UM-HSRI-78-38

MULTILEVEL STUDY OF ACCIDENT CAUSATION AND AVOIDANCE

Phase-IA Planning Report

Lyle D. Filkins
Robert E. Scott
James O'Day
Michael Kubacki

The University of Michigan
HIGHWAY SAFETY RESEARCH INSTITUTE
September 1978

Prepared for the Department of Transportation, National Highway Traffic Safety Administration under Contract No. DOT-HS-7-01669. 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.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UM-HSRI-78-38		

4. Title and Subtitle	5. Report Date
MULTILEVEL STUDY OF ACCIDENT CAUSATION AND AVOIDANCE: Phase IA Planning Report	September, 1978
	6. Performing Organization Code
7. Author(s) Lyle D. Filkins, Robert E. Scott, James O'Day, Michael Kubacki	8. Performing Organization Report No. UM-HSRI-78-38
9. Performing Organization Name and Address Highway Safety Research Institute The University of Michigan Ann Arbor, Michigan 48109	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DOT-HS-7-01669
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration	13. Type of Report and Period Covered Interim Report 10/77 - 9/78
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report presents results of Phase IA--the planning phase preparatory to undertaking field work--of the "Multilevel Study of Accident Causation and Avoidance."

The case study approach, focusing on the causes of individual accidents, has been the basis of most previous accident-causation research. Epidemiology provides an alternative in the statistical inference approach, a probabilistic model.

We recommend the statistical inference approach. It is able to deal with complex, interactive phenomena by isolating the influence of particular factors. Also, the method is compatible with the NASS.

The approach may be formulated in terms of multidimensional contingency tables, illustrated in the report by a 2x2 table. There is a growing body of theory concerning such tables and computer programs are available to assist in the analysis of data.

Projects were designed for three research topics using the statistical inference approach. These are accident experience in stolen vehicles, field dependence, and tire characteristics (vehicle handling). Sampling techniques from epidemiology are described.

17. Key Words	18. Distribution Statement
Accident-causation research Case study approach Statistical inference approach	Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

ACKNOWLEDGEMENTS

The following members of the HSRI research staff have participated in this study. The authors gratefully acknowledge their contributions to the study and to this report.

Kenneth L. Campbell, Ph.D.
Charles P. Compton
Jairus D. Flora Jr., Ph.D.
Richard J. Kaplan, Ph.D.
Paul L. Olson, Ph.D.
Michael Sivak, Ph.D.
Arthur C. Wolfe, Ph.D.

In addition, a panel of experienced scientists not affiliated with HSRI reviewed earlier drafts and made many valuable suggestions for improvement. All suggestions were evaluated carefully and incorporated as judged appropriate. No endorsement of the final report was sought from the panel as a whole or from its individual members, and none is implied by our appreciation for and recognition of their participation.

Michael R. Appleby
Automobile Club of Southern California
William L. Carlson, Ph.D.
St. Olaf College
Gerald J. Driessen, Ph.D.
Hans C. Joksch, Ph.D.
The Center for the Environment & Man, Inc.
Leonard B. West, Jr.
The University of Oklahoma

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SUMMARY

This report presents the results of Phase IA--the planning phase preparatory to undertaking field work--of the "Multilevel Study of Accident Causation and Avoidance." The major task accomplished in this phase was the selection of a methodology for conducting the accident-causation research to follow. The steps required to achieve this goal were definition and development of an accident-causation model, identification of research topics for further study, and development of experimental projects for studying the selected factors.

A major focus of our review of accident-causation literature was the search for a methodology appropriate to our goals and the current state of knowledge about accident causation. For this reason, we expanded the scope of our review to include work (primarily medical literature) outside of highway safety research which might nevertheless suggest models for accident causation or useful methodological tools.

The majority of the highway-related literature involved the case-study approach to accident causation. This consists of the determination by accident investigators and reconstructionists of the causes of individual accidents by applying a deterministic, test-of-necessity criterion to a candidate set of causal factors. The medical literature, however, suggested an alternative in a probabilistic model. This model focuses on comparing the distribution of a factor in the accident population with that in a non-accident population. No attempt need be made to relate the factor to the dynamics of a particular accident. We have called this alternative to the case-study approach the statistical inference approach to accident-causation research.

Thus, we were presented with a choice between two fundamentally different methodologies.

The case-study approach has an impressive body of literature behind it. The basic principle is that the investigators develop, for each accident under investigation, a model of how the accident happened. The components of the model include all identified factors contributing to the accident. The results reflect the prior experience and the considered judgements of

the accident investigators and reconstructionists concerning the importance of possible factors contributing to the accident under consideration.

The statistical inference approach is recommended for the accident-causation research to be undertaken during Phases II and III of the present study. It embodies a probabilistic definition of accident causation adapted from Greenberg's [1] medical model:

> A factor F is said to be a cause of accidents if the conditional probability of an accident occurring in the presence of F is greater than the conditional probability of an accident occurring in the absence of F, as determined under condition set E.
>
> $$Pr(A|F,E) > Pr(A|\text{not } F,E).$$

The probability expressions on both sides of the equation require determination of the relative frequencies of both accidents and "non-accidents" in the presence and absence of factor F (under the set of conditions E). Therefore, an essential feature of this approach is that information on traffic units not involved in accidents be obtained.

Greenberg notes, in terms of his multiple regression model adopted for discussion of smoking/lung-cancer issues, that one should look not only at main effects if one is interested in a particular variable. Interactive terms must be examined as well. In accident-causation research, the more obvious causes--roughly equivalent to the "main effects"--have been identified and quantified, to some extent, by the case-study approach. Our conclusion is that consideration of these main effects, and the countermeasures based on them, is no longer adequate. The study of higher-order and interactive terms should now be undertaken, and this is better accomplished by the statistical approach.

It is recommended that the statistical inference approach to accident-causation research be formulated in terms of multidimensional contingency tables. The probabilities in the inequality used to determine whether a factor is causal are ratios of frequencies taken from such tables, and this assists in gaining an understanding of the factor-accident relationship. Further, there exists a considerable--and growing--body of theory about estimating the parameters of contingency table models and about drawing inferences from such models. Another important advantage of this approach is that computer programs are readily available to assist in the analysis of data obtained from field experiments.

The study of the majority of traffic safety research topics will generally involve a multidimensional set of factors with several levels of many of the variables. This fact is one of the reasons that the multivariate contingency approach is attractive. Nonetheless, we have chosen to illustrate the concepts and sampling techniques in terms of a 2x2 table. This is done both for clarity in presenting the concepts and because there exist excellent texts that develop the multidimensional case far more comprehensively than could be done in this report.

Three sampling techniques, used commonly in epidemiology, can produce 2x2 tables:

> Cross-sectional sampling--in which a random sample is obtained from all drivers or vehicles--is ideal from a theoretical perspective in that the inequality defining whether a factor is causal can be evaluated directly and because cost-benefit kinds of assessments are possible. It is, however, less efficient than the other techniques.
>
> Prospective sampling--in which two random samples are obtained, one from a population having the study factor and the other from a population not having the factor--also permits direct evaluation of the cause-defining inequality. Cost-benefits assessments are not possible, however, unless supplementary data about the distribution of the factor under study in the driving population are available.
>
> Retrospective sampling--in which two random samples are also obtained, one from an accident population and the second from a non-accident, control population--provides the most efficient means of determining whether a factor is causal. An important disadvantage of this sampling method is that the magnitude of the causal relationship (if such exists) between factor and accidents is missing. This drawback of retrospective sampling, along with its inability to assess cost-benefit relationships, can be overcome if the distribution between accidents and non-accidents can be determined.

The statistical approach is not without problems. The need for non-accident, control group data has been mentioned. Obtaining such data presents both conceptual and practical problems that are not always resolvable. The approach focuses on the study of a few factors at one time, and it does not handle all factors of interest. Incorrect inferences about causal relationships and potential reductions from countermeasures are possible. This can happen if unknown variables interact with the study variables or if the analysis of known, correlated variables is not handled correctly.

The most attractive feature of the statistical approach is its ability to deal with complex, interactive phenomena in an objective manner. It also can determine whether a study factor has both positive and negative effects--such as the possibility that tinted windshields may reduce daytime accidents but increase night-time accidents--and it is thus applicable to the evaluation of countermeasures as well. The statistical approach also permits the isolation and study of individual factors that are part of a larger study topic, such as the influence of tire characteristics on vehicle handling. Finally, the approach is compatible with the evolving National Accident Sampling System.

We concluded, after weighing the relative strengths and weaknesses of the case-study and statistical approaches, that the latter is the preferred method for use in the balance of the present study.

Concurrent with our search for a methodology, we attempted to identify illustrative research topics among the large number of causation factors. The literature review was useful in this task in that the identification of factors is among the first products of any case-study investigation of accident causation. The work of the Institute for Research in Public Safety at Indiana University was of special interest. Other input concerning research topics developed from discussions with NHTSA staff members to determine their current needs for accident-causation data. NHTSA's 5-year rule-making plan was also of interest in this regard.

Three topics were chosen and research projects were designed for them. The first, concerning accident experience among stolen vehicles, illustrates cross-sectional sampling. The second topic, determination of the comparative accident experience of field-dependent drivers, may best be pursued through prospective sampling. The third topic recommended for study is the comparison of tire characteristics in the accident and non-accident populations. This is a sub-topic of the larger vehicle handling and stability issue, and it illustrates the application of retrospective sampling techniques.

A number of appendices are included with this report as by-products of the Phase-IA activities. These include a literature review, a report on the traffic conflicts technique (and its applicability to accident-causation research), and a review of the concept of induced exposure. Neither the traffic conflicts nor the the induced exposure techniques, in their present state of development, are applicable to the statistical approach.

1. INTRODUCTION

This report presents the results of Phase-IA of a three-phase study entitled "Multilevel Study of Accident Causation and Avoidance." Phase I was originally identified as the period for planning the two subsequent phases. Phase II consists of accident investigation, data collection, and data preparation, and Phase III consists of data analysis and reporting.

The Phase-I planning activities called for completion of several different summary tasks:

* developing an experimental design,
* determining accident-investigation methodologies,
* determining data-collection procedures,
* choosing or developing an accident causal model,
* establishing liaison and preliminary operating procedures in the localities selected for accident investigations.

The first four of the above activities have been identified as Phase-IA tasks, and the fifth as a Phase-IB task. NHTSA officials and the HSRI research staff agreed, early in the study, that the Phase-IA tasks should be reported and the results evaluated before undertaking the Phase-IB task, and of course, Phases II and III.

Two main thrusts were followed, both concurrently and interactively, in the workplan devised to achieve the Phase-IA objectives. One main thrust consisted of developing a methodology for conducting accident-causation research. A rather extensive review of traffic safety literature believed to be either generally or specifically pertinent to methodological issues was undertaken by the project staff. Appendix A contains the citations that were reviewed; occasionally brief annotations were prepared, and these as well as some authors' abstracts also appear in the appendix.

The literature review demonstrated clearly that the bulk of prior accident-causation research had utilized the case-study approach--also known as the clinical assessment approach--to accident-causation research. The project staff concluded that this work--most notably that of Northwestern and Indiana Universities and Calspan Corporation--was not entirely adequate for the research contemplated in this study. The corollary conclusion was that the case-study methodology had to be supplemented by an accident-causation methodology rooted in the probabilistic and interactive nature of the accident-causation phenomenon. Accordingly, a statistical inference approach to accident-causation research was developed, starting with a probabilistic definition of accident causation adapted from the medical field, and concluding with a contingency table formulation for structuring and analyzing data from accident investigations.

This first main thrust of the Phase-IA activities is reported in Sections 2-4. Section 2--Definitions of Accident Causation and Approaches to Accident-Causation Research--describes how the definition one adopts for deciding whether a factor is deemed to be causal strongly influences the data-collection activities undertaken in the field. Section 3--Characteristics of the Case-Study and Statistical Approaches--continues with an examination of the relative strengths and weaknesses of the two approaches. The focus of this section is on the kinds of research questions that are best approached by one of the two methods, and it is shown that neither by itself can handle all of the questions that are likely to be under study in the future. Section 4 examines the statistical approach in greater depth, including a discussion of Greenberg's regression model formulated for discussion of the smoking-lung cancer controversy [1]. It goes on to re-cast the same concepts in traffic safety language and in terms of a contingency table formulation. The fundamental sampling methods, adapted from the field of epidemiology, that give rise to contingency tables are reviewed, and the more important features of these sampling methods are discussed. Sample size issues are also discussed. Section 4 concludes with a demonstration of one of the most potentially serious problems in using the statistical approach, the problem of incorrect inferences caused by unknown variables correlated with the factors under study.

The second main thrust undertaken during Phase I was the identification of research topics of current interest to NHTSA. Several tasks were completed in achieving this objective. Two senior members of the research staff visited several of the NHTSA divisions that use accident-causation data to determine their current needs and interests. The RFP requirements were reviewed carefully, and the factors under study by Indiana University's Institute for Research in Public Safety, under NHTSA sponsorship, were also considered. Finally, NHTSA's latest 5-year plan containing its current rule-making priorities was also reviewed and integrated into the decision-making process. All of these activities are described in Section 5 of the report entitled "Choice of Approach and Research Topics."

The two main study thrusts described above both fed into the process of picking research topics and an accident-causation research methodology. We recommend that the statistical inference approach be used in the balance of this study and that the study topics be chosen from among those described in Section 6, "Preliminary Designs for Phase-II Projects." These include determination of the accident experience among stolen vehicles, study of the accident experience of visually field-dependent drivers, and further study of the role of vehicle handling in causing or avoiding accidents.

A number of appendices appear in the report to augment the main text. These are cited in the appropriate locations in the study. Appendix B also contains a brief review of the traffic conflicts technique and its potential applicability to accident-causation research. We explored this possibility but have concluded that, in its present state of development, it is not appropriate within the framework of the present study.

2. DEFINITIONS OF ACCIDENT CAUSATION AND APPROACHES TO ACCIDENT-CAUSATION RESEARCH

The purpose of accident-causation research is to discover stable patterns among the pre-crash events that subsequently culminate in accidents. In this context, "patterns" implies the recurrence of certain factors and variables among the pre-crash phenomena and the recurrence of recognizable combinations of these factors. "Stable" is meant to imply that such patterns would be expected to exist in the future unless changes in the traffic system occur. The identification of highly unique "causes" among accidents will have little practical benefit if there exist only specific and unique countermeasures for eliminating each specific accident.

If stable patterns exist with sufficient frequency and regularity, then countermeasure concepts would be formulated. Promising efforts would, presumably, be evaluated from a cost-benefit perspective and implemented if found worthwhile. The key issue is the identification of patterns that are stable enough in time so that it is worthwhile to try to eliminate them some time in the future and are of sufficient frequency so that cost-benefit criteria are likely to be met.

In principle, it might be possible to undertake such countermeasure-oriented research efforts without introducing the concept of accident causation into the work. In practice, however, the notion that "we can't prevent accidents if we don't know what causes them" has enough intuitive appeal and is sufficiently widespread among traffic safety practitioners that we will have to deal with the definition of an accident cause.

The definition of accident cause and the way one goes about determining accident causes are tightly bound to each other. If one first selects a definition of cause, then certain accident-investigation methodologies immediately suggest themselves, and others are immediately found to be less attractive. Conversely, if one is engaged in the business of investigating accidents for some other purpose--perhaps for determination of injury-producing mechanisms or as part of routine police investigations--then different definitions and methodologies are appropriate.

The purpose of this section is to review some of the definitions and methodologies that have been used or suggested in the recent past. The case-study, or clinical assessment approach, is by far the most common technique used heretofore, and it is reviewed in Section 2.1. A variety of other names and techniques for aggregating and systematizing data are associated with this technique, but it is our view that these are variants of the case-study approach rather than fundamentally different approaches (Benner [2], Fell [3], Recht [4]). In addition, Joksch, Reidy, and Ball [5] have recently constructed a comprehensive causal network which gives a conceptual framework for accident-related factors. Their network uses a strict concept of causality, based either on physical effects or a sequence of physiological/psychological events which can, at least conceptually, be traced.

The statistical inference approach is, however, fundamentally different. This is the approach we are recommending for the accident-causation research to be undertaken in the balance of this study. It is presented from an overview perspective in Section 2.2 and is amplified in subsequent sections.

2.1 The Case-Study Approach

The case-study approach, as implied by its name, is characterized by its focus, at least initially, on individual accidents. The facts believed to be relevant to the accident under study are obtained, and a judgement is made about what "caused" the accident. A series of accidents may be investigated, and the results from them may be aggregated and analyzed using statistical techniques, but the single case is the base unit for which "cause" is determined.

The case-study approach carries with it a definition of accident "cause," sometimes explicitly and sometimes implicitly. Three of the better known and more recent programs using the case-study approach to traffic accident causation, and the definitions used, are reviewed in subsequent sections.

2.1.1 Northwestern University The work of J. Stannard Baker and his colleagues at Northwestern University, started in the mid 1950's, has probably had the most influence on current police-investigation practices

[6]. It is also the most detailed and comprehensive insofar as creating and defining terms for determining accident causes.

Cause is defined generally to be "the combination of simultaneous and sequential factors without any one of which the result could not have occurred." In the traffic context, "the result might be a motor-vehicle traffic accident or a successful trip." A factor is "any circumstance contributing to a result without which the result could not have occurred." It is "... an element which is necessary to produce the result but not, by itself, sufficient."

Factors are further classified on two other dimensions. Sequential factors are "factors which must follow one another to contribute to the cause of an accident; generally, operational factors." Simultaneous factors are "factors which must be present at the same time to contribute to the cause of an accident; generally, condition factors."

Factors are also classified on a dimension dealing with the components of the transportation system and their operation in the system. Operational factors are "functional failures of the highway transportation system that contribute to the cause of a traffic accident. The failures may be malfunctions of perception, decision, or performance in trip planning, driving strategy, or evasive tactics." Condition factors, on the other hand, are "deficiencies in basic attributes of roads, vehicles, or people, as related to highway transportation and permanently or temporarily modified, that contribute to operational factors." And "an attribute is any inherent characteristic of a road, a vehicle, or a person that affects the probability of an accident."

2.1.2 Calspan Corporation. Kenneth Perchonok and others at Calspan have been concerned both with field data collection and analysis of accident data for many years. Perchonok does not explicitly define either cause, in a general sense, or accident cause, in a specific sense. However, the underlying structure is clear enough from the context in which the operational concepts are presented [7].

Perchonok starts, in a section titled The Meaning of Accident Causation, with the assertion that "In studying accident causes, we seek an answer to the question: why did the accident occur?" and "... causes of accidents can be presented in terms of a description of events and conditions leading up to the crash."

In deciding which events and conditions to include in the accident description, four points are made:

1) An accident is not a single event; it is a process.

2) No single factor can explain the accident.

3) There are causal links, each preceded by another.

4) Each preceding link has less relevance to the individual accident.

Perchonok goes on, from these basic considerations, to develop a machine-compatible coding format and structure so that "... hundreds or even thousands of accidents" can be studied by computer analyses. His approach "was to divide the accident generation process into its component parts, and to provide an exhaustive list of mutually exclusive items for each of these parts. The resultant series of checklists is referred to as the causal structure."

2.1.3 Institute for Research in Public Safety. The Indiana University Institute for Research in Public Safety (IRPS) has done by far by most extensive work in accident causation in recent years. Their work--2258 technician-level and 420 concurrent in-depth investigations were conducted--is well documented in a series of reports starting in 1971.

The IRPS definition of accident causation is based on the test of necessity. Specifically, "... factors are designated as being either of causal or severity increasing significance, according to the following definitions:

Causal Factor--a factor necessary or sufficient for the occurrence of the accident; had the factor not been present in the accident sequence, the accident would not have occurred.

Severity-Increasing Factor--a factor which was neither necessary nor sufficient for the accident's occurrence, but removal of which from the accident sequence would have lessened the speed of the initial impact which resulted.

The actual use of the causal factor definition was amplified by the following footnote appearing in the final report of their work [8]:

The "or sufficient" aspect of this definition was intended for situations where there were multiple sufficient causes (i.e., more than one factor which, by itself, absent any other deficiency or failure, would have caused a particular accident). For example, it is conceivable (however improbable) that a heart attack could coincidentally occur at the same time as a mechanical failure, in a situation where either alone would have led to the same accident. In this instance the "but for" test fails (i.e., neither factor by itself is necessary), but the "or sufficient" aspect would serve to retain both factors as "causes." In practice, it is doubted that circumstances of this kind were encountered, so that the operational definition was one of "necessity." In other words, a factor was considered a cause if "but for" that factor, the accident would not have occurred.

A comprehensive dictionary and structure of causal factors was used in the process of determining accident causation. The top-level breakdown of causal factors consists of:

Human Direct Causes
Human Condition and States
Environmental Factors
Vehicular Factors

These factors are all defined and further sub-classified into many more detailed factors.

The IRPS process of determining accident causation proceeds by first investigating each accident and determining which of the factors contained in the dictionary are present. Then a judgement is made whether the factors found to be present individually meet the "necessity" criterion for classification as a causal factor or as a severity-increasing factor.

These are but three examples of the uses to which the case-study approach has been put. There exists a considerable body of literature on this technique from other clinical accident investigation programs, but most such programs resemble one of the above studies in various important respects.

2.2 Definition of Accident Causation: The Statistical Inference Approach

An alternative to the case-study approach is the statistical inference approach. By the statistical approach we mean the application of experimental design principles and statistical analysis techniques to the identification of objectively-defined variables (factors) that significantly influence the probability that an accident will occur.

The rather extensive literature review did not reveal a definition of accident causation that we consider applicable. However, much past research work in the traffic safety field has utilized the principles and techniques inherent in the statistical approach, although probably not labeled as such. Further, much of that work is consistent with the definition we shall recommend and discuss. In particular, the 1962-1963 Grand Rapids study of Borkenstein et al. [9] is probably the best known and most quoted study exemplifying one of the variants of the statistical inference approach. (The basic design, as shown subsequently, can take other forms). In passing, it can be noted that the concept of accident causation is not explicitly mentioned in the Grand Rapids study, although that research work had many direct countermeasure implications.

We shall propose a definition of accident causation analogous to that given by Greenberg in a medical context [1]. Greenberg, in discussing the smoking-lung cancer controversy, observed that much confusion was created by lack of suitably defined and accepted terms relating a suspected disease-causing factor F with occurrence of the disease D.[1] After discussing disease causation in terms of a suggested definition and a multidimensional regression model, Greenberg concluded that the following definition was appropriate:

$$Pr(D|F,E) > Pr(D|\text{not } F,E).$$

In words:

> A factor F is said to be a cause of a disease D if the conditional probability of developing the disease in the presence of F is greater than the probability of developing the disease in its absence, given the "... many conditioning indigenous and exogenous events which influence the relationship."

A direct substitution of "accident" for "disease" could be made in the Greenberg definition, and the result would serve as an appropriate beginning definition for causation in traffic safety research. However, it seems sensible to anticipate subsequent application of the definition and to modify it on the basis of some of the problems which may arise.

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[1] Greenberg's notation has been modified slightly to avoid confusion in the sequel.

First, we recommend that the determination of causative factors of accidents be established by experimental investigations conducted for that purpose. The "... many conditioning events which influence the relationship" in the Greenberg definition is too broad, because traffic safety experiments are limited in several important ways. They are generally confined geographically to particular counties, regions, or states. They frequently are limited in duration to at most a few years. The accidents under study are generally a subset of all accidents occurring in that area, for example, all police-reported accidents, or all police-reported tow-away accidents, or all fatal accidents. And the nature of the factor under study itself may further restrict the range of conditions and accidents which are investigated; a study of the effects of high-intensity headlamps would necessarily be limited to nighttime accidents. Further, it is not possible to include all potential causative factors simultaneously, so the range of study variables is also restricted.

Therefore we have to acknowledge immediately that whether a factor is considered causative of accidents is circumscribed by the set of general experimental conditions under which the study was conducted. Generalizations beyond the bounds of the experimental conditions obviously must be made with great care, if at all.

The same argument can be presented in terms of evaluating the defining inequality in the tentative definition. The expression on the left of the inequality implies that the frequency of both drivers experiencing accidents and drivers not experiencing accidents be determined in the presence of factor F under a set of conditions E. Further, the right-side expression implies obtaining a second, similar set of frequencies, these determined in the absence of F but in the presence of the same set E of other conditions. It is necessary to delineate the characteristics of the at-risk population of driver-vehicle units and the pertinent characteristics of the environment in which these units operate. In short, measures of exposure, as that concept is generally understood in the traffic context, are needed.

Another facet of this same issue is pertinent. Subsequently it is demonstrated that failure to account for unknown, confounding variables--identified as "lurking" variables throughout the report--can alter the evaluation of the defining inequality. This, of course, also can change our conclusion about whether some study factor is causative of accidents or not. This problem is inherent in the statistical approach. In a sense it is a particular form of a more general problem always confronting scientific endeavors: new data and more current information can modify existing theories. Nonetheless, it is probably worthwhile to acknowledge that all determinations of accident causation are provisional in the sense that more and better data, or data obtained under a different set of exposure conditions, may modify our previous perceptions of whether factors are considered causative of accidents or not.

Together the above issues suggest that we modify the definition of causation by more than a simple substitution of "accident" for "disease." In particular, we shall add the qualifying clause "... as determined under condition set E" to the definition. By this we mean to imply that determination of whether a factor is considered causative of accidents is qualified by the experimental conditions under which the accident and exposure data were obtained, by the inclusion (necessarily) of only a limited number of factors for study, and by the extent and quality of the analyses pertaining to enumeration of the defining inequality. The definition now becomes:

> A factor F is said to be a cause of accidents if the conditional probability of an accident occurring in the presence of F is greater than the conditional probability of an accident occurring in the absence of F, as determined under condition set E.
>
> $\Pr(A|F,E) > \Pr(A|\text{not } F,E)$.

It will be appreciated that the definition, as written, discourages generalizations to the effect that "Factor F causes accidents" on the basis of limited experimentation. If such generalizations are to be made, then condition set E should be representative of accidents generally and the other variables known to be associated with the study factor F should be included in the experiment. Alternatively, there should be adequate replications in time and space of smaller experiments so that the generalization is warranted. It is in the latter sense that we are quite comfortable with the general statistical assertion that a blood alcohol concentration of 0.10 % W/V causes accidents.

This definition powerfully influences the choice and execution of the appropriate accident-causation research methodology. First, the probability expressions on both sides of the inequality each require the determination of a ratio of relative frequencies. The numerator is the frequency of accident events, or the frequency of drivers experiencing one or more accidents. The denominator is the number of drivers experiencing accidents plus the number not experiencing accidents in the same period; for brevity the latter will be referred to as non-accidents. The expression to the left of the inequality sign further implies that the frequencies of both accidents and non-accidents are to be determined in the presence of factor F under a set of conditions E. The right-side expression implies a second, similar ratio of frequencies, these determined in the absence of the factor F but in the presence of the same set E of other conditions.

These concepts are conveniently presented in the form of a 2x2 contingency table, with a, b, c, and d representing the cell frequencies.

Table 1

Illustrative 2x2 Contingency Table

	Accident A	Non-accident Not A	Row Totals
Factor F . .	a	b	a+b
Not Factor F	c	d	c+d
Column Totals	a+c	b+d	a+b+c+d

The left side of the inequality now becomes a/(a+b), and the right side is c/(c+d). The factor F will be said to cause accidents if a/(a+b) exceeds c/(c+d) by some operationally meaningful and statistically significant amount.

This method of defining and determining accident causation is fundamentally different from the case-study approach. Further, the simple extension of the case-study approach from a one-accident focus—to which it is applicable—to a many-accident focus does not thereby transform it into the statistical approach.

For illustration, let us assume that a representative sample of (a+c) accidents is obtained as part of a case-study program. Then let (a) of these (a+c) accidents be distributed into the (F,A) cell and (c) of them into the (not F,A) cell.[1]

The ratio a/(a+c), that is the Pr(F|A), could then be established. This expression, however, does not match either of those contained in the inequality proposed as a definition of accident causation. Even if that were the case, its companion probability on the other side of the inequality would not be available so that the required comparison could be made. (The appropriate contingency table analyses and inferences therefrom are discussed more fully in later sections.)

An essential feature of the statistical approach, as developed from the probabilistic definition of accident causation, is that information on non-accidents must be obtained. As amplified subsequently, this information may be obtained in either of two ways. First, sampling from a non-accident population (that is, a control population) is possible. Second, the information may be obtained by sampling a population of drivers (or, as well, vehicles) on some characteristic not explicitly related to accident occurrence. The drivers would then be classified into the appropriate accident and non-accident cells. However accomplished, the gathering of information on the non-accident population, as well as on the accident population, is the sine qua non of the proposed statistical approach and its companion definition.

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[1] The case-study determination of cause would not stop at this point, of course. The (a) accidents in the (F,A) cell would have to be further classified, by a test-of-necessity criterion, into the smaller number of cases in which F caused A.

3. CHARACTERISTICS OF THE CASE-STUDY AND STATISTICAL APPROACHES

The definition of accident causation and the investigative approaches associated with each approach together give rise to a number of important operating characteristics. The approaches differ in the kinds of research questions and study factors to which each is best suited. The nature and extent of the data collection activities differ, as do the kinds of manpower required. The associated analyses for the determination of cause are fundamentally different. These important operating features are described below.

3.1 Features of the Case-Study Approach

3.1.1 The Case-Study Model. The most important of the case-study operating characteristics derive directly from the fundamental principle underlying operation of the approach. The principle is that the case-study investigator(s) have, for each individual accident under study, a model in mind of how the accident happened. The model may be implicit at first, but it must evolve into an explicit model by the time the causal factors have been identified. The components of the model should include all of the factors that are actually pertinent to the accident occurrence, a knowledge of how these factors operate generally, and a knowledge of how the factors operate individually and in concert with other such factors for the accident under study. The case-study approach is a matter of carefully considered judgements about what factors are important and how they interact to produce the accident in question.

In principle, the scope of the case-study approach is very broad in that any factor, or set of factors, can be addressed. Indeed, as noted above, it is implicit that all relevant factors can and should be considered for each accident. Since these factors are not known before the investigation, it is incumbent on case-study investigators to consider all reasonable causative factors for each accident[1]. Therefore factors from the human, vehicular, and environmental classes are necessarily within the realm of investigation.

3.1.2 The Study of Transients. Transient factors from the human class, which are not at all easily approached with the statistical method, can be handled with the case-study method. Examples are dozing, inattention, and, from the IRPS list of causal factors, improper lookout. On the other hand, some of the more stable, but remote (in a causal sense) human factors lend themselves less well to a case-study approach. Examples include monocular vision, color blindness, and chronic disease states.

A transient condition from the vehicular realm that is best approached with the case-study method is the influence of blow-outs in causing accidents. The underlying model by which a blow-out causes an accident is sufficiently straightforward and understandable that the method would work well. The factor would be included in a candidate list of causal factors to be addressed by the investigators, the physical evidence would be present and generally unambiguous, and it is likely that the use of expert judgement would provide repeatable results.

3.1.3 Limitations. The role of vehicle-handling factors in causing accidents is an example of an important study topic not well suited to the case-study approach. This is one case in which the theoretical understanding of the phenomenon exceeds the data-collection capabilities needed to exercise the theoretical model. In order to capitalize on our understanding of vehicle-handling factors on a case-by-case basis, we would require detailed data about the pre-crash braking history and the pre-crash steering input. Also, we usually would require information on the preceding human detection, perception, decision, and action factors. Additional detailed data would be needed about each of the four tire-road interfaces. At least some of these data elements could be collected with the required accuracy and objectivity, but it is our judgement that the uncertainties inherent in the braking and steering inputs exceed the limits needed to assess the subtle influence of vehicle-handling factors on accident

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[1] Benner [2] has an excellent expostulation of this idea.

causation.

Assessing the role of tinted windshields is another example which would seem to exceed the limits of case-study capabilities. As in the vehicle-handling case, it might very well be that the requisite understanding of the physical phenomenon is sufficiently in place. Gathering the required data, however, would again seem to be beyond both present and future capabilities. If only "coarse" data--that is, data of limited resolution and detail--were gathered, then the judgements connected with establishing whether a potential causal factor was in fact causative or not would seem to be little more than guesses. The collection of more detailed data of higher resolution might be compatible with our current knowledge of the physics of the situation. However, in this case the collection of the needed data--the visual capabilities of the involved driver(s), the ambient light levels, the reflectivities of the significant objects, and the like--is not now and is likely not to be within the scope of accident-investigation capabilities.

The tinted-windshield example illustrates another fundamental characteristic of the case-study approach. The approach, by itself and without additional data-collection activities, examines only accident cases. No information on non-accident cases is available. Suppose that tinted windshields increase the risk of pedestrian accidents at dusk involving older drivers. Let us grant, for the sake of argument, that the case-study approach were able to find these accidents and correctly ascribe tinted windshields as at least one of the causative factors. But suppose also that tinted windshields in fact reduce the occurrence of daytime accidents on freeways in the summer because of reduced fatigue and glare. Such an effect would be nearly impossible to find with the case-study approach. The generalization is that the case-study approach is not well suited to finding both the positive and negative effects--the benefits and the additional risks--associated with factors having both.

The case-study approach, as noted earlier, is a matter of considered judgement. The more expert accident investigators and reconstructionists, therefore, should provide superior results. Highly qualified multi-disciplinary accident investigators are desirable. These teams are expensive, of course, with a resultant high cost per case. The IRPS work utilized both technician-level teams (Level B) and in-depth teams (Level C), and there is some indication of disagreement with respect to identification of causative factors. It would be expected, therefore, that in-depth teams would be required to maximize the accuracy of the case-study judgements and to assure maximum repeatability of results.

3.2 Features of the Statistical Inference Approach

3.2.1 Non-accident Information. The most important feature of the statistical inference approach is that information on non-accidents, as well as on accidents, is essential. This information must be obtained by either sampling directly from a non-accident, control population or by aggregating data on drivers not experiencing accidents in some given time frame as well as collecting data on accident-involved drivers. If some given factor F is found, during the analytical work, to satisfy the inequality defining accident causation [$Pr(A|F,E) > Pr(A|\text{not } F,E)$], then F is said to be a cause of accidents under condition set E. Another common way of expressing this inequality, under the particular sampling design calling for sampling from both accident and non-accident populations, is that the factor F is overrepresented in the accident population with respect to its occurrence in the control population.

3.2.2 Accident-Causation Factors. The emphasis in this development, it should be noted, is on the candidate accident-causation factor F. (This can be extended to a set of factors.) In the statistical approach, the focus is on identifying F, or a small set of F, looking at enough accidents and non-accidents involving both F and not F, and then concluding whether, according to the definition, F causes accidents. The case-study approach, in contrast, focuses on one or more accidents, seeks to determine the presence or absence of any and all of a large candidate set of factors F in the accident(s) under investigation, and then seeks to determine which of the present factors meet the test-of-necessity criterion for accident causation.

This change in focus has important implications for an entire research program as well as for specific research projects. If the statistical approach is to be adopted, then we are implicitly asserting that we have a good deal of prior information about the factors worthy of study and believe that the exploratory capabilities of the case-study approach are not needed. In this sense the statistical approach is analogous to controlled laboratory experimentation in the physical sciences following an initial period of exploratory and observational research.

3.2.3 Stability of Factors. Other operating characteristics follow from the focus on factors in both accident and non-accident populations. The most important of these is that not all factors of potential interest can be studied by the statistical approach or, at a minimum, are better studied by the case-study approach. The general requirement is that study factors possess enough stability in time so that they can be reliably presumed to exist (or, alternately, not to exist) or to be measurable in both the control and pre-crash situations. This excludes all physical conditions or mental states so evanescent that the attempt to measure them would alter or eliminate them. The point is best made by several examples.

Among candidate human factors, for example, color blindness and field dependence are both permanent, or at least slowly changing, characteristics. It would be safe to assume that samples of drivers who were field dependent at the beginning of a study year would be that way at the end of the year and that that condition held in any pre-crash situation that might have arisen. A similar situation is presumed to hold for field-independent drivers. From the vehicular realm, the presence or absence of tinted windshields can be presumed to be a stable characteristic, or at least is easily "measurable" to determine whether a gross change has occurred. Environmental features exhibiting this property are, for example, highway grade and curvature.

Another class of factors displaying less long-term stability--but nonetheless displaying the requisite stability in time--can be studied provided that sampling is effected from accident and non-accident populations rather than from factor and non-factor populations. The presence of alcohol in the blood is one such factor. It clearly is not a permanent condition, but its presence and amount changes sufficiently slowly that measurement is possible, as in the Borkenstein study [9]. Further, it can be accurately and reliably measured in a non-accident population by roadside survey techniques. The measurement of tire-pressure differentials is a comparable example from the vehicular realm, as is the presence of a wet driving surface in the environmental realm.

There exist, however, other important variables that are essentially transient in nature and do not lend themselves well to study by the statistical approach. Dozing, inattention, and improper lookout have been mentioned earlier. To these could be added loss of consciousness, inadequate search, detection/perception failures, recognition failures, and decision failures. Each of these has associated with it a complex measurement problem within the accident population, but that is not the point being raised here. Even if those measurement problems could be resolved satisfactorily in the accident population, there does not seem to be any way to define and measure the analogous behavior in the control or non-accident populations. Inability to do so presents very real limitations on the type of research questions that can be addressed by the statistical approach, particularly in the human realm.

A similar problem exists with some of the vehicular and environmental variables. Tire blow-outs, sudden brake failures, and complete loss of steering are examples of potential accident causes that should be studied by the case-study rather than the statistical method. From the environmental class, glare from oncoming headlights and slick surfaces from temporary freezing conditions fall into the same class.

3.2.4 Subsetting Complex Phenomena. The focus on factors associated with the statistical approach results in another characteristic not found in the case-study approach. Suppose that the effects on accidents of tires with less than 3/32-inches of tread--"bald" tires, for this discussion--are of interest. If they were to be studied by the case-study method, then the accident investigators would need to measure a number of variables associated with vehicle handling: braking and steering inputs, certain vehicle-design parameters, other tire parameters (for example, pressure and stiffness), and the friction characteristics of the pre-crash path(s) of the vehicle(s). Without this information an assessment of the effects of the bald tires would be inconclusive at best.

The statistical approach, however, does not require that all pertinent factors and variables be related in a physical modeling sense. The bald-tire problem could be studied effectively by measurement of only tread depth in the accident and control populations. In practice an experiment would not be constructed in such a narrow manner. We know, from our prior knowledge of the physics of the situation, that bald tires would be expected to perform more poorly on wet, slippery surfaces and relatively better on dry, high-friction surfaces. These facts would be taken into account in designing the experiment. In principle, however, an investigator need collect only the tread-depth data from both an accident population and from a suitable control population to be able to deduce the effects of bald tires on accident occurrence. This ability to break a complex phenomenon into segments and to study a smaller number of factors is one of the attractive features of the statistical approach.

3.2.5 Field Personnel. In contrast to the case-study approach, accident investigators do not have to make judgements about whether a factor is causal or to collect data so that a reconstructionist can subsequently make such a judgement. It should be the case, therefore, that less skilled and less experienced accident investigators can be satisfactorily used in a statistical program. In the earlier example of the bald-tire investigation, the data-collection requirement is to follow a prescribed measurement protocol as accurately and as objectively as possible without attention to the nuances that might influence a causal judgement.

4. THE STATISTICAL APPROACH IN GREATER DEPTH

A probabilistic definition of accident causation was presented in Section 2. The accompanying methodology, labeled the statistical inference approach, was described and some of the more important operational characteristics of the approach were presented in Section 3. The purpose of this section is to amplify these topics further and to present additional information about the statistical approach.

4.1 Accident Causation and a Multiple Regression Model

The definition proposed earlier for accident causation earlier is that:

> A factor F is said to be a cause of accidents if the conditional probability of an accident occurring in the presence of F is greater than the conditional probability of an accident occurring in the absence of F, as determined under condition set E.
>
> $Pr(A|F,E) > Pr(A|\text{not } F,E)$.

This definition, it was noted, was adapted directly from Greenberg [1]. Greenberg, before offering the medical definition of causation on which the above is based, discussed a general model of chronic disease in terms of a multiple regression model. The model, and its traffic safety analog, raises a number of our current concerns and is presented, therefore, in some depth.

$$
\begin{aligned}
Pr(D) = X_0[&[b_1X_1 + b_2X_2 + b_3X_3 + \dots + b_{n-1}X_{n-1} + b_nX_n] \\
&+ [b_{1,1}X_1^2 + b_{1,2}X_1X_2 + b_{1,3}X_1X_3 + \dots \\
&+ b_{1,n}X_1X_n + b_{2,2}X_2^2 + b_{2,3}X_2X_3 + \dots \\
&+ b_{2,n}X_2X_n + \dots + b_{n-1,n}X_{n-1}X_n + b_{n,n}X_n^2] \\
&+ [b_{1,2,3}X_1X_2X_3 + \dots \\
&+ b_{n-2,n-1,n}X_{n-2}X_{n-1}X_n] + \dots \\
&+ [b_{1,2,3,\dots,n}X_1X_2X_3\dots X_n]].
\end{aligned}
$$

The author goes on to describe the model as follows:

> (a) The entire right hand side is multiplied by a variable, X_0, which takes the value 1 when there is a known etiological agent (as

is the case of tuberculosis) which is present, and the value 0 when the agent is absent. One can alter this formulation to take into account the amount or virulence of the agent present but this modification is not necessary in the present application. When there is no known etiological organism, the variable can be dropped from the model.

(b) In the listing containing n variables within the first set of square brackets, the X's may represent such factors as age, race, sex, occupation, diet, smoking pattern, place of residence, personality type, genetic structure, plus a whole host of other main effects. These variables might be quantitative or take simply the values 0 and 1 according to the factor's absence or presence. The b's designate regression coefficients whose magnitude represents the degree of influence of the factor per se upon the probability of causing disease.

(c) In the list containing $(n+nC_2)$ variables within the second set of square brackets, there are nC_2 first-order interactions plus n quadratic terms. If the effect of the factor is quadratic, such as mother's parity upon perinatal mortality, then the appropriate term, $b_{i,i}X_i^2$, would have a nonzero regression coefficient. If a regression coefficient is nil, then the first-order interaction is non-existent and its potential effect need not be considered.

(d) Similarly, the third set of square brackets contains the second-order interactions plus appropriate cubic terms as well as interactions between quadratic terms and other variables.

(e) The limiting term in the formulation is the highest order interaction involving a host of factors.

Greenberg notes that two guides are to be drawn from the model. The first is that the one should not look only at the main effect and its regression coefficient if one is interested in some particular variable. Each term involving that variable should be examined. Second, the model (as well as experience gained from studying other chronic conditions) suggests the importance of the higher-order interactions.

It is our judgement that these arguments hold for the present state of accident-causation research. The case-study approach, used for many years, has in fact identified many of the obvious and readily apparent causes of accidents. These are roughly equivalent to Greenberg's "main effects." That approach has also quantified these effects to some extent. Further, many countermeasures have been identified and implemented based on such research, and there is no doubt that many of the countermeasures have been successful. One can argue that the obvious problems are well identified, if not solved.

Accident-causation research seems now to be in the position where consideration of primarily main effects, and countermeasures based upon them, is no longer adequate. We must now address the higher-order and interactive terms as well. The statistical approach is the superior of the two for this type of accident-causation research.

4.2 Contingency Table Formulation

The Greenberg regression model for chronic diseases was formulated as if its data elements had been obtained by cross-sectional sampling. This is the first of three sampling methods, as discussed by Fleiss [10], that can produce a 2x2 contingency table of the kind given earlier in Section 2. This can be illustrated by considering a random sample of people on each of whom many data elements are aggregated, among them a variable that describes the absence or presence of disease.

The closest analog in the traffic safety situation would be to obtain a random sample of drivers, aggregate extensive data on all their characteristics believed to be relevant to accident occurrence, and obtain detailed descriptions of their driving practices, including the occurrence and absence of accidents, over an extended time period. This analogy does not strictly hold in that a driver does not, as a separate entity, get into traffic accidents, but only as part of a driver-vehicle combination. This objection could probably be circumvented, at least conceptually, by aggregating for the drivers, as part of the driving-description data set, vehicle-specific information about trips undertaken during the study period. Apart from the latter complication, however, the practical difficulties of tracking enough people over a long enough time period with enough detailed data on each person's trips weigh heavily against such a broadside implementation of the statistical inference approach.

The above conceptualization, even though incapable of implementation at the present, is attractive. It presents an orderly and organized way for us to think about and discuss accident-causation research. Further, the concepts can be retained on a reduced, practicable scale by re-casting the regression model into a contingency table model.

A contingency table formulation offers two immediate and distinct advantages. First there is an extensive, and growing, body of theory that is immediately accessible (Bishop, Feinberg, and Holland [11]; Gokhale and Kullback [12]; Goodman [13]). This can be used to guide the design of experiments and in the subsequent interpretation of data obtained from them. Second, debugged computer programs, such as ECTA and GENCAT, are available both in MTS and elsewhere. This should preclude the need for software development to analyze data obtained during the research program, thus minimizing both analytical costs and schedules.

4.2.1 Cross-Sectional Sampling. Cross-sectional sampling, also called naturalistic or multinomial sampling [Fleiss, p. 39], occurs when a random sample is taken from a population so that only the total number of subjects is fixed. In terms of Table 1 from Section 2, reproduced below for convenience, a sample of size N=a+b+c+d is obtained. If the N subjects are distributed according to the presence or absence of each of two characteristics, in our case accident occurrence and the factor F under study, the 2x2 table is obtained.

Table 1

Illustrative 2x2 Contingency Table

	Accident A	Non-accident Not A	Row Totals
Factor F . .	a	b	a+b
Not Factor F	c	d	c+d
Column Totals	a+c	b+d	a+b+c+d

The principal advantage of this kind of sampling—a very significant one—is that all the probabilities of interest are immediately available. It will be recalled that the inequality defining whether a factor causes accidents is

$Pr(A|F,E) > Pr(A|\text{not } F,E)$.

The left side of the inequality is given by $a/(a+b)$, and the right side is given by $c/(c+d)$. The inequality can be evaluated directly, and we can decide whether the factor causes accidents.

Cross-sectional sampling also provides two other very important pieces of information. The distribution of the factor under study in the sampled population is one of the two marginal distributions. If we have little prior information about the factor and its distribution, this feature may be of great utility.

Further, as a corollary of the above, the joint distribution of the accident and factor distributions provides essential information needed for cost-benefit considerations. The maximum potential reduction in accident frequency attributable to some countermeasure, on the assumption that the countermeasure eliminates completely the deleterious effects of the factor, is $(ad-bc)/(c+d)$ for the sample of size N. Division of this expression by the sampling ratio would provide the maximum potential reduction in accident frequency for the population from which the sample was taken.

The principal disadvantage of this form of sampling, apart from the problems associated with obtaining adequate detail on the accident experience, is its potential inefficiency. By way of illustration, let us note that about 10% of all drivers have one or more accidents per year[1]. Let us assume that the proportion of some factor of interest in the driving population is, say 0.2. Then the expected proportion of drivers having an accident and the factor--the F,A cell--is 0.02. It would therefore be necessary to start with a very large N to eliminate statistical irregularities associated with small cell frequencies and to have a reasonable number of F,A entries for further study. The same information might be obtainable far more efficiently by oversampling from the subpopulation exhibiting the factor of interest. Such a sampling method forms the basis of prospective sampling, discussed in the next section.

Because of these considerations, it is likely that cross-sectional

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[1]"Accident", of course, requires some precise definition. The 10% figure is about right for accidents reported to or by official (police) agencies in a jurisdiction with a fairly industrious reporting system.

sampling will not be used widely in accident-causation research. Nonetheless, the information available as a result of cross-sectional sampling is more complete than that available from other sampling methods, and the resulting contingency table should be considered as the ideal to be obtained. Further, there exist traffic applications for which it is likely to be the preferred sampling approach. One such illustrative application appears in Section 6.1.

4.2.2 Prospective Studies. A prospective study is another form of design that can result in a contingency table formulation. It is one of two designs employing sampling from fixed margins. In epidemiologic terms, prospective sampling occurs when one sample is drawn from a population of exposed individuals, and another sample is drawn from a population of non-exposed individuals. These kinds of studies are also known as cohort studies (the preferred epidemiologic term), forward-going studies, or follow-up studies.

We shall use the term "prospective" to identify this kind of study. Table 2 depicts a 2x2 contingency table with a fixed sample of size $N_1=k_1(a+b)$ taken from the population having the factor under study--the suspected antecedent factor--and a sample of of size $N_2=k_2(c+d)$ taken from a population with the factor absent.

Table 2

Illustrative 2x2 Contingency Table
from
Prospective Sampling

	Accident A	Non-accident Not A	Row Totals
Factor F . .	k_1a	k_1b	$k_1(a+b)$
Not Factor F	k_2c	k_2d	$k_2(c+d)$
Column Totals	k_1a+k_2c	k_1b+k_2d	$k_1a+k_1b+k_2c+k_2d$

The classic application of prospective sampling is to select two samples for study, one of size N_1 having the antecedent factor of interest, and the other of size N_2 without the factor. These samples are followed forward in time for the period of the study and observed for the occurrence of disease, or accidents. Although the term "prospective" follows from this typical application, we should note at the outset that historical data can be used. Thus, for example, we might identify a sample of N_1=1000 currently color-blind drivers and another sample of N_2=2000 drivers who are not color blind. We might look only at accident experience over, say, the last five years. We might equally well choose to track the drivers forward in time over the next five years. And we might combine both of these options and still retain the prospective design. The key point is that a prospective study is characterized by fixed-margins sampling from different sub-populations having and not having the study factor F.

Advantages of Prospective Sampling. The most important benefit available from prospective sampling is that, just as with cross-sectional studies, the probabilities defining risk and accident causation are immediately available. In particular, Pr(A|F) is $k_1a/k_1(a+b)$, or Pr(A|F) equals a/(a+b) as before. Similarly, Pr(A|not F) is c/(c+d). These two probabilities needed for the defining inequality are directly available, irrespective of the fact that we have sampled from fixed marginal totals N_1 and N_2.

Fleiss [10, p. 54] demonstrates that, for the same total sample $N=N_1+N_2$, a prospective study yields a more powerful chi square test of association than does a cross-sectional study of the same total sample size N. Further, it is the case that the odds ratio (one of the most useful measures of association) is more precisely estimated in the prospective study. Thus, the prospective design is both more powerful and more precise than a cross-sectional study of the same size.

Potential Disadvantages of Prospective Sampling. Prospective sampling, in contrast to cross-sectional sampling, does not yield any information about the distribution of the factor F in the population under study. Whether this is a real disadvantage depends on what additional information may be available about the factor. If the distribution of F is known from other sources, then we should be able to re-create the cross-sectional contingency table, and hence the information, available from a cross-sectional study. If the distribution of the factor is completely unknown, however, then we may have little insight into the real size of the problem even though a/(a+b) is much greater than c/(c+d). In short, prospective sampling does not provide any of the prevalence kind of information needed to assess cost-benefit kinds of issues.

4.2.3 Retrospective Studies. Retrospective studies use the second of the two ways of sampling from fixed margins. In epidemiologic terms, retrospective studies result when primary sampling is from affected and not affected populations. In traffic safety terms, this is directly equivalent to sampling from accident and non-accident (control) populations, as in the Borkenstein et al. study [9].

The term "retrospective" is associated with "looking backward" from effects to causes. Epidemiologists prefer the term "case-history," but we shall use "retrospective" to prevent confusion between the "case-history" and "case-study" approach.

Table 3 illustrates the 2x2 contingency table arising from retrospective sampling. Here a sample of fixed size $N_3=k_3(a+c)$ is drawn from an accident population and a sample of fixed size $N_4=k_4(b+d)$ is taken from the control population.

Table 3

Illustrative 2x2 Contingency Table
from
Retrospective Sampling

	Accident A	Non-accident Not A	Row Totals
Factor F . .	k_3a	k_4b	k_3a+k_4b
Not Factor F	k_3c	k_4d	k_3c+k_4d
Column Totals	$k_3(a+c)$	$k_4(b+d)$	$k_3a+k_4b+k_3c+k_4d$

As noted earlier, the bulk of past accident-investigation work is of the case-study type and is akin to sampling only from the accident population. In this respect, such studies provided—assuming that correct sampling techniques were followed—one-half of a retrospective design undertaken as part of a statistical approach to accident causation. These studies typically did not focus on determination of accident cause—they frequently emphasized determination of injury mechanisms—and, as noted in Section 2.1, the determination of cause, if attempted at all, was undertaken in a fundamentally different manner than we are recommending here.

Advantages of Retrospective Sampling. In the preceding section it was noted that, for equal sample sizes, prospective studies are more precise and more powerful than studies using cross-sectional sampling. Fleiss [10, pp. 58-59] demonstrates further that a retrospective study is even more powerful and more precise than a prospective study of the same total N. A corollary is that a retrospective study is relatively more attractive for the study of rare events, such as accidents and some diseases.

It is appropriate to note here that the advantages of precision and power that the retrospective study has over the prospective study—and similarly for the prospective study compared with the cross-sectional study—are not at all likely to be controlling in the choice of one method or the other. It is more likely that the choice of sampling method will be based on the inherent applicability of one sampling method to the research questions and factors under study and to the need for and quality of data available from historical files. The operational ease—or lack of it—and cost of sampling the non-accident, control population are also likely to be quite influential. Nonetheless, the statistical properties of the sampling methods are important and should be included in evaluating which of the sampling methods to use.

Potential Disadvantages of Retrospective Sampling. The central deficiency of retrospective sampling is that neither of the two probabilities needed to determine directly (the reason for the emphasis will be seen shortly) whether a factor is causative of accidents is available. The $Pr(A|F)$ is $k_3/(k_3a+k_4b)$, and the $Pr(A|\text{not } F)$ is $k_3c/(k_3c+k_4d)$. Neither proportion can be evaluated without knowing both k_3 and k_4, and neither of these is available from a fixed-margins sampling method. If both of these constants were available, then the 2x2 table resulting from cross-sectional sampling could be re-constructed and all of the information in it would be available.

This is not the case, however. Careful sampling from the accident population--say with some known sampling fraction s_3--is not at all the same as knowing how the $N=N_3+N_4$ driver-vehicle combinations are distributed into the accident and non-accident marginal totals. In short, k_3 and s_3 are not related in such a manner that one can be derived from the other. Similarly, we do not generally know the k_4 associated with the control population. That is, even well-designed roadside surveys do not generally presume to know what proportion of all driver-vehicle combinations in a given area over a given time are sampled in the survey.

It is this lack of information about how the accidents and non-accidents are distributed in the margins that results in fixed-margins, retrospective sampling designs providing less information than desired. Direct information about the risk associated with the presence of factor F compared to the risk associated with absence of the factor is not available.

It certainly does not follow, however, that retrospective sampling designs are without merit. To the contrary, the cross-product ratio--also known as the odds ratio--is a highly useful measure of association, and it is available from a retrospective design. And because the cross-product ratio is available, it can be demonstrated that the inequality defining accident causation can be evaluated. The cross-product ratio and the required demonstration are presented in the next subsection.

It is also the case that relative risk--another useful measure of risk used frequently by epidemiologists--can be estimated from a retrospective design under certain simplifying assumptions. Relative risk is the ratio of risk in the presence of the factor to risk in the absence of the factor. Thus it is the ratio of the two probabilities in the inequality defining accident causation. In the notation of Table 3,

$$\text{Relative risk} = [k_3a/(k_3a+k_4b)] \;/\; k_3c/(k_3c+k_4d)]$$

$$= [k_3a(k_3c+k_4d)] \;/\; [k_3c(k_3a+k_4b)]$$

$$= [a(k_3c+k_4d)] \;/\; [c(k_3a+k_4b)].$$

If, as is frequently the case, $k_3c \ll k_4d$ and $k_3a \ll k_4b$, then

Relative risk=approx $[a(k_4d)] / [c(k_4b)]$

=approx [ad/bc].

The bracketed ratio is in fact the odds ratio, discussed in the next subsection dealing with the cross-product ratio.

4.2.4 The Cross-Product Ratio. Numerous measures of association--or interaction--between variables in contingency tables have been developed over the years. The cross-product ratio is one of these. More generally, there exists an extensive body of theoretical and practical literature on the analysis of contingency tables. Clearly, a review of this literature is far beyond the scope of this report even if it were possible. Readers are referred to Bishop, Feinberg, and Holland [11] and to Gokhale and Kullback [12] for both current information on various analytical techniques and for extensive bibliographies to the prior literature.

A brief discussion of the cross-product ratio is included here for several reasons. First, it is one of the most commonly used measures of association, it has several desirable properties, several other measures are functions of it, and, as Bishop et al. observe [11, p. 377], it plays a central theoretical role in the construction of log-linear models. Finally, the three sampling methods discussed earlier are nicely unified in terms of the cross-product ratio.

Definition. The cross-product ratio (CPR) can be defined in terms of the probabilities of the cells in a 2x2 table. Using Table 1 for illustration and notation, $p_{11}=a/N$, $p_{12}=b/N$, $p_{21}=c/N$, and $p_{22}=d/N$. Then

$$CPR = p_{11}p_{22} / p_{12}p_{21} = ad/bc.$$

We shall generally use the frequency notation for convenience.

The cross-product ratio is also equivalent to the odds ratio, and each can be derived from the other. Using the probability notation appropriate for Table 1, the odds of having an accident in the presence of factor F are p_{11}/p_{12}, and the odds of having an accident in the absence of F are p_{21}/p_{22}. The odds ratio is simply the ratio of these odds, $(p_{11}/p_{12}) / (p_{21}/p_{22})$, or $p_{11}p_{22}/p_{12}p_{21}$, the same as the CPR given above.

Invariance. One of the highly desirable properties of the cross-product ratio is that it is invariant under row and column multiplications. In Table 2, illustrating a 2x2 table from prospective sampling, row 1 was multiplied by k_1 and row 2 was multiplied by k_2. For Table 2 we have that

$$CPR = (k_1 a)(k_2 d) \ / \ (k_1 b)(k_2 c) = ad/bc.$$

From Table 3, illustrating retrospective sampling and having column 1 multiplied by k_3 and column 2 by k_4, we have

$$CPR = (k_3 a)(k_4 d) \ / \ (k_4 d)(k_3 c) = ad/bc.$$

It is readily apparent that the same result would hold had simultaneous row and column multiplications occurred.

This is an important result, and it is certainly one of the important reasons that the cross-product ratio is the most widely used measure of association. In terms of the statistical inference approach to accident causation, it means that any of the three sampling methods--irrespective of the fact that both prospective and retrospective sampling can occur with some unknown values of k_1, k_2, k_3, and k_4 not equal to one--all produce the same measure of association. (The precision with which the cross-product ratio can be measured will not, in general, be the same for the three methods). This result is as one would hope for; inferences about the association between the factor F and accidents should not depend on which sampling method is used, or, as is true of some other measures, on the size of the sample.

We demonstrated above that the cross-product ratio derived from a 2x2 contingency table obtained from a retrospective sampling design is ad/bc. If the cross-product ratio is unity (one), then the accidents occur independently from the factor F; that is, the factor is not associated with accidents. It remains to be shown that if the cross-product ratio is greater than one, then the defining inequality with which we started is satisfied.

We had that a factor F is said to cause accidents if

$$Pr(A|F) > Pr(A|\text{not } F).$$

This was related to a contingency table formulation derived from a cross-sectional sampling study as shown in Table 1. Using that table and its notation, we can evaluate the inequality defining accident causation:

$$Pr(A|F) > Pr(A|\text{not } F)$$

$$a/(a+b) > c/(c+d)$$

$$a(c+d) > c(a+b)$$

$$ac+ad > ac+bc$$

$$ad > bc$$

$$ad/bc > 1.$$

The following has been demonstrated. A factor F is said to cause accidents if the $Pr(A|F) > Pr(A|\text{not } F)$. If that is true, then the cross-product ratio necessarily exceeds one. The cross-product ratio is available from retrospective study designs, and it is in fact invariant regardless of which sampling method is used. Therefore we can determine accident causation, in a probabilistic sense, from retrospective studies regardless of the fact that we have sampled from fixed marginal totals N_1 and N_2.

But this is not the same as asserting that all three sampling methods produce the same information about risk, for they do not. Cross-sectional and retrospective sampling provide direct estimates of the risk of an accident associated with the factor under study, but retrospective sampling provides only an indirect estimate of the same risk. What is not available from a retrospective study is the level of the relationship between F and A. This is illustrated in Table 4.

Clearly, the four illustrative cases of Table 4 are very different in character and have very different traffic safety implications. Yet they differ, from a sampling point of view, only in the size of the sample taken from the non-accident population. The probabilities are included for illustration only, for they have no real meaning in this context and are not ordinarily computed. The cross-product ratio—note that it is constant—does have meaning, however, and it enables us to conclude that the factor F and accidents are associated. The table also shows how the relative risk approaches the cross-product ratio as the accidents become increasingly rarer with respect to the non-accident population.

Table 4

Illustrative Values
from a
Retrospective Sampling Design

	a	b	c	d	Cross-product ratio	Prob. (A|F)	Prob. (A|not F)	Relative risk
Case 1	50	40	50	60	1.5	.556	.455	1.222
Case 2	50	400	50	600	1.5	.111	.077	1.444
Case 3	50	4000	50	6000	1.5	.01235	.00826	1.494
Case 4	50	40000	50	60000	1.5	.00125	.00083	1.499

We are now in a position to appreciate Fleiss' defense of the cross-product (odds) ratio and of retrospective studies [10, p. 61]:

> Given these concerns, that measure of association is best which is suggested by a mathematical model, which remains valid under alternative models, which is capable of assuming predicted values for certain kinds of populations and can thus serve as the basis of a test of hypothesis, and which is invariant under different methods of studying association. Because the odds ratio, or such a function of it as its logarithm, comes closest to providing such a measure (Cox, 1970, pp. 20-21), and because the odds ratio is estimable from a retrospective study, retrospective studies are eminently valid from the more general point of view of the advancement of knowledge. Peacock (1971) warns, however, against the uncritical assumption that the odds ratio should be constant across different kinds of populations.

4.3 Sample Size Considerations

The statistical inference approach to accident-causation research relies heavily on sampling from accident and control populations. It therefore becomes necessary to look at the sizes of the samples that will be required. There may exist research topics of interest in which the approach will not work because of prohibitively large samples. And for those topics for which the method is suited, we wish to be able to estimate the number of drivers, or vehicles, required from both accident and control populations.

As an initial step, the required sample sizes were worked out for a 2x2 contingency table. Input parameters for the equations (Equations 3.14 and 3.15 from reference 6) are alpha, beta, the estimated proportion in one of the two samples under study, and the difference between the two sample proportions to be detected with power (1-beta). These equations were programmed in PIL within MTS, and the required sample sizes were tabulated for parameters in the range of interest. Table 5 presents these sample sizes for the 2x2 case.

A cursory review of the required sample sizes suggests that the statistical inference approach will probably be practicable for some topics of interest but will not work for others. For example, a small difference of 0.01 between two samples with base proportion of 0.4 requires about 12,000 cases from both samples, and this number gives an alpha of 0.2 and a power of only 0.6. However, this number drops to 900 for a base proportion of 0.1 and a difference of 0.025 with the same alpha and power. For small differences around 0.5 the required sample sizes will likely prove prohibitive, but for smaller base proportions with reasonable, interesting, and worthwhile differences between accident and control populations, the statistical approach will probably work from this perspective.

We are not, however, working with the 2x2 case in the typical traffic safety situation. Extensions of Fleiss' equations 3.14 and 3.15 have not been found in the literature for either mxn (2-dimensional) contingency tables or for multi-dimensional tables. Neither have HSRI nor Statistical Research Laboratory consultants been able to provide explicit guidance on this topic. Both because of the inherent complexity of determining sample-size requirements generally, and because we probably could not satisfactorily estimate the required parameters anyway, we will probably be forced to use the 2x2 tabulations for planning and design purposes. These can be used for guidance in future experimental work and extended to the general situation by whatever insight and judgement can be brought to bear.

Some thought, however, has been given to a simulation approach using programs like ECTA or GENCAT for helping to resolve the sample-size problem, and we will continue to investigate the feasibility of such an approach.

Table 5

Required Group Sample Sizes
for
2x2 Contingency Table
(Two-Tailed Tests)

P(A) in control	Diff. in probs.	Alpha (signif)	Power (1-Beta) .90	.80	.70	.60
.4	.01	.05	51052	38182	30882	23936
.4	.01	.10	41687	30159	23724	17704
.4	.01	.20	32031	22867	16625	12099
.4	.025	.05	8308	6237	5063	3945
.4	.025	.10	6801	4946	3911	2942
.4	.025	.20	5247	3750	2768	2080
.4	.05	.05	2131	1610	1314	1033
.4	.05	.10	1752	1284	1024	779
.4	.05	.20	1360	974	735	543
.1	.01	.05	20150	15131	12284	9575
.1	.01	.10	16498	12001	9491	7143
.1	.01	.20	12731	8841	6722	4791
.1	.025	.05	3514	2661	2177	1716
.1	.025	.10	2893	2128	1702	1302
.1	.025	.20	2252	1591	1230	900
.1	.05	.05	995	762	630	503
.1	.05	.10	825	616	499	389
.1	.05	.20	650	468	369	278
.01	.01	.05	3492	2700	2250	1821
.01	.01	.10	2916	2205	1807	1432
.01	.01	.20	2320	1703	1365	1053
.01	.025	.05	890	701	593	490
.01	.025	.10	752	582	486	396
.01	.025	.20	609	461	379	303
.01	.05	.05	357	285	243	203
.01	.05	.10	304	239	202	167
.01	.05	.20	249	192	160	130

4.4 Potential Problems

The material presented thus far has included an appraisal of some strengths of the statistical approach to accident-causation research. It was also noted that the approach is not well suited to the study of transient phenomena generally, and to the study of certain human conditions, such as dozing, whose measurement in a control population disturbs the situation being measured.

In addition to these issues, other potential problems exist with the statistical approach which users should consider. These include, as noted before, the collection of control-group data. Further, there is a potentially serious problem connected with drawing inferences from a study in which a study variable interacts with an unknown variable that influences the occurrence of an accident. Another facet of this same problem is concerned with knowing when it is possible to collapse a contingency table into one of fewer dimensions without distorting the structure of the data.

4.4.1 Control-Group Problems. The identification of a suitable control group and collection of data on members of that group is an indispensable part of the statistical approach. The general requirement is that the control group members be exposed to as nearly the same set of accident-producing factors as was the accident group.

Roadside surveys probably come the closest to matching this requirement when the study focuses on human and vehicular variables and when a retrospective design is in use. Typically survey locations are picked at places that past accidents have occurred, and the driver/vehicles passing these locations at the times past accidents have occurred are included in the survey on a sample basis. The design of roadside surveys and the practical issues regarding their conduct are well covered in the literature [14]. Wolfe's bibliography on highway travel exposure research methods also contains sections pertinent to the use of such surveys [15].

The principal disadvantage of such surveys is practical, not theoretical. They do, however slightly, interfere with the free passage of the motoring public, and the collection of data from motorists can be considered an invasion of privacy. These issues, and the perception of these issues by policy-making organizations, led us to investigate alternative ways of collecting the required control data.

In particular, the concepts and techniques of induced exposure were investigated in some depth, and the appraisal of this method of collecting control group information appears in Appendix C. Unfortunately, this technique was judged to be not appropriate for the statistical approach. Induced exposure has been tested against more conventional techniques, and generally the results have been unacceptable. Its use is certainly conceptually attractive, but the available data do not support such a choice at the present time.

The result is that the collection of the required exposure data still must be designed on an individual basis to match the research questions under study, and there is no single technique that can be universally recommended for the statistical approach.

4.4.2 Interaction between Variables. One of the most troublesome problems associated with the statistical inference approach arises when a study factor interacts with another variable that influences the accident probabilities. The most serious situation occurs when the interactive variable exists but is unknown to the investigator; this has been labeled a "lurking" variable.[1] Even if the investigator has information about interactive variables, the inferential process must be handled with considerable care. These situations are discussed in the following subsections.

Lurking Variable. We shall illustrate this issue with two examples that are completely manufactured. The data in these examples have no inherent meaning whatsoever, and they should of course not be quoted except in an illustrative context.

The study factor, in both examples, is tire condition, with two dichotomous classifications possible on this factor, "bad" and "good."

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[1] The original source of this label is not known to the staff member suggesting its use in the present context.

(These terms are purposefully not defined further). The response variable, as usual, has two levels, accident (A) and non-accident (not A). The lurking, unknown variable in these examples is driving aggressiveness, and it is measured by the two-level responses "normal" (N) and "fast" (F).

Table 6 shows the results of a hypothetical experiment using cross-sectional sampling. (This is adopted for simplicity; the choice is not central to the argument). It is readily apparent that:

$Pr(A|F) = Pr(A|\text{bad tires}) = 0.25$, and

$Pr(A|\text{not } F) = Pr(A|\text{good tires}) = 0.0625$.

We can, therefore, conclude directly that "Tire Condition = Bad" is a cause, in a probabilistic sense, of accidents. This conclusion would also follow if prospective sampling had occurred. If retrospective sampling had been used to obtain these data, we would not compute the two probabilities given above, but rather $Pr(F|A) = 0.5$ and $Pr(F|\text{not } A) = 0.167$. Irrespective of sampling technique, we would note that the cross-product ratio is $ad/bc = (100x1500)/(300x100) = 5.0$, and would arrive at the same conclusion.

Table 6

Interaction Example
All Drivers

Tire Condition	Accident A	Non-accident Not A	Row Totals
Bad .	100	300	400
Good .	100	1500	1600
Column Totals	200	1800	2000

To look at the potential savings to be realized from a countermeasure designed to remove all bad tires from the road, we would calculate $(ad-bc)/(a+c)=75$. We would conclude that, for this sample, 75 accidents could be prevented if all bad tires were removed. (This specific result does depend on having the tabulated results generated by cross-sectional sampling, but the general problem being illustrated holds irrespective of sampling technique.)

But suppose now that we had a clue--from our own prior research, from the literature, or just a good hunch--that driving aggressiveness (our heretofore lurking variable) and tire condition are in fact related. That is, the tires that fast drivers have are not the same, on the average, as the tires that normal drivers have. With that information, we would have included a measure of driving aggressiveness in our data set, of course. Our hypothetical data set can now be presented in two tables, Table 7 for normal drivers, and Table 8 for fast drivers. The two tables together produce Table 6 for all drivers when they are collapsed across the driving aggressiveness variable.

Table 7

Interaction Example
Normal Drivers

Tire Condition	Accident A	Non-accident Not A	Row Totals
Bad .	9	291	300
Good .	45	1455	1500
Column Totals	54	1746	1800

Now we have from Table 7, describing the accident experience of the normal drivers in this hypothetical data set, that the cross-product ratio is 1.0, and (ad-bc)/(a+c) is zero. For these normal drivers, there is no interaction between tire condition and accident experience, and elimination of bad tires has no effect whatsoever on the safety situation.

Table 8, however, produces a cross-product ratio of 8.27. Thus, for the fast driver subset, there is a strong interaction between tire condition

Table 8

Interaction Example
Fast Drivers

Tire Condition	Accident A	Non-accident Not A	Row Totals
Bad .	91	9	100
Good .	55	45	100
Column Totals	146	54	200

and accident experience. Evaluation of the (ad-bc)/(a+c) expression shows that the maximum potential reduction in accident frequency by eliminating bad tires is 36, not the 75 that might have been anticipated.

The first example above shows that it is entirely possible for a lurking variable to erroneously magnify the benefits to be expected by eliminating the unwanted effects of some study variable. The converse can also happen, that is, interactive effects can mask a causative factor and the accident-reduction potential of an associated countermeasure. This is illustrated in our second example contained in Tables 9-11.

Table 9

Second Interaction Example
All Drivers

Tire Condition	Accident A	Non-accident Not A	Row Totals
Bad .	40	360	400
Good .	160	1440	1600
Column Totals	200	1800	2000

Table 10

Second Interaction Example
Normal Drivers

Tire Condition	Accident A	Non-accident Not A	Row Totals
Bad .	30	330	360
Good .	70	1170	1240
Column Totals	100	1500	1600

Table 11

Second Interaction Example
Fast Drivers

Tire Condition	Accident A	Non-accident Not A	Row Totals
Bad .	10	30	40
Good .	90	270	360
Column Totals	100	300	400

The first and third tables of this second example both have cross-product ratios of 1.0, indicating that bad tires do not cause accidents and that nothing is to be gained by their elimination. However, the second table (Table 10), depicting the experience of the normal driver subset, exhibits a CPR of 1.52 and an accident-reduction potential of 9.68. Thus, if we were truly unaware of the lurking variable and its effects, we would have erroneously concluded from the first table (Table 9) that no accident reduction could have been achieved by eliminating bad tires.

Implications. These results are of obvious importance in assessing whether potential accident factors are causative and in evaluating accident-reduction potential of a countermeasure aimed at a specific causative factor. We must always be wary of claims based on single-factor analyses, and we must continue to question whether lurking variables are at work. Clearly we must attempt to expose the lurking variables, that is we must seek to identify them, include them in our data set, measure them, and then handle them correctly in our analytical and inferential work.

Three other points are worth noting. The first is that neither statistical (analytical) control nor experimental control (control in the design and conduct of the experiment) will solve the lurking-variable problem. Second, this problem is not unique to the statistical inference approach to accident-causation research; it is also present in the case-study approach. If there is a lurking variable present in some accident set under study, then the case-study investigator necessarily has an incomplete set of candidate accident-causation factors at the outset. His accident-causation model is necessarily incomplete, and thus his conclusions may be either erroneous, incomplete, or misleading. Finally, although the examples given here are strictly hypothetical and perhaps pathologic, lurking variables are not just freak anomalies that never occur in practice. Real examples from the medical field will be presented in the next subsection, and it is possible to find real examples from the traffic field.

4.4.3 Collapsing Tables. The problem of interactive variables was presented in the preceding section in the context of a lurking variable. A similar problem—they differ mostly in the perspective one adopts in looking at them—can arise when there is interaction between between fully exposed variables, that is none of them is a lurking, unknown variable. The question arises when we consider under what conditions it is possible to collapse an n-dimensional array into one of n-1 (or fewer) dimensions. Again we shall illustrate this issue with the simplest possible example, a 2x2x2 table, or equivalently, two 2x2 layers.

The reason we are interested in knowing whether it is possible to collapse arrays is that doing so is generally desirable, but only if the structure of the data is not distorted. This is a part of the whole process of searching for ways to simplify complex data sets and to find the simplest models which adequately describe the data at hand.

The general process is analogous to fitting a curve (a simple mathematical model) to a set of experimental data, say five x,y points in 2-space. A fourth-order curve relating x and y can be fit to the data—exactly, it turns out, with no error terms. The sixth-order curve, however, is likely to tell us no more about the underlying phenomenon than the five original data points. If, however, a linear model fits the data--adequately meeting goodness-of-fit criteria--then we have probably learned a great deal more about the general x,y relationship than we would have learned from a more exact, higher-order model.

Similarly, it is usually the case that we want to use the simplest model available that does justice to the data. Suppose we are interested in the relationship between alcohol use and accident experience, and suppose that age data--in the form of 10-year age groupings--are also available. We should be interested in knowing if the data can be collapsed across the age variable, for the countermeasure implications of a general finding holding for all ages differs from that of a finding true only for, say, the 15- to 25-year-old drivers.

Bishop, Feinberg, and Holland [11, p.41] provide an example using data from studies relating infant survival to amount of prenatal care at each of two clinics. Their Tables 2.4-2 and 2.4-3 appear below as Tables 12 and 13.

The mortality rates in Table 12 are seen to vary between clinics, but within clinics they differ little for different amounts of prenatal care. The cross-product ratio for Clinic A is 1.25, and for Clinic B it is 0.99. The authors note that both ratios are small and that there is little relationship between care and survival.

Table 13 presents the pooled data from the two clinics. Here the mortality rates differ markedly for "less" or "more" care, and the cross-product ratio is 2.8. Based on only this latter table, an investigator would erroneously conclude that survival and care are related.

The point of this example is that Bishop, Feinberg, and Holland have presented a set of log-linear, hierarchical models and have set forth

Table 12

Three-Dimensional, Interactive Array

Place	Amount of Care	Infants' Survival: Died	Infants' Survival: Survived	Mortality Rate(%)
Clinic A	Less	3	176	1.7
	More	4	293	1.4
Clinic B	Less	17	197	7.9
	More	2	23	8.0

Source: Table 2.4-2, Three-Dimensional Array Relating Survival of Infants to Amount of Prenatal Care Received in Two Clinics (Bishop, Feinberg, and Holland [11, p.41]).

Table 13

Collapsed Array

Place	Amount of Care	Infants' Survival: Died	Infants' Survival: Survived	Mortality Rate(%)
Both	Less	20	373	5.1
	More	6	316	1.9

Source: Table 2.4-3, Three-Dimensional Array Relating Survival of Infants to Amount of Prenatal Care Received in Two Clinics (Bishop, Feinberg, and Holland [11, p.41]).

pertinent properties and theorems. One such theorem specifies when it is possible to collapse models and when such is done only at the expense of altering the original data structure. That theorem indicates that collapsibility is not possible in the above example, and a practitioner guided by existing theory would not arrive at a false conclusion.

It is our intent to apply these lessons to the subsequent field activities to be undertaken in Phase II and to the data analytic work in Phase III. Specifically, we will try to pre-judge the factors that are likely to be correlated with the study factors and include them in the data collected during Phase II. Having done so, we will then apply the theory relating to multidimensional contingency tables to pick appropriate analytic models and to appropriately simplify the models to assist in understanding the factors under study.

5. CHOICE OF APPROACH AND RESEARCH TOPICS

The preceding sections have demonstrated that the case-study approach is better suited to the study of some topics of interest than is the statistical inference approach. They have also shown that the converse is just as surely true. Clearly, therefore, it is not generally wise to pick the study topics independently from methodological considerations. Conversely, an investigator does not generally pick his methodological approach and then shop around for appropriate study topics. Ordinarily one looks at both issues together.

In the present study, however, we are recommending that only the statistical approach be implemented in the field portion of the program. The purposes of this section are to set forth the reasons for this choice and to present the procedures that were followed in choosing topics for study.

5.1 Choice of Approach

Heretofore we have identified a number of reasons why we prefer the statistical inference approach to accident-causation research to the case-study approach. The field work associated with the statistical approach is inherently more objective and less judgemental. It seems better suited to the study of complex, interactive phenomena that do not have an obviously visible influence on accident occurrence. The approach lends itself to reducing a complex problem into sub-problems of manageable size that can be studied individually. It also has the capability of identifying both positive and negative effects of a factor, and it is suited to the evaluation of many countermeasures.

Two other reasons support our recommendation for using only the statistical approach in the balance of the present study. The first is that the case-study approach has received much more financial support and implementation in the past, and thus, as an identifiable, organized activity, it is much further developed than the statistical approach. The final report of the Institute for Research in Public Safety [8] contains a number of suggestions for improving the case-study approach, but these are mostly refinements of a methodology that is generally well in place. Our judgement is that the development of accident-causation research capability will be furthered more by major advances in the statistical approach than by fine-tuning the case-study approach.

The second reason is that the statistical approach is probably better suited to the National Accident Sampling System (NASS) than is the case-study approach. The latter reaches its maximum potential if applied by a team of skilled specialists, each devoting a considerable effort to the determination of the cause(s) of a group of individual accidents. NASS, however, is intended to serve interests other than just accident-causation determination. It is likely, therefore, that the NASS resources will not support the case-study approach to the extent needed to use it properly. The capability that the statistical approach offers to study just a few factors at one time is more attractive than implementing a case-study approach of reduced scope, whether by applying less effort per accident or by compromising representativeness by sampling fewer accidents. NASS, on the other hand, can enhance the statistical approach considerably through its acquisition of much auxiliary data. Such data will permit the testing of interactive effects and the search for lurking variables so that their effects may be minimized in future studies.

5.2 Choice of Research Topics

The initial selection of research topics for study is a matter of judgement. There are no easy answers to the question of what to study. This is because, in accident-causation research, present accident costs and future benefits from their reduction cannot really be known unless one has considerable prior knowledge about them. Specifically, the frequency and severity of accidents caused by some factor, the amenability of these accidents to reduction by countermeasures, and the costs of implementing the countermeasures all would be needed to analyze costs and benefits. Were these known in any quantitative way, a research enterprise would not be needed and we would probably not be engaged in the present study.

This is not to imply that selection of a research topic can subsequently be judged right or wrong on the basis of countermeasures resulting from its study. In this regard, the history of research on drinking drivers is worthy of mention. Drinking drivers were a major focus for a number of years. Surely they were a big problem, and the problem remains. Much has been learned about alcohol and its role in accidents, but our persistent inability to devise and implement effective countermeasures has led to frustration and a shift in research priorities. But this does not mean that decisions to undertake alcohol research were ill conceived. Apart from the spin-off benefits of such research, it was vitally important to place the alcohol issue in focus and perspective so that other causative factors can be researched properly. The point of this digression is simply that, although we have kept the countermeasure issue in mind, we have not let it dictate our choice of research topics.

5.2.1 Survey of User Needs. Senior members of the study group met with NHTSA personnel in November, 1977 to discuss program needs for accident-investigation information relevant to accident causation.

Vision was a major topic of interest in these discussions. Factors mentioned included driver vision capabilities (particularly dynamic visual acuity and field dependence), visibility restrictions related to vehicle design, tinted windshields, and innovations in vehicle lighting.

UDA's—Unsafe Driver Actions—were another focus of interest. The concept is still in its early development, but it is associated with those actions of a driver which he knows are unsafe or illegal. The premise is that such actions may be corrected by education and enforcement. A more precise definition of UDA's is needed, along with a comprehensive scheme to identify them. Countermeasures, naturally, must also be considered. Alcohol use, in itself, is not considered a UDA, but there is interest in the interactions between alcohol use and UDA's.

Youthful drivers were the subject of several conversations. Identification of accident-causation mechanisms associated with youth may be expected to lead to countermeasures.

Although the current project is expected to concentrate on passenger cars, mopeds and trucks were also mentioned in our discussions. There was also some interest in the problem of pedestrians being struck by mirrors protruding from vehicles.

Concerning vehicle factors, there was interest in obtaining accident data relevant to planned rulemaking. These topics include tires (pressure, automatic pressure indicators, mixtures of generic types, traction, and retreads), handling, and braking. The last of these includes radar braking devices, loss of control during braking, the adoption of braking standards similar to those in Europe, and the extension of braking standards to vehicles other than passenger cars.

The meetings demonstrated that the various groups are primarily interested in obtaining accident-causation information relative to their current and projected program plans. The talks were useful, and they have guided us in planning the study. However, we have not lost sight of the fact that one of our goals is the discovery of countermeasures in subject areas not yet defined or planned for.

A complete report on these discussions may be found in Appendix D.

5.2.2 Other Inputs. The questions pertinent to the selection of study topics identified in the RFP were also considered with care. These questions were sorted into human, vehicular, and environmental groups to facilitate their consideration.

The NHTSA's five-year rule-making plan was also read and discussed during the selection process. As expected, its contents and priorities were similar to those identified in the survey of NHTSA user needs.

As noted earlier in this report, we also reviewed the literature of accident causation (see Section 2 and Appendix A). This was done primarily to learn about the research methodologies that have been employed, but others' taxonomies of accident-causation factors were also useful. Of special interest were the factors used by the Institute for Research in Public Safety in its "Tri-Level Study of the Causes of Traffic Accidents" [8].

5.2.3 Assessment. Armed with these inputs, numerous topics were assessed for their amenability to study by the statistical inference approach. A table (the Accident Causation Worksheet, found in Appendix E) was prepared to summarize these preliminary assessments. We then determined which of the three sampling techniques discussed in Section 4 would work best for various topics. Finally, we chose one topic for each of the three sampling methods. These topics were selected to illustrate the methods, of course, but they are also relevant to NHTSA rule-making activities and research on them will contribute to the body of traffic safety knowledge. The topics--accident experience among stolen vehicles, accident experience among field-dependent drivers, and further research relative to vehicle handling--are detailed, along with experimental designs, in Section 6 following.

6. PRELIMINARY DESIGNS FOR PHASE-II PROJECTS

This section presents the three experimental projects that we are recommending be undertaken in Phase II. The three have in common that one or more of the research or program divisions in NHTSA has expressed interest in further study. Each is best suited to and illustrates one of the three basic sampling techniques discussed earlier.

Section 6.1 describes a project for determining the accident experience among stolen vehicles, and it illustrates cross-sectional sampling. Determination of the accident experience among visually field-dependent drivers has been chosen to illustrate a prospective sampling design, and it is described in Section 6.2. Retrospective sampling would be employed in the third study, further research on selected issues related to vehicle handling and stability. That discussion appears in Section 6.3.

6.1 Accident Experience among Stolen Vehicles

The development and specification of a theft protection standard was undertaken by the (then) National Highway Safety Bureau in the late 1960's. Although there was some discussion at that time regarding whether this was a safety measure, Dr. Haddon, Director of the Bureau, based his decision to make rules regarding theft protection on a (then) recent Department of Justice study [16] which had found that stolen vehicles were involved in crashes at a rate about 200 times greater than the average vehicle. This was based on a series of interviews with convicted car thieves, and on a number of assumptions regarding the average time the car remained stolen, etc. While there have been arguments about the "two hundred times" factor, there seems to be little doubt that stolen cars, particularly those stolen for joy-riding, are more likely to be involved in crashes than the average passenger car.

Current statistics regarding car theft emanate from many sources, and are frequently in conflict with each other. In the Journal of American Insurance [17], the National Automotive Theft Bureau's president Michael J. Murphy is quoted as saying, "We used to get recovery rates of almost 90 percent of the total theft. It's down now to around 80 percent countrywide." (This in an argument that the proportion of professional car thieves is increasing). William L. Roper, in the California Highway Patrolman [18] in April, 1976, states: "Adding to the good news, is the increased recovery rate being reported. During the 1974-75 period, 1548 more stolen cars were recovered than in the previous fiscal year. The recovery ratio rose from 81.9 to 87.1 per cent during the past year." The "200 times" figure given above was modified by Roper to ".... the chances of a stolen car being involved in an accident are 150 times that of an owner-driven car, according to insurance statistics." And recently NHTSA administrator Claybrook was quoted as saying that this number was somewhere between 48 and 200.

Cars in the United States are ordinarily listed as stolen as soon as a report is made to a police agency. By contrast, in some other countries a car must be missing for five days before it is so tabulated. The majority of recoveries seem to occur within the first 48 hours, and it is evidently these which are over-involved in accidents. A variety of other statistical information has been provided, mostly without references, but often of interest in considering possible countermeasures. For example: (1) "Estimates of annual loss through auto theft vary from $140 to $600 million." (Stated by the chairman of a congressional subcommittee having hearings on a bill to outlaw master keys[19]) (2) "It is clear that over 80 percent of the thieves are juveniles or young adults." (3) "A 1966 survey indicated that over 50% of the time (when the ignition was locked) a master key was used." (4) Richard L. Braun, of the Department of Justice, stated that in his survey [16] (about 1967) 17% of the stolen vehicles were involved in accidents. He extrapolated this to "100,000 accidents per year" with "many thousands of injuries and deaths." The problem addressed in this program is accident causation, and stolen vehicles have been identified from a number of previous studies as being overrepresented in the accident population. The question at hand, however, is to find out enough about that stolen vehicle population to develop appropriate countermeasures. Countermeasure definition is, indeed, already underway in such areas as armored ignition cables, control of master keys, buzzer warnings for keys left in locks, etc. But there still seems to be some interest in a more precise definition of the extent of the accident problem; a method for obtaining information relative to that is discussed here.

Questions to be addressed include the following: (1) How many passenger cars are stolen each year in the United States? (this question is limited to passenger cars because of the study definition). (2) Of those cars which are stolen: a. What is the distribution of the time period that the car remained missing? b. What fraction of the stolen cars were involved in accidents? c. What monetary loss was associated with the vehicle damage in these accidents? d. Were there other losses not attributable to accidents (missing wheels, other parts)? e. How many persons were injured (and to what degree) in these accidents? f. How many of these injured persons were not occupants of the stolen car (i.e. how many were pedestrians, occupants of another vehicle, etc? (3) How do the values obtained in (2) compare with the non-stolen accident involved vehicles?

6.1.1 <u>Choice of Sampling Method</u>. Of the three approaches to acquiring a sample for the study of this subject, the cross-sectional sampling method is the most attractive. Prospective sampling would require the identification of a stolen vehicle population and a parallel not-stolen vehicle population, but this would not yield directly an estimate of the answer to the first question above--the total number of stolen vehicles. The Department.of Justice survey discussed above constitutes a prospective sample--drawn by interview with convicted car thieves. It has the disadvantage of not representing very well the unrecovered vehicles, and may be biased by the reporting of the convicted thieves.

Identification of stolen vehicles in the accident population (retrospective sampling) is also difficult. With an estimated one million stolen cars per year, about 200,000 accident involvements, and about one police-reported accident for each ten registered vehicles per year, investigation of 10,000 accidents should yield about 200 stolen vehicles. Few states identify stolen vehicles adequately in accident statistics. (In the state of Washington in 1976 there were 276 stolen-vehicle accidents with a total of 218,000 vehicles reported in accidents--a number not consistent with the above estimates, and indicating the problem of inadequate identification of stolen vehicles in police accident reports. Further, this sampling method does not directly measure the stolen vehicles not involved in crashes, and would require a survey of the control population not easily conducted (e.g. in a roadside survey, asking "Are you driving a stolen car?")

These considerations make the cross-sectional sampling method attractive. Initially one may think of four cells to be defined as shown in Table 14.

Table 14

Illustrative Distribution of Stolen Vehicles

	Accident Involved	Non-accident Involved	Row Totals
Stolen . . .	20	80	100
Not Stolen .	990	8910	9900
Column Totals	1010	8990	10,000

Illustrative values have been inserted in the table for a total sampled population of 10,000 based on estimates from the literature.

6.1.2 Choice of Sampling Frames. The cross-sectional sampling method requires a sampling frame which is representative of the total population of interest--in this case passenger cars which are candidates for theft. In an interview to determine whether a car has been in an accident or whether it was stolen, however, the frame might better be a list of vehicle owners linked to the list of vehicles.

The actual sampling unit should be a vehicle-ownership-year, since comparisons will be made of the populations over that period. One complication of this is that new vehicles (or recently purchased old vehicles) may not have been with a particular owner for a one-year period. While one choice might be to restrict the study population to vehicles which have been owned for at least one year, this has the disadvantage of eliminating a group of likely particular interest--the very new cars. Further, we should be interested in owners whose vehicles have been stolen and were not recovered (say over the past year), so that the best list would be persons who owned a vehicle at sometime during that year. Vehicles acquired or disposed of during that year would be counted for only the number of months they were actually owned by that person. Disposals would include vehicles which were sold, those which were scrapped (e.g. because of crash damage), and those which were stolen and recovered. An appropriate sampling frame in many jurisdictions could be derived from the motor vehicle registration rolls as of a date a year ago, supplemented by notice of more transactions.

An alternative sampling frame could be derived by accepting the vehicles registered within the definition of a household sample conducted for another purpose. In this case the frame might consist of a list of licensed drivers, or a list of registered vehicles, depending on the questions addressed in the sample. In any case, corrections would have to be made for periods of ownership less than the one year of interest.

6.1.3 Required Sample Sizes The table above is based on a sample of 10,000 registered vehicles. Assuming a simple random sample, the estimated proportion of stolen vehicles (100 out of 10,000 or 1%) should have a 1-sigma error of about 0.09%—i.e. we could say with some confidence that the proportion of stolen cars in the U. S. was 1% + .09%. The precision of the estimate of crash involvements would be lower; based on the 100 stolen vehicles, 20 of which were involved in accidents, one standard deviation of the 20% would be 4%—i.e. the proportion of stolen vehicles which are involved in accidents could be estimated at 20% x 4%. While not of great precision, this would lead to a more precise estimate than the present "45 to 200 times" the non-stolen car accident rate.

Precision is, of course, relatively insensitive to sample size. A sample of 10,000 seems adequate to get a better estimate than is presently available. And a sample size of perhaps ten times that would be necessary to achieve a much better result.

6.1.4 Data Collection Techniques This whole approach is based on the idea that vehicle owners will recall the fact that their cars have been stolen with considerable accuracy over a period of one year; and further, that they will recall some of the details of their loss and any accidents associated with the event. The two most important statistics come from responses to the questions "Was your car stolen during the last year?" and "Was it involved in an accident?" If one, or both, of these responses is positive, further information about the length of time the car was missing and whether or not there were injuries or damage should be requested.

This information could be sought in a survey devoted solely to this subject, but it might be more economical to combine this subject with a broader survey. In particular, the stolen-vehicle topic might be added to a general exposure survey, taking advantage of the availability of a sampling frame and questionnaire. If made a part of a general purpose survey, this topic would usually (i.e. 99% of the time) add only the single question "Was your car stolen at any time during the past year?"

6.1.5 Data Collection Protocols. As noted above, the first question (having confirmed vehicle ownership) is:

Was your car stolen at any time during the
past twelve months?

If the response to this question is YES, the following questions should be asked:

How long was the car missing?
or (alternatively) When was it stolen? and
When was it recovered?
Was there any damage to the car when it was returned?
Had the car been involved in an accident?
If so, what was the property damage loss (to
your car) from the accident?
Was there an injury in the accident?
If so, describe the injury or injuries
(preferably, with prompting, in an approximation
of the Abbreviated Injury Scale).

It is assumed that data on the make and model, model year, and ownership period of the vehicle in question will have been obtained in addition--either as a part of this (special purpose) survey, or in connection with a general exposure survey.

6.1.6 Estimated Costs. Costs of acquiring data depend on the method used. Alternatives which might be considered include (1) a mail survey, (2) a telephone (random digit dialing) survey, or (3) the coupling of these questions with a more general household survey.

For the present a mail survey will not be considered. Past experience with mail surveys suggests response rates of the order of thirty percent, with some possibility of increasing that by multiple inquiries. But either the telephone or household survey method would produce much higher response rates, and they will be discussed below.

The principal advantage of a special-purpose, random-digit dialing survey is the potential for a nationwide, simple random sample. The sampling frame is basically the census of telephone numbers in the country (or the vehicles owned or controlled by the people who answer these phones). Response rates with such surveys have been of the same order as for household interviews--about 70%-80%. And with the questions proposed here the telephone survey should be economical. We estimate that $2.00 per call for ten thousand calls would cover both the telephone charges and the operator time. An additional $5,000 is proposed for planning, data processing, report writing, etc. for a total of $25,000. With a modest staff of operators (say ten) data for ten thousand interviews could be acquired over a period of a couple of months.

The household interview method might be preferred if this question could be added to some existing interview program. The recently completed Nationwide Personal Transportation Survey of the Census Bureau obtained about 20,000 interviews over a period of one year, and the number of vehicles owned by the households contacted is somewhat larger than this. The total cost of this program is about $1.5 million, and we estimate that the "stolen vehicle" question should pay for about 5% of the total--thus about $75,000 total (including processing, reporting, etc.). If a household survey were done with only 10,000 cars, the cost would again total about $25,000.

A household survey would likely be done with some sort of cluster sampling, and a design effect would probably increase the variance over that of the simple random sample. But if a household survey were being done anyway for other reasons, the possibility of comparing the stolen vehicle information with other driver and environmental characteristics would make this the preferred method.

6.2 Accident Experience of Field-Dependent Drivers

The second project recommended for implementation during Phase II is determination of the accident experience of drivers who exhibit field dependence. This topic is among the vision factors of interest to some of the NHTSA staff, and it has long been of interest to members of HSRI's Human Factors Group. It has been selected both because of its inherent worth and because it is nicely adapted to a prospective sampling design.

6.2.1 Review of the Literature. Out of a variety of sensory and perceptual measures, one of the most promising (in terms of its relation to accident frequency) is field dependence. Field dependence evaluates "... the capacity to overcome embedding contexts in perceptual functioning." [20, p.57]. Individuals differ widely on a continuum from reacting basically only to the total organization of the immediate stimulus field (field dependence), to being able to respond to various elements of the stimulus input (field independence). The usual measures of field dependence/independence are the Embedded Figures test and the Rod-and-Frame test; performance on these two tests is highly correlated [21]. In the former test the task is to identify simple forms embedded in a field of complex figures. In the latter test, the subject is required to set a rod to the upright within a tilted frame (in the absence of any other visual cues). Field-independent individuals have no problems in identifying the embedded figures and are able to set the rod to near-vertical consistently. Conversely, field-dependent individuals take a long time to identify the embedded figures and are influenced by the tilted frame in their judgement of upright.

In several rather small-scale studies, field dependence has been shown to be related to traffic accidents. Harano [22], for example, selected two groups of male subjects on the basis of their accident record the preceding three years. The 28 "accident" group members were involved in at least three accidents while the 27 "safe" group members had no reported accidents. Field dependence was measured by the Embedded Figures test. The results indicate that field-dependent drivers tended to be involved in more accidents than field-independent drivers.

Williams [23] found that the performance on a variant of the Embedded

Figures test was significantly related to accident frequency. Furthermore, the derived measure of field dependence was a better predictor than number of violations, driving experience, or annual mileage.

In two studies reported by Jameson, McLellan, & Jackson [24], a significant relation between field dependence (measured by the Embedded Figures test) and accident record was present in one but not the other study.

Mihal & Barrett [21] investigated the field-dependence continuum using 29 drivers who were accident free and 31 drivers who had two or more accidents during the preceding two years. Field dependence (measured by both the Embedded Figures test and the Rod-and-Frame test) was found to be significantly related to accident frequency.

In a recent study by Loo [25], the accident record of 28 females was compared with their performance on the Embedded Figures test. The results indicate that the field-dependent subjects had more accidents than the field-independent subjects.

In addition to the trend for field-dependent subjects to be overrepresented in accidents, there is also some explanatory evidence for this relation. Several studies showed that the field-dependent driver performs poorer on a range of driving-related skills. Barrett, Thornton, & Cabe [26], for example, found that field-dependent individuals tended to have longer brake-reaction times. Similarly, field-dependent drivers have longer reaction times to embedded traffic signs (Mihal & Barrett, [21]; Loo, [25]), and make less use of the traffic-flow information conveyed by vehicles further ahead [27].

These types of analyses indicate that field-dependent drivers are likely to be overrepresented in particular types of accidents, for example, rear-end accidents (as suggested by Olson, [27]).

In summary, there is evidence that:

a. field dependence is related to accident frequency, and

b. field dependence is related to performance on various driving-related skills.

Therefore we believe that a comprehensive study to investigate the relationship of field dependence to accidents in general and to types of accidents in particular is both warranted and potentially fruitful.

6.2.2 Choice of a Sampling Method. Technically, all three sampling approaches might be employed in the proposed investigation. The retrospective approach has appeal in that it begins with a sample of accident-involved and non-accident-involved drivers, producing the optimum levels of the dependent variables. However, the problems of attempting to contact and screen these individuals make this approach impractical for a large-scale study.

A cross-sectional study would be appropriate and indeed, the approach to be suggested fits the cross-sectional model to some extent. However, we feel there is substantial merit in following the screened populations for a period of time in the classical prospective sense. Thus, what we shall propose is a prospective study which utilizes crash data from years both before and after the screening. It is feasible to reach out some years in each direction because there is a great deal of data to show that the field-dependence characteristic is stable, at least through most of the driving years.

6.2.3 Choice of a Sampling Frame. The sampling frame appropriate for this study is a population of persons representing at least two levels on the field-dependence continuum, based on the use of a rod-and-frame test-scores range from 0° (field independent) to 224° (field dependent) for a series of eight trials. The distribution of scores has been shown to be log-normal, so that strongly field-dependent persons (those who average an error of 10 degrees or more) constitute less than 20% of the population. Thus, field-dependent persons are relatively scarce. Despite this, the typical approach has been to screen a sample of subjects and correlate their scores with the dependent variable, ignoring the distributional problems. A more sophisticated (and costly) approach would require the screening of a large sample to create two test groups matched in all respects but differing substantially in rod-and-frame test scores. We shall propose a combination approach.

6.2.4 Required Sample Sizes. Per group of 1000 persons screened, we would expect to find about 200 strongly field-dependent persons. That group of 200, in turn, would be expected to produce about 20 crashes per year. In order to extract information concerning the types of crashes a substantial data base is required. Assuming we can look backward in the accident files for a minimum of five years, and follow the sample forward for two years, 100 crashes per year involving field-dependent drivers is a reasonable estimate. Thus, 1000 field-dependent subjects are required, and a total sample of 5000 must be screened.

6.2.5 Data Collection Techniques. Three portable rod-and-frame devices will be used. They will be set up at driver licensing stations in southeastern Michigan during hours of normal operations. Individuals who appear for re-licensing will be asked to take the rod-and-frame test as well. Those who agree will fill in a brief personal history blank (age, sex, driving experience, and exposure data [mileage and type of roads travelled], plus information necessary to access accident records), sign a release form, and take the test. They will be paid $2.00 for their assistance.[1]

When the screening is complete, two matched groups will be created by taking the highest scoring 20-25% (field-dependent) subjects and matching them, in terms of the personal-history variables, with field-independent subjects selected from the lowest-scoring 50% of the group.

Two approaches will be used. In addition to the contingency table analyses described earlier, a basic correlational analysis will be run using all the subjects and crash data from the previous five years. The more important analysis will use only the matched samples (about 2000 to 2500 persons). Crash data from the previous five or more years will be assessed. Comparisons will be made in terms of total crash involvement and violations. However, as noted in the literature-review section, experimental results

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[1] Precautions will be taken to avoid biasing the sample , e.g., testing will be done throughout all weekly operating hours of the driver licensing stations.

concerning differences between field-dependent and field-independent persons lead to expectancies concerning the types of crashes in which one group or the other may tend to be involved. Thus, the data will be examined for these trends. Crash records will be followed for two subsequent years to see if the findings of the first phase hold up.

6.3 Vehicle Handling and Stability

6.3.1 Vehicle-Handling Study Objectives. Vehicle handling has been of concern to those interested in highway safety for many years, and has received considerable attention from those responsible for Motor Vehicle Safety Standards. However, delineation of characteristics and parameters that are directly related to safe use of cars on public roads, and their measurement, has proved elusive. For the purposes of safety, even a definition of vehicle handling has failed to achieve universal acceptance. While some would restrict the subject to physical characteristics of the vehicle, others would adopt a broader concept including the driver, road, and environmental factors. Even when the subject is restricted to the physical characteristics of the vehicle, the tire, and the tire-road interface, the subject is still elusive, in spite of the fact that the theory of vehicle dynamics is well developed.

We have reviewed the vehicle-handling related factors listed in the RFP, those identified by the Institute for Research in Public Safety of Indiana University [8], those discussed by the staff of MVP and P and E of NHTSA at a meeting with project staff in November, 1977 (see Appendix D), and the NHTSA Five Year Plan (Docket No. 78-07; Notice 1). We have selected those subjects which are amenable to study by the statistical analysis approach, with priority given to those currently of interest to MVP and P an E.

The subjects recommended for inclusion in the program are:

1. Deviant tire inflation pressure,
2. Tire traction on wet surfaces and tread depth,
3. Yaw stability.

Each of these subjects is discussed briefly below.

Deviant Tire Inflation Pressure. Improper maintenance of tire pressure resulting in either gross under inflation or unequal pressures has several deleterious effects. Underinflation results in decreased fuel economy and reduced tread life. Both of these are economic factors, and as such would not be addressed in the study. Gross underinflation can also lead to catastrophic failure from over-heating. Blowouts, as such, would be included, although the number of such cases that would be observed in a random sample of accidents would be small so that the likelihood of obtaining meaningful statistics on crashes "caused" by blow-outs is low.

Deviant pressures—either imbalance among the tires on a car or deviations from recommended pressures--can also affect the dynamic handling properties of a car under both steady state and transient conditions. Substantial deterioration of handling properties from poor tire maintenance practices can be studied by the statistical inference approach. A previous study at HSRI found substantial evidence of front-to-rear pressure differences on cars involved in accidents [28]. Over 29 percent of the cars had differences of over 3 psi, while 5.6 percent had differences over 8.5 psi. Unfortunately, the accident data were not accompanied by control group data adequate to draw statistical inferences. The accident data do demonstrate that large pressure deviations do exist. Furthermore, the effect of the observed deviations does effect vehicle-handling parameters substantially [29,30], nearly as much as differences in original equipment designs.

Because of the potentially large effects, and the ease of observation and measurement, we feel that in-use tire factors are prime candidates for study using the statistical inference approach. In fact, any attempt to look for differences in the safety of different vehicle models would have to include tire factors as important confounding variables.

Tire Traction on Wet Surfaces. The effects of details in tread design on wet surface traction would be difficult to study because the effects are likely to be small compared to variability in traction resulting from small variations in the road surface texture and lack of detail in the "wetness" data. However, the effects of road surface conditions by gross tread type (regular, snow) and by tread depth would be examined. Since both road surface condition and tread depth affect vehicle dynamics, these variables should also be included as control variables in any study of yaw stability.

Yaw Stability. A criterion that might be used in a yaw stability standard is not yet in place. However, the theory of vehicle directional control dynamics is well developed, and the basic physical parameters important to yaw stability are understood and are fundamental to any handling criteria that are in use or might be developed. The OEM design parameters, together with in-use tire data, would provide a base of data that could be used to investigate the influence upon accident rates of a number of handling criteria. Reference 25 is an example of a comparison of the understeer coefficient of accident-involved and at-risk vehicles; this study, like that noted above, was also limited by inadequate control-group data. Such an analysis is costly, however, and should not be attempted unless knowledge of a specific criterion suggests the effort is warranted. We are recommending, therefore, that Phase II of this project initially be limited to the tire and wet-road traction factors.

Two vehicle-handling subjects appearing in the citations of the introductory paragraph have not been included but deserve some comment. These are braking factors, including aftermarket friction materials, and wheel identification. Generally, braking factors, such as stopping distance and braking while steering, could better be examined using the case-study approach, since they are so closely linked to driver inputs and response times. The question of after-market friction material could be addressed by the statistical inference approach, but not in the context of a retrospective accident investigation program because once a brake shoe (and lining) is in service, it cannot be identified. Most after-market brake shoes are relined using original manufacture shoes. Stamped identification in the shoe relates to the OEM and not their re-manufacturer.

The subject of wheel identification presents a similar problem because wheel identification is difficult. Misuse of after-market rims is difficult to determine because such rims are not permanently identified. OEM versus non-OEM wheels could be identified, but only with difficulty because of the large number of regular production options.

6.3.2 Choice of Sampling Method. Overinvolvement in accidents by vehicle make and model could be determined by either a cross-sectional or prospective study. A sample of vehicles could be drawn from state vehicle registration files. If a random sample of all passenger cars were selected, a cross-sectional study could be conducted by following the accident experience of the sample over a specified period of time. Alternatively, samples of specific size of selected models could be drawn and form the basis of a prospective study. Such a prospective study could be done by either following future accident experience, or historically by examining the accident record of each vehicle.

Both of these methods--cross-sectional and prospective--present serious problems. Contact with owners identified through state files, and follow up to obtain data on accidents and exposure, would be time consuming and expensive (per case), even if the sample is restricted to a limited geographic region such as a county. Furthermore, the total sample would have to be very large. In Michigan, for example, there are about 12 registered vehicles for every accident in a single year. Thus, the ratio of accident vehicles to non-accident vehicles in either a cross sectional or prospective study would be very small, and the sample would be inefficient.

An even more fundamental problem exists. There are differences in the designs of American passenger cars which affect vehicle-handling characteristics, e.g. the understeer coefficient or steering sensitivity [29]. If the differences in original design are sufficient to affect safety we could expect to observe differential accident-involvement rates among different models. However, vehicle-handling parameters are also effected by in-use factors which can lead to differences (in a particular model) which are as great as the differences among models. This is particularly true of tire characteristics [29,30]. Tire factors, such as inflation pressure, along with road-surface conditions, are not stable over time. Thus, historical data would be impossible to collect, and a forward-looking, prospective study would require almost constant monitoring of the entire sample.

Because of these problems, we have concluded that the general subject of vehicle handling, as well as the specific subjects listed in Section 6.3.1, can best be examined in a retrospective study.

6.3.3 <u>Choice of Sampling Frame</u>. The sample frame would consist of passenger cars (of a range of models and model years not yet determined) using a defined geographic area in which accidents would be investigated. The control-group sampling frame would consist of the at-risk population of cars in use in the area, both transient users and those indigenous to the area. The accident-data sampling frame would consist of those cars involved in police-reported accidents in the study area.

6.3.4 Accident Data Collection Techniques. The accident data would be collected from a sample of cars involved in accidents in the study area. The sampling method will be dictated by the geographic and political characteristics of the area. A simple random or pseudo-random sample would be desirable, but a cluster sample may be more practical.

The investigations would be done off-scene since no data are required beyond that which can be obtained from a combination of vehicle inspections, post-accident site visits, police-report data, and local observation of meteorological data. Both single- and multi-vehicle accidents would be included, with no weighting based on accident severity.

6.3.5 Accident Data Requirements. Similar data would be collected for each vehicle in the areas of driver, accident, and vehicle. The driver data would be cursory, and would serve to define the general type of driver and vehicle usage. The accident data would describe the type of accident and principal environmental conditions that relate to vehicle usage and the tire-road interface. The vehicle data would include vehicle identification, items relating to weight determination, options which affect vehicle-handling parameters, and data on all four tires.

Specific accident data variables that have been tentatively selected are:

I. Driver
   1) Age
   2) Sex
   3) Purpose and length of trip
   4) Type of roads used in trip

II. Accident and Environment
   1) Type of accident
   2) Date
   3) Time of day (hour)
   4) Precipitation
   5) Temperature

6) Light
7) Class of road
8) Type of road surface material
9) Condition of surface material
10) Surface covering

III. Vehicle
1) VIN[1]
2) Occupants - location and weight
3) Major cargo - location and weight
4) Air conditioner (for weight)
5) Type of transmission (for weight)
6) Type of steering system (for steering ratio, steering system stiffness, and weight)
7) Sway bar diameter (roll characteristics and presence of standard or heavy duty suspension can be determined from the sway bar diameter)
8) Tire make and model
9) Tire size
10) Tire inflation pressure (cold)
11) Tire tread depth

6.3.6 Control Group Data Collection Techniques. Control-group data are required that will provide the same data as collected in the accident data, weighted on the amount of travel in the project area. Several methods offering possibilities can be categorized as:
1) Samples from vehicle registration files
2) Household surveys
3) Surveys of cars-in-transport.

Registration files provide a convenient means of sampling by make and model (and thus OEM design characteristics), since all such files contain VIN's. Unless the project area is large, however, identification of a proper sample frame is difficult. The problem arises because of differences between areas of use and owner residence, that is transient use in the potential study area. This problem is particularly troublesome in the confines of a large city, where much of the travel is by non-residents from the suburbs and motorists on inter-city business trips. Contact and follow-up with owners and vehicles, for mileage data and observation of unstable in-use parameters requiring frequent measurement, is difficult and expensive.

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[1]The VIN would be used to determine make, model, series, engine, base vehicle curb weight, and physical parameters published by the manufacturer.

Household surveys provide a viable method that would provide all the necessary data. Since an a priori selection of makes and models would be impossible, the method could not be used for an efficient prospective study, but would be limited to cross-sectional or retrospective studies. Although initial contact with owners would be easier than in samples drawn from registration files, the method would still be costly and would not avoid the problem of transient use.

Surveys of cars-in-transport could be accomplished in several ways, and include the most efficient (minimal time required per vehicle) methods. The most desirable technique would be a roadside survey planned and conducted to provide self-weighting on miles traveled by model, season, time of day, type of road, etc. However, the operational problems of stopping vehicles safely, and problems of privacy and interference with free movement, are formidable and make roadside surveys unattractive.

Surveys of cars already stopped, or stopping for other reasons, are much more attractive. For example, surveys could be conducted in shopping centers, parking lots, etc. This approach has several problems, however. It would be very difficult, if not impossible, to avoid biases in mileage data, since the sample would be highly dependent on use (shopping, for example) and not necessarily representative of all kinds of travel at all times of the day. Although vehicles would be readily available for inspection, contact with owners or operators to survey mileage might be difficult.

One technique that is operationally attractive is to use periodic motor-vehicle inspection stations as the contact points, and augment the inspections with supplementary data collection where necessary. States that have such inspection programs and also maintain records of consecutive odometer readings would be a source of convenient and reliable mileage data. This method has not been thoroughly investigated, and a survey of the availability of such data in the states with PMVI will be undertaken.

The method of acquiring control-group data that we recommend at this time is to sample cars at gasoline service stations. The method offers several attractive features. The sampling plan could be designed to be self weighting on mileage if the amount of gasoline purchased is recorded and an approximate adjustment is made for the relative fuel economy of the vehicle.

Problems associated with transient users could be avoided, as the survey would represent the actual at-risk driving in the study area. Observation of vehicle identification and tire parameters could be done with little inconvenience to the driver. This method has been used successfully in the past to survey tire inflation pressures [31].

6.3.7 <u>Control Group Data Requirements</u>. The data requirements for the control group are similar to those for the accident group and are listed below.

I. Driver
   1) Age
   2) Sex
   3) Purpose and length of trip
   4) Type of roads used in trip
   5) Amount of gasoline purchased

II. Environment
   1) Date
   2) Time of day (hour)
   3) Precipitation
   4) Temperature
   5) Surface covering (from precipitation) of roads in the local area of the survey site

III. Vehicle
   1) VIN
   2) Occupants - location and weight
   3) Major cargo - location and weight
   4) Air conditioner
   5) Type of transmission
   6) Type of steering system
   7) Sway bar diameter
   8) Tire make and model
   9) Tire size
   10) Tire inflation pressure
   11) Tire tread depth
   12) Tire sidewall temperature[1]

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[1] Sidewall temperature would be necessary to correct the inflation pressure from a hot (driving) value to the cold (ambient) value. The methods developed by the Stevens Institute of Technology for measuring the temperature and correcting pressure could be used [31].

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Stepwise Procedures and Direct Estimation Methods for Building Models for Multiple Classifications," Technometrics, Vol. 13, No. 1, February 1971, pp.33-61.

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Special Attention to the Problem of Drunken Driving, Auto Design, Stolen Automobiles and Highway Hazards, Pennsylvania Action Committee for Highway Safety, Philadelphia, 19 February 1971.

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APPENDIX A

ACCIDENT CAUSATION
BIBLIOGRAPHY AND LITERATURE REVIEW

Appleby, M.R., L.J. Blintz, and P.E. Keen, Jr., "Incidents Caused by Vehicle Defects," SAE 770115, Society of Automotive Engineers, International Automotive Engineering Congress, Detroit, March 1977.

Data from in-depth investigations of 1,087 incidents caused by vehicle defects reported to an automobile insurer were examined, compiled into various categories, and analyzed.

Significant results were that 530 (49%) of the incidents involved vehicle fuel system failures which caused fires. Brake system failures accounted for for 301 of the remaining 557 incidents. Conclusions and recommendations are made supportive of countermeasures such as recall campaigns, upgrading of vehicle service facilities, and vehicle owner education. The cost effectiveness of mandatory periodic motor vehicle inspection systems is questioned. Further research, generally on vehicle safety defects and specifically on the causes of vehicle engine fires, is recommended.

Babarik, P., "Automobile Accidents and Driver Reaction Pattern," <u>Journal of Applied Psychology</u>, Vol. 52, No. 1, 1968, pp. 49-54.

Taxicab drivers who reported an abnormal number of accidents in which they were struck from behind, when tested on a classical laboratory reaction-time apparatus, were found to have a reaction pattern made up of slow initiation time and compensatingly fast movement time. Drivers with this perceptual-motor pattern probably stopped their vehicles more abruptly in a way that cannot be duplicated by a following driver, or in the headway of the following vehicle. However, drivers with such an atypical perception reaction had fewer accidents in their headways and therefore had lower overall accident rates. Suggestions for further research and the possible implications of these findings were discussed. (From author's abstract.)

Baird, J.D. and E.E. Flamboe, "An Historical Overview of Research in Traffic Accident Investigation Activities," SAE 750891, Society of Automotive Engineers, Automobile Engineering meeting, Detroit, October 1975.

Two previous reviews of the research aspects of traffic accident investigations are used as starting points for presenting an up-date of accident investigation activities, both in the U.S. and in foreign countries. Elements of national accident investigation programs are discussed as well as areas of current accident investigation technology. An international accident investigation feasibility study under the auspices of NATO is also studied. (From author's abstract.)

Baker, J.S. and R.E.B. Fisher, Better Information About Causes of Accidents from Police Investigations, Traffic Institute, Northwestern University, Evanston, Illinois, 1955.

Baker distinguishes between the reporting of an accident and its investigation, and suggests that less information on most accidents coupled with detailed investigations of a few accidents would be preferable to the current system. He also notes that police functions in an accident are not directed toward discovering causes, just violations of the law.

The project described here trained groups of men in the Ohio State Patrol to analyze accidents and determine their causes. Baker concludes, after a trial run of 297 accident analyses, that officers can, with relatively little additional training, produce far better information on accidents than they have in the past.

Baker, J.S. and L.R. Horn, An Inventory of Factors Suggested as Contributing to Traffic Accidents, Traffic Institute, Northwestern University, Evanston, 1969.

Over 850 contributing factors to accidents are listed and defined using the authors' systematic approach to accident reconstruction.

Baker, J.S. and H.L. Ross, Concepts and Classification of Traffic Accident Causes, Traffic Institute, Northwestern University, Evanston, Illinois, 1960.

Baker here presents an overview of his major concepts and his approach to accidents and accident causation.

Topics discussed include the various elements of the highway transportation system, definitions of causes, the driving task, accident reconstruction, and accident proneness.

Baker, J.S. and H.L. Ross, "Concepts and Classification of Traffic Accident Causes: Part 1," International Road Safety and Traffic Review, Number 3, Summer 1961.

The authors begin by defining an accident factor as "any circumstance connected with a traffic accident without which the accident could not have occurred." Accident causes are "a combination of simultaneous and sequential circumstances without any one of which the accident could not have happened." In this combination, each factor is necessary but not sufficient to cause an accident.

Baker's emphasis is on the immediate pre-crash phase. He sees evasive maneuvers as the critical variable in whether the accident will occur.

The article is useful in that it offers the investigator a systematic scheme for reconstruction of the accident.

Baker, J.S., Limitations on Accident Reconstruction, Traffic Institute, Northwestern University, Evanston, Illinois, 1960.

How precisely an investigator can determine how a traffic accident happened depends on the completeness and reliability of the information available, on the skill of the investigator in recognizing pertinent facts in the available information and on his ability to deduce from the facts the position and motion of traffic units involved during the accident. Usefulness of such reconstruction depends on whether the precision achieved is sufficient to meet needs as determined by the purposes of the investigation. (From author's abstract).

Baker, J.S., Experimental Case Studies of Traffic Accidents: A General Discussion of Procedures and Conclusions, Traffic Institute, Northwestern University, Evanston, Illinois, 1960.

This article serves as a guide to the rest of Baker's reports on his case studies of traffic accidents. An outline of the methodology is presented, along with a discussion of alternative procedures considered by the project team. An attempt was made to descry the biases of the investigators, and a short precis of this problem, and how the team dealt with it, is included.

Baker, J.S., "Psychological Bias in Accident Reconstruction," Institute of Traffic Engineers Proceedings, Vol. 30, 1960, pp. 113-117.

The article describes an experiment in which groups of people (professional investigators, college students, engineers, etc.) were given information on a traffic accident and asked to decide who was at fault and where in the road the collision occurred. Baker was searching for bias in accident investigation and he found plenty of it. Subtle differences in the way information was presented to the subjects produced vastly different interpretations of the data.

Baker, J.S., J. Midler, and G. Blomgren, Sources of Error in Deciding How a Traffic Accident Happened, Traffic Institute, Northwestern University, Evanston, Illinois, 1960.

Experiments to find sources of error in deciding how a traffic accident happens were undertaken because experienced investigators often differ in their conclusions. This has important implications in settling lawsuits arising from traffic accidents and in trying to determine causes of accidents for accident prevention purposes.

It was hypothesized that except when circumstances are obvious, people will be biased by irrelevant psychological and physical facts. These hypotheses are supported by the experiment. But is was surprizing that there was no significant difference between technically trained people or experienced investigators and ordinary laymen. That technical peoples' performance can be improved by more time for solution and by how the problem is stated has also been demonstrated.

Thus, four kinds of factors or variables which may influence decisions about who was at fault in traffic accidents have been identified and tested:

1. Irrelevant psychological information that is suggestive to begin with and so beguiles the investigator.

2. Irrelevant physical information that misleads the investigator as to position and direction of movement.

3. Time available to the investigator.

4. Instructions given or approach to the problem.

The manner in which these variables operate is discussed. (From author's abstract)

Baker, J.S., "Concepts and Classification of Traffic Accident Causes - Part II: Analysis of Accident Causes," International Road Safety and Traffic Review, Number 4, Autumn 1961.

These articles are condensations of larger reports bearing the same title.

In Part I, Baker defines the concepts that form the foundation of his clinical assessment project on the causes of traffic accidents. The most basic of these is the factor: "any circumstance connected with a traffic accident without which the accident could not have occurred." Cause is "a combination of simultaneous and sequential circumstances without any one of which the accident could not have happened." Because all contributing factors must be present, Baker sees no reason to differentiate between primary and secondary factors.

Baker's system is anchored in time. This becomes clear in Part II, which is largely concerned with accident reconstruction. Important events in an accident are 1) the point of possible perception under normal conditions; 2) the point of possible perception under existing conditions; 3) the point of actual perception; 4) the point of response; and 5) the point of no escape. The last of these may occur anywhere in the sequence. The general procedure in analysis is the description of the sequence. A sample case study is presented.

Baker, J.S., "What Are the Causes of Traffic Accidents?" Traffic Digest and Review, Vol. 9, No. 10, October 1961, pp. 11-16, 28-31.

The author explains his view of accidents and his scheme for discovering their causes. An accident is a breakdown or failure in the series of operations necessary to make a trip on a highway without injury or damage.

Baker further defines a factor as "any circumstance connected with a traffic accident without which the accident could not have occurred." From this, it follows that all factors contributing to any accident must be present to bring it about. Hence, it is meaningless to designate primary and secondary factors in his causal scheme.

Baker, J.S., A Condensed Report on Case Studies of Traffic Accidents, Traffic Institute, Northwestern University, Evanston, Illinois, May 1961.

Baker, J.S., "Accident Reconstruction Research," National Safety Congress Transactions, Vol. 24, Part 2, 1964, pp. 8-15.

This paper concerns the role of police in accident reporting and research. Because of the demands placed on police services, Baker recommends that police functions with respect to accident investigation (and especially cause analysis) be clarified. He suggests that police avoid all but broad supervisory work in connection with accidents. The accident work itself would then be handled by other agencies, possible traffic engineering departments or insurance companies.

Baker, J.S., "Single-Vehicle Accidents on Route 66," 46th Annual Meeting, Highway Research Board, January 1967.

This is the report on a "level 1-1/2" study on five months of single-car accidents on the entirety of Route 66. It contains some interesting categories for accident causation.

Baker, J.S., "Reconstruction of Accidents," Traffic Digest and Review, Vol. 17, No.3, March 1969, pp. 9-16.

Experiments were conducted at the Traffic Institute to discover how successfully various kinds of investigators can reconstruct accidents from photographs of the roadway and post-accident situation diagrams. Police and insurance claim investigators did no better than college freshmen. Baker's point is that special training is required for proper data collection and analysis.

Baker, J.S., Traffic Accident Investigation Manual, The Traffic Institute, Northwestern University, Evanston, Illinois, 1975.

Baker, J.S., "Traffic Accident Analysis," Transportation and Traffic Engineering Handbook, Prentice-Hall, Englewood Cliffs, New Jersey, 1976, pp. 377-403.

Accident analysis, the author points out, may involve the study in detail of individual accidents or the study of groups of accidents occurring at the same or similar locations. The two types serve different purposes.

This article is a manual for would-be accident analysts. Topics include accident reconstruction techniques, weighting of accidents by severity, countermeasures, and cost-benefit estimation.

Barrett, G.V., P.E. Panek, H.L. Sterns, R.A. Alexander, and W.L. Mihal, Information Processing Skills Predictive of Accident Involvement for Younger and Older Drivers, Technical Report AND-1, The University of Akron, September 1976.

Barrett et al investigated the information-processing capacities of drivers in the areas of selective attention, perceptual style, and perceptual-motor reaction time. Significant age-related differences appeared which are specifically linked to accident involvement. Information-processing ability decreases about the mid forties and individuals cannot compensate for this by "trying harder."

Benner, L. Jr., "Accident Investigations: Multilinear Events Sequencing Methods," Journal of Safety Research, Vol. 7, No. 2, June 1975, pp. 67-73.

In these three articles, Benner proposes a "Multilinear Events Sequencing Method" of modeling accidents. The model is a time-scaled linear sequence in which each event is an action by an actor (animate or inanimate) in response to a perturbation. Several actors may be involved.

Important concepts for Benner are the beginning of an accident sequence and its end. The beginning is when homeostasis (equilibrium) ends. The ending is a return to homeostasis after the last injury or damage producing event.

The method differs from fault-tree analysis in that a) relative time is preserved in the sequence; b) no logic (and/or gates) is used; and c) the model is not quantitative with probabilities - each event did happen. It is descriptive rather than probabailistic.

This view differs markedly from Perchonok's. No "critical event" is sought, and any predefined taxonomy of events is avoided. These, Benner believes, interfere with the process of discovery. A methodology directed towards the identification of a "cause" is somewhat artificial, and can mask the importance of interrelationships.

Benner, L., Jr. "Accident Theory and Accident Investigation," Proceedings of the The Society of Air Safety Investigators Annual Seminar, Ottawa, Canada, October 1975, pp. 148-154.

Benner, L.A. Jr., "Hypothesis Generation for Rare Events Research," Rare Event/Accident Research Methodology, NBS Special Publication 482, Proceedings of a Workshop held at the National Bureau of Standards, Gaithersburg, Maryland, May 1976, National Bureau of Standards, U.S. Department of Commerce, Washington, D.C., July 1977, pp. 25-28.

Blair, I., Causes and Effects of Traffic Accidents: Part II - The Environment, Department of Transportation and Environmental Planning, University of Birmingham, June 1969.

425 accidents were investigated using the in-depth (clinical assessment) approach. Included were pedestrian, urban, and rural accidents. Variables were either active (wind gusts, tire failure), or passive (potholes, parked cars, ice). Driver error, judged subjectively by experts, was classified by means of the Baker (1960) system. This work is similar to Indiana's but less rigorous.

Blotzer, P., R.L. Krumm, D.M. Krus, and D.E. Stark, Accident Causation, Pennsylvania Turnpike Joint Safety Research Group, Harrisburg, 1954.

This 18-month study of accident causation on the Pennsylvania Turnpike concludes that 86.5% of accidents were caused by driver error and the rest by vehicle failures. Environmental conditions are treated as a given, a backdrop against which driving experience occurs. Eight categories of factors are listed:

1. Failure to cope with road conditions.
2. Illegal or unsafe actions.
3. Inattention.
4. Vehicle failures.
5. Deficiencies in routine driving skills.
6. Misperception.
7. Failure to avoid objects in road.
8. Intoxicants.

Bohlin, N. and L.E. Samuelson, "A Methodology for Coding Accident Configuration," Proceedings of the International Accident Investigation Workshop - Pilot Study on Road Safety, National Highway Traffic Safety Administration, Washington, D.C., 1974, pp. 19-23.

Bohlin proposes a coding system for accident types, driver reaction, and vehicle movement. A six-digit code is used.

The first two digits describe the type of accident (crossroads, single vehicle, pedestrian, two same direction vehicles, etc.), the third describes braking, the fourth, steering, and the last two, skidding and vehicle movement. The system is organized to describe a case vehicle. Thus, an accident may have more than one six-digit code.

Bonder, S., A Qualitative Highway System Model, Highway Safety Research Institute, July 1966. (Unpublished.)

The paper lists the components in a model of the highway system. These factors include System Effectiveness Measures (measures of the quality of service and the safety provided), Subsystem Performance Measures (capabilities of vehicles, the highway, medical facilities, etc.), Control Streategies (a measure of the system's flexibility), Hardware Performance Measures (capabilities of driving subsystems, including humans), Physical Hardware Characteristics (brake lining thickness, highway material, etc.), and Environmental Parameters (weather, noise level, time of day, etc.). A paradigm is then presented to define the interrelationships of the parts.

The model is used to determine the interactions and resultant performance capabilities for the subsystems usually associated with the highway system.

Bonder, S., D.E. Cleveland, and D. Wilson, Report of the Ad Hoc Systems Study Group, Highway Safety Research Institute, The University of Michigan, Ann Arbor, 1967.

The objective of the Ad Hoc Systems Study Group was to create a highway systems model for use as a guide in allocating research resources. This large document examines a number of topics, including transportation demand, traffic flow, accident prediction, degradation, the driver, vehicle dynamics, and costs.

Borkenstein, R., The Role of the Drinking Driver in Traffic Accidents, Department of Police Administration, Indiana University, Bloomington, February 1964.

Brill, E.A., "A Car-Following Model Relating Reaction Times and Temporal Headways to Accident Frequency," Transportation Science, Vol. 6, No. 4, November 1972, pp. 343-353.

Brill, referring to studies showing reduced reaction time with an integrated brake/accelerator pedal, attempts to relate braking reaction time to accident frequency. To this end, he creates a model for rear-end collisions during rush hour on city freeways. Examples are given to demonstrate his conclusion that additive changes in reaction time correspond to multiplicative changes in collision probability.

Brown, D.B., Systems Analysis and Design for Safety - Safety Systems Engineering, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1976.

Browner, H.D., "Analysis of Relationships between Accidents and Geometrics and Traffic Characteristics on the Interstate System," Institute of Traffic Engineers, World Traffic Engineering Conference, Montreal, September 1971.

The study collected detailed information on roadway segments of the interstate system pertaining to highway design and geometrics, traffic volume and type, and accident occurrence and severity. Regression anlysis indicated a correlation between design features (ramps, lane types, etc.) and types of accidents, but this correlation explained only 5 to 20% of the variance in accident rate. The author believes this is an upper limit on the amount of variance design characteristics can account for. He indicates that traffic volume is a more important predictor.

Burger, W.J., R.L. Smith, J.E. Queen, and G.B. Slack, Accident and Near Accident Causation: The Contribution of Automobile Design Characteristics. Final Report, Dunlap and Associates, Inc., La Jolla, California, November 1977. DOT HS-802 714.

This study was conducted to: 1) determine the frequency and severity of driver/vehicle design mismatch problem contribution to accidents and near accidents; 2) relate driver and vehicle characteristics to severity and frequency of problems experienced by drivers; 3) develop and validate the method used to measure mismatch problems; and 4) identify vehicle design countermeasures which would reduce problem frequency or severity. Five direct mail questionnaires were developed and pilot tested on a sample of 800 U.S. Government employees. Results were analyzed and a modified questionnaire recommended for a large scale survey of drivers. Subsequently, a direct mail survey was sent to 10,000 drivers from California and New Hampshire. Results strongly indicate the survey approach is valid and that driver/vehicle design mismatch problems are not trivial as contributors or causes of accidents. (From author's abstract).

Cameron, D.H., "Accident Rate Analysis and Confidence Limits," Proceedings of the Fifth Conference of the Australian Road Research Board - Volume 5, 1970, pp. 117-138.

This analysis is built on the premise that the number of accidents for a given exposure (measured in miles) assumes a Poisson distribution. The accident rate (accidents per mile) is computed and also assumed to be a random variable.

An illustration is provided in which accident rates are computed separately at each level of up to three different "attributes." These may be thought of as different variables which define discrete categories of exposure. A chi-square test is used to search for differences in accident rates under the null hypothesis that the rates are the same at each level of the attribute in question. Approximate equations are presented to compute confidence intervals for each rate.

An argument is cited, based on this analysis, that the minimum accident count for any category is about 30 (thirty). At this point, ±34% of the accident rate will be an approximate 95% confidence interval.

Carlson, W.L., "Sampling from Highway Crash Populations," Accident Analysis and Prevention, Vol. 8, No. 3, September 1976, pp. 177-186.

The problem of obtaining unbiased estimates using samples from sequential populations is examined using Monte Carlo simulation. These sequential populations are composed of superposed renewal processes. One example of a sequential population is the population of highway crashes within a geographic area over a specific time period. The simulation results indicate that samples at fixed or random count intervals provide unbiased estimates of the proportion of elements from each subpopulation, whereas samples at specific times which are defined at fixed or random time intervals result in biased estimates. A multiple regression analysis showed this bias to be related to the actual subpopulation proportions and the difference in the relvariances (squared coefficient of variation) of the subpopulation interarrival times. The results are shown to apply to an actual population of highway crashes obtained from a midwestern county over a one year time period. (From author's abstract).

Carr, B. et al., International Conference on Research Methodology for Roadside Surveys of Drinking-Driving — Alcohol Countermeasures Workshop, National Safety Council, Chicago, September 1974. DOT HS-801 220.

Clayton, A.B., "An Accident-based Analysis of Road-user Errors," Journal of Safety Research, June 1972 .

Clayton, in a British study using at-scene accident investigations, suggests that an "accident" is such a disparate collection of events that its use conceptually is limited. Causation research should concentrate on specific errors committed rather than seek a unique cause. He also points out that an individual who commits errors of a particular type may possess different psychological traits from one who commits another type of error.

Clayton, A.B., "Aetiology of Traffic Accidents," Health Bulletin, Vol. XXXI, No. 4, October 1972.

Clayton used an interdisciplinary team (a mechanical engineer, psychologist, surgeon, and traffic engineer) for his clinical assessment of 625 accidents in Birmingham, U.K. He notes that accidents tend to be caused by a combination of factors. Road-user errors, alone or in combination with other factors, were present in 90% of accidents. Of these errors, the most common were failure to look and excessive speed.

Cohen, J., and B. Preston, Causes and Prevention of Road Accidents, Faber and Faber, London, 1968.

This book addresses various causative mechanisms which are thought to be related to accident causation in the British experience. Particular attention should be paid to chapter 6 of Part I, concerning communication on the road. The authors analyze the reasons for communication failures and resulting crashes.

Cooper, P.J., Predicting Intersection Accidents, Road and Safety Motor Vehicle Traffic Safety Office, Canadian Ministry of Transport, Ottawa, September 1973.

The author used the Traffic Conflicts Technique in an attempt to predict accident rates at intersections. Exposure (traffic volume), conflicts, and accidents were counted, with conflicts being defined as the actions of one vehicle causing another to take evasive action. A good correlation was found between exposure, conflicts, and accidents, but conflicts were not as good a predictor of accident rate as was exposure. The author suggests that the conflict technique is probably not useful as an accident predictor but it is useful in determining problem areas in specific intersections, particularly when the observer is a traffic engineer.

Cromack, J.R. and G.M. Barnwell, A Critical Analysis of Traffic Accident Data, SAE 750916, Society of Automotive Engineers Automobile Engineering Meeting, Detroit, October 1975.

Cromack and Barnwell assert that most traffic accidents result from defects in driver performance, and that underlying psychological and behavioral variables have been neglected in accident investigations. They recommend a systems approach based both on the paradigm of the human operator performing simultaneous tracking, vigilance, and decision tasks, and on the linking of mathematical models, computer simulation, and laboratory experimentation.

Curry, G.A. et al. Task Load in the Motor Vehicle Operator: A Comparative Study of Assessment Procedures, Department of Psychology, Queen's University, Kingston, Ontario, July 1975.

Curry et al assessed four methods of establishing driving task load. Cardiovascular measures and a verbal tapping task were found to be good discriminators of traffic routes of differing complexities. Sugestions are made for the use of driver overload measures (when better developed) in driver testing, road design, etc.

Driessen, G.J., Cause Tree Analysis: Measuring How Accidents Happen and the Probabilities of their Causes, National Safety Council, Chicago, September, 1970.

This article concerns the general topic of safety, not specifically highway safety. It is a good, brief introduction to fault-tree analysis, probability calculation, and the identification of countermeasures. Also included is a good bibliography, up to 1970.

Dugoff, H., "Implications of a Simplified Systems Model: The Elements of Pre-Crash Safety," Unpublished Memorandum dated March 5, 1968, Highway Safety Research Institute, The University of Michigan, Ann Arbor.

Dunlap and Associates, Inc., An Analysis of Risk and Exposure in Automobile Accidents, Stamford, Connecticut, 1953.

The occurrence of automobile accidents is modelled using a combination of three causes: exposure (determined mainly by the environment), risk acceptance (determined mainly by the driver), and the probability of an accident. For two-vehicle accidents, exposure is taken to be a passing or overtaking (the amount of passing is related to the traffic density and the speed distribution). Risk acceptance is a conditional probability describing the likelihood that the driver will take certain specific actions given the exposure. Risk acceptance is modelled in terms of risk estimation, and is related to traffic density by considering the frequency at which traffic conflicts or potential danger situations are presented to the driver. The probability of an accident is then conditional on the specific action taken by the driver when presented with a specific exposure situation.

Exposure in terms of traffic density is compared with accident counts using tollroad and other data. In general, the relationship is found to be inadequate. Further discussion of the model for risk taking describes how this factor has the potential to explain some of the observed discrepancies. The probability of an accident is not estimated.

Edwards, C.B. and J. Gurland, "A Class of Distributions Applicable to Accidents," American Statistical Association Journal, Vol. 5-6, September 1961, pp. 503-517.

This article extends the accident proneness model by compounding the correlated bivariate Poisson distribution through a Gamma distribution. Recurrence relations and expressions for the required probabilities are illustrated with two sets of data, and the compounded distribution fits as well or better than the correlated bivariate Poisson from which it was derived.

Ehrman, L., "Causes of Highway Accidents; United States Experience," Traffic Quarterly, Vol. 12, January 1958, pp. 30-57.

Ehrman, writing in 1958, emphasizes the need for more comprehensive accident data. Also discussed are the costs of accidents, highway design features, and traffic volume.

Erlander, S., "A Review of Some Statistical Models Used in Automobile Insurance and Road Accident Studies," Accident Analysis and Prevention, Vol. 3, No. 1, July 1971, pp. 45-75.

Fell, J. and V.J. Esposito, "Accident Data Collection, Analysis and Findings," Young Driver Accidents, Paris, OECD, March 1975, pp. 121-145.

Fell, J.C. and K.J. Tharp, Multi-Disciplinary Investigations to Determine Accident Causation: Report No. 2 - Accident Case Analysis and Data Processing Procedures, Report No. VJ-2224-V-2, Cornell Aeronautical Laboratory, Inc., Buffalo, October 1969.

The data collected by the multi-disciplinary team investigations of motor vehicle accidents were used to reconstruct the pre-, at-, and post-impact conditions and dynamics of the accident event. An individual accident report - referred to as a summary - was written and provided a summarization of the observations and data collected, a description of the various stages of the accident, and a listing of the causation factors as concluded by the investigators.

The individual case report was then processed for use with CAL's computer equipment. Processing consisted of partial numeric and alphanumeric coding of the data obtained and an alphanumeric presentation of the description and causation factors in a semi-structured form.

This volume is a manual of data processing procedures for the study. (From author's abstract).

Fell, J.C., "A Motor Vehicle Accident Causal System: The Human Element," Human Factors, 1976, Vol. 18, No. 1, pp. 85-94.

Fell, J.C., "ACCIDENT CAUSATION AND AVOIDANCE: METHODOLOGICAL APPROACHES - Introduction and Systems Overview," Motor Vehicle Collision Investigation Symposium Volume I: Proceedings, Report No. ZQ-5731-V-1, Calspan Corporation, Buffalo, pp. 458-480. DOT HS-801 979.

The article presents four examples of accident causal models. The first two, the "Indiana Accident Causal Taxonomy" and the CALSPAN (Perchonok) model of accident generation, are all-inclusive schemes designed to categorize large numbers of accidents. The "Human Factors Causal System" and the "Miami Causal Model for Single Vehicle Accidents" have more limited and specific goals.

Fell, J.C., "A Motor Vehicle Accident Causal System: The Human Element," Motor Vehicle Collision Investigation Symposium Volume I: Proceedings, Report No. ZQ-5731-V-1, Calspan Corporation, Buffalo, pp. 505-523. DOT HS-801 979.

Fell considers first the IRPS and Perchonok models of accident causation. The body of the article then draws upon these models, concentrating on the human pre-crash elements of a collision, to create a human accident causal model. The author preserves the chronology of the accident through the use of causal chains (a cause is followed by an effect, which becomes a cause for the next effect).

Fergenson, P.E., "The Relationship between Information Processing and Driving Accident and Violation Record," Human Factors, Vol. 13, No. 2, April 1971, pp. 173-176.

Fergensen studied the relationship of information processing ability to accident and violation records. High violation/zero accident group was the best information processor; high violation/high accident group, the worst. 17 subjects, all male, were matched for driving experience.

Ferreira, J. Jr., "Driver Accident Models and Their Use in Policy Evaluation," Analysis of Public Systems, Massachusetts Institute of Technology, Cambridge, 1972.

This paper is an outgrowth of the DOT Auto Insurance and Compensation Study. The author's goal is to "illustrate the potential role of operations research analysis in formulating quantitative approaches to policy evaluation."

The paper focuses on two problems: overrepresentation in accident statistics, and driver improvement programs.

The overrepresentation study is based on six years of accident data for a sample of 7,842 licenced California drivers. He compares a Poisson "equally likely" model with a negative binomial model, and concludes that accident prone drivers exist. However, he also concludes that most of the proneness results from people who have no more than a handful of reported accidents during their entire lifetime. Because of this, he claims, the concept of proneness is of little value.

The section on driver improvement programs develops a probabilistic model to measure the reduction in accidents one might expect from driver improvement programs. Using the California data, he concludes that measurable reduction in accidents would only occur after several years. Furthermore, over a ten-year period, from three to ten drivers would have to be trained for each accident prevented.

Because Ferreira's work on overrepresentation does not compare accident and exposure data, it is not applicable in determining causation from accident data.

Fleiss, J.L., Statistical Methods for Rates and Proportions, John Wiley & Sons, New York, 1973.

Flynn, L., (Compiler), Accident Risk Forecasting - A Bibliography, Report No. 22, Technical Reference Division, National Highway Traffic Safety Administration, Washington, D.C., August 1977. DOT HS-802 567.

This bibliography represents accident forecasting literature acquired by the NHTSA since its establishment in 1967. It contains NHTSA contract reports, reports of other organizations concerned with highway safety, and articles from periodicals in related fields. (From author's abstract).

Garrett, J.W., Editor, Motor Vehicle Collision Investigation Symposium - Volume 1: Proceedings, Report No. ZQ-5731-V-1, Calspan Corporation, Buffalo, August 1976. DOT HS-801 979.

The objectives of this symposium were to exchange ideas and discuss accident investigation plans and programs, new technology for improving accident investigation, accident study designs, and accident data reduction and analysis. Major emphasis was placed on new or planned federal data systems, collision reconstruction, and accident causation methodology. A feature of the symposium was a crash clinic in which a staged collision was investigated and reconstructed by a composite investigation team made up of members of teams throughout the U.S. (From author's abstract).

Glennon, J.C., "Roadside Safety Improvement Programs on Freeways; A Cost-Effectiveness Priority Approach," National Cooperative Highway Research Program Report, 148, 1974.

Glennon developed a cost-effectiveness priority approach to the allocation of funds for roadside safety. A probability-based hazard index model was developed which considers vehicle encroachment frequencies, lateral displacement of encroaching vehicles, lateral placement of roadside obstacles, and the accident severity associated with the obstacle.

Glennon, J.C., W.D. Glauz, M.C. Sharp, and B.A. Thorson, Critique of the Traffic Conflicts Technique, Presented at the 56th Annual Meeting of the Transportation Research Board, January 1977.

Goeller, B.F., Modeling the Traffic-Safety System, Rand Corporation, April 1968.

The author suggests there is a need for a model of the traffic safety system that can predict the consequences of various safety-related activities in terms of deaths, collisions, injuries, and property damage.

The paper develops a conceptual framework for such a model and attempts to identify the types of research needed to make that framework into an operational model of practical use.

Goeller, B.F., "Modeling the Traffic-Safety System," Accident Analysis and Prevention, Vol. 1, October 1969, pp. 167-204.

Goeller assumes that the driver is the major causative factor in accidents, but concedes that driver improvement is not necessarily the most cost effective way to improve traffic safety. The model defines driver "vulnerability" as the sum of four sub-categories: perception, judgement, skill, and chance. This factor is multiplied by exposure, and by the probability of danger, to yield the expected confrontation rate for accidents. He concludes that much research is needed to turn his preliminary model into an operational one.

Goodenough, D.R., "A Review of Individual Differences in Field Dependence as a Factor in Auto Safety," Human Factors, 1976, Vol. 18, No. 1, pp. 53-62.

Goodenough cites evidence in support of the notion that field-dependent drivers are more often involved in accidents than are field-independent drivers. Four reasons are suggested: slow recognition of developing hazards, slow response to embedded road signs, poor control of skidding vehicles, and lack of defensive driving in high speed traffic.

Gordon, D.A. and T.M. Mast, "Drivers' Judgements in Overtaking and Passing," Human Factors, 1970, Vol. 12, No. 3, pp. 341-346.

Gordon and Mast looked at driver estimation of the required overtaking and passing distances in an actual driving situation. Consistant underestimation was found: 15% at 18 mi/hr and 68% at 50 mi/hr.

Gordon, J.E., "The Epidemiology of Accidents," American Journal of Public Health, Vol. 39, April 1949, pp. 15-27.

This twenty-three year-old study is considered a classic in accident epidemiology. The argument presented for an epidemiological approach to accident causation is convincing despite the use of outdated concepts and case studies.

Greenberg, B.G., "Problems of Statistical Inference in Health with Special Reference to the Cigarette Smoking and Lung Cancer Controversy," Journal of the American Statistical Association, Vol. 64, No. 327, September 1969.

Haddon, W. Jr., "The Changing Approach to the Epidemiology, Prevention, and Amelioration of Trauma: The Transition to Approaches Etiologically Rather Than Descriptively Based," Behavioral Research in Highway Safety, Vol. 1, No. 1, January 1970.

The author rails against "prescientific concepts and terms." The concept of accident is one such concept, being descriptive rather than etiologic. The etiologic approach examines forms of energy exchange which must occur in excess of body injury thresholds. Haddon compares the notion of accident to the medieval use of "wasting" as a disease. Only later, when physicians came to see wasting as a result rather than a cause, did they make any progress on the diseases that cause it.

Haddon also makes the point that the effectiveness of accident countermeasures does not parallel the ranking of accident causes.

Haddon, W., Research with Respect to Fatal Accident Causes:Implications for Vehicle Design, Society of Automotive Engineers Summer Meeting, 1961.

This address calls attention to the role of interior vehicle design in collision injuries. Haddon outlines four strategies for the reduction of crash-related injuries.

The first strategy is to modify vehicle use patterns by rearranging workdays to stagger traffic loads and banning the use of motor vehicles for individuals who are "partying." Given the dependence of the society on private vehicle use, this strategy would be of limited effectiveness.

His second suggestion is to strengthen law enforcement and improve engineering design in order to reduce accidents.

A third stretegy would attempt to prevent or lessen injuries by improving interior vehicle design.

Finally, he suggests improving emergency services and aftercare for accident victims.

Haddon, W., "A Logical Framework for Categorizing Highway Safety Phenomena and Activity," Journal of Trauma, Vol. 12, No. 3, March 1972.

Haddon suggests a systematic analysis of accidents with a view to loss reduction rather than accident prevention. He cites examples of countermeasure strategies that have proven successful in reducing crash severity (e.g. - high-penetration-resistant windshields).

He also distinguishes between the priority order of countermeasures in terms of their contribution to loss reduction and the rank order of accident causes. The author estimates that a third of a million drivers in the U.S. have unnecessarily lost their lives because of hard, spearlike steering columns.

Haight, F., H. Joksch, J. O'Day, P. Waller, J. Stutts, and D. Reinfurt, Review of Methods for Studying Pre-Crash Factors, The Highway Safety

Research Center, University of North Carolina, Chapel Hill, October 1976. DOT HS-802 054.

Haight, F.A., Problems in Transport Safety, Pennsylvania State University, University Park, July 1970.

This work is the transcript of a series of lectures given in Karlsruhe. Taken as a whole, the six talks comprise an overview of highway safety research. Topics include accident proneness, accident models, driver behavior, exposure models, and strategies for future research.

Haight, F.A., Indirect Measures for Measuring Exposure Factors as Related to the Incidence of Motor Vehicle Traffic Accidents, Pennsylvania Transportation and Traffic Safety Center, University Park, September 1971.

Haight, F.A., "Induced Exposure," Accident Analysis and Prevention, Vol. 5, No. 2, June 1973, pp. 111-126.

Henderson, M., Human Factors in Traffic Safety: A Reappraisal, Traffic Accident Research Unit, Department of Motor Transport, New South Wales, February 1971.

Henderson, looking at the australian experience, concludes that the modification of human behavior is not the answer to the traffic safety problem. He recommends research in areas of driving skills, highway system demands, socio-cultural environment, and enforcement. He also recommends action on drinking driver identification and control, driving and accident records, and seat belts.

Horodniceanu, M., E.J. Cantilli, M. Shooman, and L.J. Pignataro, Transportation System Safety Methodology - First Year Final Report, Report No. TR-76-505, Polytechnic Institute of New York, Brooklyn, November 1976. DOT-TST-77-17.

The Transportation System Safety Methodology is composed of two major sections: a Management section and a Transportation System Safety Program.

The Management portion describes the ideal philosophy and attitude of safety management, and provides guidelines for appropriate organization and staffing of safety activities within the parent organization, and for policy and objective development, selection, training, certification and motivation of personnel, data base requirements, assignment of accountability, and measurement of program effectiveness.

The Program section provides a description of the hazard identification and analysis, and investigation and review processes, and introduces the techniques to be used in safety analysis. These analytic methods are discussed in their application to each phase of the transportation activity cycle: concept formulation, preliminary design, engineering design, production, and operation and maintenance, providing specific guidelines to the transportation system safety process in any given modal organization. (From author's abstract).

Hutchinson, T.P., "Statistical Aspects of Injury Severity. Part I: Comparison of Two Populations When There are Several Grades of Injury," Transportation Science, Vol. 10, No. 3, August 1976, pp. 269-284.

Hutchinson, T.P., "Statistical Aspects of Injury Severity. Part II: The Case of Several Populations but Only Three Grades of Injury," Transportation Science, Vol. 10, No. 3, August 1976, pp. 285-299.

In the first paper, the proportion of cases in one population that exceed each level of injury severity is plotted against the proportion of cases in the other population exceeding the same threshold level. In general, deviations of this plot from a 45^0 line indicate differences in the level of severity for the two populations. If the relationship shown on this plot may be described by a simple function, then calculation of the parameters in the function provide a means of quantifying differences in the distributions of injury severity in the two populations.

This approach is extended in the second paper to the case of only three levels of injury but where several categories are defined based on the levels of other factors (e.g.--age). The injury distribution is again assumed to be exponential and the influence of the different categories of the factor on the injury distribution is assumed to be described by changes in the value of the parameter in the exponential distribution. When the proportions associated with two of the injury levels are plotted against one another at each of the levels of the added factor, the relationship may be expected to be a power function.

Data are presented to demonstrate a correlation between the proportion seriously injured and the proportion killed. Curves are fitted to these data assuming both the exponential distribution of injury severity and a normal distribution with constant variance. A better fit is obtained under the assumption of the exponential distribution. The result lends support to the use of the power function in comparing the proportions of seriously injured and killed at various levels of another factor such as age. These results would seem to be most useful in comparing data from different sources where variations exist in the reporting thresholds and definition of injuries.

Institute for Research in Public Safety, Study to Determine the Relationship between Vehicle Defects and Failures, and Vehicle Crashes, Volume 1, Indiana University, Bloomington, May 1973. DOT HS-800 850.

Results of the Indiana Tri-Level Accident Investigation Program are reported. The study focused on the determination of the relative roles played by human, environmental, and vehicular deficiencies in causing accidents.

This is the first of four volumes. It presents findings concerning component outage rates, representativeness of samples, and other study topics. (From author's abstract).

Institute for Research in Public Safety, A study to Determine the Relationship between Vehicle Defects and Crashes, Indiana University, May 1973.

In this study, 999 accidents were investigated immediately after their occurence by teams of technicians; 219 of these same accidents were independently examined by a multidisciplinary team. Baseline information about the study area and national driver, vehicle, roadway and accident populations was acquired.

The author concludes that study results from the Indiana work may be generalized to the national accident picture.

Institute for Research in Public Safety, Tri-Level Study of the Causes of Traffic Accidents: Interim Report I, Volume I, Indiana University, Bloomington, January 1975. DOT HS-801 334.

This is the final report of the first year of the "Tri-Level Study of the Causes of Traffic Accidents." This is Volume I, covering study findings.

Institute for Research in Public Safety, Study to Determine the Relationship between Vehicle Defects and Failures, and Vehicle Crashes, Volume 2. Final Report, Indiana University, Bloomington, May 1973. DOT HS-800 851.

Results of the Indiana Tri-Level Accident Investigation Program are reported. The study focused on the determination of the relative roles played by human, environmental, and vehicular deficiencies in causing accidents.

This is the second of four volumes. It presents findings concerning component outage rates, representativeness of samples, and other study topics. (From author's abstract).

Institute for Research in Public Safety, A Procedures Manual for a Rapid-Response System to Generate Highway Crash Data - Final Report, Report No. DOT- HS-034-2-410-74-RR1, Indiana University, Bloomington, November 1974. DOT HS-801 259.

The NHTSA uses a multilevel approach for collecting the accident data it requires. One of these approaches is the bi-level study. The bi-level methodology consists of adding specialized data elements to a standard police accident reporting form. The desired data had therefore to be collectable by the police officer investigating the accident. This approach yielded valuable data but suffered from lengthy delays between the identification of an information void and the point where aggregated and analyzed data were available. The goal of the study was to analyze the bi-level methodology and redesign it to eliminate the delays. The result was the rapid-response system (RRS).

This article describes the procedures used in the RRS. (From author's abstract).

Institute for Research in Public Safety, Tri-Level Study of the Causes of Traffic Accidents: Interim Report II. Volume I: Causal Factor

Tabulations and Trends, Indiana University, Bloomington, December 1974. Unpublished.

Institute for Research in Public Safety, An Analysis of Emergency Situations, Maneuvers, and Driver Behaviors in Accident Avoidance, Indiana University, February 1975.

The IRPS effort involved the development of taxonomies of both accident situations and vehicle maneuvers that might be taken to avoid accidents. Attention was focused particularly on the "emergency traffic conflict" situations. These involve more than one roadway user and require rapid and unplanned actions to avoid collision. Subjective estimates of the probabilities of accident avoidance "success" were developed for all feasible combinations of emergency situations and maneuvers. (From author's abstract).

Institute for Research in Public Safety, Tri-Level Study of the Causes of Traffic Accidents: Interim Report I, Volume II, Appendices, Indiana University, Bloomington, January 1975, DOT HS-801 335.

This is the final report of the first year of the "Tri-Level Study of the Causes of Traffic Accidents." This is Volume II, containing the report apendices.

Institute for Research in Public Safety, TRI-LEVEL STUDY OF THE CAUSE OF TRAFFIC ACCIDENTS: INTERIM REPORT II (Volume III: Driver Vision and Knowledge Testing, and Other Special Study Topics), Report No. DOT-HS-034-3-535-75, Indiana University, March 1975.

This volume presents results of the reliability and validity assessments of a Dynamic Vision Tester (DVT). Test/retest comparisions were made to assess tests reliability, and a test was administered to both accident and control populations to determine the relevance of vision test scores to accident involvement and types of accident causing error committed. The authors also examine the relationship between driving knowledge test scores and accident involvement.

Also included in this report are results of the cluster analysis of both in-depth and on-site investigation team data, and a discussion of new methodologies for measuring driver characteristics and determining their relationship to accident causation. (From author's abstract).

Institute for Research in Public Safety, TRI-LEVEL STUDY OF TRAFFIC ACCIDENTS: INTERIM REPORT II (Volume II: Radar and Anti-Lock Braking Payoff Assessment), Indiana University, June 1975. DOT HS-801 631.

A set of accidents investigated in-depth by a multidisciplinary team was examined to assess the benefit derived from the hypothetical application of various combinations of radar and anti-lock braking systems. A total of 215 accidents was considered. An accident analyst evaluated on a case-by-case basis the benefit which would have been derived if one or more of the vehicles involved in each accident had been equipped with various types and combinations of these hypothetical systems.

On one extreme, it was found that two-wheel anti-lock systems, by themselves, have relatively little accident prevention potential. On the other extreme, the most complex of the systems defined, comprised of a non-cooperative radar system with both activation and warning potential, coupled with a four-wheel anti-lock system, would definitely have prevented 18% of the accidents, with some possibility of prevention of up to 41.9% of the accidents. (From author's abstract).

Institute for Research in Public Safety, Rapid Response System to Generate Highway Crash Data - Final Report, Report No. DOT-HS-034-2-410-75-RR5, Indiana University, Bloomington, January 1976. DOT HS-801-796.

The document presents the final report of a study to design, test and document a system which can rapidly provide specified highway crash data responsive to the needs of the NHTSA. The topic selected for the field test phase of the contract was the impact of the seatbelt-ignition interlock on restraint usage. Data were collected in Pennsylvania during four separate periods between November 1973 and January 1975. A total of 872 cases of accident-involved 1974 model passenger cars were studied. Another 876 cases of accident-involved 1973 models were also analyzed for comparison purposes. This document also presents the results of this test study. (From author's abstract).

Jacobs, H.H., "Mathematical Models Applied to Accident Processes," Mathematical Models of Human Behavior. Proceedings of a Symposium, Dunlap and Associates, Darien, Connecticut, 1955. AD 079 529.

The problem addressed here is one of developing some procedure for studying the contagion phenomenon in accident processes in the presence of a population liability distribution. The difficulty is that contagion and liability distribution effects can resemble each other in any set of accident data. The author suggests using what he calls an "accident probability rate model," in which at any instant of time, we consider the probability of the occurrence of an accident.

Jagger, D., Study to Determine an Accident Research Methodology, Report No. CAL VJ-1378-V-1, Cornell Aeronautical Laboratory Inc., Buffalo, July 1960.

Johnson, W.G., "Sequences in Accident Causation," Journal of Safety Research, Vol. 5, No. 2, June 1973, pp. 54-57.

The author describes the Management Oversight and Risk Tree (MORT) and urges its use in the analysis of accidents. MORT is similar to fault-tree analysis, and is basically a practical guide as to what facts to seek when conducting an accident investigation. It focuses on three major areas: specific oversights and omissions, assumed risks, and management system failures. Johnson stresses discovering the sequence of events leading to an accident as the best way to develop countermeasures.

Johnson, W.G., "MORT: The Management Oversight and Risk Tree," Journal of Safety Research, V7, N1, March 1975, pp. 4-15.

MORT (Management Oversight and Risk Tree) is a structure for investigating and analysing accidents. Though it is based in part on logic trees, the emphasis in MORT is on management functions. In fact, the MORT tree could be used even before an accident happened to review and assess preventive measures.

The focus is clearly on industrial accidents, and it is not clear MORT is applicable to highway safety. Johnson points out that MORT is too time-consuming for use in large numbers of accidents. The current (1975) structure - the generalized tree - identifies nearly 300 basic problems relating to cause or preventive measures. This suggests the complexity of the formulation.

Johnson, W.G., "Investigative Methods Useful in Safety," Rare Event/Accident Research Methodology, NBS Special Publication 482, Proceedings of a W kshop held at the National Bureau of Standards, Gaithersburg, Maryland, May 1976, National Bureau of Standards, U.S. Department of Commerce, Washington, D.C., July 1977, pp. 11-23.

Joksch, H.C., An Accident Trend Model - Final Report, Center for the Environment and Man, Inc., Hartford, Connecticut, March 1975.

A trend model for motor vehicle deaths is described. Expressions were developed for the effects of vehicle safety features and the proportion of small cars as a function of the calendar year. These expressions are used to adjust the number of deaths prior to fitting arbitrary models to past data, and to compute projected death rates under various assumptions of safety features and vehicle mix.

The only model consistently fitting the adjusted death rates for a base period, and giving good projections beyond, used the number of registered passenger cars in three age groups as independent variables. Other (less successful) predictor variables included the Federal Reserve Board Index of Industrial Production, and vehicle miles traveled.

The model is used to project the number of automobile occupant deaths to 1985.

Joksch, H.C. and J.C. Reidy, Jr., Construction of a Comprehensive Causal Network - Volume 2: Literature Review and Bibliographies, CEM Report No. 4206-583b, The Center for the Environment and Man, Inc., Hartford, Connecticut, September 1977. DOT HS-802 592.

The literature on accident causation was reviewed to identify empirical and hypothetical causal relations. The findings are presented. (From author's abstract).

Joksch, H.C., J.C. Reidy, Jr., and J.T. Ball, Construction of a Comprehensive Causal Network - Phase III: Final Report (Volume 1), CEM Report No. 4206-583, The Center for the Environment and Man, Inc., Hartford, Connecticut, September 1977. DOT HS-802 591.

A comprehensive network is presented which provides a conceptual framework for accident-related factors. The basic dimensions of this network are the elements (causal factors), and the time sequence. A coding s~heme organizes the factors according to time sequence, accident element, and hierarchical relationships within major categories of elements.

A significant aspect of this approach is the inclusion of the "driving cycle" in the time sequence. This cycle includes the driver perception, judgement, decision, and action. Emphasis is placed on the retention of "causal chains" or "links" between the various factors. This seems an important consideration.

The effort is, in many respects, an extension of the Calspan and fault-tree directions in accident-causation research. The implementation of this approach does not appear feasible in the foreseeable future since the necessary assessments on the part of investigating teams are considerably beyond the capabilities of current teams. Indeed, it is doubtful whether the factors involving the driver, his perceptions, and decisions, can ever be objectively ascertained within this approach. The results, while of greater detail and dimension, would still seem to suffer the same subjectivity as much of the current work. The value of the network developed, then, is primarily as a conceptual tool.

Kemp, C.D., "On a Contagious Distribution Suggested for Accident Data," Biometrics, June 1967, pp. 241-255.

Cresswell and Froggatt (1963) devised a model leading to a three-parameter distribution, which they called the "short" distribution, to describe accident data. It is the convolution of a Poisson distribution and a Neyman Type A distribution. The paper considers first its general properties. The authors then derive a recurrence relationship for the probabilities, and also the maximum-likelihood equations, from the probability generating function by a very simple differentiation method. An Algol program was written to solve these equations and an example is given. The efficiency of the method of moments for estimating the parameters is also examined. Results suggest that, in general, because of extremely high correlations between them, the estimates of the parameters (by either method) will be subject to very large sampling errors. This implies severe limitations on the use of the distribution. (From author's abstract).

Kemp, C.D., "An Elementary Ambiguity in Accident Theory," Accident Analysis and Prevention, Vol. 5, No. 4, December 1973, pp. 371-373.

Kemp points out that for any generalized power series distribution in which there is a simple general relationship between missing data and the parameter of interest (the bias), the modified distribution has the same functional form so that the bias cannot be separated from the parameter of interest.

Kemp, R.N., I.D. Neilson, G.C. Staughton, and H.A. Wilkins, A Preliminary Report on an On-The-spot Survey of Accidents, Report No. TRRL LR 434, Transport and Road Research Laboratory, Crowthorne, England, 1972.

Detailed investigations by the Road Research Laboratory into how road accidents occur were resumed with an on-the-spot study over a period of seven months in 1968-9. A total of 247 accidents was investigated. The method included judgement by the team as to the factors contributing to the accidents. It was found that vehicle factors and road factors each occurred in one quarter of the accidents, and that road user factors occurred in three quarters.

Braking and tire defects were sufficiently common to suggest that these factors should be studied further. Loss of control occurred in 40% of the accidents. The features of some of the main accident black spots were studied and remedial measures have been suggested.

The results reinforce the need for research into the conspicuity of vehicles to pedestrians, the optimum placing of warning signs on the approach to hazards, and the potentially dangerous movements of pedestrians. (From author's abstract).

Kianfar, F., "Optimal Design for Systems Safety Using Fault Tree Analysis and Dynamic Programming," Journal of Safety Research, Vol. 8, No. 3, September 1976, pp. 126-135.

In most cases, there are many design alternatives where the safety of

a given system is concerned. Each design alternative has a probability value for occurrence of an undesirable event (accident) in the system and a total cost. For a given probability value, there is a design that has the lowest cost and meets this probability. In this paper, a method is presented for finding the optimal design and its total cost without explicitly enumerating all the possible design alternatives. In addition, it is shown how the optimal cost and design change as the acceptable probability level of the undesirable event changes. The method uses fault tree analysis and dynamic programming techniques. The problem of selecting an optimal restraint system for a car is presented as an example and is solved by the method. (From author's abstract).

King, B.G., "Human Factors in Accident Causation," *National Safety Congress Transactions*, Vol. 6, 1960, pp. 44-50.

This article describes the role of the physician and the safety engineer in accident prevention. The author cites a need for a safety philosophy to be instilled in designers and operators to effect a reduction in accidents.

Knoblauch, R.L. et al *Causative Factors and Countermeasures for Rural and Suburban Pedestrian Accidents - Accident Data Collection and Analyses — Appendices*, BioTechnology, Inc., Falls Church, Virginia, June 1977. DOT HS-802 474.

This was an in-depth clinical assessment study of pedestrian accidents. Included in this volume are forms and documents referenced in the study's final report.

Knoblauch, R.L., *Causative Factors and Countermeasures for Rural and Suburban Pedestrian Accidents: Accident Data Collection and Analysis. Phases I and II*, BioTechnology, Inc., Falls Church, Virginia, March 1977. DOT HS-802 266.

This was an in-depth clinical assessment study of pedestrian accidents in urban and rural areas. Subjective judgements were made by field investigators in determining the causes of accidents. Exposure data were collected by roadside survey.

Countermeasures are suggested for pedestrian accident groups in similar circumstances.

Kontaratos, A.N., "A Systems Analysis of Road Casualties in the United States," Accident Analysis and Prevention, Vol. 6, No. 3/4, December 1974, pp. 223-241.

Kontaratos rejects the epidemiological approach to accident causation in favor of a systems approach. Factors are associated with the driver, vehicle, environment, or combinations of these, and the analysis is aimed at developing action programs to ameliorate these factors. To measure the cost-effectiveness, he concludes, we must be prepared to measure system losses before and after an action program is put into effect.

Kritz, L., "On the Classification of Accidents by Type," Paper presented at the OECD symposium on the use of statistical methods in the analysis of road accidents, Crowthorne U.K., April 1969.

Kritz remarks on the need to develop a priority system for determining causes of accidents which would enable the investigator to determine the primary cause. This is difficult, he points out, since accidents are rarely caused by a single factor, but rather by an intimate interaction of various factors. Thus, it is often impossible to determine which factor was the more important.

Road traffic is viewed as a man-milieu system in which the driver and his environment must be well adapted in order for the system to function without major problems. Kritz believes the dysfunctions in the man-milieu adaptations must be looked at very closely to determine (and classify) situations in which adaptation breaks down.

A classification system much used in Sweden has, as a leading principle, the intended courses of vehicles immediately before the accident. The course of the vehicles after evasive maneuvers have been attempted is irrelevant to this scheme. Thus, a head-on collision resulting from a driver steering left to avoid impact with a stopped vehicle in his headway would not be classed as a head-on, but rather as an overtaking accident. In this scheme, the on-coming vehicle is a "traffic disturbance." The search for "traffic disturbances" is essential to determining accident causation by this scheme.

The system has some weaknesses but offers the investigator an opportunity to view more closely the accident situation in the immediate pre-crash phase. It also provides a new perspective in assessing the interactional quality of the traffic situation.

Kurucz, C.N. and B.W. Morrow, "A Causal Structure for Single Vehicle Accidents," Motor Vehicle Collision Investigation Symposium Volume I: Proceedings, Report No. ZQ-5731-V-1, Calspan Corporation, Buffalo, pp. 535- 549. DOT HS-801 979.

Kurucz describes a causal model developed at the University of Miami for use in single vehicle accidents. The model may be easily adapted for use in other accidents simply by considering one vehicle at a time.

The scheme consists of an event sequence and the causal factors involved in these events. The author believes that his system makes the search for countermeasures more efficient.

Kwong, K.W., J. Kuan, and R.C. Peck, Longitudinal Study of California Driver Accident Frequencies I: An Exploratory Multivariate Analysis - Final Report, California State Department of Motor Vehicles, Sacramento, June 1976.

This paper presents an explorative multivariate analysis of driver license records. Stepwise regression techniques are used to develop models to predict accident involvement and improve the "point system."

Significant variables involve previous driving violations, previous accident involvement, sex, and drivers with black hair. The "best" regression model explains only 7% of the total sum of squares (variation). A negative binomial is shown to handle the distribution of accidents for each driver very well (x^1=.71, p>.70).

Mack, R.B., Engineering Science Techniques in Experimental Case Studies of Traffic Accidents, Traffic Institute, Northwestern University, Evanston, Illinois, 1960.

Mack, R.B., Engineering Science Techniques in Experimental Case Studies of Traffic Accidents, Traffic Institute, Northwestern University,

Evanston, Illinois, 1960.

This report describes the activities of the engineering member of the research team. The engineer is primarily interested in the vehicle and road in relation to accidents. The techniques and tools used by him in the data gathering process are described. The evaluation of the engineering data and its integration into the comprehensive case study are outlined. Mapping positions of traffic units at various times during the accident is an important engineering contribution to accident reconstruction. Twenty-two potentially hazardous conditions were found on ten cars examined in detail, though none was considered to have contributed to the specific accident. (From author's abstract).

Mackay, G.M., Causes and Effects of Traffic Accidents:Part III - The Vehicles, Department of Transportation and Planning, University of Birmingham, June 1969.

This is one of five volumes describing a British study of roadway accidents using the clinical assessment approach. The similarities to the Indiana study are striking, and the conclusions of the two groups are not dissimilar.

Major differences arise from the differing vehicle populations. Smaller cars are the rule in the U.K., along with a larger population of motorcycles and bicycles. The authors also note that right turns are three times as dangerous as left turns. In the U.S., one would expect the opposite to be true.

636 accidents were examined, involving 1049 vehicles.

Mateyka, J., R. Danzeisen, and D.W. Weiss, "Fault- Tree Applications to the Automobile Industry," SAE 730587, Society of Automotive Engineers, Automobile Engineering Meeting, Detroit, May 1973.

"Fault tree" is a name given to a logic diagram that develops all of the subsystem and component faults and combinations of faults which can result in particular system symptoms or faults. This type of logic diagram can be extremely useful in all phases of automobile design and service. Applications are discussed to the following areas:

1. As a reliability tool for identifying and cataloging specific problems, to preclude their being incorporated in new designs.

2. As a diagnostic aid to maintenance personnel in systematically screening potential vehicle performance problems.

3. As an aid in assessing accident causation factors and the potential contribution of vehicle defects to accidents.

Examples in each area are presented. Particular emphasis is placed on the value of such logic diagrams over conventional troubleshooting charts and manuals in aiding mechanics to pinpoint specific problems. Problems and pitfalls in developing such detailed logic diagrams and implementing the results in a field service environment are also discussed. (From author's abstract).

Mateyka, J.A. and J. Talley, "System Safety/Risk Analysis Techniques Applied to Motor Vehicles and Rapid Transit Systems," Journal of Safety Research, Vol. 9, No. 1, March 1977, pp. 2-14.

The article concerns fault tree analysis directed at the automobile, the transit bus, and the rail rapid transit system. The authors discuss the utility of fault tree analysis techniques in setting safety requirements and goals for new equipment designers and system managers. The prioritization of safety requirements and goals was obtained through effects or cost-benefit analyses and was an integral part of the fault tree analysis technique. The safety analysis of the automobile was confined to component degradation as a causation factor in automobile accidents. The transit bus safety work analyzed over 92 types of accidents, both onboard and offboard. Two major outputs were derived from the safety analysis of rail rapid transit systems. These were safety criteria and a system safety program plan for the future design and development of such systems. In all three transit modes the analytical methodology, results, and conclusions are presented.

McClean, J.R. and E.R. Hoffman, "Analysis of Drivers' Control Movements," Human Factors, 1971, Vol. 13, No.5, pp. 407-418.

This work examines the periodicity of steering wheel reversals.

Control movements were found to be in two frequency ranges: .1 to 0.3 hz. and 0.35 to 0.6 hz.

This suggests that two different vehicle output variables are being controlled by the driver, or alternatively, demonstrates the use and nonuse of preview.

McDaniel, W.C., "A Measure of Safety Effectiveness," Proceedings of the 6th Congress of the International Ergonomics Association, 1976, pp. 222-225.

Managerial decisions concerning safety programs are often made using accident rates as a criterion of safety effectiveness. This paper describes a concept based on the Poisson process that may provide a better criterion of safety effectiveness than presently used accident rates. Results indicate this conceptual model may be more sensitive than accident rates in determining overall safety effectiveness and hazard reduction. (From author's abstract).

McKnight, A.J. and B.B. Adams, DRIVER EDUCATION TASK ANALYSIS - Volume I: Task Descriptions - Final Report, Technical Report 70-103, Human Resources Research Organization, Alexandria, Virginia, November 1970. DOT-HS 800 367.

McKnight, A.J. and B.B. Adams, DRIVER EDUCATION TASK ANALYSIS - Volume II: Task Analysis Methods - Final Report, Report IR D1-70-1, Human Resources Research Organization, Alexandria, Virginia, November 1970. DOT-HS 800 368.

McKnight, A.J. and A.G. Hundt, DRIVER EDUCATION TASK ANALYSIS - Volume III: Instructional Objectives - Final Report, Technical Report 71-9, Human Resources Research Organization, Alexandria, Virginia, March 1971. DOT-HS 800 369.

McKnight, A.J. and A.G. Hundt, DRIVER EDUCATION TASK ANALYSIS - Volume IV: The Development of Instructional Objectives - Final Report, Report IR D1-71-1, Human Resources Research Organization, Alexandria, Virginia, March 1971. DOT-HS 800 370.

These publications describe results of a study of specific driving behaviors with a view to developing objectives for driver education and evaluating tools by which attainment of these objectives can be measured.

The first task was the creation of a list of specific driving behaviors affecting the transportation system. Goals of the transportation system (safety, efficiency, comfort, and responsibility) were analyzed with a view to the specific behaviors they encourage.

Over 1700 driving behaviors are listed. They are organized as follows:

I. On-road

- A. Basic control
- B. General Driving
- C. Situational

II. Off-road

- A. Pre-driving
- B. Maintenance
- C. Legal Responsibilities

Each of these behaviors was then rated by several highway safety authorities "in terms of its criticality to the highway transportation system."

Based on this list of rated behaviors, a list of rated performance objectives for beginning drivers was prepared. Finally, a driving test and a written exam were created to measure driving ability and knowledge. Performance objectives with high criticality ratings were given proportionately more weight in the scoring of these tests.

This study is of little help to us in terms of methodology or specific causes of accidents.

McLean, A.J., "The Development of an In-Depth Study of Accidents in Metropolitan Adelaide," Paper 11, Road Accident Information Seminar, C berra, March 1974.

The author discusses his plan for a study of accidents in metropolitan Adelaide (Australia). He is particularly interested in the environment, and he discusses features of the environment (signing, road surface, traffic controls, etc.) that he believes are worthy of study. Another of his concerns is the elimination of bias in investigators.

Mela, D.F., "Exposure Data Needs," Motor Vehicle Collision Investigation Symposium Volume I: Proceedings, Report No. ZQ-5731-V-1, Calspan Corporation, Buffalo, pp. 132-142. DOT HS-801 979.

The author discusses the NHTSA's need for exposure data and the uses to which it will be put. NASS is seen as a major tool in the collection of this information, since NASS makes it possible to collect detailed data on road type, driver age and sex, and vehicle make.

Mihal, W.L. and G.V. Barrett, "Individual Differences in Perceptual Information Processing and Their Relation to Automobile Accident Involvement," Journal of Applied Psychology, 1976, Vol.61, No. 2, 229-233.

Mihal and Barrett studied the relationship of perceptual information processing to accident rates of drivers. Both field dependence (visual) and selective attention (auditory) were found to correlate positively with accident frequency. Reaction time measures were not predictive.

Miller, C.H., C.R. Baird, and V. Doiron, An Improved Causal Factor Recording Procedure for Highway Accidents, Vehicle Safety Research Team, Nova Scotia Technical College, Halifax, Undated.

Miller provides a method of coding causation factors defined in Fell's model (expanded to include the 9-cell NHTSA highway safety program matrix). In the human precrash cell, four effects and five causes of information processing errors are defined by the model.

Though Miller agrees with the categories, he criticizes the terms "cause" and "effect." Effects become causes for subsequent effects, he notes, and thus the words are ambiguous.

The coding scheme he presents for Fell's model uses a 5-character code for 1) the NHTSA matrix number; 2) a causal statement number from an expanded version of Fell's model; 3) a ± value for increased risk or reduced severity; 4) a confidence index; and 5) an accident contribution index. This latter is a measure of the importance of the factor to the accident in question. This is expressed by an integer from one to nine, the sum of the indices for all factors being nine. This, he claims, reduces subjectivity by removing the concept of a "principal cause."

Regarding his coding scheme, Miller writes that when the sum of the positive indices equals the sum of the negative indices, the accident is insignificant with respect to that particular driver and vehicle. This is not clear, and seems questionable.

In general, this work has some value for coding accident data vis-a-vis Fell's causation model. However, it is not clear how the chronology of events would be preserved. In addition, the method does not address any of the problems of Fell's work.

Mucciardi, A.N., E.C. Orr, and J.K. Chang, Highway Safety Program Effectiveness Model. Final Report, ADI 517, Adaptronics, Inc., McLean, Virginia, September 1977. DOT HS-802 594.

The purpose of this project was to construct a model capable of relating highway safety (DOT/NHTSA) program outputs to (intermediate) risk factors, and then to accidents, injuries, and fatalities. The model inputs and outputs were obtained from a conceptual Causal Network which displayed the factors believed to influence the occurrence of an accident and their postulated interdependencies in leading to an accident. Also depicted in the network were the outputs of the highway safety activities as they were believed to interact with the intervening factors.

The models constructed were each nonlinear polynomial functions known as Adaptive Learning Networks (ALNs). The ALN methodology was applied to the factors set forth in a Causal Network constructed especially for this project. The relationships between the program outputs, the intervening factors, and the occurence of accidents displayed in the network were tested along with various other variable combinations using nationally representative data. In essence, the postulated network was checked and appropriately altered so as to trace quantitatively the effects of the outputs of highway safety programs in deterring accidents through the control of the intervening factors. This deterrent effect was estimated by asympotically reducing the outputs of the highway safety programs to zero and observing the impact of these reductions on the intervening factors, and in turn, the effect of these alterations in the intervening factors on accident occurrences. (From author's abstract).

Mucciardi, A.N., E.C. Orr, and J.K. Chang, Highway Safety Programs Effectiveness Model - Final Technical Report, Report No. ADI 517, Adaptronics, Inc., McLean, Virginia, September 1977. DOT HS-802 594.

MVMA Task Group # 5, R.T. Bundorf, Chairman, Data Acquisition for Accident Causation Analysis (With Emphasis on Vehicle, Handling, Safety Bulletin Number T.G. #5-79, April 1975.

National Committee on Uniform Traffic Laws and Ordinances, "Accident Investigating and Reporting," Traffic Laws Commentary, Vol. 4, No. 2, September 1975.

This pamphlet is a reference work on state laws concerning accident reporting. It describes the differing definitions of "accident," and the duties of drivers, vehicle owners, garages, and police. Also listed are the property damage reporting thresholds in the various states. The authors note a trend away from written accident reports.

Neilson, I.D., The Theoretical Reconstruction of Events Leading to an Impact in a Road Accident, TRRL LR 575, Transport and Road Research Laboratory, Crowthorne, England, 1973.

An accurate reconstruction of events immediately leading up to an accident is desirable for the police, insurance companies, and researchers on road safety. An understanding of vehicle impact dynamics helps in these investigations because it provides a link between the various pieces of evidence which may be available:

1. The verbal evidence.

2. The position of damage to vehicles and to fixed objects.

3. The extent of damage to vehicles.

4. Tire marks on the road and the condition of the surface.

5. Movements of vehicles after impact.

6. The distribution of debris.

Such evidence may enable the initial paths and speeds of travel to be estimated. The relative masses and the initial point of contact also determine how the vehicles rebound after impact. The relative stiffnesses of the parts of the vehicle in contact play an important part in the situation, though their evidence can be misleading.

Some examples of accident situations demonstrate that the estimation of velocity changes at impact is a relatively complicated task, and the results vary greatly with the assumptions made. It is concluded that though theoretical calculations may help in the understanding of a situation, their results must be used with discretion. (From author's abstract).

Nertney, R.J. "Practical Application of System Safety Concepts," Professional Safety, Vol. 22, No. 2, February 1977, pp. 29-33.

The author recommends the use of advanced systems of safety analysis for even small industrial operations. What is known about safety can be of value to any industry, and what has been done can be scaled down and applied to industrial operations in a practical and cost-effective manner.

MORT is of value as a conceptual framework and not merely as a set of rules for conducting a rigorous accident investigation.

North Atlantic Treaty Organization, Committee on the Challenges of Modern Society, Accident Investigation, Report No. CCMS 26, National Highway Traffic Safety Administration, Washington, D.C., July 1974.

Under the auspices of NATO's Committee on the Challenges of Modern Society, thirty-two accident investigation teams in nine countries were organized to collect information on vehicle deformation and injury severity. Standardized report forms and a common coding scheme were used. This was basically a pilot study to test the feasibility of establishing an on-going international accident investigation system.

The methodology has little application to causation research.

O'Day, J., A.C. Wolfe, and R.J. Kaplan, Design for NASS: A National Accident Sampling System - Volume 2: Appendices, Report No. UM-HSRI-SA-75-14-2, Highway Safety Research Institute, The University of Michigan, Ann Arbor, May 1976. DOT HS-801 914.

A design is presented for a national accident investigation program based on sampling theory. By limiting the number of investigations within a strict sampling plan it is possible to record sufficient detail about each accident to produce national estimates of injury, property damage, and other accident characteristics which will be useful in cost-benefit analyses. The system described has three major facets - a program for continuous acquisition of data of a random sample of all towaway, pedestrian, bicycle, and motorcycle accidents occurring in the U.S., a program for occasional acquisition of additional data on selected topics quickly and on-call, and a program for conducting in-depth or multidisciplinary accident investigations for accidents of particular interest. (From author's abstract).

O'Day, J., A.C. Wolfe, and R.J. Kaplan, Design for NASS: A National Accident Sampling System - Volume 1: Text, Report No. UM-HSRI-SA-75-14-1, Highway Safety Research Institute, The University of Michigan, Ann Arbor, May 1976. DOT HS-801 913.

O'Day, J., Interviewee, "Accident Data Needs and a National Accident Sampling System," HSRI Research Review, Vol. 6, No. 2, Nov.-Dec. 1975, pp. 3-8.

In this interview, O'Day argues for a National Accident Sampling System (NASS). He explains the value of the plan, developed at HSRI, in providing accurate, detailed, and consistent data.

Older, S.J. and B.R. Spicer, "Traffic Conflicts — A Development in Accident Research," Human Factors, Vol. 18, No. 4, August 1976, pp. 335-349.

Paddock, R.D., "The Traffic Conflicts Technique: An Accident Prediction Method," Transportation Research Record, No. 486, 1974, pp. 1-10.

Peranio, A., An Expanded Cybernetic Model for Analyzing Driver Behavior, International Symposium on Psychological Aspects of Driver Behavior, Noordwijkerhout, The Netherlands, August 1971.

The author concentrates on the physiological limitations of man as an operator of automobiles. Stressing the complexity of the perception-decision-action sequence in driving, the author recommends reducing the number of complex driving environments. This would give the physiologically degraded driver more time for completion of the sequence.

Peranio, A., "Conceptualization and Use of Road Safety and Traffic Engineering Formulas," Traffic Quarterly, Vol. 25, No. 3, July 1971, pp. 429-446.

Perchonok, K., Accident Cause Analysis, Report No. ZM-5010-V-3, Cornell Aeronautical Laboratory, Inc., Buffalo, July 1972. DOT HS-800 716.

A system was developed to describe the process of accident generation. It was then modified and applied to accident reports from a variety of sources ranging from routine police reports to intensive, on-scene investigations.

Comparisons are made among the samples in terms of their value in providing causation information. Frequently occurring accident causal structures are determined. The influence upon modes of involvement and culpability are measured for drinking, lighting conditions, driver education, and selected driver characteristics. (From author's abstract).

Perchonok, K., "The Accident Generation Process," Motor Vehicle Collision Investigation Symposium Volume I: Proceedings, Report No. ZQ-5731-V-1, Calspan Corporation, Buffalo, pp. 481-503. DOT HS-801 979.

The author describes what he calls "causal structure." The most important parts of this scheme are the critical event (the last maneuver before the crash becomes inevitable), the target (the accident event, such as a rollover or head-on collision), the accident configuration, the critical reason (primary cause), and culpability (degree of blame).

Perchonok, K., "Application of the Causal Structure," Motor Vehicle Collision Investigation Symposium Volume I: Proceedings, Report No. ZQ-5731-V-1, Calspan Corporation, Buffalo, pp. 524-534. DOT HS-801 979.

Perchonok offers some examples of how accident data may be coded in terms of cause, a discussion of the role of such analysis in accident prevention, and a few remarks on directions for accident causation research.

Perchonok, K., Driver and Vehicle Characteristics as Related to the Precipitation of Accidents, Report No. ZQ-5276-V-4, Calspan Corporation, Buffalo, May 1977. DOT HS-802 355.

Accidents reported by police were coded in terms of elements of the accident generation process. Analyses were done to relate general driver and vehicle characteristics to responsibility for the accidents and to reasons for the accidents. Driver and vehicle characteristics included driver age, sex, license type, restraint use, and drinking. Vehicle characteristics were age and general vehicle type. The main reasons for accident generation were information failures, control failures, and control failures associated with slippery roads. (From author's abstract).

Philipson, L.L., Investigation of the Feasibility of the Delphi Technique for Estimating Risk Analysis Parameters, Institute of Safety and Systems Management, University of Southern California, Los Angeles, April 1974.

Philipson used a Delphi method to assess the liklihood and the costs of accidents in transporting hazardous materials. These then formed the inputs to a previously developed risk-analysis model for evaluating alternative transportation modes.

Phillips, D.P., "Motor Vehicle Fatalities Increase Just After Publicized Suicide Stories," Science, Vol. 196, No. 4297, June 24, 1977.

The study of suicide on the highway has been hampered by a lack of clever methodology. Phillips' ingenious study suggests one direction for study.

The article is an extension of earlier work showing that suicides reported prominently in newspapers stimulate a wave of imitative suicides for a few days thereafter. In the current study, Phillips shows that motor vehicle deaths also rise after such stories appear. Further, the more publicity given the suicide, the greater is the increase in roadway fatalities. The average increase in fatalities is 9.12% in the week following the story.

Phillips' work suggests that previous estimates of suicide as a cause of highway fatalities are too low.

Porterfield, A.L., "Traffic Fatalities, Suicide, and Homicide," American Sociological Review, Vol. 25, December 1960, pp. 897-901.

The author, looking at sixty major U.S. cities, finds that the combined homicide/suicide rates correlate with traffic fatality rates. The more homicides and suicides a city has, the more fatal car accidents it will have. The study is an attempt to demonstrate that the level of violence immanent in a society is a factor in accident causation.

Rapoport, A., "Research on the Alcoholic Driver: A Critique," The Prevention of Highway Injury, Proceedings of a Conference held April 19-21, 1967, Highway Safety Research Institute, The University of Michigan, Ann Arbor, 1967, pp. 78-85.

The difficulties in developing effective countermeasures for the problem of the drinking driver are the subject of Dr. Rapoport's address. His remarks focus on the perception of risk by the individual and social attitudes toward accident prevention.

Though there is little here on accident causation per se, the discussion is certainly relevant to any effort at tranforming knowledge about safety into accident reduction.

Raymond, S., and M.D. Hodgkinson, "The Relationship between Road Accidents and Urban Structure," Transportation Planning for a Better Environment, Plenum Press, N.Y., 1976, pp. 361-371.

The study of the variation in road accident statistics between different nations has become a well-accepted part of road accident analysis over the last few years. Little work has been completed, however, on the internal variations within one country, between different urban areas. The research outlined in this paper attempted to look at this variation within England, Scotland and Wales, using a multi-stage statistical approach. The variation was studied both spatially and temporally using data from the years 1960-1970. Such studies perform a two-fold function. Besides being valuable for use in deriving basic properties, and much needed system models, they are also useful in investigating the relative effectiveness of countermeasure treatments. (From author's abstract).

Recht, J.L., "Systems Safety Analysis: The Fault Tree," National Safety News, Vol. 93, No. 4, April 1966, pp. 37-40.

This brief introduction to the fault tree describes its initial development in the aerospace industry and its later use in product safety and reliability. Recht suggests a wider application in safety engineering, though uses in highway safety are not mentioned.

Recht gives a short description of the method, and illustrates it with an example in a home fire alarm system, restricting the discussion to its qualitative use. Quantitative uses are mentioned later, along with shortcomings that have been overcome by computerization.

Rice, R.S. and F. Dell'Amico, An Experimental Study of Automobile Driver Characteristics and Capabilities, Calspan Report No. ZS-5208-K-1, Calspan Corporation, Buffalo, N.Y. March 1974.

An experimental program to obtain quantitative data on how drivers use the performance and handling characteristics of their vehicles was performed. Over one hundred drivers participated in the experiment, which consisted of self-paced driving through a specially-constructed course. C^ntinuous measurement of primary input variables (steering wheel motions and brake pedal activity) and the principal vehicle responses (speed and lateral and longitudinal accelerations) were made throughout each trial. Total time in the course and incidents of failure to maintain pąth were also measured. Driving techniques (e.g., hand position on the wheel, foot used for braking) of the subjects, who were selected to provide an appropriate representation of the driving population with respect to age, sex, and years of driving experience, were subjectively measured.

Experimental results are analyzed primarily in terms of the application of the maneuvering potential of the vehicle used by the subjects in negotiating the the various driving tasks which they encountered in the course. It is interesting to note that the subjects, even when encouraged to drive at the limit of their willingness, did not normally attempt to operate near the limiting capabilities of the automobiles. It is concluded that in addition to the analyses given in this report the extensive data accumulated in the program can also be applied to many other investigations of driver behavior. (From author's abstract).

Rorbech, J., "A Model Describing the Motorway Traffic Flow Process Related to the Traffic Areas Level of Risk," Traffic Speed and

Casualties. Proceedings, Laboratory of Road Data Processing, Copenhagen, April 1975, pp. 84-96.

The author describes a road traffic model. A summary is given of some of the most important results from work on the model, particularly with reference to the problems concerning the influence of speed limits on the traffic flow process and the accident risk of the motorists. The road traffic model is based on the theory of stochastic processes, and in its construction it is closely related to a special data collection technique. The data used in the work on the model were recorded on the Elsinore Road, a 4-lane motorway north of Copenhagen. (From author's abstract).

Ross, H.L. and R.B. Mack, Synopses of Accidents in Experimental Case Studies of Traffic Accidents, Traffic Institute, Northwestern University, Evanston, Illinois, 1960.

Ross, H.L., Schematic Analysis of the Driving Situation, Traffic Institute, Northwestern University, Evanston, Illinois, 1960.

Ross introduces the "social model" (the interaction of the competing goals of drivers) into the analysis of the vehicle-roadway-driver system.

Ross, H.L., Ignorance of Collision Course as a Factor in Traffic Accidents, Traffic Institute, Northwestern University, Evanston, Illinois, 1960.

Experimental Case Studies of Traffic Accidents looked closely at forty-three accidents. Of these, a considerable number were found to involve a lack of awareness, on the part of one or both drivers, that a collision was imminent.

This lack of awareness is divided into two classes - delayed perception and erroneous prediction.

Delayed perception is the result of impediments to vision or of inattentiveness. An impediment can be a dirty windshield or a mischievious child passenger. It can also be a view obstruction outside the car, such as a parked car or a tall hedge.

Erroneous predictions resulted when other vehicles failed to perform as expected. The reason may be a failure to signal or a failure in receiving a signal, or actions that differ from those prescribed by law or custom.

Rubinstein, E., "The Mobile In-Depth Accident Survey in Victoria," Paper 12, Road Accident Information Seminar, Canberra, March 1974.

The author describes procedures for a clinical assessment study of injury-producing and fatal accidents in Victoria (Australia). The plan draws on earlier studies in Brisbane and Adelaide.

Sabey, B.E., "Accident Analysis in Great Britain," First International Driver Behavior Research Conference, Zurich, October 1973.

This paper outlines the various levels of accident investigation in Britain, and the ways in which the methods complement each other. The value of national statistics, for example, is in identifying gross trends, while vehicle defects may more easily be discerned in in-depth on-scene investigations.

Sabey, B.E., "Accident Studies Related to Vehicle Safety," Sixth International Conference on Experimental Safety Vehicles, Washington, D.C., October 1976.

Sacks, W.L., "Vehicle Factors and Traffic Accident Causation: an Interim Report," Traffic Quarterly, January 1973.

The author discusses vehicle factors in accidents with a view to countermeasures. He demonstrates methods of cost-benefit analysis for safety standards, and suggests "informal" inspection of large numbers of vehicles coupled with a thorough examination of only a few vehicle elements.

Scerbo, F.A. and J.J. Pritchard, "Fault Tree Analysis: A Technique for Product Safety Evaluation," Professional Safety, Vol. 22, No. 5, May 1977, pp. 12-16.

The enactment of the Consumer Product Safety Act and recent product liability legal trends have made product safety an area of major concern for the manufacturer. The article reviews Fault Tree Analysis as it may be used for product safety analysis. (From author's abstract).

Schaeffer, M.H., "An Evaluation of Epidemiologic Studies Related to Accident Prevention," Journal of Safety Research, Vol. 8, No. 1, March 1976, pp. 19-22.

The epidemiologic approach was first suggested as a tool for the study and prevention of accidents in 1948. Most epidemiologic accident research, however, has been performed in the area of traffic accidents rather than industrial accidents. There are some notable examples of the application of an epidemiologic approach to occupational accident studies and these are discussed. The utility of epidemiologic methods for reducing occupational accidents lies mainly in the capability to define the nature and extent of a new problem area. As a research strategy, however, the epidemiologic approach has the following major shortcomings: (1) no systematic use of the approach in practice; (2) failure to classify environments; (3) failure to study social and psychological indices of the host; (4) failure to study the influence exerted by the socioeconomic environment; and (5) too much concentration on broad descriptive survey results. To achieve its theoretical potential, future epidemiologic research must correct these flaws. (From author's abstract).

Schmidt, R., "Accident Investigation in the Evaluation of Safety Standards - A Survey of Methodology and Applicability," Proceedings of the Fourth International Congress on Automotive Safety, Washington, D.C., 1975, pp. 605-665.

Despite the lack of a nationwide data base for accidents, data can be prepared for complex cost/benefit analysis of safety measures in ways suitable for the evaluation of safety standards from the automotive engineer's point of view. The author argues that absolute nationwide numbers of injuries versus accident type, seat position, impact location, single vehicle, and vehicle-to-vehicle accidents can be determined. He describes an accident projection technique and a method of evaluating accident data with a view to accident mechanics. He also suggests a method of judging the effectiveness of safety measures.

Shaffer, J.W., "Biorhythms and Highway Crashes: Are They Related," Archives of General Psychiatry, Vol. 35, No. 1, January 1978.

The theory of biorhythms is explained and its literature reviewed. The Japanese transportation system has used biorhythm theory to reduce accidents, but these reports are sketchy and not well substantiated. None of the other studies examined showed any significant corelation between biorhythms and accidents.

Shaffer's work looked at 135 male driver fatalities or accidents having the potential for fatal driver injury. In all, the case drivers were legally culpable. Their birthdays were checked and their biorhythms calculated for the accident day. No significant relationships were found.

Shaoul, J.E., "The System Concept and the Study of Accidents," Transportation Planning for a Better Environment, Plenum Press, New York, 1976, pp. 339-348.

The author's major idea is that the cybernetic research model for accident research is faulty. The notion of a driver/car/road/environment system is handy, but is only as useful as the assumptions it makes about the driver. These, Shaoul asserts, are often simplistic in that they reduce the human driver to a passive receptor of stimuli. Any psychological view of man as other than an open, adaptive being who creates his own universe is inadequate.

Shinar, D., S.T. McDonald, and J.T. Treat, "The Interaction between Causally-Implicated Driver Mental and Physical Conditions and Driver Errors Causing Traffic Accidents," Proceedings of the 6th Congress of the International Ergonomics Association, 1976, pp. 329-334.

The relationships between driver behaviors causing and immediately preceding an accident (direct causes) and accident causative impairments in drivers' predisposing mental and physical states (indirect causes) were analyzed from a representative sample of 420 traffic accidents. A Relative Involvement Factor (RIF) was developed to reflect the change in the likelihood of any accident-causing behavior being implicated, given the existence of a causally relevant mental or physical impairment. The analysis indicates that causative conditions and states suppress certain direct causes while increasing the likelihood of others. Specific relationships are discussed. (From author's abstract).

Smeed, R.J. "The Usefulness of Formulae in Traffic Engineering and Road Safety," Accident Analysis and Prevention, Vol. 4, No. 4, December 1972, pp. 303-312.

This is a response to a critique by Peranio of formulae used in traffic engineering. Smeed objects to a blanket rejection of all such formulae, and makes a case for a formula he had prepared in 1948 to summarize data on road deaths, vehicles, and population.

Smillie, R.J., and M.A. Ayoub, "A Computer Simulation Approach for Analyzing Occupational Accidents," Proceedings of the 6th Congress of the International Ergonomics Association, 1976, pp. 226-235.

This study used a computer algorithm, the Graphical Evaluation and Review Technique (Q-GERT), to model the accident process. Five simulation examples were presented to illustrate the basic concepts and the flexibility of the proposed approach. Discussion focuses on the usefulness of this simulation technique as an aid for the accident investigator in the discovery of potential hazards in the occupational system. (From author's abstract).

Snyder, H.L., "Braking Movement Time and Accelerator-Brake Separation," Human Factors, 1976, Vol. 18, No. 2, pp. 201-204.

Snyder studied accelerator/brake control separation distances, for which he noted no prior exerimental evidence. The recommended separation currently used as a design standard produced significantly longer reaction times than an experimental configuration. The new configuration would double the lateral separation of the two controls and have no vertical separation.

Snyder, J.C., "Environmental Determinants of Traffic Accidents: An Alternate Model," Transportation Research Record, No. 486, 1974, pp. 11-18.

The author used the Oakland County (Michigan) accident file to determine the correlation between accident rates and the type of urban structure adjacent to the roadway. He found the number of accidents could be predicted from the type of roadway and the traffic volume of the road. The number of intersections, type of road, and number of young drivers all interact with traffic volume to determine the number of accidents.

Staughton, G.C. and V.J. Storie, Methodology of an In-Depth Accident Investigation Survey, TRRL LR 762, Transport and Road Research Laboratory, Crowthorne, England, 1977.

The circumstances leading up to the occurrence of road accidents are so complex that a reliable assessment of accident causation can only be made with detailed knowledge of the many aspects of road environment, vehicle and road user which may have contributed to the accidents. This report describes in detail the techniques adopted for an On-The-Spot investigation into accident causation starting with attendance at the scene and ending with a full assessment of the contributing factors.

The organization, staffing, investigating and analytical procedures used are described; difficulties encountered and possible improvements in technique are also discussed. (From author's abstract).

Stimpson, W.A., W.K. Kittelson, and W.D. Berg, "Methods for Field Evaluation of Roadway Delineation Characteristics," 56th Annual Meeting of the Transportation Research Board, January 1977.

Sublett, F.L. and W.T. Roe, "Human Factors/ Ergonomic Aspects of Vehicular Accident Investigation - 1975 Update," SAE 750898, Society of Automotive Engineers, Automobile Engineering Meeting, Detroit, October 1975.

This paper presents a case for the growing application of Human Factors/Ergonomic expertise to develop decisions that take place within the transportation industry. It offers a definition of the HF/ERG engineering in traffic safety, research, training, and education. (From author's abstract).

Surry, J., Industrial Accident Research: A Human Engineering Appraisal, Department of Industrial Engineering, Toronto University, Ontario, June 1969.

Surveys & Research Corporation, Data Coding System for Highway Accident Reports, Surveys & Research Corporation, Washington, D.C., August

1969.

Recognizing that the police accident report, though not uniform, will continue to be an important source of information to highway safety researchers, the authors undertook a project to design a system to code accident reports into a single data fund.

The work involved analysis of 3,000 fatal highway accidents from six states.

Tabachnick, N.D., "A Theoretical Approach to Accident Research," Bulletin of Suicidology, No. 6, Spring 1970, pp. 18-23.

This article concerns the psychological reasons for accidents. The death instinct and related theories are discussed, as well as the concepts of mental illness and adaptational mishaps.

There is some worthwhile theory here on human motivations, but Tabachnick adds little to the understanding of the more concrete and identifiable causes of accidents.

Tabachnick, N., Accident or Suicide; Destruction by Automobile, Charles Thomas Publishing, Springfield, Illinois, 1973.

Tabachnick's book describes a psychoanalytic study of one-car accident-involved drivers. This group is compared to a group of persons who attempted suicide and a group of post-appendectomy patients. The study seeks suicidal and self-destructive urges in drivers to explain their accident involvement.

Taylor, D.H., "Accidents, Risks, and Models of Explanation," Human Factors, Vol. 18, No. 4, August 1976, pp. 371-380.

Taylor presents a "rule following" model, combining a causal model and a purposive one. Neither of the later two, he states, is sufficient to handle the problem of accidents. His model takes into account risk and loss of control, and considers both the positive and negative aspects of each. This is largely a philosophical discussion following from the fact that pure causal models require "observable" data that cannot be obtained in the real world.

Tharp, K.W., and J.W. Garrett, Multi-Disciplinary Investigations to Determine Automobile Accident Causation, Report No. VJ-2224-V-1, Cornell Aeronautical Laboratory, Inc., Buffalo, December 1968.

Accidents in three towns in the area of Buffalo, New York were investigated by a multi-disciplinary team. The goals were reconstruction of the accidents and determination of causes.

This volume contains a description of the study methodology - training of investigators, data collection procedures, investigation forms, etc. Also included are some preliminary findings.

Thedie, J., "Road Accidents and Probable Causation," International Road Safety Traffic Review, Vol. 6, No. 2, 1958, pp. 35-38.

This is a philosophical discussion of the concept of causality. Thedie emphasizes the complexity of the issue and differentiates causality from responsibility.

Thorpe, J.D., "Calculating Relative Involvement Rates in Accidents without Determining Exposure," Australian Road Research, Vol. 2, No. 1, September 1964, pp. 25-36.

Tolle, J.E., "Probabilistic Aspects of Safety in Traffic Flow," Traffic Engineering and Control, Vol. 14, No. 10, February 1973, pp. 489-490.

Tolle presents several models of traffic flow synthesized from deterministic and probabilistic models. He points out that since traffic flow involves human factors as well as physical laws, a purely deterministic approach is not adequate.

Transport and Road Research Laboratory, "On-the-Spot Accident Investigation, Road/Environmental Factors in Accidents, and Vehicle Defects and Their Contribution to Road Accidents," T.R.R.L. Leaflets LF 392, LF 387, and LF 374, Road Accident Reduction for Highway Engineers and Police, PTRC (UK) Limited, London, pp. 1-6.

These three leaflets summarize results of a four-year in-depth study of 2,130 accidents. Each case was examined to determine the cause or causes. A road user factor was deemed contributory in 91.5% of the accidents.

Treat, J.R. and K.B. Joscelyn, A Study to Determine the Relationship between Vehicle Defects and Crashes, Interim Report: Methodology, Report No. DOT-HS-034-2-263-71-A, Institute for Research in Public Safety, Indiana University, Bloomington, November 1971. DOT HS-800 661.

Procedures and techniques developed for the Indiana Tri-Level Accident Investigation Program are described. Included here are the principal data collection forms, and accompanying criteria and instructions.

Treat, J.R. and K.B. Joscelyn, "The Role of Steering and Suspension Degradations and Failures in Accident Causation," SAE 740150, Society of Automotive Engineers, Automotive Engineering Congress, Detroit, March 1974.

Despite inherent difficulties in assessment, accident investigation can provide useful estimates of the role of steering and suspension degradations and failures in causing accidents. Indiana studies indicate that such factors probably account for no more than 5% of accidents, and other causation studies record similarly low involvement percentages. However, neither the influence of different original equipment capabilities nor the role of degradations as a source of driver fatigue has been adequately considered. Another group of studies has shown that degradations in steering and suspension components can adversely affect vehicle handling, and that such degradations are common in the vehicle-in-use population. (From author's abstract).

Treat, J.R. and D. Shinar, "A Methodology for Assessing and Classifying Traffic Accident Causes," Motor Vehicle Collision Investigation Symposium Volume I: Proceedings, Report No. ZQ-5731-V-1, Calspan Corporation, Buffalo, pp. 432-457. DOT HS-801 979.

This paper describes the evolution of the methodology for the Indiana "Tri-Level Study of the Causes of Traffic Accidents." Definitional problems are discussed (e.g. - prime vs. contributing cause) as well as the ways in which the team dealt with investigator bias. The authors acknowledge the difficulties of investigators in choosing correct categories within the Indiana causal hierarchy, and suggest ways in which the system might be improved by other researchers.

Treat, J.R. et al., TRI-LEVEL STUDY OF THE CAUSES OF TRAFFIC ACCIDENTS: FINAL REPORT Volume I: Causal Factor Tabulations and Assessments, Report No. DOT- HS-0134-3-535-77-TAC(1), Institute for Research in Public Safety, Indiana University, Bloomington, March 1977.

Volume 1 of Indiana's final report provides causal result tabulations from the study, and related analyses.

Data were collected on three levels of detail. Police reports and other baseline data on the Monroe County, Indiana study area were collected on Level A. On Level B, teams of technicians responded to accidents at the time of their occurrence to conduct on-scene investigations; a total of 2,258 investigations were conducted. Concurrently, 420 of these accidents were examined independently by a multidisciplinary team on Level C. Other special surveys were also conducted.

One or more human factors was cited by the in-depth team as a probable cause in 92.6% of accidents investigated. Environmental factors were cited as probable causes in 33.8% of these accidents, while vehicular factors were identified as probable causes in 12.6%. (From author's abstract).

Treat, J.R. and R.L. Stansifer, "Vehicular Problems as Accident Causes -- An Overview of Available Information," SAE 770117, Society of Automotive Engineers, International Automotive Engineering Conference, Detroit, March 1977.

This article provides final results of an accident investigation project, emphasizing the role of vehicular factors in accident causation. Also, these results are put in context with other studies which have offerred conclusions on the same topic.

Vehicular degradations, malajustments, and failures were identified as definite causes in 4.5% of the 420 accidents investigated by a multidisciplinary team, and 4.1% of the 2,258 accidents investigated by technicians. Vehicular problems were considered either definite or probable causes in 12.6% of accidents by the in-depth team, and in 9.1% by the technicians. Problems with brakes and tires predominated as vehicular causes, with gross brake system failure and inadequate tread depth being two of the leading problems identified.

The other studies referenced also reflect brakes and tires as predominant problem areas. (From author's abstract).

Treat, J.R. et al., TRI-LEVEL STUDY OF THE CAUSES OF TRAFFIC ACCIDENTS: FINAL REPORT Volume II: Special Analyses, Report No. DOT- HS-0134-3-535-77-TAC(2), Institute for Research in Public Safety, Indiana University, Bloomington, March 1977.

Volume 2 of Indiana's final report presents several special analysis reports dealing with driver vision, knowledge, psychological make-up, etc.

Data were collected on three levels of detail. Police reports and other baseline data on the Monroe County, Indiana study area were collected on Level A. On Level B, teams of technicians responded to accidents at the time of their occurrence to conduct on-scene investigations; a total of 2,258 investigations were conducted. Concurrently, 420 of these accidents were examined independently by a multidisciplinary team on Level C. Other special surveys were also conducted.

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Treat, J.R., N.S. Tumbas, and R.W. Drahos, "Accident Prevention and Avoidance Assessment Methodologies," Motor Vehicle Collision Investigation Symposium Volume I: Proceedings, Report No. ZQ-5731-V-1, Calspan Corporation, Buffalo, pp. 550-568. DOT HS-801 979.

This paper describes two studies by the IRPS: an assessment of possible benefits from improved braking systems, and an assessment of various maneuvers with respect to emergency traffic conflict situations. Both studies built on existing IRPS data files.

The authors' objective is "to consider recent uses of accident data in assessing accident avoidance and prevention measures."

Treat, J.R., "Tri-Level Study of the Causes of Traffic Accidents: An Overview of Final Results," American Association for Automotive Medicine. 21st Conference. Proceedings, 1977, pp. 391-403.

Final results of a Tri-Level Accident Causation Study are reported, as well as the results of special analysis projects investigating the relationship of driver vision, knowledge, and psychological attributes to accident involvement. A total of 2,258 accidents investigated by technicians, and 420 accidents investigated by a multidisciplinary team are reported. Human factors were cited as probable causes in 93% of accidents, compared to 34% for environmental factors and 13% for vehicle factors. Leading human factors included improper lookout, excessive speed, inattention, and improper evasive action. View obstructions and slick roads were leading environmental factors. The most frequently-involved vehicle factors were gross brake failure, inadequate tread depth, side-to-side brake imbalance, and underinflation. Vision (especially poor dynamic visual acuity) and personality (especially poor personal and social adjustment) were related to accidents. However, knowledge of the driving task was not shown to be related. (From author's abstract).

Tumbas, N.S., J.R. Treat, and S.T. McDonald, "An Assessment of the Accident Avoidance and Severity Reduction Potential of Radar Warning, Radar Actuated, and Anti-Locking Braking Systems," SAE 770266, International Automotive Engineering Congress and Exposition, Society of Automotive Engineers, Detroit, March 1977.

A group of 215 in-depth accident reports prepared as part of a tri-level accident causation study by a multi-disciplinary team was examined to assess the benefit derived from the hypothetical application of various combinations of radar warning, radar actuated, and anti-lock braking systems. The approach was to have an accident analyst evaluate post hoc the benefit which would have accrued if one or more of the vehicles involved in each accident had been equipped with various types and combinations of these hypothetical systems. Ten system types or combinations were defined. On one extreme, it was found that two-wheel anti-lock systems, by themselves, had relatively little accident prevention potential; only one of the 215 accidents (0.5%) would definitely have been prevented by such a system, although with less assurance there was some possibility of prevention of up to eight accidents (3.7%). On the other extreme, the most complex of the systems defined, comprised of a non-cooperative radar system with both actuation and warning potential, coupled with a four-wheel anti-lock system, would definitely have prevented 39 of these accidents (18.0%), with some possibility of prevention of up to 90 accidents (41.9% of those examined). From author's abstract).

VanWagoner, W.T., "Investigating the Roadway Environment," American Association for Automotive Medicine. 21st Conference. Proceedings, 1977, pp. 305-333.

This paper is a discussion of investigation techniques for assessing the environment's role in accident causation. Included in the discussion are environmental variables to be considered, methods of measuring or assessing the role of the variables, and examples of environmental contributions to accident causation. This work is primarily applicable to in-depth investigations involving on-scene study.

Vaughan, R.J., and G. Goulbergh, "A Two-Stage Model for Traffic Accident Prediction," Proceedings of the Fifth Conference of the Australian Road Research Board - Volume 5, 1970, pp. 365-378.

The major street system of metropolitan Adelaide has been divided into some 250 road sections for the purposes of accident evaluation. The object of the study was to determine the worst sections. For each section the million vehicle miles was calculated and plotted against accident damage. A linear relationship was shown to exist between m.v.m. and accident damage; from this a weight was assigned to each section to make a comparison between sections possible. Sections with major geometric differences were not compared. The virtue of the system lies in that it can detect minor differences in road geometries to which the variation in accident damage is attributed. (From author's abstract).

Veney, J.E. and D.L. Kaiser, "Development of a Computer Simulation of Highway Accident Prevention and Treatment," Accident Analysis and Prevention, Vol. 8, No. 4, December 1976, pp. 279-291.

This paper describes the application of a dynamic systems model to the general problem of automobile accident prevention, treatment and control. The paper describes the development of a Dynamo simulation model to describe the accident prevention, treatment and control system. In the development and description of this model, assumptions about the nature of the system are specified and several hypothetical runs of the model are described. The specific applications of the model deal with the cost and benefit of modification in speed limits and the mandatory use of seat belts and air bags. The consequences of such systems changes are noted and discussed. Implications for future research of this type are suggested. (From author's abstract).

Waller, J.A., "Epidemiologic Approaches to Injury Research," *Rare Event/ Accident Research Methodology*, NBS Special Publication 482, Proceedings of a Workshop held at the National Bureau of Standards, Gaithersburg, Maryland, May 1976, National Bureau of Standards, U.S. Department of Commerce, Washington, D.C., July 1977, pp. 29-46.

Waller's paper begins with a brief overview of epidemiology and two basic designs used by epidemiologists for testing hypotheses about determinants of injury. These are the case history and cohort methods. Waller then discusses two epidemiologic methods based on the interaction between the host (victim) and the injury agent (physical energy). The first model presented deals with determining causes while the second is concerned with identifying the range of countermeasures options. (From author's abstract).

Watkins, C.J., "Uniform Road Traffic Accident Reporting Procedures," *Australian Road Research*, Vol. 4, No. 7, November 1971, pp. 67-82.

The author argues for a uniform system of gathering and coding information on traffic accidents in Australia, and presnts his plan for such a system.

Weber, D.C., *A Stochastic Model for Automobile Accident Experience*, Institute of Statistics, North Carolina State University, Raleigh, January 1970.

White, J.G., A Systems Approach to Collision Avoidance, Report No. TMVS 7503, Vehicle Systems Division, Transport Canada, Ottawa, June 1975.

This report presents the concept of a collision avoidance model as a method of assessing the probable safety value of presumed collision avoidance countermeasures. Accident causation concepts are reviewed in the context of an automotive transport system. A review is also made of methods of classifying accident causation factors and of causation studies.

A possible program of research is outlined directed at evaluating specific vehicle systems countermeasures through technical feasibility studies and analysis of accident data using the collision avoidance model concept. (From author's abstract).

Wigglesworth, E.C., "A Teaching Model of Causal Mechanisms and a Derived Theory of Countermeasure Selection," American Society of Safety Engineers Journal, Vol. 17, No. 8, August 1972, pp. 27-32.

Injury countermeasures traditionally have been oriented toward the removal or engineering control of potentially damaging energy, but the use of techniques directed at the reduction of non-culpable error constitutes an additional and potentially fruitful field for injury countermeasures.

These two parallel approaches are here combined into a simple teaching model from which a conceptual outline of preferential countermeasure selection is derived. It is suggested that, from this model, a course of formal study can be structured in a manner suitable for incorporation into the curriculum of those who will be professionally concerned with the prevention of accidental injury. (From author's abstract).

Wilde, G.J.S., "The Risk Compensation Theory of Accident Causation and Its Practical Consequences for Accident Prevention," Osterreichische Gesellschaft fur Unfallchirurgie Annual Meeting, Salzburg, 1976.

Wilson, D.G., Transportation Resource Allocation Based on New Methods of Accident Reporting, Engineering Projects Laboratory, Department of Mechanical Engineering, M.I.T., Cambridge, Mass. August 1969.

This report uses analytic methods to determine cost-benefit ratios of various countermeasures. In a discussion of accident causation, the author discusses the interactive effects of various causes of accidents and how

isolation of a single cause is particularly difficult.

Wolf, R.A., An Overview of Highway and Vehicle Research, SAE 680271, Automotive Engineering Congress, Detroit, January 1968.

Wright, P.H. and Baker, E.J., "Causes of Traffic Accidents," Traffic Engineering, V43(9), June 1973.

Wright, P.H. and E.J. Baker, "Factors Which Contribute to Traffic Accidents," Transportation Planning and Technology, Vol. 3, 1976, pp. 75-79.

Youngman, J.H.R., "Some Problems Arising in Before-and-After Accident Studies with Limited Data," Proceedings of the Sixth Conference of the Australian Road Research Board - Part 3, pp. 384-392.

APPENDIX B

TRAFFIC CONFLICTS TECHNIQUE

TRAFFIC CONFLICTS TECHNIQUE

Background

The Traffic Conflicts Technique (TCT) was originally developed by the General Motors Research Laboratories in 1967. It is a method for predicting the number of accidents at an intersection based on the number of conflicts (near misses) which occur.

The original technique separated conflicts into five categories: left turn, weave, cross traffic, red light, and rear end. Counts were made by type of the number of conflicts occurring during a standard time period—five hours in the first experiments, ten hours in subsequent studies. Each leg of the intersection was observed and the number of conflicts on that leg recorded.

The assumption behind the technique is that the number of conflicts correlates with the number of accidents at a given intersection. If this is so, TCT should be useful for ranking intersections in terms of relative safety and for predicting the number of accidents at an intersection. Further, as a surrogate for accident data, TCT could be a powerful tool in assessing the effectiveness of safety-related design changes to intersections.

Effectiveness of the TCT

In an excellent review of studies done using the Traffic Conflicts Technique, Glennon et al. [1] found no consistent evidence that the number of traffic conflicts at an intersection can be used to predict the number of accidents that will occur there. Indeed, the volume of traffic has been shown to be a better predictor. Another problem mentioned by the reviewers is that the numerous studies employing the TCT are difficult to compare, since the definitions of conflict vary so widely and the nature of the field measurements is subjective. Glennon concludes that the technique requires further refinement and evaluation before its use can be justified.

Potential Use of the TCT in Accident-Causation Research

The TCT, as currently used, attempts to correlate conflicts with accidents for the purpose of predicting the number of accidents at an intersection. Other than subsetting unsafe driver actions into several general classes, and counting such actions, no evaluation of the cause of the conflict is recorded.

To obtain information regarding the cause of a given driver action, a more detailed examination of each conflict would have to be made. This could be done photographically, visually, or perhaps by a post-conflict interview with the driver. However, obtaining such information would not solve the basic problem of the unproven relationship between conflicts and accidents. Furthermore, previous studies have indicated that the types of conflicts which occur at a given intersection are highly dependent on the design of the intersection. This supports the use of the technique for individual intersection evaluation, but would confound its use for a causation study of broader scope.

Another drawback to the use of the TCT is that the assessment of conflicts is subjective and dependent upon the judgement of the observer. Conflicts, according to the theory, are a continuum, with minor avoidance or braking maneuvers at one end and actual accidents at the other. The identification of a conflict, therefore, is an important decision that can only be made subjectively.

A causation study using the TCT would become a clinical assessment of near misses rather than accidents. If the relationship between conflicts and accidents were clear and if the definition of a conflict could be objectively applied, then there would still remain the question of the cause of the conflicts.

In light of the uncertainty of the relationship between conflicts and accidents, and because of the inherent subjectivity of the method, no accident causation study based on this technique can be recommended at this time.

Reference

1. Glennon, J.C., W.D. Glauz, M.C. Sharp, and B.A. Thorson, Critique of the Traffic Conflicts Technique, Presented at the 56th Annual Meeting

of the Transportation Research Board, January 1977.

APPENDIX C

INDUCED EXPOSURE

INDUCED EXPOSURE

The fact that the statistical approach requires data on the non-accident, or exposed population, has been stressed repeatedly. This requirement is particularly clear in the context of retrospective studies as discussed in Section 4.2.3 of the main text.

Exposure has been a troubling problem to accident researchers for many years, both conceptually and pragmatically. Many of the problems are with us yet. Researchers have considered the matter of importance ever since they first recognized the value of contrasting segments of the total traffic community in terms of accident rates.

Because of the importance of exposure data, and because of the administrative problems and expense in gathering it, the concepts and techniques of induced exposure have been examined with some care. The hope was, of course, that this approach would prove applicable and would enhance the statistical approach to accident-causation research by reducing one of its more burdensome data-collection tasks.

Induced Exposure

In 1964, Thorpe [1] described a method of calculating relative involvement rates without explicitly measuring exposure. The method used only data available from accident records and has become known as "induced exposure." Thorpe's method is based on the following five assumptions (taken directly from Thorpe):

> (1) Single vehicle accidents are caused entirely by attributes of the driver-vehicle combination concerned (this ignores the part played by the road, which is common to all vehicles and drivers).
>
> (2) Collision accidents are caused by the first two vehicles to hit. (Collision accidents involving more than two vehicles constitute only 5 percent of all collision accidents and those in which the first two vehicles to hit did not cause the accident would have no significant effect on the general accident pattern. The Commission's accident reports record details of only the first two vehicles to hit in collision accidents).

(3) In each collision accident there will be a 'responsible' and a 'not responsible' driver-vehicle combination (this is an over-simplification which is discussed later).

(4) The relative likelihood of a driver-vehicle combination being the 'responsible' combination in a collision-accident will be the same as the relative likelihood of that combination being involved in a single vehicle accident.

(5) The likelihood of any particular driver-vehicle combination being innocently involved in a collision accident, i.e., the 'not responsible' combination, will be the likelihood of meeting that combination anywhere on the road.

Assumption (5) has been used as the operative definition of induced exposure. However, Thorpe did not require a case-by-case assessment of the "responsible" or "innocent" driver-vehicle combination. Presumably, a reliable assessment of responsibility was not available. Instead, Thorpe used assumption (4) to determine the proportion of a combination as the innocently involved combination in collisions (two-vehicle accidents). To do this, he needed only the distribution of the combinations of interest (e.g., age groups or alcohol level in collisions and in single-vehicle accidents. This modest data requirement is one of the virtues of Thorpe's method.

The most sophisticated mathematical discussion of induced exposure has been given by Haight [2,3]. It might be appropriate to relate some of Haight's observations before continuing with a general discussion. Haight restricts the use of the term "induced exposure" to the method of Thorpe, i.e., the application of both assumptions (4) and (5). Several other investigators have used induced exposure, but have used case-by-case assignment of responsibility to derive the exposure population rather than using the single-vehicle accident set. Haight calls this technique "quasi-induced exposure."

Using Thorpe's method, the proportion of total exposure that is contributed by attribute i (N_i) is equal to twice the proportion of attribute level i in the two vehicle accident population (T_i), minus the proportion in the single-vehicle accident population (S_i), or $N_i=2T_i-S_i$. Both Thorpe and Haight note that it is possible for N_i to be negative. Thorpe seems to dismiss this problem as one which results from sampling error with small numbers, since the difference N_i can be extremely sensitive to errors in T_i or S_i.

This appears to be a rather simplistic dismissal, however. If the exposure of an attribute level is correlated with factors which are in turn highly correlated with the propensity for single-vehicle accidents, then N_i could be negative regardless of sample size. For example, suppose that young persons drove only at night when traffic is light and therefore a high proportion of their accidents are single vehicle. Then the incidence of young persons in two-vehicle crashes (T_i) would be small, but their involvement in single vehicle crashes—and hence S_i—would be large, resulting in a negative N_i. This correlation of an attribute with factors associated with single-vehicle crashes presents a fundamental problem with the use of single-vehicle crashes for determining responsibility in two-vehicle collisions, and thus with the concept of induced exposure. This will be discussed further in a later paragraph.

Haight [2,3] has modified Thorpe's model to remove the possibility of negative results. Haight's formula is based on a weaker assumption regarding responsibility. Rather than assuming an attribute level is responsible in the same proportion among two-vehicle accidents (doubles) as many single-vehicle crashes, he assumes the ratio of responsibility of two attributes is the same in doubles as their ratio in singles. In order to solve for the exposure of each attribute under this weaker assumption, the data requirements are more stringent. The two-way classification of the attributes in two-vehicle accidents is required. However, this is still a modest requirement. While Haight's formula always leads to positive results, it has one defect which Thorpe's does not have.[1] It violates the "Null Categorization Postulate" [2]. If driver-vehicles are categorized by unequal groups defined by a random variable unassociated with accidents, e.g., a dichotomy based on license plate digits, Haight's formula does not lead to the same proportions in the exposed and single-vehicle populations—a spurious over-representation. Haight [2] modified his earlier model (Haight's modified formula) to meet the Null Categorization Postulate and still give positive results. These developments still provide induced

[1]Haight's formula gives quite different results from Thorpe's results, a fact illustrated in Haight's 1970 paper.

exposure in that they use the single-vehicle accident experience to deduce the responsible vehicle in a group of two-vehicle accidents.

Quasi-Induced Exposure

A number of investigators have used the methods of induced exposure with empirical data sets, although none have employed Haight' formulas. These include Carr [4], Hall [5], Carlson [6], Joksch [7], and Waller et al. [8]. With an exception discussed later (Carr), all have used quasi-induced exposure. Carr and Waller both attempted to validate the concept. Most have used the quasi-induced exposure concept for two reasons. One is that many investigators are suspect of Thorpe's fourth assumption. The second is that police investigators frequently assign and record responsibility. Thus most investigators appear to prefer the use of police assignment of responsibility rather than single-vehicle accident experience to establish the "responsible" involvement of an attribute in two-vehicle crashes. On the other hand, the validity of assignment of responsibility by police has been questioned. Haight [9] states "It would, except in very well-defined circumstances, be assuming too much if we supposed that the proportions of guilty and innocent parties were decided by the reporting authorities."

Carr used the quasi-induced exposure method to examine the relative overinvolvement—which he called "relative risk"—for categories of age, experience (in years of driving), light condition, and blood alcohol level. He attempted to validate the concept using exposure as determined from driver registration data, and also to validate Thorpe's method by comparing the single-accident relative risk with two-vehicle accident relative risk, both obtained using driver registration data. He found significant discrepancies in both comparisons. While he raised several issues in discussing the discrepancies, he does not seem to have questioned the validity of assignment of responsibility by investigating officers.

Carr, along with most other investigators, starts with the premise that exposure is measured by vehicle miles.[1] Both Thorpe and Carr recognize that gross vehicle miles driven may not be a sufficient measure of exposure, and that the conditions and environment under which travel is accrued may also be important. Thus, the failure of quasi-induced exposure to replicate the results using driver registration data noted by Carr could result from failure of driver registrations to represent miles driven, as well as from errors in assigning responsibility.

It is very possible—if not likely--that different levels of a driver parameter, or different driver-vehicle combinations, may not have the same risk of involvement in single-vehicle accidents as in two-vehicle accidents. This could explain the discrepancy Carr noted in the comparison of single and two-vehicle accident results; this possibility was also noted by Thorpe. More importantly, such a correlation would invalidate the methods of Thorpe and Haight. An example of how this could happen in the case of young drivers was given earlier.

Waller, et al. conducted a study of induced exposure similar to that of Carr except that, in addition to driver registration data, gross-vehicle-miles data were available from origin-destination studies. Their results were similar to Carr's in that accident rates based on quasi-induced exposure did not agree with those based on vehicle-miles data--relative single-vehicle accident rates did not agree with those derived from vehicle miles. The issues raised above with regard to Carr's work also apply here. The police assignment of responsibility was not verified and only gross vehicle miles were available. Furthermore, the relative risk of single- versus two-vehicle involvements may be correlated with the study parameters, age and sex.

Applicability of Induced Exposure

There are several conclusions that can be drawn from the above discussion relative to the use of the concept of induced exposure in the study of accident causation. The concept of exposure can be extended from a simple vehicle-miles measure to a much broader measure of the risk of involvement. Under this broader concept, validation or invalidation of

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[1] Thorpe explicitly stated that N_i is the proportion of the total vehicle miles accrued by driver-vehicle combination i.

induced exposure by comparison with vehicle miles would be impossible. Even if a multi-factor model of exposure is selected, attempts to validate induced exposure would be as much a test of the multi-factor model as of induced exposure. This is the reason Haight has suggested that the basic idea of induced exposure is neither provable or unprovable.

The use of single-vehicle accidents to determine relative responsibility, and in turn to derive relative exposure from the two-vehicle accident population, has serious problems. It is very likely that the relative likelihood of single-vehicle versus two-vehicle involvements would be correlated with the factor under study as cited in the example of young drivers. It is entirely possible that the subject of a particular study would be the relation between an attribute (factor) and the type of accident. If such a relation did exist--that is dependence, and hence correlation between the factor and the type of accident--assumption (4) would be violated and Thorpe's concept would be invalid.

This leaves the possibility of using the quasi-induced exposure method incorporating a case-by-case assessment of responsibility. Professional multi-disciplinary investigation teams might provide assessments with more reliability than is represented in mass-accident data, and without reliance on an extant set of statutes. However, our concept of the statistical detection of overrepresentation is inconsistent with data collection by a case-by-case (clinical) assessment of responsibility.

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APPENDIX D

REVIEW OF TECHNICAL DISCUSSIONS

REVIEW OF TECHNICAL DISCUSSIONS

This is a review of the conferences held at NHTSA between the HSRI project personnel and several "users" in the MVP and TSP areas. Meetings were held over a two-day period.

Discussions at the first meeting were centered around the TSP needs for accident causation information. Mention was made of the North Carolina UDA study, and the feeling was expressed that the UDA's as defined therein were not adequate to NHTSA's needs. In particular, there were no countermeasure implications. And the opinion was given that the reliance on police data meant that there was not much new information provided. Our interpretation of this was that in-depth investigations might provide a new level of detail or insight into UDA's not available in police records.

There is a current emphasis in TSP on the youthful driver. The current Lansing program, described as a sort of modified STEP activity, is oriented toward the youthful driver. We had considerable discussion about the definition of "youth"—whether this should include just the novice driver, the 18-20 year old, etc. No firm categories resulted, but there is interest in many groups—the novice (e.g. the 16-17 year old beginning driver), the 18 to 25 year old, less than 21 vs. 21 and over, etc. They see a need to identify particular age groups which might be susceptible to treatment—possibly from a driver education point of view.

There seems to be a need for a good operational definition of speeding, and of other actions. Is there a possibility of quantifying reckless driving or inattentiveness? Some mention was made of the interaction between speed and alcohol, though it was pointed out that alcohol as such is not considered a UDA as UDA is currently defined.

Again the need for an operational definition of speeding was expressed. The North Carolina report defines speeding in several ways—e.g. more than 5 mph above the posted limit, speeding in a 55 mph zone, etc.

Another topic of interest to this group was driver vision—broadly defined; and also driver knowledge (this with reference to the motorcycle course currently being given in California).

Lastly, there is a current interest in field dependence/independence.

A subsequent meeting continued these discussions. No new specific topics were mentioned, but the interest in youthful drivers was confirmed.

During the afternoon we met with staff members from Motor Vehicle Programs. Topics were generally how the MVP people hoped to get information from accident investigation activity which would support their planned standards work, or assist them in finding areas in which standards were needed.

The MVP staff noted that priorities were currently being "firmed up" in discussions with NHTSA administrators, but that a high priority topic was fields of view (A-pillar width, direct visibility, and blind spots). There was concern about the depth of accident investigation necessary to identify problems in this area.

The MVP also want considerable detail on make/model of vehicle in order to properly identify problems. Sub-categories are necessary (2-door or 4-door) in order to know whether there is a problem of visibility to the right rear. For example, there are several models of the Hornet which have different visibility properties, and if one of these were overrepresented in "lane change" accidents it would be important to have detailed make/model information.

Mention was made of a likely ANPRM on direct visibility and tinting. One vehicle under suspicion as a visibility problem is the small 2-door coupe with the "dark sail area" (a windowless panel behind the door area).

Another area of current interest and concern was mentioned—pedestrians, motorcyclists, or bicyclists being struck by mirrors which project out too far from cars or trucks. there was some discussion here about causative vs. severity-increasing factors.

Another topic discussed was the need for empirical evidence about the overinvolvement of tinted windshields in dusk/dark accidents. We had some discussion about the difficulty of handling the multiple variables in such a problem--tinted windshields were shown in an earlier paper (by Arvai et al) to correlate with older drivers, bigger cars, travel at different times of day, etc. It is hard to get a simple correlation of accident rate with darkness, but the need is still there.

There is also some concern about tires---pressure, tread, mixtures--- and with suspension system alterations.

MVP staff talked about their limit yaw stability work, and noted that detailed vehicle identification (e.g. the VIN) plus fairly complete identification of tires (make, model, condition) was necessary to an understanding of that. He referred to the European standards (for brake pressure distribution) and noted that NHTSA is interested in pursuing a standard in that area. He would like to know the "types" of vehicles involved in limit loss of control maneuvers.

We asked what a limit yaw control standard would look like, and they answered that it would likely be a specification of allowable performance similar to the CALSPAN carpet plots--reference was given to an SAE paper on this subject. There was some discussion about rear lighting of trucks, and evidence of differential accident experience with striking of lowboy trucks as opposed to high well lighted trucks. However, an MVP staff member said that the present contract would be limited to passenger cars.

The effects of weather on accident frequency for various types of vehicles were discussed. They are interested in specific vehicle types being overrepresented in accidents on wet roads, in fog, etc.

There was some discussion about radar braking, but this is evidently still long-range planning. A notice of proposed rulemaking is "planned" for about 1982.

There is still some interest in stolen vehicles--from a safety point of view, and of fire.

Under the general heading of adverse weather, there is interest in the effects of spray from trucks--reference was made to an old Pennsylvania Turnpike study which identified this problem.

Under the heading of tires and wheels, mention was made of tire traction, wheels , retreads, tread depth, original equipment wheels and non-OEM wheels and tires, multipiece rims in non-passenger vehicles, and wheels falling off.

Again under the handling category: loss of control during braking, and the European braking standard (front wheels must lock first under nearly all conditions of road friction). There is interest in how lockup occurs in wet road accidents.

Interest was expressed in recreational trailers and load leveling hitches. Involvement rate for such vehicles is of interest. There was a brief discussion here about the Kentucky MDAI study of recreational vehicles.

In summary, the Office of Crash Avoidance priorities include: fields of view (direct, tinting, mirror visibility, headlighting), and the extensions of the 105 standard to light and medium trucks.

The next meeting was held with the Planning and Evaluation group. We discussed several planned standard areas from the point of view of the need for accident causation information. These included:

Lighting Standards (generally)

Side Lights

Headlight glare—particularly comparisons of the 1978 and 1979 model years with earlier years, since the manufacturers are permitted to increase candlepower in these years. It is expected that by 1979 about 30% of the American production will be upgraded to the more intense headlamps. Will this increased candlepower create problems?

Braking—the opinion was expressed that accident data was lacking here, but that NHTSA is looking forward to improved braking systems.

Tire pressure—some discussion about automatic low/high pressure indicators, and a need for knowledge of overrepresentation of deviant tire pressure in crashes.

Electromagnetic interference (there was an RFP on this subject in the summer of 1977—concern about radio interference with electronic ignition, braking systems, etc.)

There was some discussion about motorcycle braking.

There was some discussion about vans and light trucks, particularly the extension of 201,202,204 and 208 to cover these vehicles.

Vans seem to be a candidate for a study of limited vision capability, and might be expected to show up in the accident data because of that.

There was mention of the extension of the power window standard (a standard aimed at preventing children from closing windows on themselves) to light trucks and vans.

Several other topics were mentioned lightly: theft, the 302 standard, and the limit yaw stability standard.

On Thursday, November 3, 1977, HSRI staff along with the CTM for the project met with two members of the Office of Driver and Pedestrian Programs. The two are concerned primarily with driver education.

Information is needed about what techniques, or lack thereof, get drivers (generally) and young drivers (specifically), into accident-producing situations. A specific interest was expressed in left-turn situations leading to accidents. There was some discussion of the prior Driving Task Analysis (done by McKnight in 1971), which was to have produced the Safe Driving Curriculum. McKnight apparently used some sort of "expert-opinion-technique" to make a "criticality assessment" of driving mistakes and their role in causing the accident under assessment. The MDAI file was used in this work. A review of the McKnight work seems appropriate.

There was some discussion of knowledge tests, and it was observed that the general problem is that we "don't know what questions to ask." It is certainly true that there is no "tried and true" knowledge test, and they observed further that the existing literature on the subject suggests that lack of knowledge is not a factor in causing accidents. ODPP is looking to the DeKalb County (Georgia) demonstration program for guidance, but it was not clear to me at the time whether there were specific research questions being addressed or not. This phase of the discussion concluded with the observation that there is not any current effort directed to re-writing of standards and curricula in the Driver Education area.

ODPP opinions and priorities about what is important for Driver Education, in terms of Pages 13-17 of the RFP, are as follows. Items 1a(What are the ten most frequent direct human behavioral/information processing failures which cause or increase the severity of accidents?), 1b(What are the ten most frequent human conditions or states associated with the causes of accidents?), 1d(What are the ten most frequent environmental conditions or factors which cause or increase the severity of accidents?), le(What clusters of human behavioral errors correlate highly with certain environmental (or vehicle) conditions?), and lf(What are the ten most frequent Unsafe Driving Acts (UDAs) causally related to these accidents?) are the priority items. An ODPP staff member observed that la, although a priority item, seemed least feasible in terms of a "do-able" research methodology. He observed that item lb would be amenable to the statistical inference approach. The content of item ld was re-phrased as "Can we type accidents?" Item lf on UDA's was seen as a very large research program.

Continuing on to Page 14/17, item 2a(By what degree (if any) is alcohol overinvolved in noninjury accidents?) was seen as interesting, but not very important. Items 2f(Is information processing ability as measured by the information processing test lower for accident drivers vs. exposure-to-risk drivers?) and 2g(What environmental conditions were overrepresented in the accident group vs. the roadside survey data or its equivalent?) were seen by ODPP as having the most important implications for Driver Education. There may not be much payoff in the vision area, but there is considerable interest within NHTSA in this topic. Events immediately preceding the accident--the errors, acts, and conditions--were important because the least is known about them.

Mopeds are of current concern because nobody really knows whether there is a problem or not.

The afternoon session of November 3 was spent with staff of the Office of Driver and Pedestrian Research (ODPR).

The discussion began with a description of ODPR's interest in UDA's. UDA's are driving behaviors causally related to accidents, and one of the key concepts to a UDA is that the driver must be aware of what he is doing. Speeding is an example; if the driver is purposefully driving 65 in a 55 zone, that behavior constitutes a UDA. If, however, he is not aware that he is driving 65 in a 55 zone, that is not a UDA. "Tail gating" is another example of a UDA. (There was considerable discussion later about what is and what isn't a UDA. At one point an ODPR staff member went to the blackboard and defined a UDA as a "driver error of commission" as opposed to a "driver error of omission.")

The UNC Highway Safety Research Center UDA study was discussed. An ODPR staff member felt strongly that better accident data are needed and that police report data are not adequate. He suggested that perhaps 50-100 Level II accident investigations would be necessary. Also needed would be better definition (in the sense of specification) of driver behaviors, definition of accident types, and correlations between the two. In this discussion he also referred to information failures, wherein the driver is aware of what he is doing but fails to process the information he has correctly; he cited "following too closely" as an example.

He mentioned again that UNC HSRC had examined police reports, but there was insufficient information there. It would be necessary to get, by accident type, the UDA behavior, the reason(s) for the behavior, the situations that the behavior(s) occurred in, and the driver characteristics. He went on to a discussion of the role of Roadside Surveys in a research program. It was noted that it would be necessary to develop a general causal scheme for using RS's, to develop observational methods, and to look at the RS locations carefully. In response to a question about emphasis on youth, he responded that they certainly should be included, but he definitely would not want to restrict a UDA research program to youth only.

The topic of alcohol was also discussed. ODPR would definitely like to have BAC's, but primarily they would be interested in the interactions between alcohol and UDA's. Serious injury accidents and BAC's are of concern.

There was further discussion about a lane-changing-maneuver UDA.

The UDA-centered part of the discussion was concluded by an ODPR staff member's observation that if this becomes part of the Accident Causation Study, then we should look carefully at the NC work and that more meetings between NHTSA and HSRI staff would be needed. Subsequently, he stated that he would like to know where we stand on the UDA topic as soon as possible, because a new procurement is currently at NHTSA's contracts office. The new procurement, it was implied, might depend significantly on our inclusion or exclusion of the UDA topic.

Another ODPR staff member then took over the discussion and stated that he has three priority items. In RFP terms, these are:

Page 14, Item 2d) Are certain driver defects in vision (as measured by low scores on the vision tests) overrepresented in accident drivers?

Page 14, Item 2e) Is information processing ability ability (as measured by the information processing test) lower for accident drivers vs. exposure-to-risk drivers?

Page 15, Item 3e) For various accident configurations, accident locations, and ambient conditions, what are the "Environmental Conduciveness Indices"? (The citation is DOT-HS-3-335 "Further Data Analyses").

The priorities are as given above. He started the discussion with the last item. The interest is in the two seconds prior to impact. What is the environmental situation? What is the environmental situation that would permit escape or recovery? Indiana University's Institute for Research in Public Safety (IRPS) looked at this topic in their predecessor work. Hard-copy plan view drawings were prepared from a review of the existing accident documentation. This preparation was done after the fact, and he believes that the plan view drawings were not as good as they would have been had the accident investigators had this interest specifically in mind at the time they were on the scene.

The discussion then shifted to the vision topic---this is his highest priority item. Honeywell has developed a vision tester which tests dynamic acuity (the ability to detect motion) and low-level-light acuity. The vision test battery takes about twenty (20) minutes to administer. Normative data are being collected under another NHTSA contract.

The specific interest is in giving this same battery of tests to about ten thousand (10,000) accident-involved drivers. It would further be necessary to sort out the accidents into those which are vision related and those which are not. The latter point was pursued in some depth, in that the HSRI project group expressed some concern about the ability of accident investigators (or analysts scrutinizing case documentation after the fact) to perform the required subsetting operation. The ODPR staff member concluded that it would be necessary to be able to differentiate between vision-related accidents and non-vision-related accidents. This is related to the numbers of accidents to be expected. Blanket screening of accident-involved drivers in the present study would not produce enough cases to be of interest, so another procurement will get at screening of all accident-involved drivers.

The discussion then shifted to the field dependence/independence topic. Any work in this area is definitely exploratory research. In contrast to the vision work discussed earlier and described above, all accident-involved drivers would be the subject of this exploratory research. The basic approach would be to provide portable field-dependence testing equipment and test accident-involved drivers, do the same for control drivers, and look for over/underrepresentation. Rod and frame equipment and paper/pencil tests were mentioned as being available. A reference was made to NPSRI and/or McKnight, but further closure cannot be made at the present.

Attention then shifted to the second priority topic, that of maneuver selection and environmental conduciveness. Here the reference was item 3a on page 14 of the RFP:

Page 14, Item 3a) Determine potential effects of various vehicle subsystem improvements or changes and driver evasive maneuvers in preventing or reducing the severity of accidents. Using the Indiana University model /19/, determine the percentage of accidents which could have been avoided if all drivers had selected the optimal maneuver for their situation, if one driver had selected the optimal maneuver, etc.

A current 6-months contract — with IRPS — is looking at accident data relative to training objectives. In this work an attempt is being made to isolate the driver and focus questions around him. Questions, apparently of a conceptual nature, are: How to approach this topic? What models should be employed? How to incorporate information from accident investigations? An ODPR staff member summarized the current NHTSA concern as: "We have reached the end of the rope with respect to driving task analysis." What are needed are observable, measurable behavioral antecedents to the accident, and good quality, empirical, objective accident data.

As a general observation it was noted that the references to the ten (10) "products" of the RFP on page 13 had no meaning as such and should be scratched. The products are ok but the "10" should be scratched.

APPENDIX E

ACCIDENT CAUSATION WORKSHEET

Factor	CM	P(F|A)	Diff	Know	P(F|A')	Diff	Know	Applicab Infer	Applicab Case	Theory	Field Variables	Interacting Variables
Departing from mean speed by 1.3 S.D. . .	Governors Cruise cont Enforcement	>.20	2	3	.20	5	5	4	3	4	Speed Mn speed dist	
Fol too close <1 C.L./10 M	Signs Education Radar brake	.07	2	3	<.07	4	4	3	4	4	Speed Dist btw cars Brak in acc .	
Lft of Cntr	Median Wide roads Education .	.06	4	3	99	4	3	2	4	9	Acc dynamics Veh position Roadmarks . .	
Disregard traffic sign	Education Enforcement Btr Signing	.04	4	3	<.04	4	2	3	4	9	Sign location Interview . .	
Pulling in front on-coming traffic . .	Enforcement Training Signs . . .	.12	4	3	99	4	2	4	3	9	Crash type .	
Turning in front on-coming traffic . .	Enforcement Training Signs . . .	.03	4	3	99	4	2	4	3	9	Crash type Speed Maneuvers . .	
16-18 yr-old drivers . .	Restrict lic Education .	.10	5	5	.06	4	4	5	2	4	Driver age .	Light cond Time of day Sex Veh type Day of week Mar stat Occupation .
18-25 yr-old drivers . .	Restrict lic Education .	.35	5	5	.20	4	4	5	2	4	Driver age .	Light cond Time of day Sex Veh type Day of week Mar stat Occupation .
Field dependent drivers . .	Restrict lic Training Signing . .	>.05	2	3	.05	4	4	4	2	3	Meas of FD .	Age, Sex, Vis factors Light cond .
Dyn vis acu-poor . .	Restrict lic Training Signing . .	>.05	2	3	.05	3	4	4	3	4	Meas of DVA .	Age, Sex, Vis factors Light cond .

ACCIDENT CAUSATION WORKSHEET
(Continued)

Factor	CM	P(F|A)	Diff	Know	P(F|A')	Diff	Know	Applicab Infer	Applicab Case	Theory	Field Variables	Interacting Variables
Low light level visual acuity-poor	Restrict lic Education Btr lights .	>.05	2	3	.05	3	4	4	3	4	Measure of VA Age	Vis factors .
Col Blnd	Restr lic .	.02	4	2	.02	5	5	4	2	4	Vision test	Acc var Type eye cond . . . .
Monocular drivers . .	Training Mirrors . .	99	5	2	.01	5	5	4	4	4	Vision test	Acc variables Mirrors . . .
Blackout . .		.005	2	2	99	2	2	2	4	3	Interview . .	
Dozing . . .		.005	2	2	99	2	2	2	4	4	Interview . .	
Failed to observe stop sign .	Warn strips Lit signs Big signs .	.07	4	3	99	4	2	4	4	3	Sign/no sign Stop/no stop	Age, Sex Stolen veh Vis factors .
A pillar wid angle block= largest 10%	Design chng Mirrors Education .	.10	4	2	.10	5	4	4	2	4	Make/model Driver ht. .	Day-night Acc geometry
Dark sail area	Design chng Education .	.10	4	3	.10	5	4	4	3	4	Make/model Driver ht. Mirrors Restraint sys	Acc type Weather Day-night Road config Intersec/not
Tinted windshield .	Design chng	.50	4	2	.50	4	3	4	2	3	Make/model Glass type .	Driver age Car wt Mirrors Seat ht Time of day Eyeglasses Vis factors .

ACCIDENT CAUSATION WORKSHEET
(Continued)

Factor	CM	P(F|A)	Diff	Know	P(F|A')	Diff	Know	Applicab Infer	Applicab Case	Theory	Field Variables	Interacting Variables
Projecting mirror projection= largest 10%	Soft mirror Periscope .	.10	4	2	.10	4	2	3	4	2	Mirror type Veh type . .	Acc type Location Day-night Motorcycle .
Tread Depth<2/32 .	Wear indics Enforcement Longer wear-ing tires .	.05	4	4	.05	3	3	4	4	4	Tire type Tread depth Wear pattrn .	Make/model Weather Road surface
Tire pres F-R differs 10 lb from manufac rec	Wear indics Enforcement Longer wear-ing tires .	.01	3	3	.01	4	3	3	3	4	Tire pres Tire type Load Rec pres . .	Acc type Road surface Turning . .
Tire mix MMA unaccept	Inspection Education .	.04	5	3	.01	5	3	5	2	3	Model/size for each two	Veh type Acc type Weather . .
Bias/radial mix	Inspection Education .	.01	5	3	.01	5	3	5	2	3	Mixed/not . .	Driver exp Veh type Acc type . .
Suspension system modifics . .	Inspection Education .	.01	4	3	.01	4	3	3	3	3	Observe modifications	
Yaw stabil .	Design chng	.02	3	3	.02	4	3	4	2	3	Make/model Wt Speed No occupants	Maneuvers Braking Weather Acc type . .
Improp brake proport . .	Design chng	.02	3	3	.02	4	3	4	2	3	Make/model Wt Speed No occupants	Maneuvers Braking Weather Acc type . .
Rain	Speed lims Btr tires Wipers Defrostr . .	.10	5	5	<.10	4	2	4	4	3	Rain/not Intensity Road surface Grade	Speed, Tires Make/model Acc type Driver exp .

ACCIDENT CAUSATION WORKSHEET
(Continued)

Factor	CM	P(F|A)	Diff	Know	P(F|A')	Diff	Know	Applicab Infer	Applicab Case	Theory	Field Variables	Interacting Variables
Fog	Flash signs Fog lights 1-way roads	.01	5	5	<.01	4	2	4	4	4	Fog dens Visibility .	Speed, Tires Make/model Acc type Driver exp .
Snow/ice .	Salt Chains Tires Close road .	.05	5	5	<.05	4	2	4	4	3	Rate of fall Visibility Ground snow Salt	Speed, Tires Make/model Acc type Driver exp .
Sun glare .	Clean wind- shield, Tint windshield .	.002	4	3	.002	4	3	3	4	4	Travel direct Time of day Cloud cover .	Age Tinted glass
Stolen vehicles .	Wheel lock Key warning Btr ign cabl	.005	5	3	.00005	3	3	4	2	3	Stolen/not .	Age Acc type Fire . . . .
Inattention		.18	3	3	99	2	3	1	4	3	Interview . .	Age, Sex Time of day Veh type Road famil .
Internal distract .	Partition .	.05	4	3	99	2	2	1	4	3	Interview . .	Age, Sex Time of day Veh type Road famil .
External distract .	Tidier environs . .	.02	4	3	99	2	2	1	4	3	Interview Scene data .	Age, Sex Time of day Veh type Road famil .
Improper lookout . .		.20	3	3	99	2	2	1	4	3	Interview . .	Scene data Acc type . .
Decision errors . .		.40	3	3	99	1	2	1	4	3	Interview . .	Scene data Acc type . .

ACCIDENT CAUSATION WORKSHEET
(Continued)

Factor	CM	P(F|A)	Diff	Know	P(F|A')	Diff	Know	Applicab Infer	Applicab Case	Theory	Field Variables	Interacting Variables
Perform errors . . .		.08	3	3	99	1	2	1	4	3	Interview . .	Scene data Acc type . .
Alcohol . .	Various . .	.10	4	4	.10	4	4	4	3	4	Blood-alc level	Age, Sex Time of day Day of week Veh type . .
Drugs . . .	Enforcement	.05	2	2	.05	2	2	3	3	3	Interview Analyze blood	Age, Sex Time of day Day of week Veh type . .
Physical handicap . .	Restrict lic Devices . .	.01	3	3	.01	3	3	4	2	3	Interview . .	Age, Sex Time of day Day of week Veh type . .
Mental & emotional .		.05	2	2	99	2	2	2	4	2	Interview . .	Age, Sex Time of day Day of week Veh type . .
Driver inexperience	Restrict lic	>.01	4	3	.01	4	3	4	3	3	Age, Exp Veh type . .	Human factors
Vehicle unfamil . .	Standardi- zation . . .	.01	4	3	.01	4	3	4	3	3	Driver/veh ownership pattern . . .	Veh data . .
Road unfamil . .	Signing Radio . . .	.10	4	3	<.10	4	3	4	2	3	Interview . .	Human factors