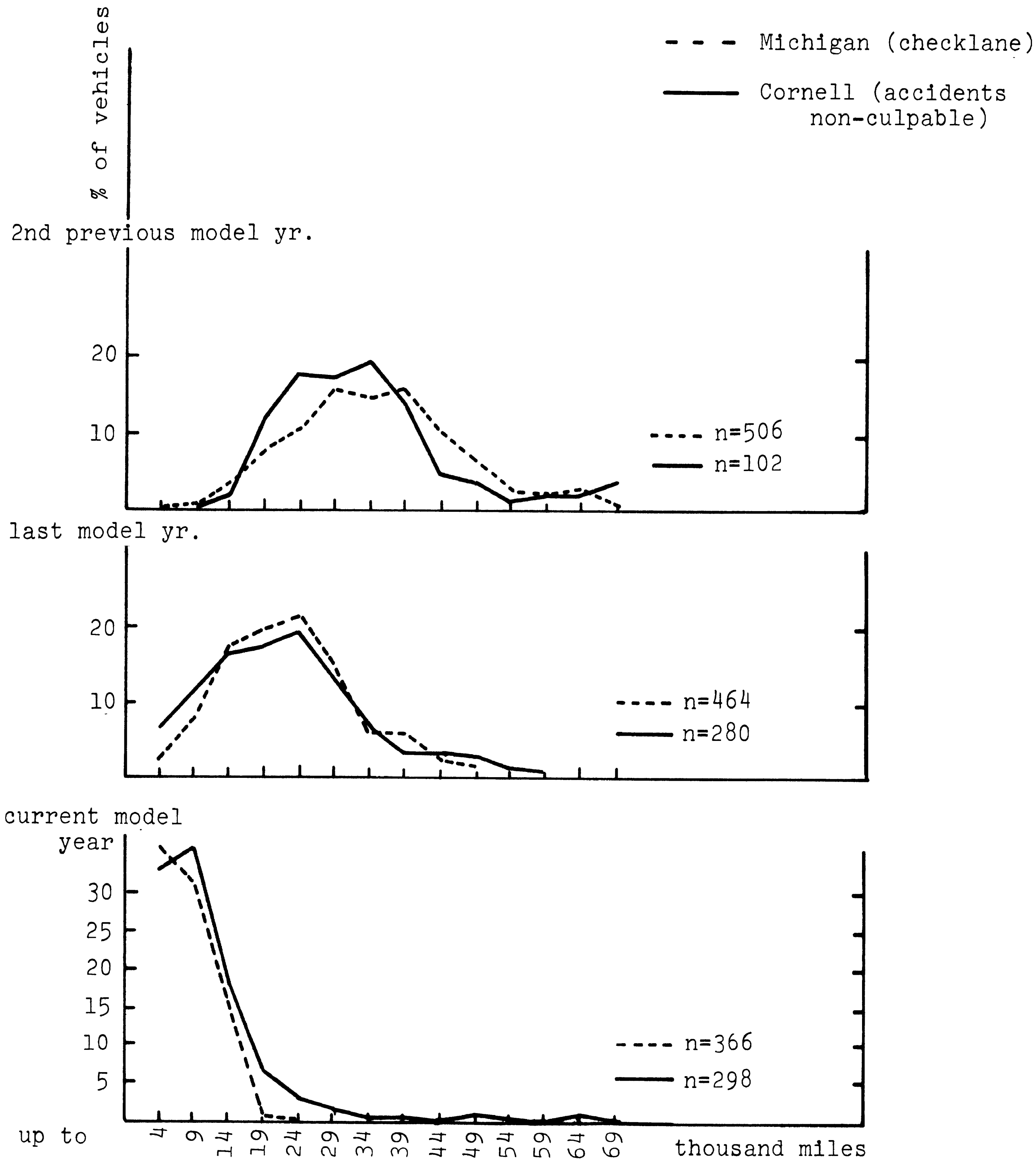
CHARACTERISTICS OF ODOMETER READINGS

Sample Size	Cornell	Michigan
total	1014	17,000 (approx)
current model year	298	366
previous model year	280	464
2nd previous model year	102	506
remainder	334	15,700 (approx)
current model year	1965	1968
location	several states	state police districts covering three Michigan counties
source	accident involved cars	sporadic check lanes
length of time covered	18 months (1964-1965)	4 months (1968)

The accompanying graphs (Figure 12) do not show any substantial differences in mileage for the two samples. Both show the same change over model year. In the previous model year, the Cornell sample is more widespread, and in the second previous year, the Michigan sample is more widespread. In the current model year the Cornell sample has higher percentages for high mileage vehicles. The reason may be that the Cornell study extended three months beyond the end of the model year, while the Michigan study ended about a month before that point.

POPULATION, VEHICLE REGISTRATIONS, AND ROADWAY MILEAGE

This section presents the results of correlation analyses among three independent variables (population, number of vehicle



ODOMETER-READING DISTRIBUTIONS

Figure 12

registrations, and number of miles improved roadway) vs. six dependent variables (number of fatal accidents, number of injury accidents, number of property damage accidents, total number of accidents, number of fatalities and number of injuries). Each independent variable was postulated to be a reasonable predictor of accident frequency, and hence an indirect measure of exposure. Data on all nine variables was obtained for the state of Michigan, by county, nominally for the year 1968.

Population was used instead of numbers of licensed drivers because data on the latter was not available by county. Projected population data was obtained for 1970 by the Michigan Department of Commerce, and was arranged in 5-year age groups (0-4, 5-9, etc.). Data for 1970 was chosen in preference to 1965 because 1970 is closer to 1968--the most recent year for which all other data was available.

Vehicle registration data by county was obtained from the Michigan Department of State, and was classified by vehicle type (passenger, commercial, trailer, motorcycle and municipally-owned).

Roadway mileage data by county was obtained from the Michigan Department of Highways, and was classified by urban (trunkline, primary and secondary) and rural (trunkline, primary and secondary).

Accident data by county was obtained from the Michigan Department of State.

The independent variable data set included 83 values (one for each county in Michigan) for population in each of the twenty population age groups, for registrations in each of four vehicle groups, and for road miles in each of six road types.

The dependent variable data set included 83 values for each of the six accident categories within each of the independent variable groups above.

Each correlation analysis consisted of 83 data points (a given county value of a certain independent variable group vs. the corresponding value of a dependent variable). There were 240 possible correlations (40 independent variable groups and 6 dependent variables).

A summary of typical results of the correlation analysis is shown in Table 21. Only four of the population age groups are shown, and only one dependent variable (total accidents) is included. (The pattern of correlation with the other five dependent variables was very similar to that shown for total accidents.)

The population of all age groups except the first (0-4 years) had correlation coefficients over 0.95 for each dependent variable. Total population had correlation coefficients over 0.99 for each dependent variable. Passenger and commercial vehicles had correlation coefficients over 0.95 for each dependent variable. Trailers and motorcycles had values over 0.90. Municipal vehicles had the lowest coefficients among vehicles ranging from 0.64 to 0.70. Urban road groups had coefficients over 0.90 for all dependent variables, but rural road groups had rather low coefficients, ranging down to 0.02 for rural trunklines vs. total accidents.

From the correlation analysis it is clear that population (in total and by age group) is more highly correlated with total accidents than are vehicle registrations or roadway mileage. The same is true for the correlations with the other accident variables, e.g., fatals, property damage. The correlations of accidents with population are so high that adding another predictor to population will cause only a minimal improvement in correlation level.

It is also seen that correlations of vehicle registrations and road mileage vary significantly (especially for municipal vehicles and rural roads). Hence, even if population data were used as an indirect exposure measure, the data could not be

TABLE 21

CORRELATION COEFFICIENTS BETWEEN INDEPENDENT VARIABLE GROUPS AND TOTAL ACCIDENT FREQUENCY IN MICHIGAN COUNTIES

Independent Variable Levels	Correlation with Accident Frequency
Population Groups	
age 20-24	0.982
age 40-44	0.971
age 60-64	0.993
age 80-84	0.997
Vehicle Type Groups	
passenger vehicles	0.98
motorcycles	0.92
municipal vehicles	0.70
commercial vehicles	0.96
Roadway Type Groups	
rural trunkline	0.02
rural primary	0.56
rural secondary	0.11
urban trunklines	0.94
urban primary	0.97
urban secondary	0.977

adequately classified further (by vehicle type and road type) through the use of vehicle registration and roadway mileage data.

INSURANCE PREMIUMS

The automobile insurance premiums collected from a subet of the population reflect the total cost of accidents experienced by that group. Virtually all automobile insurance premiums are set on the basis of the experience of that group during some previous time interval, usually the previous year. Thus, insurance premiums would be an indirect measure of exposure in some previous time interval.

Insurance premiums include an overhead charge levied by the company over and above the cost of losses. Since this is different for each company, this charge should be deducted for analysis purposes. We are more interested in the total social cost of accidents, not just the biased cost experience of insureds. This suggests replacement of insurance premiums by cost figures from mandatory state accident report forms. Unfortunately, the accuracy of such data is very poor at present.

Another problem is the implicit value judgment in placing any cost on human lives, and in assuming that the true cost of an injury is the cost of the medical care that the injured is willing to pay for in treatment.

REVIEW

None of the indirect measures considered is preferrable to the recognized direct exposure measure (vehicle miles data obtained by driver survey). Although some of the alternative measures correlate well with vehicle miles of travel and/or accidents, none of them in their presently available form, are classified according to driver-vehicle-road combinations. The costs of improving indirect exposure data (by obtaining it according to classifications) would be as high as or higher than the costs of a direct exposure survey. The resulting accuracy still would not be as good as in a direct survey. Therefore, it is concluded that indirect exposure measures do not provide a cost-effective alternative to direct exposure surveys.

SECTION 9

RECOMMENDED EXPOSURE SURVEY PROGRAMS (TASK 6)

The purpose of this section is to synthesize the findings of the preceding tasks -- i.e. the needs for exposure surveys and the efforts required--and to make "recommendations for future exposure data collection programs."

In Section 3, the needs for continuing, national exposure survey programs were stated in terms of the crucial role of exposure data in the computation of accident rates for countermeasure evaluation. Recommended exposure survey variables and unique driver-vehicle-road-environment classifications were determined in Section 4. The discussion of Section 5 indicated the value of annual exposure surveys, and concluded that random samples of drivers is the best source of exposure estimates. In Section 6, the superiority of mail questionnaires with trip logs for exposure surveys was shown on the basis of cost and accuracy. This section deals with the sponsorship of exposure programs, and it incorporates the previous findings in a continuing sequence of recommended programs which will help to establish a permanent capability for countermeasures evaluation.

SPONSORSHIP OF EXPOSURE SURVEY PROGRAMS

From the structure of alternative exposure survey choices in Section 5, three choices remain to be made, all dealing with survey program sponsorship: sample representation, implementation authority, and implementation responsibility. These choices were delayed because they do not affect the previous choices on a technical basis, but they do affect the political and financial ramifications of recommendations for official programs of a permanent nature.

Two possibilities were defined for sample representation: a national aggregate, or a full set of state-by-state aggregates which can be subsequently combined into a national aggregate. A survey sample of drivers which provides representation of a national aggregate of exposure data does not require a sampling stage which represents drivers within each of the states. Instead, it only requires that all drivers in the nation have an equal chance of being selected in the sample; sampling stages could involve regional groups of states or urban-rural strata which might not result in the selection of drivers in every state. Even if drivers were selected in all states, they would not necessarily be in proportion to driver populations. The resulting data would estimate national aggregates of both total exposure and exposure by driver-vehicle-road-environment classes.

On the other hand, a survey sample which provides representation of aggregates of exposure data in each state (plus the District of Columbia) starts with 51 independent sampling stages where each driver in a given jurisdiction has an equal chance of being selected in the sample to represent that jurisdiction. The results would estimate aggregates of total exposure and class exposure within the state. By proper weighting of data, the state-by-state aggregates could then be combined into national aggregates. In this case, the total sample size would be larger than that required for national aggregates only.

Because every state has a unique combination of countermeasures and a unique distribution of system characteristics among driver-vehicle-road-environment classes, there are unique relationships of accident-rate data within and among states. Each state needs its own data to control its own unique highway safety program. Further, comparisons of accident rates among states are needed to evaluate the differences of similar countermeasures in different settings, i.e., the synergistic effect of countermeasures combinations. Thus, state-by-state sampling is preferred on the basis of state needs. However, its required sample size would be on the order of five times as much as for nation-as-a-whole sampling, and its costs would be about twice as high.

(Costs for sample construction are nearly the same for both approaches. Since sampling costs are over half the total for a mail survey, the other costs in a state-by-state sample would do no more than double the costs for a national sample). State-by-state representation is recommended in spite of greater costs because of its much higher value to the individual states.

Implementation authority for future exposure surveys may be held by either the federal government or the individual states. Arguments for federal authority are uniformity of exposure data quality and high likelihood of covering all states. Arguments for individual state authority are its consistency with parallel, existing programs for accident data collection in the states, and the fact that states must be cooperatively involved anyway in the sample design process. In either case, it can be assumed that federal funding will support future exposure surveys. Thus, many states might find some appeal in the concept of state authority for the surveys, since they would spend the funds. On the other hand, it would probably take several years before all states would be ready to take on survey authority. The total costs would be somewhat greater for state authority because of inefficiencies in decentralized administration. Therefore, it is recommended that implementation authority be assigned to the federal government, specifically the National Highway Traffic Safety Administration.

Implementation responsibility may be held by the federal government itself or by either a private firm or research institution under contract. Costs and accuracy would be comparable in any case. Over the long term, it is recommended that the federal government have implementation responsibility for official exposure surveys, primarily because permanence of responsibility would be assured.

FIELD TEST PROGRAM

A field test program for a nationwide mail survey of driving exposure is recommended for the calendar year 1972. It would be the first attempt to implement the survey plan on a large scale in the real world, including all the required operational procedures. Its purposes, explained in Section 6, would be to validate cost and accuracy estimates, to evaluate procedures for which estimates of performance were not made, and to determine and rectify problems.

Although a field test program would not necessarily have as large a scope as the ultimate operational plan (i.e., all states and full sample size), it would be desirable for it to provide a representation of exposure for the entire nation. This is, in fact, one of the guidelines in Section 6 used in selecting a mail survey for the first year of an exposure survey. Thus, it is recommended that the field test program be considered as the first year of a continuing operational survey.

Among the other guidelines in Table 17 were provisions for evolution of an initial plan over a period of years to a plan that might be ultimately more desirable, and inclusion of auxiliary surveys in the first year to permit verification of estimated accuracy and cost comparisons among the alternatives with higher potential.

In order to satisfy the criteria, there should be a comprehensive plan for the first year which allows alternative methods to relate to the primary Mail Survey. An obvious choice for one alternative is the Home Interview plan on a national scale; it can be done cheaply by coordinating with one of the annual surveys performed by survey organizations on existing samples; further, its results can be used as a check against the aggregate results of the state-by-state Mail Survey. The remaining methods that were in contention in Section 6 (Office and Home Interviews, state-by-state) can be done in a few typical states as a check at the state level. The total plan is summarized in Table 22.

TABLE 22

RECOMMENDED FIRST-YEAR SURVEY PLAN

I. Primary Method - Mail Survey: Questionnaires mailed to random samples of drivers in each state. Follow-up reminders are sent in two more waves, with expectation of 80-90% total response. First waves would be quarterly to one fourth of samples (in later years, daily mailings). Questions include selected independent variables plus gross estimates of mileage (e.g., year, month), and Trip Records for a selected day just prior to, or just following, receipt.

II. Auxiliary Method - Home Interviews (national): Probability samples of sampling areas representing nation as a whole. Random sampling of households. Home interviews covering questions above. Trip Records excluded. Quarterly. Comparison with National aggregate of Method I.

III. Auxiliary Method - Home Interviews (certain states): Probability samples of counties within a few selected states. Random sampling of drivers within counties. Home interviews covering questions above, including Trip Records. Performed in one selected quarter for comparison with selected states of Method I.

IV. Auxiliary Method - Office Interviews (certain sampling areas): A few of the same sampling areas as in Method II. Probability sampling of offices within sampling areas. Random sampling of driver license applicants at the offices. Office interviews, questions same as above, including Trip Records. Performed in one selected quarter for comparison with selected areas of Method II.

The effort required for this total program can be estimated from the cost data in Section 6. In the primary mail survey plan, a total sample size of 25,000 is recommended. Because of small-sample inefficiencies in most of the states, the average cost per subject is estimated as $10, producing a total cost estimate of about $250,000. In the auxiliary home interview (national) plan, a sample size of 2,000 is assumed, with a total cost of only about $10,000 because costs would be shared with other research projects. In the other two auxiliary methods, required sample sizes are indefinite, but an upper limit of about $50,000 each would probably be sufficient.

If a first year field test plan is limited to the primary mail survey plan only, the cost would be $250,000. If all three of the auxiliary methods are used, the total cost would be approximately $375,000. Additional effort for further research using the field test data might be added.

The necessary organizational effort in the federal government to prepare for a field test program in 1972 might cause delays in implementation beyond the first sampling quarter. Liaison with states and sample design should take place early in the year to allow for initial sampling at the end of March 1972. If the auxiliary survey plans are adopted, their organization in a federal agency would probably be for only one year. For these reasons, the first-year field test program probably should be performed by an outside organization while a permanent survey organization in a federal agency is being formed.

OPERATIONAL EXPOSURE SURVEY PROGRAM

The second year of an official exposure survey program (calendar 1973) would represent the beginning of a fully operational program, i.e., field tests would have been completed and evaluated, and resulting changes would have been incorporated in the plan. Data from the auxiliary field test surveys would be considered for future evolution of the survey method, but they would not affect the recommendation to proceed in the second year with a mail survey.

In the operational mail survey, questionnaires would be sent out continually, rather than by quarters. One possible procedure would be to assign drivers randomly to each day of the year for their one-day trip logs, and an alternative is to pick days of the year randomly for assignment to sample drivers. In the latter case, there would not have to be mailings for every day of the year.

The recurring annual cost of an operational exposure survey program is estimated as about $250,000 -- the same as for the mail survey field test. This estimate is based on a sampling plan which produces national aggregate exposure data, but not state-by-state data. Few substantial cost reduction efficiencies can be expected in the sampling design and mailing procedures, which represent a majority of the costs. Reductions in other areas (e.g., data reduction by optical readers) could be achieved but they would be relatively small. If the sample sizes are increased within the states so that valid state-by-state exposure data is produced, the total sample could approach 100,000 and the annual cost would be on the order of $500,000.

CONTINUING SURVEY-EVALUATION PROGRAM

Data from the field test program and the operational program can be analyzed with respect to unique driver-vehicle-road-environment classes in order to determine whether new variables should be included and new classes should be defined. As countermeasures become effective, it is expected that the suitability of the classes will change. Therefore, there should be a continuing exposure research program associated with the operational survey program. The needed magnitude of effort on such a program will become clearer after the analysis of field test data.

AUXILIARY INDIRECT-EXPOSURE PROGRAM

The results of Section 8 on indirect exposure measures do not indicate a high degree of promise in the value of indirect exposure data compared to direct survey data. Nevertheless, it is expected that states will continue to use gasoline consumption data as an aid in determining or validating estimates of vehicle mileage on their road systems, and some states will continue to obtain odometer readings at the time of vehicle inspection. Also, as accident data is improved by the reduction of biases and inclusion of fault identification, there is a possibility that induced exposure measures may be derived that can be compared with direct exposure estimates. Thus, it is recommended that indirect-exposure research be pursued at appropriate times, independent of survey programs.

OTHER EXPOSURE SOURCES

In addition to surveys, there are several opportunistic methods of obtaining direct or semi-direct estimates of exposure. These may be incorporated into a total exposure research program at some later date.

1. Require all driver license applicants in states to make an estimate of their driving during the past 12 months on their application form.
2. Require all vehicle owners to record current odometer readings on applications for vehicle registration.
3. Require that odometer readings be recorded at the time of periodic motor vehicle inspection.
4. Require that odometer readings be recorded for all vehicles identified on accident reports.

Although these exposure sources are not capable of driver-vehicle cross-classification, they may serve as partial checks on direct vehicle-mile surveys. It is recommended that they be considered for inclusion in future revisions of highway safety program standards.

SECTION 10

CONCLUSIONS AND RECOMMENDATIONS

The basic conclusions of this study are as follows:

1. Comprehensive exposure data is needed in highway safety research to permit calculation of accident rates as the key measure of effectiveness.
2. On the basis of the established need, official exposure surveys should be conducted in the future.
3. Future exposure surveys should use estimates of vehicle miles of travel as the measure of exposure.
4. Independent variables should include vehicle type, driver sex, road type, light condition (day/night), driver age, and vehicle model year.
5. The six independent variables should be used to define unique classifications of exposure, i.e., driver-vehicle-road-environment combinations.
6. Future exposure surveys should be national in scope, on an annual basis.
7. Drivers should be the source of exposure estimates.
8. Small random samples of drivers are adequate for exposure surveys, and necessary economically.
9. The basic mode of exposure data collection should be by means of mailed questionnaires, which have the lowest relative cost.
10. The basic method of drivers' vehicle-mile estimation should be by means of trip logs of one-day duration, which have the highest relative accuracy.
11. Field tests of a recommended exposure survey plan are feasible and desirable prior to full-scale operational implementation.
12. There are no available indirect measures of exposure which are preferrable, on a cost-effective basis, to direct measurement of vehicle miles.
13. Eventually, national exposure survey programs should be conducted on a state-by-state basis, so that each state may apply measures of effectiveness to its own unique set of highway safety countermeasures.

14. Official sponsorship authority of future exposure survey programs should be held by the National Highway Traffic Safety Administration.

15. Implementation responsibility of future exposure survey programs should be held by the National Highway Traffic Safety Administration.

16. It will be feasible to conduct a field test of a nationwide mail survey of exposure in 1972, with a sample size of about 25,000 and a cost of about $250,000.

17. It will be feasible to begin operational implementation of annual exposure surveys in 1973.

18. Sample sizes approaching 100,000 will be necessary in annual exposure surveys to provide valid state-by-state classifications; at this level, total costs will approach $500,000 annually.

19. Survey procedures for annual exposure surveys will require continual revision and the need for gradual evolution of basic data collection methods may be anticipated in the long run.

20. Auxiliary survey methods, if tested periodically, will provide data on needed changes in survey methods.

21. Data classes from annual exposure surveys, when analyzed continually, will indicate the need for new variables and exposure classifications in the long run.

22. Indirect and opportunistic exposure data will be available in the long run, and it may be used as a partial check on annual exposure surveys.

23. Exposure data from annual exposure surveys will be most important as a factor in the computation of accident rates for critical driver-vehicle-road-environment combinations in the highway system, thus providing an essential measure of effectiveness for the evaluation of countermeasures.

Five future exposure programs are recommended:

1. Field Test Program-A nationwide mail survey of driving exposure should be conducted in the calendar year 1972. Quarterly mailings should be sent to randomly selected drivers in all states, distributed by random selection of each of the seven types of day of the week. State subsamples should be proportional to driving population. Total sample size should be about 25,000, thus providing statistically significant national results in the 26 unique exposure classes defined in Section 4.

2. Operational Exposure Survey Program - Annual, nationwide mail surveys of driving exposure should be conducted, starting in 1973, including modifications derived from the field test program. State subsample sizes should be increased when possible to provide statistically significant state-by-state exposure estimates. Survey designs should continue to evolve as new insights are obtained from yearly re-evaluations. Eventually the total, national sample size should be on the order of 100,000.

3. Continuing Survey-Evaluation Program - Data from the field test and operational programs should be analyzed continually to determine new variables and exposure classes, and new procedures. This program should involve continuing research, in conjunction with analysis phases of the operational programs.

4. Auxiliary Indirect-Exposure Program - Although the potential in the indirect-exposure area is not highly promising, it is likely that gasoline sales data and odometer data will continue to be collected. Also, induced exposure data, derived solely from improved accident data, is still considered worthy of further investigation. Therefore, it is recommended that indirect-exposure research programs be pursued independently at appropriate times, and that the results be compared with results of operational exposure surveys.

5. Other Exposure Sources - Direct and semi-direct exposure data may be obtained opportunistically by means of driver estimates or odometer readings at the time of licensing, vehicle registration and inspection, and accident reporting. Though these exposure sources may not be capable of driver-vehicle cross-classification, they may serve as partial checks on direct vehicle-mile surveys. It is recommended that they be considered for inclusion in future revisions of highway safety program standards.

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