TRANSPORTATION RESEARCH RECORD
486

Formerly issued as Highway Research Record

Traffic Accident Analysis

4 reports prepared for the 53rd Annual Meeting of the Highway Research Board

subject areas
51 highway safety
53 traffic control and operations

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

Washington, D. C., 1974

NOTICE

These papers report research work of the authors that was done at institutions named by the authors. The papers were offered to the Transportation Research Board of the National Research Council for publication and are published here in the interest of the dissemination of information from research, one of the major functions of the Transportation Research Board.

Before publication, each paper was reviewed by members of the TRB committee named as its sponsor and accepted as objective, useful, and suitable for publication by the National Research Council. The members of the review committee were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the subject concerned.

Responsibility for the publication of these reports rests with the sponsoring committee. However, the opinions and conclusions expressed in the reports are those of the individual authors and not necessarily those of the sponsoring committee, the Transportation Research Board, or the National Research Council.

Each report is reviewed and processed according to the procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved by the President of the Academy upon satisfactory completion of the review process.

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering, serving government and other organizations. The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities but also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

TRR 486
ISBN 0-309-02272-X
LC Cat. Card No. 74-6877
Price: $1.80

Transportation Research Board publications may be ordered directly from the Board. They are also obtainable on a regular basis through organizational or individual supporting membership in the Board; members or library subscribers are eligible for substantial discounts. For further information write to the Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue N.W., Washington, D.C. 20418.

CONTENTS

FOREWORD

The papers in this RECORD discuss several techniques and methods used in traffic accident prediction and analysis.

Paddock discusses the traffic conflicts technique as an accident prediction method. The technique was first developed by General Motors as a method of measuring accident potential. It is based on tabulation of evasive maneuvers as evidenced by brake-light indications or lane changes. The paper reviews the Ohio evaluation of the conflicts technique, which concluded that the technique is sound and provides the traffic engineer with a new tool for intersection evaluation.

The paper by Snyder summarizes a study concerned with the identification and quantification of environmental determinants of traffic accidents and with the construction of a conceptual model of traffic accidents based on environmental factors. The analysis of data, derived from a sample of 135 road segments, indicates that the number of accidents on a road segment is best predicted from traffic volumes and accident rates, whereas accident rates are best predicted from the type of road, intensity of road frontage development, and percentage of population between 16 and 24 years old residing in the region.

Hall and Dickinson report on research designed to evaluate the effectiveness and desirability of the differential truck speed limit on Interstate facilities in Maryland and to examine the operational implications of changing this limit. Vehicular speed and accident data were collected and analyzed for 84 study sites located on Interstate, U.S., and state routes throughout Maryland. Attempts were made to develop models for the prediction of truck accident rates on limited-access facilities. The existence of a posted differential speed limit was not found to be related to truck accidents, although truck compliance with the differential limit was comparatively low. Significant equations were developed that are capable of explaining truck accident and involvement variables by changes in traffic speed parameters.

In the final paper, Abramson presents an analysis of accidents to evaluate the effectiveness of traffic controls at intersections in an effort to develop new traffic control warrants. The paper discusses a quantitative means of comparing accident histories at intersections. An accident evaluation index is computed by using a percentage distribution of accidents by the following types: pedestrian, right-angle, rear-end, left-turn, and all others.

THE TRAFFIC CONFLICTS TECHNIQUE: AN ACCIDENT PREDICTION METHOD

Richard D. Paddock, Ohio Department of Transportation

A traffic conflicts technique was developed by General Motors as a method of measuring accident potential and is based on tabulation of evasive maneuvers as evidenced by brake-light indications and lane changes. For accident potential at intersections, 20 specific conflict classifications are defined. As a result of an FHWA-financed research program, Ohio became involved in the evaluation of the GM technique. At the time that the federal program ended, Ohio decided to pursue its own evaluation of the technique. This was prompted by a conviction that the theory behind the conflicts technique was sound and by a desire to find an accident prediction technique for use in Ohio. An accident projection technique is useful if it reflects the accident trends of the subject area. Early tests indicated that the algorithm published by FHWA could not be easily calibrated for Ohio data trends. Although Ohio data were used in generation of the FHWA method of accident prediction, it was felt that the data from the states of Virginia and Washington were of such volume and different nature as to bias the resulting algorithm. During 1972 and the first half of 1973, the Ohio data base was enlarged from 196 projects (more than 400 approaches) to 410 projects providing 922 approaches, of which 611 were usable for analysis purposes. A series of regression models was applied to this enlarged data base in an attempt to find a reliable accident prediction model. As a result of this analysis, accident prediction algorithms were developed that provide a mean accuracy of ±1.1 accidents per year and a 75th percentile accuracy of ±1.8 accidents per year. In addition, substantial insight into the workings of the conflicts technique has been obtained.

•A TRAFFIC CONFLICTS TECHNIQUE was developed by General Motors Research Laboratories to evaluate intersection operation. The basic premise of the conflicts technique is that the number of evasive maneuvers and brake-light indications can be used both to estimate the number of accidents that will occur over a given period of time and to evaluate the operational problems of the subject intersection. A GM procedures manual (2) gives details of the actual counting procedure.

During 1969, the Federal Highway Administration negotiated contracts with the states of Ohio, Virginia, and Washington to conduct an evaluation of the traffic conflicts technique. Under the federal program, each state was to conduct conflicts counts at a minimum of 100 intersections both before and after some engineering improvement. These counts were to be made over a 1-year period during which each state would conduct its own evaluation of the technique and forward it along with the data collected to FHWA for statistical analysis.

The stated purpose of the program was to determine whether conflicts counts conducted at the state level could provide information useful in determining safety improvement needs. In addition, the combined data from the various states would be utilized by FHWA to determine whether any correlation existed between conflicts and accidents.

Publication of this paper sponsored by Committee on Traffic Records.

As a result of the federal analysis program (1), 1,306 approaches were counted and analyzed. The results of this analysis are provided below.

All three states found that the conflicts technique provided the information needed for the design of safety improvements. Indeed, where accident data were available, the conflicts count not only verified the accident analysis but also provided insight into the conditions precipitating accidents.

The basic conclusions drawn from the federal program are summarized as follows:

1. The data compiled in the study tended to support the hypothesis that conflicts and accidents are associated;
2. On the basis of the experience of the three states, it appeared that safety deficiencies at intersections could be pinpointed more quickly and reliably by using the GM technique than by using conventional methods;
3. The GM technique may be particularly valuable at low-volume, rural intersections where the accident reporting level is low;
4. The traffic conflicts technique, because of its usefulness in pinpointing intersection problems more precisely, should lead to low-cost remedial actions;
5. The technique can be applied with minor modification to locations other than intersections;
6. The effect of intersection improvements may be demonstrated from conflicts counts taken shortly after completion of a spot improvement; and
7. The general surveillance information obtained during the collection of conflicts count data may be valuable in improving the overall operations of intersections.

Thus, previous efforts have shown the traffic conflicts technique to be a potentially valuable tool for the evaluation of intersection operation. Of particular interest to the state of Ohio was the possible application of the technique to the prediction of accident rates at newly improved intersections. To pursue this application, we began an in-house analysis program upon termination of the FHWA program.

CONFLICTS ANALYSIS PROGRAM

In February 1972, a program of conflicts analysis was initiated by the Traffic Studies Section of the Ohio Department of Transportation. Initial steps of this program were acquisition of the data base management programs from FHWA and enlargement of the Ohio data base.

The programs obtained from FHWA consisted of data base edit/update, card reformatting, and correlation analysis. In addition, the Ohio data file maintained by FHWA was obtained. After several modifications were made to the FHWA programs to make them compatible with our computer system, a major file update was begun.

This program of data compilation, coding, keypunching, editing, and, finally, master file updating increased our data base from the 196 projects obtained during the FHWA study to 356 projects of current data by November 1972. By May 1973, all available conflicts counts and the latest available accident data had been placed in the master file and numerous minor errors were corrected, giving some 611 usable data points.

Under the initial Ohio conflicts analysis program, we decided that attention would be directed to the possible relationship between intersection accidents and conflicts. Although we were interested in other possible applications of the technique, such as pinpointing operational problems and freeway analysis, we felt that prediction of accidents at intersections would provide a much more valuable tool for the traffic engineer. In addition, we felt that the basic theories of the conflicts technique could be tested most effectively by such an analysis program.

For an accident projection technique to be useful, it must reflect the accident trends of the area to which it will be applied. Thus we decided that only Ohio data would be used in the analysis. After several initial tests of the expanded Ohio data base against projections using the algorithm proposed by the FHWA study, it became apparent that the FHWA algorithm was not sufficiently sensitive to accident trends in Ohio. Although Ohio data were used in the generation of the FHWA algorithm, it was felt that the urban nature of the Washington and Virginia data used in the development of these equations biased the equations toward urban accident trends. Because the Ohio data are predominately rural in nature, new relationships that would be more sensitive to rural conflict trends needed to be developed. Thus, the ultimate objective of Ohio's analysis program was to generate prediction equations for accidents based on the data collected in a conflicts study within Ohio.

In addition, it was hoped that insight might be gained into potential alterations or improvements in the conflicts count technique. In particular, attention was to be given to the utilization of any additional parameters such as cross-street volume and percentage of commercial vehicles not included in the previous analyses.

Procedure

The procedure used for this project can be broken into the following three basic phases:

1. Update data base to reflect all conflicts counts and accident data available,
2. Determine relationships among various measures of conflicts, exposure, accidents, and so forth to establish variables for use in prediction equations, and
3. Generate accident prediction equations and verify them against data obtained after cut-off date (final output was to be a report consisting of the results of this study and a user's manual for predicting accidents from conflicts counts).

Data Base Update

As stated earlier, before the initial data base was modified, several programming modifications were necessary. These changes in the edit/update program corrected for those differences between the FHWA computer and that of the Ohio Department of Transportation. Once these changes were completed, approximately 15,000 records were added to the data base. This addition of data ensured that all available conflicts counts and accident data were on the master file, thus providing the largest data base possible.

Data Analysis

Although some preliminary analysis was done while the data base was being built, serious analysis began November 7, 1972. This analysis was obtained through use of BMDO2R, SAS, and our own GENPLOT programs. BMDO2R is a multiple regression program developed by the Health Science Computing Facility at UCLA (4). This program was used for the initial analysis phase.

Output from the program consists of variable means and standard deviation, covariance matrix, correlation matrix, linear regression coefficients, and residual plots.

The statistical analysis system (SAS) is a group of statistical routines developed by the University of North Carolina for work such as that under discussion (3). Once obtained and on-line, SAS provided more useful, efficient, and informative output than BMD and was used almost exclusively during the later phases of the analysis.

The third program, GENPLOT, is a general plot and polynomial regression program that has been used to check for data trends, to plot data, and to generate least squares fits for the data.

A total of 11 dependent and 26 independent variables were included in the data analysis phase. In addition, data were classified according to various combinations of the following groups.

1. Average daily traffic range (ADT),
2. Conflict type,
3. Environment,
4. Intersection type,

5. Major to minor route volume ratio (split), and
6. Intersection control (signalized versus unsignalized).

Table 1 gives the classification systems tested, and, as can be seen, results of the analysis were somewhat discouraging. Although an occasional particular data subset gave correlations as high as 0.36 to 0.37, the given classifying system did not provide acceptable correlation factors for other subsets. Typically, R^2 for the regressions was far from the initially desired minimum of 0.3.

It was suspected that the rural and retail strip nature of the data contributed to the low correlations found in this initial phase. In most cases, the number of accidents per year on any given approach varied between 0 and 4, resulting in rather large standard deviations (approximately 2.5) in the accident rates as compared to the mean of about 2.2. Efforts at normalizing the data with exposure originally resulted in little or no improvement.

In mid-December of 1972, a major breakthrough was made in predicting accidents at unsignalized intersections. This breakthrough resulted when volume split was introduced as a variable in conjunction with normalizing accidents by ADT. At this point, it was found that, if the total observed cross volume was divided by the observed volume on the counted approach, this volume split became a critical variable. Also, when accidents are expressed in terms of accidents per 2 years per 1,000 ADT, the regression equations generated for unsignalized approaches were more reliable. The net result of these changes in the prediction model was a mean accuracy of about ±2 accidents per year with a standard deviation of 0.2. An investigation of those points where our prediction error was greater than six accidents per 2 years revealed that several assumptions made earlier in the analysis phase were invalid. A new analysis of the data was made and resulted in development of a new, larger data base and even more reliable regression equations. After a regression model for unsignalized approaches was obtained, the next step was to find a model for signalized approaches. After some initial investigations and another update of the data base, a series of SAS runs was made to obtain regression equations.

The result of these final SAS runs was a set of equations for both of the individual control classes (signalized and unsignalized) and all data combined. Data points were classified by environment, intersection type, and accident type and were tested for possible use in the new models.

Finally, regressions were run on both raw accidents per 2 years and accidents per 2 years per 1,000 ADT. Although the environment and intersection type classifications appeared to provide good equations for some of the data, neither was consistent enough over all the data points to justify its use. In the end, it was decided that classification into signalized and unsignalized was sufficient.

Upon comparison of the projected accident rates to the actual accident data, the resulting error was within acceptable limits. Plots of this error are shown in Figure 1. It should be noted that, upon investigation of those points with the greatest prediction error, certain common characteristics were found.

1. Bad data point—In several cases it was found that accident records had been attributed to the wrong approach. In one case the correction of the coding error reduced the average prediction error over four approaches from roughly eight accidents per 2 years to about three accidents per 2 years.

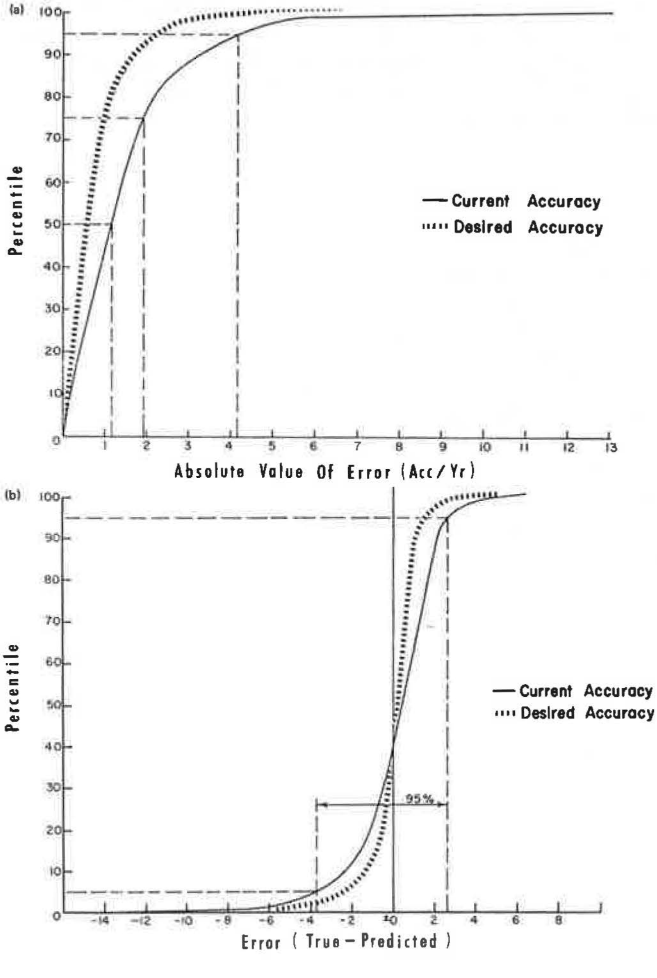
2. More than one approach lane—In most of the conflicts counts taken in Ohio, only one approach lane was provided on each leg of the intersection. In several cases studied where more than one lane existed on a given leg, the prediction error for that leg was high. This may be attributed to the sampling of only one lane for conflicts at such locations. It is suggested that, in future evaluations and regression runs, the number of approach lanes be included as either a variable or a clasfification criterion.

3. Combination of high volume and high speed—At several locations a high-volume, high approach speed leg had a poor prediction. A prime example of this is I-280 and Walbridge Road in Wood County. At this location, an at-grade intersection is signalized on the I-280 main line. The resulting interruption of flow on I-280 produced 31 accidents in 2 years. When a conflict count was run at the intersection, a rather low

Table 1. Classification systems tested.

Classifications	General Results			
	Sample Too Small	Poor	Average	Good
ADT range			X	
0 to 2,000		X		
2,001 to 7,000		X		
7,001 to 12,000			X	
More than 12,000	X			
Conflict type		X		
Weave			X	
Cross				X
Opposing				X
Rear end			X	
Environment			X	
Rural			X	
Retail strip		X		
Residential	X			
Intersection type			X	
T and Y	X			
Right angle			X	
Skew		X		
Volume split (unsignalized)		X		
Intersection control				X
Signalized				X
Unsignalized (including flasher)				X

Figure 1. Prediction error distribution for (a) absolute value and (b) true versus predicted value.



conflict-per-opportunity ratio was observed resulting in a prediction of only three accidents per 2 years. It is obvious from investigation of this and similar cases that our current prediction equations cannot be applied to such abnormal locations. As such, the reader is cautioned to apply the current algorithms with care.

4. Alteration during accident period—Ordinarily, accident data are recorded for a period 2 years before the conflicts count and 2 years after the count. In several cases an improvement was made during this period, and the resulting change in operation of the intersection naturally had an effect on the accident trends. When an accident projection was made from the conflict count, the error was often high in such cases. During any further analysis or attempts at generating accident trend equations, care will be taken to adjust the accident report period to reflect the operational characteristics sampled by the conflict count.

5. Unusual geometrics—The final basic type of poor prediction point was that generated at an intersection with unusual geometrics. Such a location might be found at a ramp junction, where a jug-handle is used for left turns. Because most of the data used in the regressions were from T and cross intersections, other types of intersections are not predicted well. Any location where "other" is coded as the intersection type should be excluded from analysis with the algorithms developed by this program.

Generation of Accident Prediction Equations

As stated earlier, after a substantial number of classification systems had been investigated, we decided that a simple division into signalized and unsignalized intersections would provide the most reliable accident prediction equations. The variables chosen for inclusion in the equations and the equations themselves are provided below. (The reader is cautioned that the blind use of these equations, as with any empirical model, may well produce poor results. Should anyone care to apply the results of our research in other states or under other than primarily rural conditions, he is encouraged to attempt to calibrate the basic model by analyzing data collected in his area.)

The variables used by Ohio were chosen by the SAS forward selection method of multiple linear regression (3) and are defined below.

Variable	Definition
ADT	Average daily traffic (in thousands) calculated from the conflict count
SPLIT	Ratio of the sum of the counted cross-street volumes to the counted approach volume
OPOPP	Opposing conflict opportunities
RROPP	Rear-end conflict opportunities
TTOPP	Total observed conflict opportunities
CPT	Total conflicts per 10 opportunities
OPCON	Opposing conflicts
TTCON	Total conflicts
OCPO2	Square of opposing conflicts per 10 opportunities
RATE	Accidents per 2 years per 1,000 ADT
AP2Y	Accidents per 2 years

The general form of the prediction equation for accidents at signalized approaches is

$$AP2Y = A + B \times ADT - C \times CPT - D \times D \times RROPP + E \times OCPO2 + F \times TTOPP - G \times OPOPP$$

Unsignalized approaches use the following equation form:

$$\text{RATE} = A + B \times \text{SPLIT} - C \times \text{ADT}^{1/2} - D \times \text{SPLIT}^2 + E \times \text{ADT} - F \times \text{OPOPP} + G \times \text{OPCON}$$
$$\text{AP2Y} = H + \text{RATE} \times \text{ADT}$$

In these equations, ADT is that value obtained from the conflict count. Although this often differs from the true ADT for the particular route, two limitations dictated that ADT be calculated from the count sheets. First, ADT is not normally available for the local streets and county roads counted in the conflicts program. Second, we felt that the traffic flow rate existing during the count period should be used to normalize the data inasmuch as the count day is very likely not to be an average day. In future analysis we hope to improve our predictions by using true ADT in the prediction equation.

In addition, the number of conflicts and opportunities used in the equations are those counted during a standard 10-hour period (ten 15-minute counts). Detailed descriptions of the count procedures, data reduction, and accident prediction algorithm may be found in other publications and in the Ohio Conflicts Procedure Manual, which will be published in 1974.

COMMENTS AND CONCLUSIONS

As a result of Ohio's analysis of the traffic conflicts technique, our traffic engineers have been provided with a means of determining the accident potential of a newly improved intersection, thus facilitating before and after studies. In addition to the accident prediction technique, Ohio has gained insight into the workings of the conflicts technique and an appreciation of the many possible applications of the theory of conflicts. The Appendix shows the kind of data collected in a conflict count and how they can be used in accident prediction.

Among the areas planned for future study is use of a modified conflict technique to evaluate freeway signing in gore areas. A pilot project run in 1973 has shown promise for the technique in evaluating the flow and safety of various areas of flow conflict such as freeway weave and gore sections. In addition, Ohio plans to conduct more research into the basic intersection analysis application to verify the equations we now have and improve on them to give more accurate before and after projections.

Thus, Ohio has conducted substantial research into the application of the traffic conflicts technique to accident prediction at rural intersections and has shown the method to be a potentially useful engineering tool. With some future development and "polishing" of the prediction algorithm, the basic model should provide an easily calibrated means of projecting the accident rates at newly constructed and improved intersections. Also, analysis of freeway sections may be simplified to some extent through application of a modified conflicts technique, and evaluation of conflicts data may well provide valuable input to the designing of new facilities and upgrading of existing ones. Indeed, conflicts may well help us move closer to preventive rather than remedial traffic engineering.

REFERENCES

1. Baker, W. T. Evaluating the Traffic Conflicts Technique. Traffic Performance and Analysis Div., Office of Traffic Operations, Federal Highway Administration, July 1971.
2. Perkins, S. R. GMR Traffic Conflicts Technique Procedures Manual. General Motors Research Laboratories, Warren, Mich., Aug. 1969.
3. Service, J., Barr, A., and Goodnight, J. A User's Guide to Statistical Analysis System. Dept. of Statistics, North Carolina State Univ., Aug. 1972.
4. Dixon, W. J. Biomedical Computer Programs. Univ. of California Press, Los Angeles, 1967.

APPENDIX

SAMPLE CALCULATIONS

This Appendix is intended to show exactly what sort of information is gathered in a conflicts count and how it is used to predict accidents. Figures 2 and 3 show sample calculations for signalized and unsignalized accident rates. (Conflict counts are recorded on data sheet C, and volume counts are recorded on data sheet D.)

The variables tested for possible use in the regression equations are listed below.

Variable Name	Interpretation
ADT	Average daily traffic in thousands
ADT2	Square root of ADT
ADT3	ADT squared
APVOL	Counted approach volume
APYR	Accidents per year
AP2Y	Accidents per 2 years
CADT	Cross volume
CCPO2	CRCPO squared
CPT	Total of WVCPO, OPCPO, CRCPO, and RRCPO
CPT2	CPT squared
CRACC	Cross accidents
CRCON	Cross conflicts
CRCPO	Cross conflicts per 10 opportunities
CROPP	Cross conflict opportunities
NCTS	Number of 15-minute counts taken
OCPO2	OPCPO squared
OPACC	Opposing accidents
OPCON	Opposing conflicts
OPCPO	Opposing conflicts per 10 opportunities
OPOPP	Opposing conflict opportunities
RATE	Accidents per 2 years per 1,000 ADT
RCPO2	RRCPO squared
RRACC	Rear-end accidents
RRCON	Rear-end conflicts
RRCPO	Rear-end conflicts per 10 opportunities
RROPP	Rear-end conflict opportunities
SPLIT	Ratio of CADT/ADT
SPLT2	SPLIT squared
TTCON	Total conflicts
TTOPP	Total conflict opportunities
WCPO2	WVCPO squared
WVACC	Weave accidents
WVCON	Weave conflicts
WVCPO	Weave conflicts per 10 opportunities
WVOPP	Weave opportunities

Figure 2. Signalized intersection accident projection.

A. ADT. (data sheet D)

1. Total All Fields except Field 4 = 1777 =APVOL

2. $\frac{APVOL * 0.0066}{NCTS}$ = 1.1728 =ADT

B. CPT

1. Data Sheet C.

(a) Total Fields 1, 2 & 3, "No. Vehs." columns= 16 =WVOPP

(b) Total Fields 1, 2 & 3, "No. Confs."columns= 0 =WVCON

(c) Total Fields 4 & 5 "No. Vehs." columns= 205 =OPOPP

(d) Total Fields 4 & 5 "No. Confs."columns= 0 =OPCON

(e) Total Fields 6 thru 10, "No. Vehs." columns= 0 =CROPP

(f) Total Fields 6 thru 10, "No. Confs" columns= 0 =CRCON

(g) Total Fields 11 thru 22 = 44 =RRCON

2. Data Sheet D

(a) Total Fields 1, 2, 3, 5, 6, 10 thru 14, (-)Minus Field 4 = 934 =RROPP

3. (a) $\frac{WVCON}{WVOPP} * 10$ = + 0 =WVCPO

(b) $\frac{OPCON}{OPOPP} * 10$ = + 0 =OPCPO

(c) $\frac{CRCON}{CROPP} * 10$ = + 0 =CRCPO

(d) $\frac{RRCON}{RROPP} * 10$ = + 0.4711 =RRCPO

4. WVCPO + OPCPO + CRCPO + RRCPO = = 0.4711 =CPT

C. RROPP (see B, 2, (a)) = = 934 =RROPP

D. OCPO2 (see B, 3, (b))

1. (OPCPO = 0)^2 = 0 =OCPO2

E. TTOPP (see B, 1, & B, 2)

1. WVOPP = 16

2. OPOPP = 205

3. CROPP = 0

4. RROPP = 934

5. WVOPP + OPOPP + CROPP + RROPP = 1155 =TTOPP

F. OPOPP (see B, 1, (c)) = 205 =OPOPP

G. AP2Y

1. +11.6345 * (ADT= 1.1728) = + 13.6449

- 0.0503 * (CPT= 0.4711) = - 0.0237

- 0.0321 * (RROPP= 934) = - 29.9814

+ 0.0387 * (OCPO2= 0) = + 0.0000

+ 0.0285 * (TTOPP= 1155) = + 32.9175

- 0.02255 * (OPOPP= 205) = - 4.6228

+ 1.6153

Algebraic Total = Accidents per 2 Years = 13.5498 =AP2Y

H. Confidence Intervals: APYR = AP2Y / 2.0 = 6.78

1.

Percentile	X	APYR - X	APYR + X
50th	1.50	5.28	8.28
75th	2.40	4.38	9.18
90th	3.70	3.08	10.48
95th	4.60	2.18	11.38

Figure 3. Unsignalized intersection accident projection.

A. SPLIT

1. APVOL (Data Sheet "D")

(a) Total all fields except field 4 = 522 =APVOL

2. CROPP (Data Sheet "C")

(a) Total of fields 6 thru 10, "No Vehs" Columns=

683 =CROPP

3. $\frac{\text{CROPP}}{\text{APVOL}}$ = 1.3084 =SPLIT

B. SPLT2 (see A, 3 above)

1. (SPLIT= 1.3084)^2 = 1.7119 =SPLT2

C. ADT (see A, 1, (a))

1. $\frac{(\text{APVOL}= 522) * 0.0066}{\text{NCTS}}$ = 0.3132 =ADT

D. ADT2 (see C, 1)

1. $\sqrt{(\text{ADT}= 0.3132)}$ = 0.5596 =ADT2

E. OPOPP (Data Sheet "C")

1. Total Fields 4 & 5, "No Vehs" Columns = 152 =OPOPP

F. OPCON (Data Sheet "C")

1. Total Fields 4 & 5, "No Confs" Columns = 0 =OPCON

G. AP2Y

1. RATE

(a) +17.7731 * (SPLIT= 1.3084)= +23.2542

- 1.6785 * (SPLT2= 1.7119)= - 2.8734

+18.2544 * (ADT = 0.3132)= + 5.7173

-36.7045 * (ADT2= 0.5596)= -20.5398

- 0.0264 * (OPOPP= 152)= - 4.0128

+ 0.8385 * (OPCON= 0)= + 0

+ 22.3568

Algebraic Total = Accident Rate = 23.9023 = RATE

2. AP2Y

(a) [(RATE= 23.9023) * (ADT= 0.3132)] + 0.36 = 7.8462 =AP2Y

H. Confidence Intervals: APYR = AP2Y / 2.0 = 3.92

1.

Percentile	X	APYR - X	APYR + X
50th	1.10	2.82	5.02
75th	1.75	2.17	5.67
90th	2.70	1.22	6.62
95th	3.80	0.12	7.72

ENVIRONMENTAL DETERMINANTS OF TRAFFIC ACCIDENTS: AN ALTERNATE MODEL

James C. Snyder*, Georgia Institute of Technology

This study is concerned with identification and quantification of environmental determinants of traffic accidents and with the construction of a conceptual model of traffic accidents based on environmental factors. Dependent variables include accident numbers and rates (number of accidents per million vehicle-miles of travel). Independent variables include physical characteristics of the road, the road frontage (adjacent land use), and physical and social characteristics of the region. Data are derived from a sample of 135 road segments, each 2 miles long, in Oakland County, Michigan. A wide range of environmental characteristics are represented. Automatic interaction detection, multiple classification analysis, and multiple regression techniques are used to construct a series of predictive models. Analysis indicates that the number of accidents on a road segment is best predicted from traffic volumes and accident rates, whereas accident rates are best predicted from the type of road, the intensity of road frontage development, and the percentage of population between 16 and 24. Inspection of the formulated models suggests a conceptual macromodel that is different from traditional models of traffic accidents.

•MUCH of the previous research on traffic accidents has focused on the road itself, with some consideration of roadside characteristics (1, 2). Also, much of the work has dealt either with particular road sections or types or with large cross-sectional areas. Many of the basic relationships have been defined (such as the positive relationship between accident rates and traffic volume) although quantitative results have varied among studies.

The focus here, however, was on the development of a conceptual model of traffic accidents based on environmental factors across a regional geographic area with a wide range of environmental characteristics. The hypothesized general model is shown in Figure 1.

STUDY AREA AND DATA

Oakland County, Michigan, was selected as the study site. The county has an area of approximately 900 square miles and a population of approximately 900,000. The county is totally urban in the southeast, the intensity of which diminishes through suburban development to a totally rural character in the northeast.

A stratified, systematic, unaligned sample of 135 road segments, each 2 miles long, was selected. Measurements were then taken for each roadway, the land use adjacent to the roadway, and the spatial area around the segment to a distance of 3 miles. The areal measurements were derived from spatially indexed data (i.e., census districts) and weighted by a distance decay factor based on a distribution of travel distances.

The accident statistics came from the Oakland County accident file and included 13,498 reported accidents from 1968 to 1970. The resultant file contained 135 road

*This report summarizes research conducted by the author while he was with the Highway Safety Research Institute, University of Michigan.

Publication of this paper sponsored by Committee on Traffic Records.

segments, each with a number of dependent and independent variable measurements. The variables used include accident rate, accident number, road type, road volume (ADT), number of intersections, percentage of developed frontage, percentage of commercial frontage, percentage of residential frontage, number of land use category changes, percentage of regional land developed, vehicle density, employment density, population density, residential density, value of homes, rent, and percentage of the population between 16 and 24. In the figure, the road, the road frontage, and the region are the overall environment in which travel occurs. The travel activity, constrained by a set of environmental factors, produces some accident set. The underlying causal model logic is this: Travel activity has certain attendant characteristics; that is, it has an origin and destination, a mix of drivers and vehicles, a mix of dynamic parameters such as speed, vehicle density, and traffic volume, and a mix of physical parameters such as the roadway, lighting, sound, and visual appearance—all of which constitute a complex set of interacting factors. These factors affect the driver and vehicle and thus the accident set.

Although many studies have focused on some subset of these factors, this study attempts to look at the broader determinants of these factors. More specifically, the study addresses the construction of a series of mathematical predictive models of accident numbers and rates in a spatial, geographic context. The resultant models are static and descriptive and were derived from cross-sectional, spatially indexed, empirical data. Inspection of these models suggested an overall conceptual model.

ANALYSES

Methods

Bivariate relationships were examined via correlation matrices and bivariate regression plots. Second, automatic interaction detection (AID) was used to explore the structure of the data and to reveal interactions between variables. Then variables were selected for entry to multiple classification analysis (MCA) and finally to multiple regression analysis.

Accident Numbers and Rates

Initial analysis revealed two points of interest. First, the correlation between accident numbers and accident rates improved with increasing traffic volume. That is, variations in numbers of accidents and in traffic volumes, on which rates are calculated, produced less variation in rates where numbers and volumes were large. Therefore, rate prediction on low-volume roads was not successful. Numbers of accidents, however, were successfully predicted on all roads.

Second, significant intercorrelations existed within types of predictor variables (e.g., road, road frontage, and regional) because several variables used were surrogates for the same underlying factor. For example, percentage of developed frontage, percentage of commercial frontage, and number of intersecting roads each related to the intensity of road frontage activity. Selecting variables for future study may well rely on convenience of data collection rather than on a search for the best predictor within a class of predictors.

The first AID analysis of all 135 road segments showed that the type of road was the best overall predictor of accident rates. The AID tree is shown in Figure 2.

The AID analysis uses analysis of variance techniques to subdivide the sample into a series of subgroups, which maximizes the ability to predict values of the dependent variable. The program operates by finding the dichotomy, based on an independent variable, that produces the lowest within-group sum of squares for the dependent variable. This bifurcation accounts for more of the variance of the dependent variable than any other split. Each subgroup is further split in a similar manner until preselected criteria are met (e.g., minimum N for a subgroup). Each box of the AID tree gives the name of the independent variable, variable categories or values, number of cases, and value of the dependent variable for that group.

In this case, the first split was made on the type-of-road variable (categories in-

Figure 1. Conceptual traffic accident model.

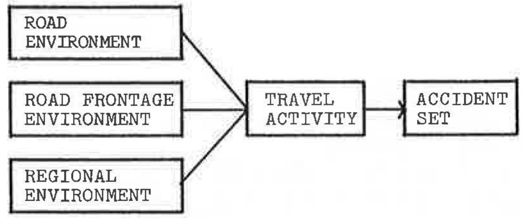


Figure 2. AID analysis of accident rates.

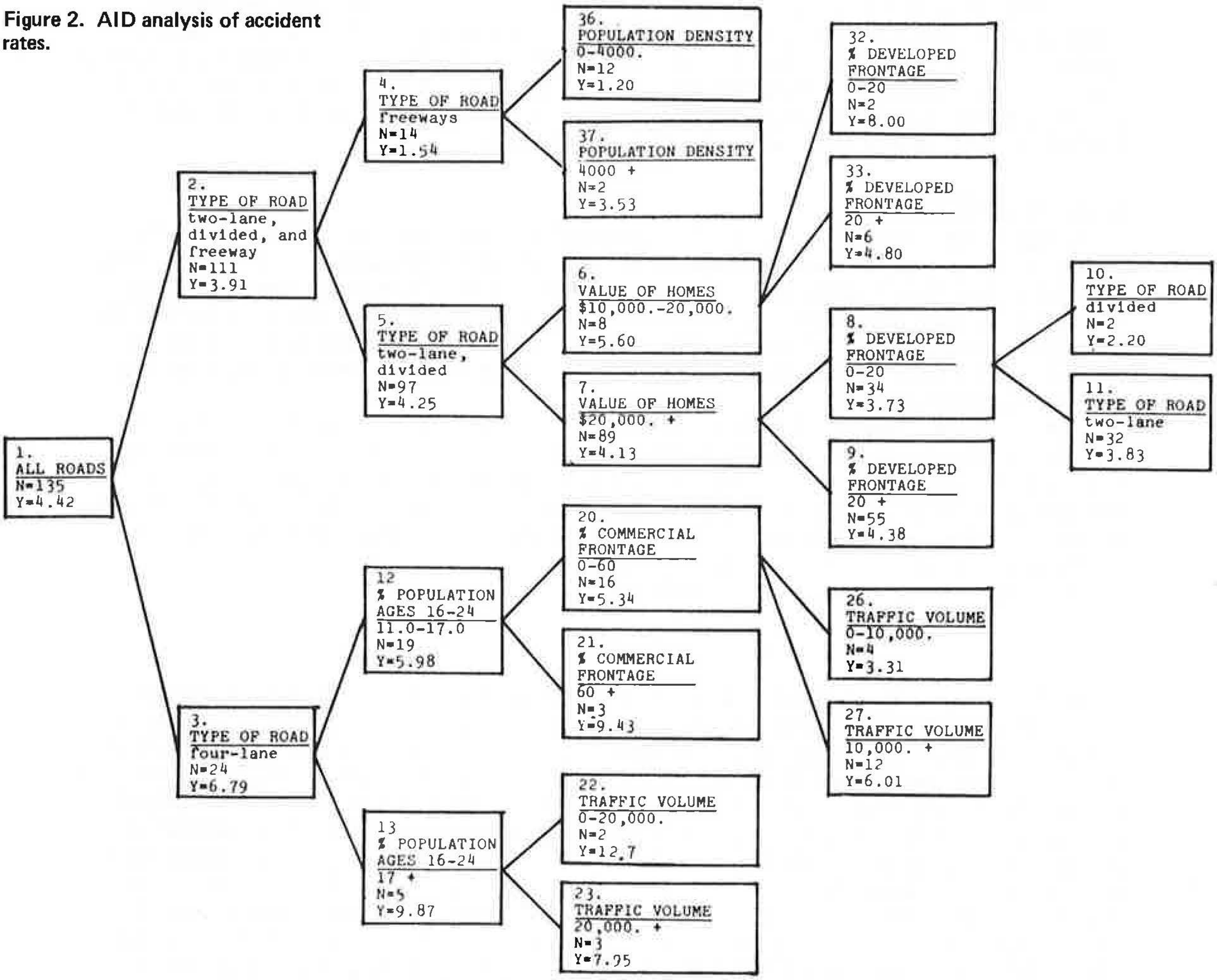
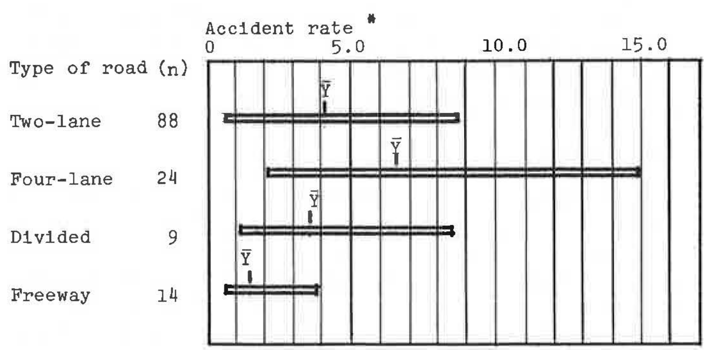


Figure 3. Means and ranges for accident rates by road type.



* accident rate = number of accidents per one million vehicle-miles

clude two-lane, four-lane, divided, and freeway), indicating that the type of road was the best overall predictor of accident rate. Each road type grouping was then split on different predictor variables.

This asymmetry indicated interaction among road type and the other independent variables. That is, different sets of environmental factors were affecting each road type. Figure 3 shows the means and ranges for accident rates for each of the road types.

When an AID analysis was conducted with number of accidents as the dependent variable, three closely competing predictor variables were found: type of road, percentage of area developed, and percentage of commercial frontage. Interaction between the type of road and other predictors was again existent. Figure 4 shows the means and ranges for number of accidents for each road type. Each road type was analyzed separately in order to avoid complex interaction terms.

Two-Lane Roads

Accident rates varied widely on low-volume two-lane roads as expected, and thus accident rate prediction was unsuccessful. The numbers of accidents, however, were best predicted from traffic volume and measures of road frontage activity. The AID tree (Fig. 5) split first on traffic volume, second on percentage of developed frontage, and third on the number of intersecting roads. However, the latter two were closely competing, intercorrelated measures of road frontage activity, and thus the tree was essentially symmetrical.

The conceptual model called for the inclusion of regional effects, but regional intensity measures such as population and vehicle density tended to be intercorrelated with road frontage measures. One of the qualitative measures, the percentage of population between 16 and 24, had a positive correlation with number of accidents and no significant intercorrelation with other independent variables. Thus those three variables were entered into the MCA (Tables 1 and 2).

This analysis produces a model of the form

$$Y_{ijk} = Y + a_i + b_j + c_k + \ldots + e_{ijk}$$

where Y_{ijk} is an individual case-dependent variable value, i, j, and k are categories on successive predictors to which the case belongs, and a_i, b_j, and c_k represent adjustments to Y, the grand mean for the dependent variable. Hence, the effect of predictor A is a_j. Thus, one simply finds the three variable categories for a particular case and makes the appropriate adjustment to the grand mean to arrive at the estimated dependent variable value. Thus, for a particular road segment, the predicted number of accidents would be the mean number of accidents for that road type plus adjustments for each of the independent variable categories. The unadjusted deviation considers only the effect of that one independent variable, whereas the adjusted deviation considers the effect of that variable given the effects of the other independent variables. The η statistic is the correlation ratio and indicates the ability of the predictor to explain variation in the dependent variable. η^2 indicates the proportion of the total sum of squares explainable by the predictor. The β statistics are analogous to the η statistics but are based on adjusted means rather than raw means.

The multiple regression is given in Tables 3 and 4. The R^2 is higher in the regression models because there is no loss of information with continuous data, whereas the MCA divides the data into subgroups.

Other Roads

The same types of analyses were conducted for accident rates and numbers for each of the other road types. Accident rates for four-lane roads were best predicted from percentage of developed frontage and percentage of population between 16 and 24. Accident numbers were best predicted from traffic volume, percentage of commercial frontage, and percentage of population between 16 and 24. The rate prediction models differed from the number prediction models in that the former did not include traffic volume as a predictor.

Figure 4. Means and ranges for number of accidents by road type.

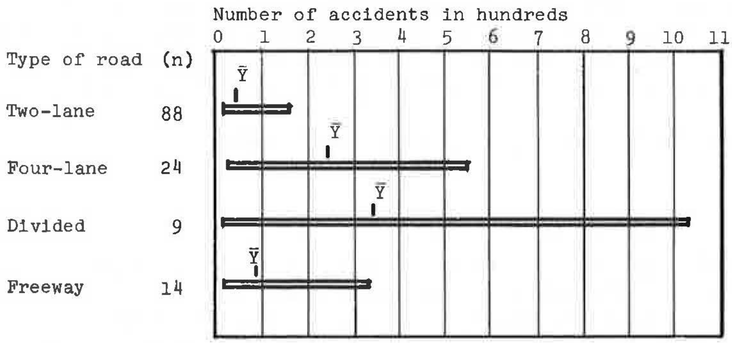


Figure 5. AID analysis of number of accidents on two-lane roads.

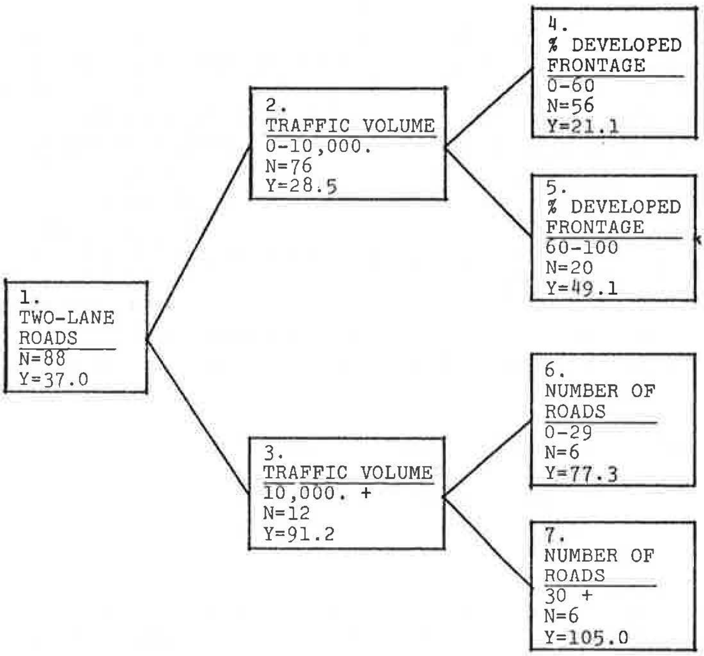


Table 1. MCA of number of accidents on two-lane roads.

Variable	η	η^2	β	β^2
Traffic volume	0.812	0.660	0.576	0.331
Percentage of developed frontage	0.695	0.483	0.310	0.096
Percentage of population between 16 and 24	0.464	0.216	0.263	0.069

Model building for divided and freeway segments was limited by a small sample number. The accident rate on divided roads was best predicted from the percentage of commercial frontage and on freeways by the regional population density. Prediction of numbers was not necessary because, on high-volume roads, the rates and traffic volumes are relatively stable and numbers can be computed directly from those statistics.

Table 5 gives a summary of all of the MCA and regression models developed in this study.

ALTERNATE MODEL

The general model of traffic accidents based on environmental factors appears to have been substantiated. The models exhibit operationally acceptable R^2 values. The inclusion of regional scale variables contributed in two ways: importance in terms of additional specification of models and substitutability of those terms for more traditional measures. The former contribution can be measured in β values, which, in this case, ranged from 0.073 to 0.429. In the latter case, several bivariate models used regional variables as the best predictor. The availability and convenience of areal data may justify additional substitution in operational situations.

Inspection of the models, as a group, leads us to consider the general relationship among accident numbers, rates, and traffic volume. Accident numbers tended to increase with increasing levels of traffic volume. A positive relationship was exhibited for all four road types, with bivariate regression R values of 0.845, 0.702, 0.831, and 0.735. Also, accident numbers tended to increase with increasing accident rates except on two-lane roads where the variability was high because of small numbers of accidents and low traffic volumes. Bivariate regression plots of accident rates and numbers for the remaining three road types exhibited R values of 0.750, 0.961, and 0.928. Accident rates, however, exhibited no significant relationship with traffic volumes in this study (R of -0.033 for all roads, -0.155 for two-lane roads, and 0.149 for four-lane roads).

All of this leads to the suggestion of a conceptual model that is different from the traditional traffic volume-accident rate model. This alternate model is based on two relationships:

$$\begin{aligned} \text{Number of accidents} &= \text{f (traffic volume, accident rate)} \\ &= \text{traffic volume} \times \text{accident rate} \\ \text{Accident rate} &= \text{f (type of road, road frontage} \\ &\quad\ \text{environment, regional environment)} \end{aligned}$$

The relationships are shown in graphic form in Figure 6.

Traffic volume and accident rate determine the number of accidents on a road segment in a simple multiplicative relationship. The type of road, road frontage characteristics, and percentage of the population between 16 and 24 determine the accident rate. Traffic volume does not directly affect the accident rate, but volume is associated with the variables that affect the accident rate. For instance, highly developed road frontage activity and heavy traffic volume tend to occur together. And traffic volume is, of course, closely associated with the type of road. This basic set of relationships is modified for two road types. First, road frontage is not an important variable for freeways because these roads have limited access. Second, the importance of the 16 to 24 age group is not exhibited on divided roads and freeways, not because it does not exist, but because the longer trip distances on those roads reduce the effectiveness of a 3-mile radius areal population measurement. For these reasons, regional variables do not appear in the divided road model, and residential density is the best predictor for freeways.

CONCLUSIONS

This study has attempted to use a wide range of environmental variables in the prediction of traffic accidents over a wide range of road types. Although cross-study

Table 2. Deviations for variables in MCA of number of accidents on two-lane roads.

Independent Variable	Number of Cases	Class Mean	Unadjusted Deviation From the Grand Mean	Adjusted Deviation From the Grand Mean
Traffic volume (ADT)				
<5,000	53	18.4	-18.6	-12.7
5,000 to 9,999	23	51.6	14.5	8.6
10,000 to 14,999	9	89.3	52.2	43.4
15,000 to 19,999	1	124.0	86.9	35.4
20,000 to 24,999	2	84.5	47.4	26.0
Percentage of developed frontage				
0 to 19	34	15.7	-21.3	-10.3
20 to 39	26	36.0	-1.0	0.6
40 to 59	14	53.2	16.1	6.2
60 to 79	8	59.3	22.2	15.6
80 to 99	6	95.6	58.5	20.6
Percentage between 16 and 24				
11.0 to 12.9	13	24.6	-12.3	1.1
13.0 to 14.9	52	33.5	-3.5	2.5
15.0 to 16.9	16	37.3	0.2	5.0
17.0 to 18.9	4	83.7	46.6	26.0
19.0+	3	89.3	52.2	30.7

Note: Grand mean number of accidents = 37.0; N = 88.

Table 3. Results of multiple regression analysis of number of accidents on two-lane roads.

Variable Number	Variable Name	Mean	Standard Deviation	Range Min	Range Max
12	Number of accidents	37.0	32.2	1.0	164.0
10	Traffic volume	5,014.7	4,266.0	173.0	20,000.0
3	Percentage of developed frontage	30.3	26.2	0.0	98.0
12	Percentage between 16 and 24	14.3	2.0	11.0	23.0

Table 4. B, β, and significance levels for regression analysis.

Item	Road Volume	Percentage Developed	Percentage Between 16 and 24
B	0.00516	0.262	0.024
β	0.692	0.214	0.073
F ratio	84.97	8.49	1.413
p	$\leq$0.01	$\leq$0.01	$\leq$0.05

Note: In the overall regression, R = 0.94, F = 231.2, and $p \leq 0.01$. $R^2 = 0.89$, N = 88, and constant term = 0.0.

Figure 6. Alternative model.

Table 5. Summary of statistical models.

Road Type	Dependent Variable	N	Road Variable	β	Road Frontage Variable	β	Regional Variable	β	MCA R^2	Regression R^2
Two-lane	No. of accidents	88	Traffic volume	0.692	Percentage of developed frontage	0.214	Percentage between 16 and 24	0.073	0.742	0.890
Four-lane	Accident rate	24			Percentage of developed frontage	0.525	Percentage between 16 and 24	0.429	0.234	0.890
Four-lane	No. of accidents	24	Traffic volume	0.644	Percentage of commercial frontage	0.226	Percentage between 16 and 24	0.119	0.780	0.890
Divided	Accident rate	9			Percentage of commercial frontage					0.880
Freeway	Accident rate	14					Population density			0.690

comparisons are difficult at best, it appears that the models developed here are at least as successful as previous attempts in terms of variance explained. It appears that the inclusion of regional variables is justified and that the underlying conceptual model is at least tentatively supported.

The use of such models has been documented in numerous previous studies and need not be elaborated here. However, the operational tasks of problem area identification, factor identification, and the like may in some cases find marginal benefit in using these models because of the relative ease of collecting the independent variable data.

In conclusion, although this approach is basically sound, much additional work is warranted in this general area.

ACKNOWLEDGMENTS

The author is now an assistant professor of city planning at the Georgia Institute of Technology. The work reported here was conducted at the Highway Safety Research Institute, University of Michigan, and was part of a PhD dissertation with co-chairmen Donald Cleveland and John Nystuen, with the assistance of William Pollock of HSRI.

REFERENCES

1. Kihlberg, J. K., and Tharp, K. J. Accident Rates as Related to Design Elements of Rural Highways. NCHRP Rept. 47, 1968.
2. Traffic Control and Roadway Elements—Their Relationship to Highway Safety, Rev. Ed. Highway Users Federation for Safety and Mobility, published in 12 separate chapters, 1968 to 1971.

TRUCK SPEEDS AND ACCIDENTS ON INTERSTATE HIGHWAYS

J. W. Hall and L. V. Dickinson, Jr., University of Maryland

The research reported in this paper was designed to evaluate the effectiveness and desirability of the differential truck speed limit on Interstate facilities in Maryland and to examine the operational implications of changing this limit. The research effort was directed toward (a) determining the degree to which trucks comply with existing speed limits, (b) developing a procedure for comparing truck speeds and accident rates on particular sections of highway, and (c) determining the likely operational impact of modifying differential truck speed limits on Interstate highways. Vehicular speed and accident data were collected and analyzed for 84 study sites located on Interstate, U.S., and state routes throughout Maryland. Multiple regression techniques were used to determine whether a significant relationship could be found among speed parameters, accidents, and accident rates. Attempts were made to develop models for the prediction of truck accident rates on limited-access facilities. The existence of a posted differential speed limit was not found to be related to truck accidents, although truck compliance with the differential limit was comparatively low. It was not possible to develop a statistically significant equation for the prediction of the overall rate of truck accidents. Significant equations that are capable of explaining truck accident and involvement variables by changes in traffic speed parameters were developed. The impact of modifying the differential truck speed limit could not be determined with certainty, but it was suggested that the limit be temporarily altered on a test section.

•AMONG the many factors cited as criteria on which judgment of the operating efficiency of the highway transportation system can be based, the most frequently mentioned parameters are speed of travel and economy of operation. Numerous studies have been undertaken in the broad domain of highway system analysis for the purpose of evaluating these parameters. Studies have spanned the spectrum from applied to theoretical and have ranged from specialized studies at a single location, with little general applicability, to extensive system-wide studies, frequently used as the basis for subsequent design, traffic operations, or analysis procedures. With some notable exceptions, the majority of the studies concentrate on passenger vehicle operation and tend to disregard trucks.

In the United States, trucks constitute more than 17 percent of all vehicle registration, are responsible for approximately 20 percent of all vehicle-miles of travel, and transport more than 20 percent of the intercity ton-miles of freight. Trucks are an important and sizable element in the highway transportation system, but they pose special problems in the evaluation of highway operating efficiency. These difficulties are primarily due to the differences between trucks and passenger vehicles, among which are the following:

Publication of this paper sponsored by Committee on Traffic Control Devices.

1. Truck weights are significantly greater than passenger car weights;
2. Primarily because of their weight (or more specifically, their power-weight ratio), trucks have poorer acceleration capabilities than passenger cars and have greater difficulty maintaining their speed on upgrades;
3. Trucks have a slower rate of deceleration in response to braking than do passenger cars;
4. Average operating and maintenance costs, on a per-mile basis, are higher for trucks than for cars;
5. A truck's operation on the street system is restricted to those locations where geometric design elements are sufficient for its passage;
6. The property damage costs for truck-involved accidents tend to be higher than for accidents involving only passenger cars; and
7. The average truck is 2 years older than the average car, with the result that new vehicle design standards require more time for implementation in the truck population.

Each of these factors introduces some complications into the evaluation of truck operation and may restrict alternatives for possible improvements. They are of special concern in a consideration of the speeds at which trucks can operate safely and efficiently. The literature indicates that attempts have been made to analyze some of these factors with attention being devoted to criteria for establishing truck climbing lanes in mountainous areas, to the effect of trucks on the capacity of a street or highway, and to operating costs for commercial vehicles.

However, one of the more obvious heterogeneities in the operating environment, the differential truck speed limit, has been the subject of only limited investigation. This type of speed limit restricts trucks to travel at speeds less than those posted for passenger cars. It is based on the premise that, from any given speed, a truck requires longer to decelerate to a lower speed or to brake to a complete stop than does a passenger car. The supposed objective of differential speed limits for trucks is to increase highway safety by making the differences in braking distance more compatible. However, there is valid concern that enforced speed differentials may cause a higher number of vehicular conflicts, and thus increase the likelihood of certain types of accidents (e.g., truck rear-end collisions).

Despite some confusion on the relative merits of differential speed limits, approximately one-half of the eastern states have enacted legislation providing for lower statutory speed limits for vehicles that exceed a certain size or weight. The research reported in this paper was undertaken to evaluate the effect of the existing differential truck speed limit on Interstate highways in Maryland and to examine the operational implications of altering this limit.

PREVIOUS RESEARCH

Most previous research on the topic of speed-safety relationships has concluded that higher speeds are more closely related to increased accident severity than to accident causation. The effect of speed on severity is especially noticeable at speeds greater than 50 mph, which are characteristic of limited-access facilities. The results of several studies on this topic are summarized in a 1969 report (6), which indicates that the ratio of persons injured to persons killed decreases sharply at higher speeds. Similarly, the National Safety Council reports that the improper driving category "speed too fast" is recorded for a higher percentage of fatal accidents than for either injury or all accidents. Several researchers have noted an increase in the percentage of single-vehicle accidents at higher speeds, as opposed to rear-end and angle collisions, the dominant types of collision at lower speeds

On the basis of intuition as well as numerous research studies, there is reason to believe that the relationship of speed to accidents is most closely related to variation from the average speed. Accident involvement rates are highest for vehicles traveling much less than the average speed and are lowest for a 10-mph speed range in the vicinity of the mean speed of travel. A plot of involvement rate as a function of variation from average speed produces a concave upward curve, with a minimum value in the vicinity of the average speed (7, 8). All of the reports stress that the relationship is not necessarily causative but that it could reflect the operating strategies of the drivers or other factors that were not investigated.

Several studies have focused on the operating speeds of trucks. Some of the work concerned with truck speeds on vertical grades has been used by the American Association of State Highway Officials to establish warrants and design criteria for truck climbing lanes. Other studies have found that accident rates are higher on grades than on tangent, level sections. Similar characteristics were found for truck accidents, especially rear-end collisions on upgrades. A recent study of truck climbing lanes presents data that indicate a fourfold increase in accidents when truck speeds are reduced to 10 mph below the average speed of traffic and a 16-fold increase with a 20-mph reduction.

Related work has sought to establish the relationship between truck operation and highway capacity. The currently accepted procedures for the determination of freeway capacity, as outlined in the Highway Capacity Manual (4), rely on passenger car equivalency factors. These factors depend on the percentage and length of upgrade and the percentage of trucks in the traffic stream. The effect of trucks on capacity is due primarily to their inability to maintain speed on extended upgrades, although a small effect is noted on level sections simply because of their larger size. With the exception of steep or lengthy downgrades where trucks are required to use low gears, the Manual notes that the effect of trucks on downgrades is minimal. The effect of truck speeds on operating economy has also been examined, and results indicate that the increased operating cost at higher speeds over long hauls may be balanced by savings in such areas as driver wages, fleet size, and terminal consolidation.

A recent study (3) of the differential truck speed limits on Interstate facilities in Virginia found that, at most study sites, the 85th percentile truck speed was in excess of the posted limit, although at only one site was the speed greater than 60 mph. Partially on the basis of this study the truck speed limit in Virginia was increased from 50 mph (differential speed limit of 65/50 at time of study) to 55 mph, and subsequently to 60 mph.

STUDY ACTIVITIES

Site Selection

To accomplish the objectives of the study, we selected site locations on the basis of posted speed limits (differential and equal), geometric design, and operational characteristics. A total of 55 sections of roadway in Maryland, some with two-directional studies, were analyzed on Interstate, U.S., and state routes, resulting in 84 study site locations (Fig. 1). The study sites were grouped according to their posted speed limits.

Along with the selection of representative study sites, it was necessary to determine an adequate sample size for data collection. The determination of sample size is dependent on the desired accuracy of the sample and the size of the sample standard deviation. Research indicated that the standard deviation is normally in the range of 5 to 10 mph with the higher value on steep upgrades. With a standard error of 0.5 mph and an estimated standard deviation of 7 mph, a sample size of approximately 200 vehicles (trucks) was required. Preliminary data analysis verified the adequacy of this sample size.

Data Collection

Based on other research, it was felt that data needs existed in four primary areas. The major data requirement was accurate spot speed information for trucks and (separately) for cars at each of the study sites. Also, traffic volume at the sites was an essential data factor. The accident experience, both at the study sites and on the total state-administered system, was of prime importance. Finally, the geometric characteristics for each site were needed. These four sets of data—speed, volume, accidents, and geometrics—formed the basis of the analysis.

The speeds of free-flowing cars and trucks were measured with a radar unit and simultaneously marked on a graphic recorder. Differentiations between passenger car and truck speeds were made on the recorder output, and at the same time traffic volume and vehicle classification data were recorded. Accident data for the years 1970 and 1971 and copies of the geometric design plans for each of the sites were furnished by the Maryland State Highway Administration.

Speed data for the trucks and cars were used to construct histograms showing the speeds of vehicles at each directional site. These served as an input to a computer program that performed the calculations to determine central tendency and dispersion parameters for the speeds of trucks, passenger cars, and a combined sample of trucks and cars at each site. The program also prepared a graph of the cumulative speed distributions.

Data Analysis

As a reference point for special speed studies, a study site was chosen where speeds could safely be measured from roadside and overpass vantage points. The site was also used for nighttime, wet-weather, and follow-up studies. Because of its high level of geometric design and its frequency of "free-flowing" traffic, I-95 at the Van Dusen Road overpass (site 051 NB) was selected for this purpose.

Initial data analysis was undertaken to determine whether the presence of roadside observers on an Interstate facility affected vehicular speeds. Analysis of extensive speed measurements indicated that both the mean and the 85th percentile truck speeds were statistically equivalent for roadside and overpass observations, whereas the mean passenger car speed showed a slight (1.5-mph) reduction for roadside observations. Because the primary emphasis in this study was truck speeds, we decided that overpass observations might be more desirable but that roadside observations would yield similar results and could be employed when necessary.

One of the most obvious findings in the examination of the data from all of the sites was the generally low level of compliance with the posted speed limit for both passenger cars and trucks. One criterion frequently used in determining and posting speed limits is the 85th percentile speed, although most references strongly recommend that consideration be given to design and control features and to accident experience. The assumption is that most drivers will exercise good judgment in the selection of their travel speed, especially if they are aware of the nature of the environment in which they are driving. In the case of limited-access facilities, however, the maximum speed limit is normally specified by state statute.

Table 1 gives the results of a comparison of passenger car and truck compliance with their respective posted speed limits. (Study sites with unusual geometric conditions, including long, steep grades or sharp horizontal curvature, are not included.) Of the 55 sites listed, the percentage of truck compliance exceeds the percentage of passenger car compliance at approximately half of the sites. At 12 of the sites (all on upgrades), more than 85 percent of trucks comply with the limit, while none of the sites exhibited a level of passenger car compliance in excess of 85 percent. For all the sites listed in Table 1, average truck compliance with the posted speed limit is 58 percent, whereas average car compliance is 56 percent. For the 17 sites with a 60/60 limit, the average level of truck compliance with the posted limit is 73 percent, while at sites with a differential speed limit, only 51 percent of the trucks are in compliance. The difference is statistically significant.

It should be noted that the sites with a 70-mph posted limit for cars tend to be of a higher level of geometric design, both in fact and as perceived by the driver. To further examine this point, we selected two representative sites for comparison: site 055 SB, on a rural Interstate facility that has a 70/60 speed limit and representative geometric and operational characteristics for sites with differential speed limits, and site 251 SB, located on a suburban Interstate section that has a 60/60 speed limit and is representative of sites without differential limits. Although the geometric design features at these two sites are similar, their environmental settings and the nature of the contiguous roadways are sufficiently different that the truck driver is inclined to choose a slightly higher operating speed at site 055 SB. The cumulative truck speed distributions at these two sites are shown in Figure 2.

Figure 1. Study site.

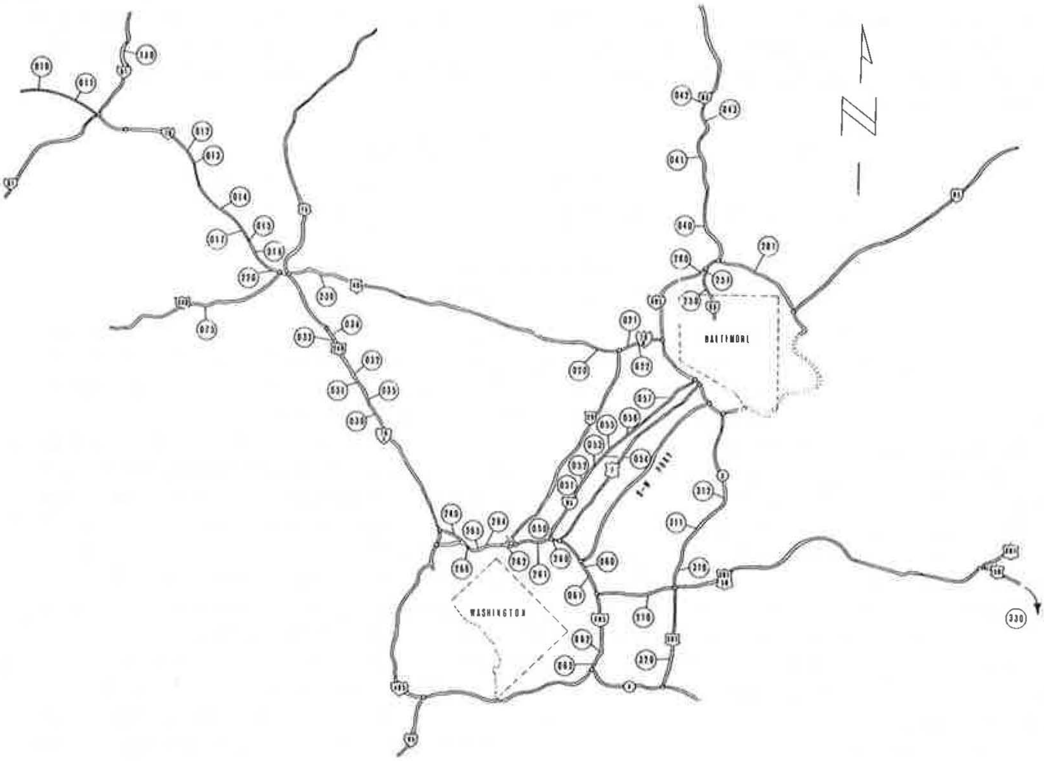


Table 1. Some variables used in speed-accident analyses.

Site	Speed Limit	Percentage of Compliance		Site	Speed Limit	Percentage of Compliance	
		Truck	Car			Truck	Car
261 WB[a]	60/60	97	46	033 SB	70/60	54	69
250 NB[a]	60/60	97	54	042 SB	70/60	53	79
031 SB[a]	70/60	96	83	055 SB	70/60	52	35
262 EB[a]	60/60	95	65	281 WB	60/60	49	30
262 WB[a]	60/60	94	60	060 WB	70/60	49	76
035 NB[a]	70/60	92	75	280 EB	60/60	47	34
220 WB[a]	60/60	91	39	110 SB	65/60	44	65
240 NB[a]	60/60	89	43	020 EB	70/60	41	69
063 SB[a]	70/60	88	60	061 EB	70/60	41	71
054 SB[a]	70/60	87	66	014 EB	70/60	40	71
030 SB[a]	70/60	87	84	110 NB	65/60	40	50
210 WB[a]	60/60	86	44	056 NB	70/60	39	39
011 EB[a]	70/60	79	60	042 NB	70/60	38	81
250 SB[a]	60/60	77	47	220 EB	60/60	38	11
055 NB[a]	70/60	74	44	011 WB	70/60	36	53
034 NB[a]	70/60	72	60	041 SB	70/60	36	66
251 SB[a]	60/60	71	30	010 WB	70/60	34	58
056 SB[a]	70/60	68	49	054 NB	70/60	34	38
021 EB[a]	70/60	67	65	030 NB	70/60	33	71
281 EB[a]	60/60	65	52	032 NB	70/60	33	54
041 NB	70/60	65	77	014 WB	70/60	30	59
240 SB[a]	60/60	65	32	022 WB	70/60	29	65
261 EB[a]	60/60	63	32	052 NB	70/60	29	50
020 WB	70/60	62	69	052 SB	70/60	29	57
051 NB	70/60	62	66	063 NB	70/60	24	57
260 WB[a]	60/60	61	30	062 NB	70/60	24	55
210 EB[a]	60/60	58	34	010 EB	70/60	22	51
051 SB	70/60	58	72	Average	60/60	73	40
				Average	70/60	51	62

[a]Sites where truck compliance is greater than passenger car compliance.

It has been well established that vehicular speeds are affected by roadway geometrics including grades and horizontal curvature. To examine the influence of geometrics on the Maryland Interstate System required that the study sites be divided into the following categories:

Type	Characteristic
Level	Grades between -0.75 and +0.75 percent
Downgrades	Grades between -7.0 and -0.8 percent
Upgrades	Grades between +0.8 and +4.5 percent
Special	Horizontal curvature > 5 deg
Other	Variable conditions

Analysis of truck speed data as a function of roadway geometrics is discussed in a separate report (2). Specifically, it was found that existing AASHO standards for the construction of speed profiles are deficient in that they actually represent the operation of the second percentile truck rather than the assumed 15th percentile truck.

To approximate the results, for each site, of a spot speed study that would not have distinguished among vehicle types, we calculated a combined sample after the speed parameters had been separately calculated for trucks and passenger cars. Analysis of these modified data verifies the minimal effect of grades on passenger car operation. However, the averages of the 85th percentile truck speeds for upgrade, level, and downgrade sections were respectively 57.5, 64.2, and 67.0 mph. This is a clear indication that, under certain conditions, a sizable percentage of trucks that are legally limited in Maryland to 60 mph are capable of maintaining higher speeds.

Another important factor related to truck performance on limited-access highways is the weight-horsepower ratio. Existing highway design criteria assume a 400:1 ratio, that is, a weight of 400 lb/unit (net) horsepower. It was clear from the initial studies that trucks maintaining higher speeds (>50 mph) on sustained grades were single-unit trucks rather than fully loaded tractor trailer units. In fact, heavily loaded vehicles were occasionally found to be traveling at less than 20 mph, and the 15th percentile truck speeds at five sites were less than 25 mph. Data supplied by the American Trucking Association indicate that 550 hp would be required for a fully loaded (73,280-lb) unit to maintain a speed of 50 mph on a sustained 3 percent grade. Trucks with this power rating are not commercially available and, if they were, would be expensive to operate.

In an attempt to relate the operating characteristics of trucks to their weight, a special study was conducted. Because there are no truck weighing stations on the Maryland Interstate System, it was necessary to use a site on US-301. The site is located on a slight (-0.4 percent) downgrade approximately 1 mile north of the weigh station. Trucks were identified as they passed the study site, and the speeds of free-flowing vehicles were recorded. At the weigh station, the weight and axle configuration of each truck were recorded. Regression techniques were used to determine the existence of possible relationships between truck weight and speed and between percentage of legal loaded weight and speed. Although the general trend for both analyses at this site indicates that heavier trucks travel at higher speeds, the average difference between the lightest and the heaviest trucks was small, and no statistically significant relationship could be found. Others have used an alternate approach that employs portable roadside weighing scales and the measurement of truck speeds in advance of the weighing station. This approach may provide better information on truck speed-weight relationships.

SPEED AND ACCIDENTS

There are several manners in which vehicular speeds can be considered important in accident causation. Speed, per se, is closely related to stopping distance, the braking distance being a function of the square of vehicular speed. Even a comparatively small difference in speed can have a significant effect, as evidenced by the fact that the stopping distance at 65 mph is 15 percent greater than the stopping distance at

60 mph. It has also been noted that speed differences contribute to accidents, especially rear-end and lane-changing accidents. In the case of trucks, these speed differences may be brought about by an inability to maintain speed, as on an upgrade, or by enforced differential truck speed limits.

The analysis of speed and accidents undertaken as part of this study was based on two separate criteria: the measured values for truck speed, primarily the mean and 85th percentile truck speed, and the speed difference, obtained by subtracting the mean truck speed from the mean car speed (or the 85th percentile truck speed from the 85th percentile car speed). Preliminary analysis indicated a high degree of correlation between the mean and 85th percentile truck speeds and between the speed difference variables obtained by using these parameters.

At only one of the study sites (on a -7.0 percent grade) was the 85th percentile truck speed greater than the 85th percentile car speed. At three sites, the mean truck and car speeds were equivalent. For all of the remaining study sites, the previously defined speed difference was a positive value. Whereas the speed differences at one site were as high as 26 mph, it was found that the (mean) speed difference was equal to or less than +4 mph at more than half of the study sites. Of the 53 sites with a posted differential truck speed limit, more than two-thirds have a mean speed difference of +6 mph or less and an 85th percentile speed difference of +8 mph or less. All of the sites that have an 85th percentile difference in excess of +12 mph are on upgrades of 3.0 percent or steeper. In other words, the actual speed difference is normally less than the posted 10-mph differential except in those cases where trucks cannot maintain their speeds because of roadway geometrics.

Three interrelated approaches were used in an attempt to determine the relative operating safety at locations with different speed characteristics. Initially, analysis was conducted on a site basis, with consideration being given to all accidents (on the main roadway) within 1 mile on either side of the study site. Second, comparisons were also made among groups of sites with similar characteristics. Because of the indecisiveness of the results of these first two procedures, a third type of analysis was undertaken for extended subsections of Interstate routes.

Approximately 3,700 accidents (total for 1970 and 1971, two directional) occurred within the set of 1-mile sections surrounding the study sites. As shown in Figure 3, trucks were involved in 15.5 percent of all accidents on roadway sections with a differential speed limit and 19.5 percent of all accidents on roadway sections without a differential speed limit. The figure indicates that the major portion of the difference in percentage of truck-involved accidents is found in the category of truck-passenger car accidents.

The average Interstate accident rate for 1970-1971 in Maryland was found to be 1.7 accidents per million vehicle-miles (acc/MVM). In the vicinity of the study sites on the Interstate System, the 2-year accident rates were grouped as follows:

Accident Rate (acc/MVM)	Percentage of Study Sites
>0.55	24
0.55 to 1.10	29
1.10 to 1.70	31
>1.70	16

It was noted that, at the study sites with an accident rate greater than 1.7 acc/MVM, the percentage of truck-involved accidents is less than the average percentage of truck involvement for all sites. On the other hand, all of the sites with an above-average percentage of truck involvement have comparatively low accident rates. Neither the accident rate nor the percentage of truck-involved accidents was significantly different from the average at those Interstate study sites that were initially chosen on the basis of a high number of truck accidents.

The investigating officer's accident report, which forms the basis for the Maryland computerized accident record system, provides for the citing of a "probable cause" of

Figure 2. Truck speed distributions at two representative sites.

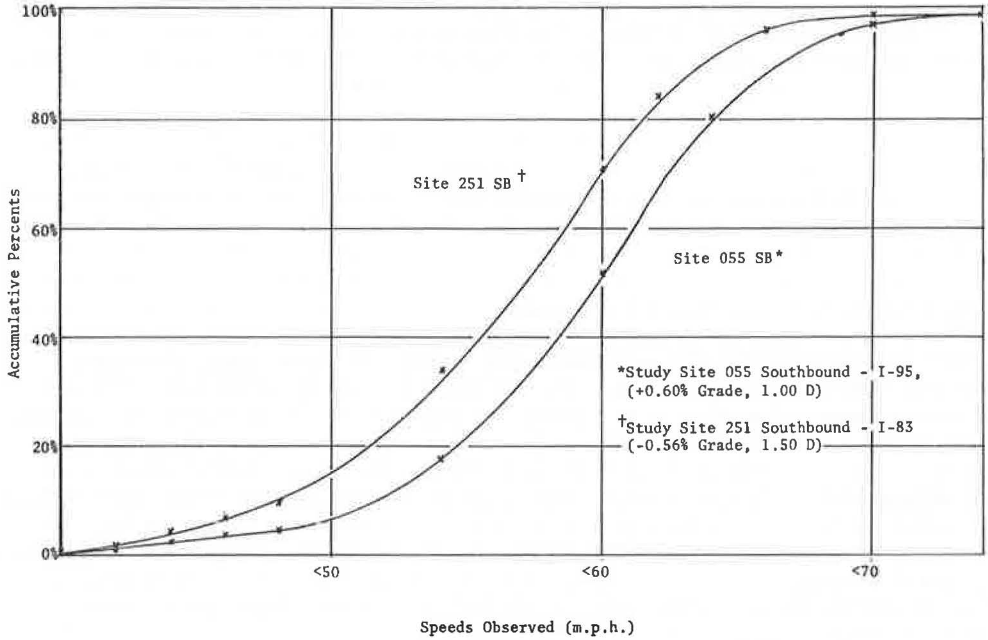
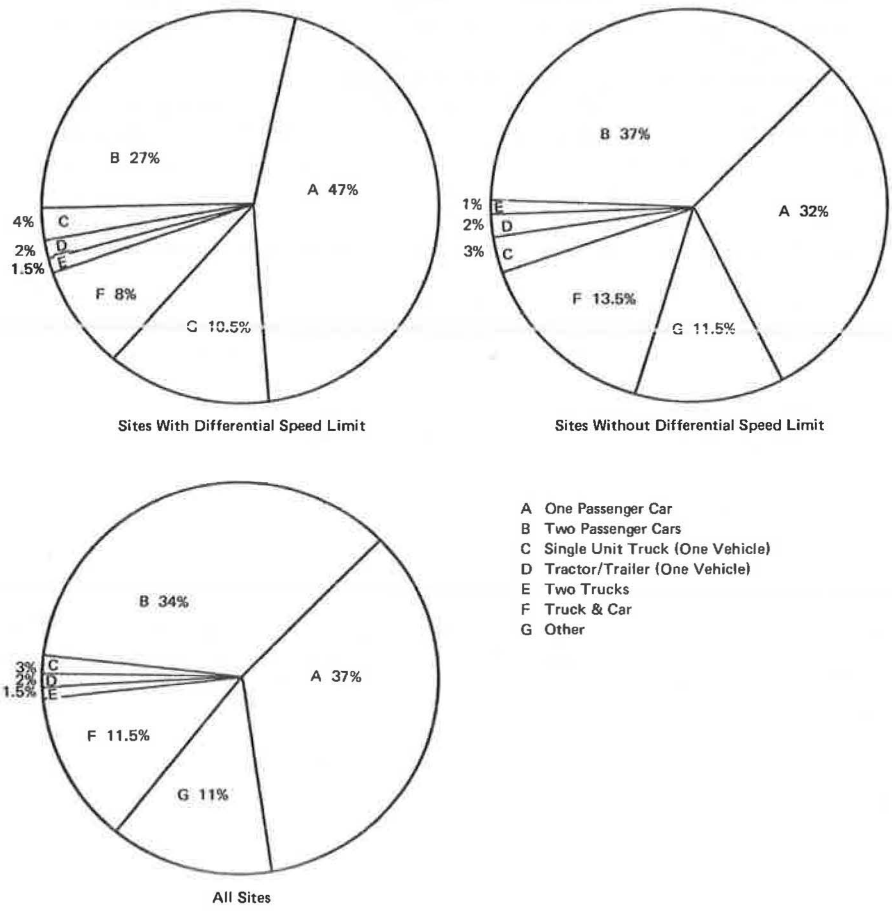


Figure 3. Summary of accident characteristics near study sites (not including ramp accidents).



the accident. From these data it was found that, in approximately 12.9 percent of all truck-involved accidents on Interstate facilities, the cited probable cause was "driving at speeds considered unsafe for existing conditions" or "other speeds and exceeding 60 mph." The probable cause "failing to reduce speed" was attributed to trucks in an additional 7.6 percent of the accidents in which they were involved. The total of 20.5 percent is less than the percentage of all rural accidents in which the National Safety Council (1) reports that speed was the element of improper driving involved. In other words, despite the comparatively poor level of compliance with posted speed limits, vehicular speed is not cited as a probable cause in an unusual portion of truck-involved accidents in Maryland.

On a site-by-site basis, no significant relationship could be found among vehicular speed, mean or 85th percentile speed differences, total accident rate, and percentage of truck involvement. This was due in part to the gross nature of the previously discussed analysis, which did not distinguish direction of travel or manner of collision. In addition, the small number of reported accidents at some sites precluded in-depth analysis. To circumvent some of these problems, we identified 17 extended sections of highway in the vicinity of each study site. Each of these designated sections was characterized by relatively uniform operational and design characteristics. When speed data were available at two or more sites within a section, they were averaged and assumed to be representative of operation on the section. All analysis was done by direction of travel. Six traffic volume variables, 19 speed parameter variables, and 21 accident and accident rate variables were calculated for each section. The variables that proved to be important in subsequent analyses are given in Table 2.

A standard statistical program processed the data and calculated a correlation matrix for all variables and multiple regression equations for a set of 12 dependent variables. Because of their obvious interdependence, several of the variables exhibited a high degree of correlation. For example, truck mean speed and truck 85th percentile speed had a correlation of +0.97. The majority of the 1,058 correlation coefficients were low (between -0.6 and +0.6). Given the sample sizes involved, it is possible to determine at the 5 percent level of significance that a relationship does exist between two variables if their correlation coefficient is less than -0.35 or greater than +0.35. However, the specification of a mathematical relationship between the variables is misleading unless the absolute value of the correlation coefficient is somewhat higher.

A detailed examination of the speed and accident variables led to the following conclusions.

1. The 85th percentile speed of the combined sample and the rate of dry-weather truck rear-end accidents are negatively correlated (-0.67).
2. None of the truck speed variables is significantly related to the number or rate of truck accidents.
3. The speed difference variables are negatively correlated with truck and total accident rates.
4. The presence of a posted differential speed limit is not significantly related to any of the accident or accident rate variables.

The absence of a linear relationship between speed and accident variables is in general accord with the results of other research. Part of the difficulty in identifying such a relationship is the nature in which the data are quantified. Extreme values for either speed or accident variables at one or two sites can noticeably affect the analysis of the data and disguise relationships among the parameters. This difficulty was relieved in part through the use of a rank order comparison, in which the truck speeds in each direction on the 17 extended sections were arranged in ascending order and assigned a rank value, with 1.0 assigned to the lowest speed and 34.0 assigned to the highest speed. Ranks were assigned in a similar manner to an accident rate variable for these sections. A Spearman rank order correlation coefficient was used to evaluate the nature of the relationship between the rankings of the speed and accident variables. When this procedure was used at the 5 percent level of significance, a negative relationship was found between the ranks of the truck mean speed and the rate of truck involvement. On the basis of these data, hypotheses that the rate of truck accident involvement is independent of truck speed, or that it increases with higher truck speeds, must be rejected. When truck speed is used as a single dependent variable, however, it is not possible to develop a reliable predictive equation for the rate of truck accident involvement.

Because variables other than truck speed can have an influence on truck accidents, an attempt was made to determine the possible existence of a multiple-independent variable equation that would adequately predict accident variables. Using a standard computer program, we performed a set of multiple regression analyses with accidents and accident rates as the dependent variables. As might be expected, the regression equations developed to estimate truck accidents primarily depend on a measure of truck travel.

Attempts to use multiple regression techniques to predict rates of total and passenger car accidents did not produce useful results. However, multiple regression equations for the rate of truck involvement and the rate of all dry-weather accidents yielded multiple correlation coefficients between 0.67 and 0.70. Given the number of degrees of freedom, these equations are on the borderline of statistical significance at the 5 percent level.

It was possible to develop statistically significant equations to predict three of the truck accident rate variables. In order of increasing significance these were the rate of dry-weather truck accidents (RDTAC), the rate of dry-weather truck accident involvement (RDTINV), and the rate of dry-weather rear-end truck accidents (RDTRED). A five-variable equation for RDTAC is given by

$$\begin{aligned} \text{RDTAC} = 6.548 - 0.391(\text{ASD}) - 0.094(\text{CM}) + 0.306(\text{A85}) \\ -0.264(\text{C85}) - 3.112(\text{TPER}) \end{aligned} \quad (1)$$

The multiple correlation coefficient R for this equation is 0.60, but the F-ratio test indicates that the equation is significant at the 0.05 level. This result must be interpreted carefully by considering the following points:

1. The possibility should not be ruled out that other variables not included in the regression model could better explain the rate of daytime truck accidents and
2. Relationships among the independent variables may be such that they are not truly independent.

The second point is relevant to the regression equation shown above. Data given in Table 3 indicate the high degree of positive correlation between the combined sample mean speed (CM) and the passenger car 85th percentile speed (A85), between the combined sample 85th percentile speed (C85) and A85, and between C85 and CM. Because of the high degree of correlation, these pairs of variables are not independent, and the assumptions underlying the development of the equation are not met. As a result, Eq. 1 should not be used for predictive purposes.

The following five-variable equation was developed for the prediction of RDTINV. It has a multiple R of 0.66 and is significant at the 0.01 level:

$$\begin{aligned} \text{RDTINV} = 2.290 - 0.136(\text{TSD}) - 0.057(\text{T85}) + 0.052(\text{APC}) \\ -2.513(\text{TPER}) + 0.242(\text{DUMMY}) \end{aligned} \quad (2)$$

Table 4 indicates that the correlation coefficients between the terms in this equation are comparatively low and that they can be assumed to be independent. The equation indicates that increases in the truck standard deviation (TSD), the truck 85th percentile speed (T85), and/or percentage of trucks (TPER) are associated with a reduction in the rate of dry-weather truck accident involvement. It can also be seen that RDTINV increases slightly with the percentage of passenger cars in the modified 10-mph pace (APC). The existence of a differential speed limit, included in the equation through the use of the variable DUMMY, has a positive effect on RDTINV.

The relative importance of the independent variables in this equation becomes clear only when the actual values of these variables are inserted into the equation. The mean values for the five variables used in Eq. 2 show the following relationship:

T85 > APC > TSD > DUMMY > TPER

From a practical viewpoint, the variables that can be most easily changed are DUMMY and T85. Eliminating the posted differential limit would change DUMMY from 1 to 0, whereas the level of enforcement of speed regulations will affect the value of T85. The other three variables, TSD, APC, and TPER, are characteristics of the traffic that are difficult to control.

Two of the extended study sections had an 85th percentile truck speed of 69.0 mph. In comparison with the averages for all sites, the values for TSD on these two sections were slightly higher than average, the values for APC were less than average, and the values for TPER were approximately equal to the average. Both sections currently have a 70/60 differential speed limit. When the data values from these sites are used in predictive Eq. 2, the estimated value for RDTINV is significantly less than for all sites. Actual accident data from these sites are in good agreement with the results of this equation.

The best multiple linear regression equation developed from the data was for the prediction of the rate of dry-weather rear-end truck accidents (RDTRED). This equation, which has a multiple R of 0.78 and a very high F-ratio significant at the 0.01 level, is given by

$$\begin{aligned} \text{RDTRED} = {} & 5.467 + 0.069(\text{TM}) + 0.290(\text{CSD}) - 0.149(\text{C85}) \\ & -4.414(\text{TPER}) + 0.001(\text{MVM}) \end{aligned} \quad (3)$$

Data given in Table 5 indicate that, with the possible exception of a negative relationship between TM and combined sample standard deviation (CSD), the variables in this equation are independent. The mean values for the five variables used in this equation show the following relationship:

MVM > C85 > TM > CSD > TPER

When modified by the appropriate coefficients in Eq. 3, the term that contributes the most (in absolute value) to the equation is C85, followed in descending order by TM, CSD, and TPER. The variable MVM has a very small impact on the results obtained by using the equation. Data from the 34 study sites were inserted into the equation, and the predicted values of RDTRED were compared to the actual rates at these sites. Figure 4 shows this comparison. It can be seen from the figure that 70 percent of the predicted values are within ± 0.2 acc/MVM of the actual rate.

For fixed values of TPER and MVM, tests with the model indicated a general reduction in values for RDTRED with increasing speed values. This is in accord with research conducted by others (8). However, it is interesting to note that none of the speed difference variables was important enough to be included in the five-variable regression equation. Previous research has concluded that speed difference is an important parameter in accident causation, but the regression equations developed by using the data collected in this study indicate that other parameters may be more important in predicting truck accident rates on limited-access facilities.

The models described in Eqs. 2 and 3 are statistically significant. This means that to a reasonable extent they are capable of explaining the variation in their respective dependent variables by changes in traffic volume and speed parameters. For the data collected in this study, they are the most consistent models that can be developed. It should be remembered, however, that other variables not included in the model could be of equal or greater importance. This is especially important in this type of model, which attempts to predict a discrete occurrence (i.e., an accident or a specific type of accident) on the basis of general factors related to roadway operation, such as speed and travel. The speed measurements taken at each site are representative of the operation at a particular location and are reproducible, as verified by follow-up studies at several sites. However, it is difficult to identify the speed characteristics of a particular vehicle involved in an accident. A truck involved in an accident at a particular site could have been traveling at the 10th, 50th, or 85th percentile speed.

Table 2. Vehicle compliance with posted speed limits.

Variable	Description	Average
TM	Truck mean speed (mph)	56.4
TS	Truck speed standard deviation (mph)	6.7
T85	Truck 85th percentile speed (mph)	62.8
ASD	Passenger car speed standard deviation (mph)	6.1
A85	Passenger car 85th percentile speed (mph)	70.4
APC	Modified passenger car 10-mph pace[a] (percent)	62.2
CM	Combined sample mean speed (mph)	63.3
CSD	Combined sample standard deviation (mph)	7.2
C85	Combined sample 85th percentile speed (mph)	69.9
DELMTA	Passenger car mean speed minus truck mean speed (mph)	8.3
DEL85A	Passenger car 85th percentile speed minus truck 85th percentile speed (mph)	7.5
TPER	Percentage of trucks in traffic stream	14.4
MVM	Mean 1970-71 travel (MVM)	104.4
DUMMY	0 = no differential speed limit; 1 = differential speed limit	0.8
RTINV	Rate of truck involvements	1.7
RDTAC	Rate of dry-weather[b] truck accidents	0.9
RDTINV	Rate of dry-weather[b] truck involvements	0.9
RDTRED	Rate of dry-weather[b] truck rear-end accidents	0.5
RDACC	Rate of dry-weather[b] total accidents	0.6

Note: 27 other variables were included in the study analyses.

[a]Percentage of vehicles in 10-mph range immediately below the 85th percentile speed.
[b]Dry pavement surface and driver condition reported normal.

Table 3. Correlation coefficients for variables in RDTAC model.

Variable	ASD	A85	CM	C85	TPER
ASD	1.00	0.56	0.34	0.56	0.47
A85		1.00	0.94	0.99	0.37
CM			1.00	0.95	0.33
C85				1.00	0.40
TPER					1.00

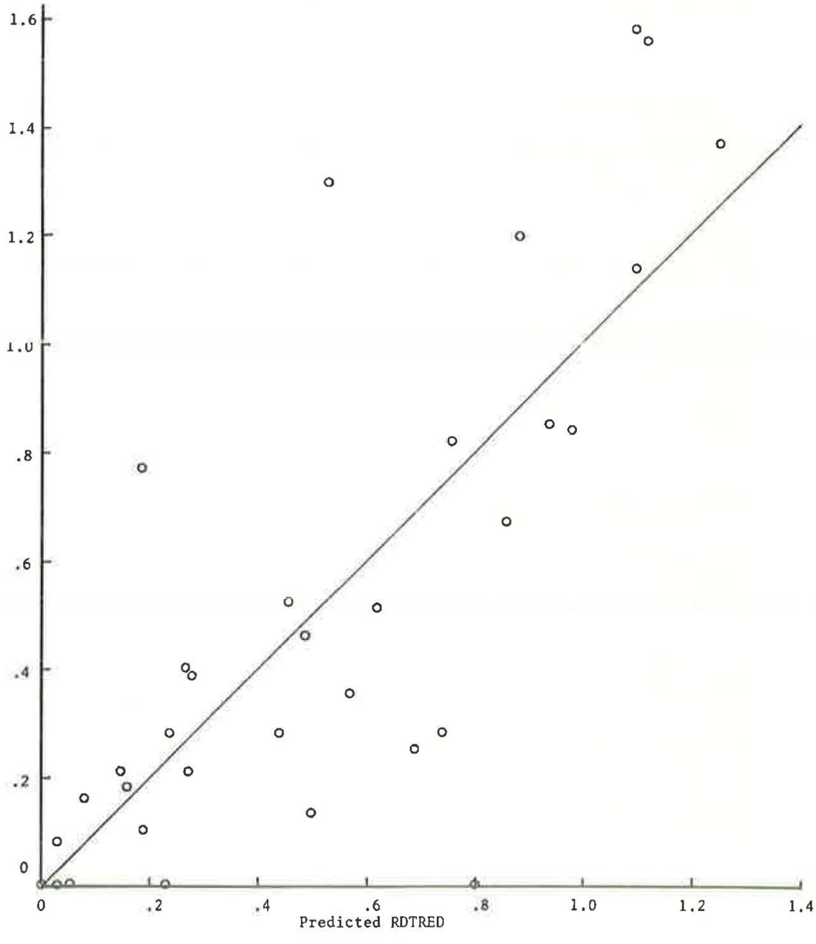
Table 4. Correlation coefficients for variables in RDTINV model.

Variable	TSD	T85	APC	TPER	DUMMY
TSD	1.00	-0.71	-0.26	-0.30	0.29
T85		1.00	-0.01	0.41	0.17
APC			1.00	-0.48	-0.54
TPER				1.00	0.11
DUMMY					1.00

Table 5. Correlation coefficients for variables in RDTRED model.

Variable	TM	CSD	C85	TPER	MVM
TM	1.00	-0.73	0.47	0.40	0.12
CSD		1.00	0.23	-0.03	-0.17
C85			1.00	0.40	0.01
TPER				1.00	-0.17
MVM					1.00

Figure 4. Predicted versus actual rates of dry-weather truck rear-end accidents.



The only input that exists with respect to this point is the "probable cause" of the accident cited on the investigating officer's report. These data indicated a less than average amount of speed-related "probable causes" in truck-involved accidents on Interstate facilities.

There is reason to believe that accidents that occur at higher speeds are more severe in terms of both injuries and costs. This is reflected in part by the fact that, for all Interstate truck accidents, the ratio of injuries to accidents is 0.52; whereas, for those Interstate truck accidents with speed factors cited as the "probable cause," the ratio is 0.66 injury/accident. However, a study of costs for truck-involved accidents on the Interstate System produced some conflicting results. The data base for this analysis was the investigating officer's estimate of "total amount of damage." It was found that, for two-vehicle and multiple-vehicle truck-involved accidents on Interstate highways, total estimated amount of damage was $200 to $400 higher for those accidents with speed factors cited as the "probable cause" than for all truck-involved accidents on Interstate highways. However, for single-vehicle truck accidents, which constitute approximately 30 percent of the truck accidents on Interstate highways, the reverse situation was found, with the damage costs for those accidents with speed cited as a "probable cause" estimated at $200 less than for all single-vehicle truck accidents. Although it is possible that there are errors in the estimated damage costs, it is hypothesized that these would be common to all truck accidents and would thus not significantly affect this comparison.

CONCLUSIONS

The study supplements other research in finding that the geometric design of the facility is clearly an important factor in determining vehicular speed and that one geometric element, percentage of grade, has a minimal effect on passenger car speeds, but a much larger effect on limiting truck speeds. It was found that, on level or downgrade sections, however, trucks are capable of traveling faster than the 60-mph speed to which they are limited in the state of Maryland. Prior to the recent speed limit reductions brought about by the fuel shortage, 22 states posted truck speed limits greater than 60 mph on Interstate highways and 13 of these states posted speed limits at 70 mph or more (5).

It was determined that the actual speed difference was less than the 10-mph posted speed limit differential except on upgrades. The existence of a posted differential speed limit that contributed to an actual speed differential was not found to be related to truck accidents.

Regression techniques were used to develop models for the prediction of truck accident rates on limited-access facilities. Although it was not possible to develop a statistically significant equation for the prediction of the rate of truck involvement in accidents, a rank order correlation test suggested that lower rates of truck involvement are associated with higher truck speeds. Two significant models were developed for the prediction of the rate of truck accidents that occur on dry pavement. Both the models, for RDTINV and RDTRED, indicate that lower truck accident rates can be expected with higher truck speeds.

Although the models do a good job of indicating trends, a discrete event such as an accident is very difficult to predict. Thus, even though the predicted rates obtained by using the models may differ to some extent from actual observed values, the trends suggested by the models are valid. It would be unwise to conclude, however, that other factors, such as vehicle defects, vehicle (truck) weight, roadway design, or driver characteristics, have no effect on the occurrence of truck accidents. The unexplained variance in the models might be reduced if such factors were included in the analysis.

It would be contrary to intuition to suggest that the trends indicated by the models would continue to extremely high speeds. Only four of the 84 directional sites had an 85th percentile truck speed as high as 69 mph, and less than 3 percent of all measured truck speeds were in excess of 70 mph. Though removal of the differential truck speed would result in higher truck speeds on some roadway sections, it would not bring about increased speeds on extended upgrades, where truck speeds are limited by the vehicles' capabilities.

On the basis of this study, it was recommended that the truck speed limit be temporarily increased to 70 mph on two segments of the Interstate System in Maryland. The results of this change, including the effects on both speeds and accidents, were to be examined. The recent fuel shortage and the subsequent reduction in posted speed limits for all vehicles have made the implementation of this recommendation unfeasible at the present time.

REFERENCES

1. Accident Facts. National Safety Council, Chicago, 1972.
2. Baluch, S. J. Speed Profile Analysis for Cars and Trucks on Controlled-Access Highways. University of Maryland, Master's thesis, May 1973.
3. Ferguson, W. S. Truck Speeds in Virginia. Virginia Highway Research Council, Jan. 1968.
4. Highway Capacity Manual—1965. HRB Spec. Rept. 87, 1965.
5. Motor Vehicle Speed Limits. Highway Users Federation for Safety and Mobility, Jan. 1973.
6. Maximum Safe Speeds for Motor Vehicles. National Highway Safety Bureau, Jan. 1969.
7. Muden, J. M. The Relation Between a Driver's Speed and His Accident Rate. Road Research Laboratory, 1967.
8. Solomon, D. Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle. Bureau of Public Roads, Traffic Systems Research Div., 1964.

AN ACCIDENT EVALUATION ANALYSIS

P. Abramson, KLD Associates, Inc., Huntington, New York

This analysis of accidents is motivated by a need to evaluate and compare the effectiveness of traffic controls at intersections and thereby develop new traffic control warrants. The purpose of this paper is to obtain a quantitative means of comparing accident histories at intersections. An attempt is made to recognize the fact that accident frequency alone is not adequate and can be misleading in making this comparative judgment; hence, the severity and type of accident are incorporated in this analysis. Based on cost figures gathered from several published studies, accident severity weightings are obtained. An accident evaluation index and accident evaluation factors are then computed by using percentage distribution of accidents by type, that is, pedestrian, right-angle, rear-end, left-turn, and all others. The accident evaluation factors are multipliers that, when applied to an accident history profile for an intersection, yield a single figure of merit.

THE NUMERICAL BASIS for accident analysis is the overall costs caused by accidents. Cost evaluation depends not only on the frequency of accidents but also on the severity and type of accidents. For example, upgrading a traffic control, say from a sign to a signal, may in fact result in an increase in the frequency of accidents at the intersection. However, the upgrading may still be warranted if the degree of severity is reduced. This would be reflected in a decreased total cost of accidents, if accident severity is appropriately considered in the cost assignments.

The ultimate objective is to obtain a more valid assessment of the role that accidents should play in the determination of traffic control warrants and to aid in the comparative analysis of various traffic control devices. A consequent purpose is to determine the form and type of accident data that should become part of the signal warrant specifications. For example, in addition to accident frequencies, the need for data on the type and severity of accidents can be specified.

This paper presents cost studies to determine the range of values for fatal, injury, and property-damage-only (PDO) accidents. A discussion of the cost elements and differences in estimation is a necessary part of this summary. These severity cost values differ for rural and urban cases and are further analyzed by type. Then, severity values are summarized and representative values chosen. The analysis by type is based on the following accident categories: right-angle, rear-end, left-turn, and pedestrian. From this analysis, an accident evaluation index is produced that yields a figure of merit for accidents at an intersection based on accident history.

The extreme difficulty of determining the cost of accidents, or of even defining what costs should be included, is well known. Two aspects of the problem, determination of cost elements and assignment of dollar estimates for these cost elements, must each be considered in turn.

COST ELEMENTS

A number of classification schemes and cost breakdown techniques have been proposed (1). For example, there are direct and indirect costs, user and societal costs, on-site and off-site costs, present and future costs, and tangible and intangible costs.

Publication of this paper sponsored by Committee on Traffic Control Devices.

These schemes are further complicated by the fact that the individual categories are not easy to separate. The task of determining reliable cost figures relative to any scheme faces the additional problem of lack of data. For the present purpose, the only practical approach is to tailor accident costs from previous studies to fit our present needs.

Most accident studies have generally emphasized user costs such as property damage, medical expenses, legal and court costs, and wages lost because of lost work time. The justification for these particular cost items is that they are readily available in most cases. Furthermore, for the majority of accidents, these costs usually represent a high percentage of the total costs. However, this is not the case for accidents involving fatalities. Here, a wide disparity of estimates exists because of differences in the cost elements included.

In most studies reported in the literature, cost items are summarized in three categories: PDO, injury, and fatalities. The unit costs that have been given for these three categories will form the basis for the estimates used herein.

An initial and significant problem in the analysis of previous work in this area is that frequently the results are not comparable. There are a number of reasons for this. First, the unit cost values are sometimes given per accident and other times per involvement. The number of involvements in a given accident is the number of individual vehicles involved in an accident. Furthermore, the individual cost elements included vary from one study to another even though both are based on the same classification scheme. For example, nonreported accidents are included in some studies and not in others. The ratio of total cost for all accidents to reported cost varies, in one study from 1.541 for rural accidents to 1.848 for urban accidents (2). For PDO accidents the corresponding ratios are 3.233 and 3.972 for urban and rural accidents respectively. In this paper, data will be given on a per-accident basis inasmuch as this is the more easily used form.

In the case of fatalities and some injury accidents, cost estimation differences occur for a number of reasons. Estimation of net present worth or probable future income is an involved computation affected by the procedure used and by the subjective assumptions made. For example, future income has been predicted by using an average income rate for the remaining working years and also by using predicted yearly incomes. Discounting of future incomes will yield different results for these two cases. Inclusion or omission of funeral costs is another factor that will alter the final estimates. Finally, for a valid comparison, all cost estimates must be updated to the same time.

In the following section, a number of accident study results will be summarized. These form the basis for the cost estimates used in the accident evaluation index.

ACCIDENT COST STUDIES

Unless otherwise stated, the costs considered in these studies are the value of damages and losses to the motor vehicle owner and to persons injured in an accident, which would not have occurred without the accident.

Illinois Study

In the Illinois study (2), the cost items include property damage, treatment of injuries, loss of use of the vehicle, value of time lost, legal and court expenses, and damages awarded in excess of known cost. The property damage costs account for the damage to the vehicle and the property within as well as for the damage to objects struck by the vehicle. Injury treatment includes ambulance costs, doctor and dentist fees, and hospital and treatment costs, but excludes funeral costs. Damages awarded refers to settlements in or out of court for amounts in excess of known costs and may include some direct costs and, possibly, some amount for past or future loss of income. These excess awards do not duplicate known costs accounted for elsewhere.

A major difference between the results of this study and others lies in the fatal injury class of accidents. The Illinois study did not include the loss of future earnings as an element of direct cost. The value of work time lost only includes gainfully employed persons. This cost item is the single most important component in total costs in fatal accidents.

Table 1 gives the total costs for urban intersection and nonintersection accidents relative to the unit costs that have been itemized for the 1958 Illinois study.

The figures shown for cost per accident are computed from the total costs and number of accidents. For PDO accidents, nonreported accidents are included in the total number of accidents; however, nonreported costs are not. The total PDO figure is approximately $92 million. The information used is from a secondary source (1) and differs somewhat from results given elsewhere for the same data. For example, in NCHRP Report 130 (3) the corresponding figures on cost per accident are $5,242 for fatal, $821 for injury, and $100 for PDO accidents. The values reported are averages for both urban and rural accidents and may differ on other grounds as well.

These values present a rough cost framework for these three types of accidents. More pertinent to our purposes is a breakdown of rural and urban intersection accidents for these three accident categories (Table 2).

Note the consistently and significantly high values in all accident categories as compared with Table 1. This may be accounted for by the fact that a large proportion of intersection accidents involve at least two vehicles. The figures used in Table 2 were computed from figures obtained in 1958 and updated to 1966 by a factor of 1.25 (1).

The figures given in Table 2 include both truck and passenger car accidents. In regard to the differences in urban and rural cost values, it should be noted that Illinois state law requires the reporting of all fatal and nonfatal injury accidents and PDO accidents of $100 or more. In Chicago, however, it is required that PDO accidents of $50 or more be reported.

The rate of accidents based on exposure cannot be determined from these tables because neither the number of intersections nor the traffic volumes are known. It has been determined, however, in the Illinois study that accidents are more costly as the number of traffic lanes increases. The probable explanation is that the number of involvements per accident increases as the number of lanes increases. The Illinois study does show that for all highway types there are more vehicles involved in an accident on the average in urban traffic than in rural traffic. However, the Illinois statistics show that for intersection accidents the involvement rate is about the same (1.696 for urban traffic and 1.719 for rural traffic).

Washington, D.C., Study

The report of the Washington study (1964-65) uses involvements rather than accidents. Vehicle involvement is classified by the severity of the accident rather than the severity applicable to each vehicle involved. Thus, a vehicle may be included in the fatal category because it was in a fatal accident even though no one may have been injured in the vehicle and little or no cost may have been incurred. One cost element in this study not included in the Illinois report is the net present worth of probable future earnings, which amounted to almost 91 percent of the total cost figure in the case of fatal accidents. The future earnings were computed by using an average rate of income for each fatality for all the remaining expected working years. Another method would be to use an income for each year. In either case, this task involves consideration of differences in individual earning power as a function of age, sex, race, employment status, and level of education. In addition, estimation of work-life-spans must be made. Particular problems are encountered when areas such as housewife services and maintenance costs for accident victims are evaluated.

The study uses a 4 percent discount rate per year to compute these future earnings. Subsequent studies (4) have suggested that this rate is too low and also that damage awards and the full cost of funeral expenses should not be included. Table 3 gives the values obtained from these data under these three viewpoints. When these are compared with the urban area figures from the Illinois study, the results are similar only in the injury case. The major difference in fatality values is the inclusion of lost future earnings, and the primary reason for difference in the PDO category is that the Washington, D.C., study used only reported accidents whereas the Illinois study included all accidents, both reported and unreported. If it is assumed that there are 1.2 fatalities per fatal accident, then the per-accident cost of a fatal accident is given as

$71,400 (4). These differences give some indication that the cost of traffic accidents cannot be assigned specific values. Cost estimates and results often reflect subjective feelings and inadequate statistical data.

Texas Study

A recent study by the Texas Transportation Institute (5) uses cost data developed in other states and studies (Illinois 1958, Massachusetts 1953, New Mexico 1955-56, and Utah 1955-56) to develop a method for estimating Texas accident costs. The cost estimates are per involvement and include property damage, medical costs, legal and court fees, values for loss of work time and loss of vehicle use, damages awarded in excess of costs, and, for fatalities, the present value of expected future earnings. Frequency data for involvements and accidents were obtained for reported Texas accidents in 1969 and used to develop weights to apply to the cost data. Fatal accident costs are obtained by adding direct costs and a value for the loss of future earnings. The results are given in Table 4. Differences between Table 3 and Table 4 are probably attributable to the per-accident as opposed to per-involvement tabulation and the use of highway data.

A cost breakdown of particular interest that is obtainable from this report is in terms of head-on, rear-end, angle, sideswipe, and turning accidents. These values are given in Table 5. A very rough rank ordering, excluding pedestrian accidents, indicates that head-on accidents are most costly, followed by angle accidents. Rear-end and turning accidents are next, and sideswipes are the least costly among these categories.

Societal and Intangible Costs Study

A recent study (6) attempted to define and estimate in economic terms the losses in "societal welfare" or "level of social well-being." The categories included in this analysis are property damage, medical costs, productivity costs, insurance administration, losses to other individuals, employer losses, funeral costs, community service losses, pain and suffering, and miscellaneous accident costs. The breakdown does not separate rural and urban accident experience. It is to be pointed out that current data are inadequate for precise estimation of these costs; thus, $234,960 for a fatality, $11,200 for an injury, and $500 for a PDO accident must be considered as gross estimates.

Other studies have attempted to include the intangible and noneconomic losses due to accidents in the analysis of highway improvement projects (4, 7). A calculation for a particular highway project (4) leads to a value of $550,000 for intangible costs necessary to make the net benefit zero. Widerkehr's approach (7) depends on fractional reductions in accidents attributable to a given safety improvement. He classifies accidents into two categories: fatalities and/or injuries and PDO. Fatalities and injuries are combined because fatality sample sizes are too small for reliable estimation and because fatalities can be regarded as random events among injury accidents. A formula is developed for the total economic gain or the total calculable dollar benefit from a given highway improvement.

Crash Damage Study

A recent study (8) was conducted by Allstate Insurance, Kemper Insurance, Liberty Mutual Insurance, and State Farm Mutual Insurance Companies, in cooperation with the American Mutual Insurance Alliance, in which detailed information was analyzed on 89,060 crash repair estimates on a nationwide basis. A number of significant results have been established for the cost distribution of repairs. The average repair bill was $321. Different patterns of cost are noted for property damage liability claims as opposed to collision claims because car owners generally pay for damage below $50 or $100 collision deductibles. Thus, collision claim averages tend to be higher. For our purposes, the values obtained for liability claims are more appropriate. Interesting is the distribution of repair costs by point of impact on the vehicle. The frequency of claims and the average repair cost are given for various points of impact. Some general findings that can be deduced are that about 70 percent of all crash damage occurs at either the front or rear end and front-end damage is generally more costly. Further analysis indicated that front- and rear-end involvements occur with about equal frequency in low-speed crashes.

Other Sources

Other sources of cost information that have been investigated include the National Safety Council (NSC) statistics, insurance agencies such as the Insurance Information Institute (I.I.I.) and the Insurance Services Office, and legal sources.

NSC statistics were examined from a number of council publications (9, 10). The latest information obtained (1971) gave the following cost breakdown: fatal, $52,000; injury, $3,100; and PDO, $440.

I.I.I. (11) used NSC figures on traffic deaths, but all other figures such as number of traffic injuries, number of traffic accidents, and economic losses are based on its own projections. The figures are computed by using a sampling of state traffic accident reports and include all injuries and accidents whether on private roads and property or on public streets and highways. The figures for 1971—$48,115 for a fatality, $2,850 for an injury accident, and $570 for a PDO accident—include adjustments for the cost-of-living index and the general price level. It should be noted that these values include wage loss, medical expense, property damage, and insurance administrative costs for insurance companies and self insurers. This latter cost is the difference between premiums paid to insurance companies and the claims paid by them.

I.I.I., which is a public relations and educational organization sponsored by the insurance industry, also publishes a yearbook of insurance facts. In the 1972 edition (10), average paid claim costs for injury and PDO accidents are $1,923 and $345 respectively. These data were obtained from the Insurance Services Office. This office provides rating and statistical services to insurers and other organizations based on a compilation of insurance coverage and claims paid as filed by participating companies.

A legal source of data on accident costs was sought to ascertain unit cost estimates from the viewpoint of the courts. Statistical data have been compiled and categorized in a series of handbooks (13) to indicate the average jury-verdict award for a wide variety of injury and fatality accidents. The "verdict expectancy for injury" values are determined from a data base consisting of more than 75,000 court cases. Most of these cases are automobile accident cases, but industrial accidents are also included. The tabulations are made by state and county. Although the data are not summarized in a form suitable for our needs, they could be. This would represent a significant data bank for future investigations and could provide a more definitive basis for estimating injury and fatality costs, including the "pain and suffering" element, as currently judged by juries throughout the country. This is not to claim that these are the "true" societal values of injuries and fatalities, only that they form a numerical data base that indicates trends and can serve to supply much needed data in this area. Although this source was not pursued further, it was determined that tabulations do exist for automobile court case histories under a number of different categories, including but not limited to the following: intersection collisions, pedestrian hit by car, and rear-end, head-on, change-of-lane, passing-vehicle, and speeding collisions.

ACCIDENT EVALUATION INDEX

The summary of cost studies presents the background and state of the art in this area of investigation. It will be used as a basis for the development of a quantitative figure of merit or index to aid in the evaluation of accidents as it affects the decision-making process inherent in the definition of traffic signal warrants. For this purpose our main interest is the relative numerical weight to apply per accident to each of the accident categories in the traffic signal warrant decision process. The accident cost study results given in economic terms will thus be used to yield pure number "weightings" (which will not be interpreted as dollar values).

Accident Severity Weightings

Table 6 gives the relevant accident severity cost figures as given in the unit cost study, which are generally comparable in that losses due to work time lost are included

Table 1. Urban accident costs for Illinois.

Accident Severity	No. of Accidents	No. of Involvements	Total Cost (dollars)	Cost per Accident (dollars)
Fatal	536	690	2,908,590	5,426
Injury	92,509	144,863	79,569,672	860
PDO	809,855	1,227,952	92,422,214	114

Table 2. Intersection accident costs for Illinois.

Area	Accident Severity	No. of Accidents	Cost per Accident (dollars)
Urban	Fatal	247	7,272
	Injury	53,579	1,633
	PDO	287,641	165
Rural	Fatal	191	9,330
	Injury	6,630	1,490
	PDO	23,420	255

Table 3. Cost (in dollars) per involvement for Washington, D.C.

Accident Severity	Original Study (4 Percent Discount Rate)	Damage Awards and Funeral Costs Deleted: 4 Percent Discount Rate	Damage Awards and Funeral Costs Deleted: 10 Percent Discount Rate
Fatal	47,481	47,000	20,300
Injury	863	770	740
PDO	193	193	193

Table 4. Cost (in dollars) per accident for Texas.

Accident Severity	4 Percent Discount Rate	10 Percent Discount Rate
Fatal	50,227	29,927
Injury	1,917	1,917
PDO	334	334

Table 5. Cost (in dollars) per accident at 4 percent discount rate.

Study	Cost Unit	Accident Severity: Fatal	Injury	PDO
Washington, D.C.	Involvement	47,481	863	193
Texas	Accident	50,227	1,917	334
Societal (6)	Accident	234,960	11,200	500
NSC	Case	52,000	3,100	440
I.I.I.	Case	48,115	2,850	570

Table 6. Accident severity cost summary (in dollars).

Accident Severity	Accident Type: Head-On	Rear-End	Angle	Sideswipe	Turning	Pedestrian
Fatal	58,116	53,693	55,013	54,399	51,842	46,879
Injury	3,341	1,932	1,873	1,302	1,875	1,433
PDO	595	310	405	246	321	–
All	3,500	700	900	400	700	5,100

Table 7. Percentage of accidents by vehicle movement.

Accident Type	Vehicle Movement	Fatal Accidents: Urban	Fatal Accidents: Rural	All Accidents: Urban	All Accidents: Rural
Right-angle	Entering at angle	12.4	9.5	17.4	9.3
Rear-end	Both going straight	0.4	0.4	3.0	0.8
	One turn, one straight	0.4	0.5	3.5	3.3
	One stopped	0.3	0.5	5.1	2.4
	All others	–[a]	0.1	0.9	0.7
Left-turn	One left, one straight	3.3	1.5	5.1	2.5
All others	Both going straight	1.2	0.6	1.1	0.4
	All others	0.1	0.1	0.4	0.4

[a] Less than 0.05 percent.

Table 8. Severity rates and accident evaluation indexes by urban and rural accident types.

Accident Type	Urban: Fatal	Urban: Injury	Urban: PDO	Urban: Accident Evaluation Index	Rural: Fatal	Rural: Injury	Rural: PDO	Rural: Accident Evaluation Index
Pedestrian	0.0188	0.9812	–	3,390.0	0.0727	0.9273	–	5,950.0
Right-angle	0.0010	0.0700	0.9290	690.0	0.0069	0.1380	0.8551	1,120.0
Rear-end	0.0001	0.0070	0.9930	520.0	0.0014	0.0280	0.9706	630.0
Left-turn	0.0009	0.0630	0.9360	670.0	0.0041	0.0820	0.9139	870.0
All others	0.0012	0.0840	0.9150	730.0	0.0059	0.1180	0.8761	1,030.0

and the same discounting rate (4 percent) appears to have been used. Note, however, that the values quoted are not all updated to the present. Because we seek only general estimates, reflecting relative magnitudes, this disparity is not significant. For a fatality the weight assignment W_F will be 50,000/accident. A value of 200,000/accident can be considered an upper bound value if a range of values is desired. These values for W_F are convenient and generally conservative if the costs are updated to present values. For injury accidents, 10,000/accident delimits the upper end of the range. To arrive at a weighting value for injuries, W_I, requires that the figures all be in terms of per-accident values because the involvement rate per accident for injuries is approximately 1.8. (For fatalities, this rate is usually taken to be 1.2.) With this value, the Washington, D.C., figure becomes $1,553. Using this result, together with the other values given in Table 6, gives a weighting value of 2,500/accident for an injury accident.

For PDO accidents all five values in Table 6 can be used to yield a single value, W_P, if the Washington, D.C., value of $193 is converted to a per-accident value of $328 by using an involvement-per-accident rate of 1.7. Although the average property damage value obtained after this adjustment is $434, we will use a weight of W_P = 500/accident, which reflects the more recent estimates that tend to be higher. Thus, W_F = 50,000, W_I = 2,500, and W_P = 500. These values will now be transformed into cost-per-accident values for accidents categorized by type. This will permit, for example, distinguishing accident characteristics of different traffic signal control types, in particular, between stop sign control and traffic signal control.

Analysis of Intersection Accidents

From past experience it appears that the most significant change in accident history at an intersection after a change in control type is the relative increase in the frequency of rear-end accidents and relative decrease in angle and head-on accidents. This basic assumption requires that costs be stratified for these two accident types.

In this analysis intersection accidents will be classified into the following categories: right-angle, rear-end (including sideswipes), left-turn, pedestrian, and all others. These categories have been selected because it is felt that, if differences in signal control type affect accidents, distinct differences in the distribution of these types of accidents will be observed. This will constitute a more detailed evaluation of the relation of accidents to traffic control changes than merely differences in the total number of accidents.

If we use NSC figures for 1970, the percentage of fatal pedestrian accidents relative to all pedestrian accidents is approximately 1.9 for urban accidents and 7.3 for rural cases. It will be assumed that all other pedestrian accidents involve negligible property damage; therefore, 98.1 and 92.7 percent are injury producing for the urban and rural cases respectively. Therefore, the accident evaluation index for urban and pedestrian accidents is $(0.019)(50,000) + (0.981)(2,500) = 3,403$, and for rural accidents it is $(0.073)(50,000) + (0.927)(2,500) = 5,968$.

For right-angle, rear-end, left-turn, and all other accidents, values from the directional analysis and accident by selected movement table for fatal and all accidents, published by NSC (9), were combined. The directional analysis breakdown for intersection accidents used in this publication closely matches our categories. However, for rear-end accidents we have combined all the accidents described as "entering intersection same direction." The "all other" category includes accidents involving two vehicles entering from opposite directions and both going straight. Intersection accidents involving non-motor vehicles such as trains or bikes and collisions with fixed objects in the road have been omitted.

The portion of the directional analysis table used is given in Table 7. (The percentages in each column add to 100 in the full table, which includes nonintersection accidents as well.) Thus, for example, the values in the column designated fatal urban accidents represent the percentage of all fatal urban accidents that occurred at the given location and for the given vehicle movement. If f represents the percentage of fatal accidents for a given set of conditions as shown in Table 7, t represents the percentage of all accidents under the same conditions, and n_f, n_t represent the number of fatal and all accidents for the given conditions, then the percentage of fatal intersection accidents for each type of vehicle movement is $(f \times n_f)/(t \times n_t)$ where $n_f = 16,300$ and $n_t = 11,500,000$ for the urban case and $n_f = 30,500$ and $n_t = 4,500,000$ for the rural case.

To obtain the relative percentages of injury accidents for each type of vehicle movement, we used NSC figures for the number of nonfatal injuries per death (10), i.e., 70 and 20 nonfatal injuries per death for urban and rural accidents respectively. It is recognized that these figures are for all accidents, including nonintersection accidents; however, they are adequate for our purposes of obtaining approximate weighting factors. (Because an average injury weight has been approximated, an average ratio is appropriate to approximate the offsetting effects of higher ratios and lower average costs.) All other accidents (neither fatal nor injury producing) are then assumed to be PDO accidents.

The resulting severity rates and accident evaluation indexes for the five types of accidents are given in Table 8. The indexes are obtained by multiplying the rates by the appropriate accident severity weights—W_F, W_I, and W_P.

More simply, the following factors can be used to convert an accident history profile of an intersection to a figure of merit. For an urban intersection the factors are 6.5, 1.3, 1.0, 1.3, and 1.4 for pedestrian, right-angle, rear-end, left-turn, and other accidents respectively; for rural intersections, the factors are 9.4, 1.8, 1.0, 1.4, and 1.6 for pedestrian, right-angle, rear-end, left-turn, and other accidents respectively. The values of the accident evaluation index are intended to serve as a means for combining accident history distributions into a single figure of merit. Subsequent analysis will relate this figure to different traffic control types by using accident profiles obtained in an accident survey.

As an illustration, suppose the accident profiles for a common time period at two given urban intersections are 0, 3, 5, 2, and 2 and 2, 1, 3, 2, and 1 for pedestrian, right-angle, rear-end, left-turn, and all other accidents respectively. The two figures of merit are then

$$0(6.5) + 3(1.3) + 5(1.0) + 2(1.3) + 2(1.4) = 14.3$$

and

$$2(6.5) + 1(1.3) + 3(1.0) + 2(1.3) + 1(1.4) = 21.3$$

Thus, the accident impact appears more severe at the second intersection even though it has had fewer accidents.

Initial application of these factors to accident records has indicated that although signalization may show an increase in accident rates, this is usually offset by a reduction in the figure of merit or "disutility" value per accident leading to no significant change in total accident-related disutility.

ACKNOWLEDGMENT

This work was sponsored by the American Association of State Highway Officials, in cooperation with the Federal Highway Administration, and was conducted under the National Cooperative Highway Research Program. The opinions and conclusions expressed or implied in the report are those of the research agency and not necessarily those of the sponsoring agencies.

REFERENCES

1. Winfrey, R. Economic Analysis for Highways. International Textbook Co., 1969.
2. Cost of Motor Vehicle Accidents to Illinois Motorists, 1958. Div. of Highways, Illinois Dept. of Public Works and Buildings, Dec. 1962.
3. Taylor, J. I., McGee, H. W., Seguin, E. L., and Hostetter, R. S. Roadway Delineation Systems. NCHRP Rept. 130, 1972.
4. Arthur D. Little, Inc. Cost Effectiveness in Traffic Safety. Praeger, 1968.

5. Burke, D. Highway Accident Costs and Rates in Texas. Texas Transportation Institute, Texas A&M University, Dec. 1970.
6. Hartman, G. Societal Costs of Motor Vehicle Accidents. NHTSA, April 1972.
7. Widerkehr, R. A Methodology for Programming Highway Safety Improvement Projects. Second Cost-Effectiveness Symposium, Washington Operations Research Council, 1968.
8. Crash Damage to Automobiles. Allstate, Kemper, Liberty Mutual, and State Farm Mutual Insurance Companies in cooperation with the American Mutual Insurance Alliance, Oct. 1972.
9. Accident Facts, 1971. National Safety Council.
10. Traffic Safety Memo 113. National Safety Council, July 1972.
11. Traffic Accident Experience in the United States. Insurance Information Institute, March 1972.
12. Insurance Facts. Insurance Information Institute, 1972.
13. Personal Injury Valuation Handbooks. Jury Verdict Research, Inc., Cleveland, 1968-1971.

SPONSORSHIP OF THIS RECORD

GROUP 3—OPERATION AND MAINTENANCE OF TRANSPORTATION FACILITIES
Lloyd G. Byrd, Byrd, Tallamy, MacDonald, and Lewis, chairman

Committee on Traffic Control Devices
J. R. Doughty, Pennsylvania Department of Transportation, chairman
John L. Barker, Robert L. Bleyl, Frank Carroll, Robert E. Conner, Charles E. Dare, John O. Elstad, Roy D. Fonda, Arthur Freed, Albert L. Godfrey, Sr., Alan T. Gonseth, Robert L. Gordon, John Gray, Rudolph J. Israel, Ken F. Kobetsky, Hugh W. McGee, Robert D. McMillen, Joseph A. Mickes, Zoltan A. Nemeth, Juri Raus, James I. Taylor, Francis E. Twiss, Earl C. Williams, Jr., Jason C. Yu

Committee on Traffic Records
David M. Baldwin, Federal Highway Administration, chairman
J. Stannard Baker, William T. Baker, Noel C. Bufe, B. J. Campbell, John Carnaghi, William H. Franey, John D. Hromi, Alan F. Huggins, A. Dewey Jordan, Edwin M. Kahoe, Jr., John C. Laughland, Ronald D. Lipps, Bruce B. Madsen, J. P. Mills, Jr., A. C. Nelson, Jr., James O'Day, Darrell E. Roach, Thomas H. Rockwell, H. Laurence Ross, Stephen Edwin Rowe, John L. Schlaefli, Langston A. Spell, Richard L. White, Robert M. Williston

James K. Williams, Transportation Research Board staff

Sponsorship is indicated by a footnote on the first page of each report. The organizational units and the chairmen and members are as of December 31, 1973.