TRANSPORTATION RESEARCH RECORD 643

Traffic Records, Law Enforcement, and Motorist-Aid Systems

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Contents

Indiana Traffic-Accident Record System (INTRACS)

James P. Klausmeier and Gerald Kmack, Vogt, Sage, and Pflum Consultants, Indianapolis

The Indiana Traffic-Accident Record System represents a major statewide effort and is being developed to geographically locate accidents on road segments anywhere in the state. When completed, the system will provide a procedure for analyzing accident rates and their relation to physical roadway conditions. The results will be used to identify critical accident locations and conditions that cause accidents. The system is founded on a geographic data base that allows automatic assignment of X-Y coordinates to all coded accidents. The process requires only simple information commonly coded on accident forms. Because of its unique design, it provides a comprehensive system capable of efficient and meaningful analysis of coded accident information. Roadway sections, intersections, corridors, and geographic areas can be examined over any specified period of time for a complete accident history. Accidents can be identified by type, precise location, or any other descriptive criteria included on accident-report forms. Accidents can also be correlated with roadway characteristics, jurisdiction, and federal-aid classification.

There were 195 672 traffic accidents involving 68 883 injuries and 1133 fatalities in Indiana in 1975. The state, through its Highway Commission, Department of Traffic Safety and Vehicle Inspection, and State Police is committed to a policy of improving highway safety in cooperation with federal and local agencies.

Highway safety can be improved by implementing countermeasures in the three general categories of the vehicle, the driver, and the roadway. Countermeasures to improve the safety of the vehicle include seat-belt requirements, collapsible steering columns, and vehicle inspections. Countermeasures among the human factors that affect highway safety include driver education, licensing, and alcohol safety. Countermeasures relating to the roadway include the installation of safety features, such as regulatory and warning signs, guardrails, breakaway signs and lighting supports, bridge and curve widenings, and various construction techniques.

This last category of accident countermeasures has been of recent concern in Indiana. The concern has been that a lack of systematic information that relates the locations of accidents to the physical roadway conditions has resulted in less than effective countermeasures. As a result of this concern, the Indiana Traffic-Accident Record System (INTRACS) has been designed and is being implemented throughout the state with the general goal of developing a capability for systematically determining hazardous roadway locations so that appropriate countermeasures can be implemented. The system has the following specific objectives:

1. To provide a uniform and systematic method of locating traffic accidents throughout the state,
2. To relate accident locations to roadway characteristics,
3. To produce standard graphical and tabular statistical summary reports on a periodic basis,
4. To produce special graphical and tabular locational summaries for routes or areas,
5. To produce special summaries of locations having high accident rates, and
6. To serve as a research tool for determining the cost-effectiveness of implemented countermeasures.

With these objectives, various resource information and data were identified for incorporation into the design of the system.

RESOURCE DATA

The basic resources for the design and implementation of INTRACS include roadway-inventory data and maps, the state plane-coordinate system and the U.S. Geological Survey (USGS) maps, aerial photography, and accident reports.

Roadway Inventory Data and Maps

The roadway system of Indiana consists of 150 000 km (93 000 miles) of variously classified urban and rural roads. About 37 000 km (23 000 miles) is on the federal-aid system.

A computerized inventory of the entire system is maintained and routinely updated by the state highway commission. Subsections along the inventory are designated for the purpose of recording physical characteristics. The inventory includes the following items: county code, district code, city code, record number, revision status, roadway jurisdictional code, state route number, roadway condition, number of lanes, directions of travel, surface type, surface width, roadbed width, right-of-way width, median type, median width, surface type, surface width, curbs, access control, section length, traffic volume, rural-urban size classification, functional classification, section number, federal-aid classification, urban-area classification, population-group code, and travel-over code. A series of maps describe the roadway system numbers throughout the state and relate it by numeric codes to the computerized inventory.

State Plane-Coordinate System and U.S. Geological Survey Maps

A plane-coordinate system has been established for the entire state and marked on the USGS maps. Thus, any point (accident location) or series of points (roadway locations) can be uniquely described relative to an established grid.

USGS maps at a scale of 1 cm = 240 m (1 in = 2000 ft) provide controlled cartography relative to the state plane-coordinate system. These maps were used as the basis for the process that determines the coordinates of points that describe the roadway system.

Aerial Photography

Aerial photographs taken by the state highway commission were used to update the USGS maps by the addition of recently constructed roadways and streets. This process is a way to verify that the road inventory file is complete and provides current maps of the entire roadway network.

Accident Reports

Reports are prepared for all accidents that result in fatalities, personal injury, or significant property damage. The reports are prepared by the State Police, the local police, or the individual drivers (when police are not called to the scene). These reports are standardized for computer processing and contain the information usually found in such reports.

SYSTEM CONCEPT

INTRACS is designed to automatically compute the X and Y plane coordinates of traffic-accident locations and to relate these specific locations to the roadway characteristics found in the highway inventory files. The system is designed to produce annual or periodic summaries of hazardous roadway locations in tabular form or in computer-plotted graphic form by using the coordinates that describe accident locations and those that describe the roadway system.

The system is designed to produce these summaries by the processing of six interrelated data files: These are (a) the roadway files (the road inventory, road number, road network, and road index files) and (b) the accident files (the accident-statistic and accident location master files). The roadway information is prepared or updated in batches by geographic matrix or political jurisdiction and entered into the appropriate files. The accident files are updated daily with new reports.

Road Inventory File

The road inventory file describes the roadway characteristics, such as pavement type and width and traffic volumes. The file is regularly updated by the state highway commission as roads are constructed or reconstructed. The roadway inventory assigns a unique road number to every roadway, and subsections along the inventory are designated for recording the physical characteristics. A change in any one characteristic requires that a new subsection be established. The beginning of each subsection is identified by its distance from the beginning of the roadway. Thus, the inventory system is linear (rather than two-dimensional) in that the roadways are described by distances along their lengths.

The roadway inventory file is used by INTRACS as a data resource for preparing the road number and road network files and as an analytical resource in conjunction with the accident-statistic and accident-location master files.

Road Number File

All the roads and streets are assigned a unique four-character road number by the road inventory file. The road number file is simply a directory that provides the equivalent road number for every road or street name. The road number file, shown in Figure 1, is used by the police to translate street and road names to unique road numbers.

Road Network File

The road network file is the framework of INTRACS. It contains descriptive information and the X-Y coordinates for all of the intersection and alignment points that collectively describe the street and roadway network.

The road network file is created for 2000 independent, but interlocking matrices or data cells for data processing and quality control. Each matrix is 6096 by 9144 m (20 000 by 30 000 ft) and further subdivided into six submatrices of 3048 m^2 (10 000 ft^2). The roadways in each matrix are traced from updated USGS maps onto stable mylar material to provide an accurate and permanent record of the system. Intersection points, roadway numbers, functional classifications, roadway distances and other descriptive information required to link INTRACS with the road inventory file are recorded on the matrix maps as shown in Figure 2. The data for each point are manually coded into the record forms by using the completed matrix maps as the resource. The X-Y coordinate for each of the points is determined quickly from the matrix maps by using the electronic digitizer shown in Figure 3. The digitizer operator aligns the cursor over each point in sequential order, and the coordinates are determined automatically by an electronic grid in the surface of the table. The coordinate output is then merged with the manually coded data into a record format as shown in Figure 4. Finally, these records are edited by a series of logic and computer plots to ensure that the matrix is accurately described by the file.

The resulting road network file is a two-dimensional computer-stored map of the road and street system that is linked to the road inventory file. Portions of the network can be plotted by the computer at specified scales to illustrate various roadway characteristics and to locate traffic accidents.

Road Index File

The road index file is created by the INTRACS programs and contains a record of every intersection as shown in Figure 5. The file is a directory that associates the road numbers of intersecting streets and highways with the unique intersection number. Thus, an accident referenced to the intersection of two roads can be determined to be at a specific intersection point number for which the road network file has a coordinate location and other information that leads to the roadway characteristics in the road inventory file.

Accident-Statistic Master File

The accident-statistic master file contains a record for each accident that has the accident number, driver, vehicle, injury, weather, and other data taken from the standard reports submitted by police agencies. This file is used to generate a variety of standard state summaries of accidents on an annual basis and by INTRACS as a resource from which specific records can be retrieved for special analysis.

Accident-Location Master File

The accident-location master file contains a record for each accident with its accident number (which links it to the statistical master file) and a variety of information that locates the accident as shown in Figure 6.

The first 51 characters of the record are coded manually from the accident reports, and the last 64 characters are computer-generated by the INTRACS programs.

The accident-location master file is created in the following manner:

1. Coders extract the following information from every accident report form—identification of the road on which the accident occurred (its name and the county and city), identification of a nearby road that intersects with the road on which the accident occurred (the intersection formed is referred to as the reference intersection), and the distance and direction of travel from the accident location to the reference intersection.
2. The coders then refer to the road number file, ex-

Figure 1. INTRACS road number file coding form.

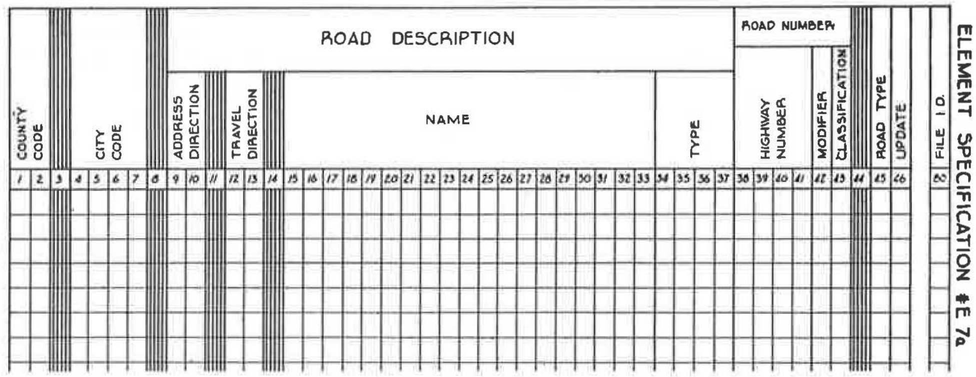
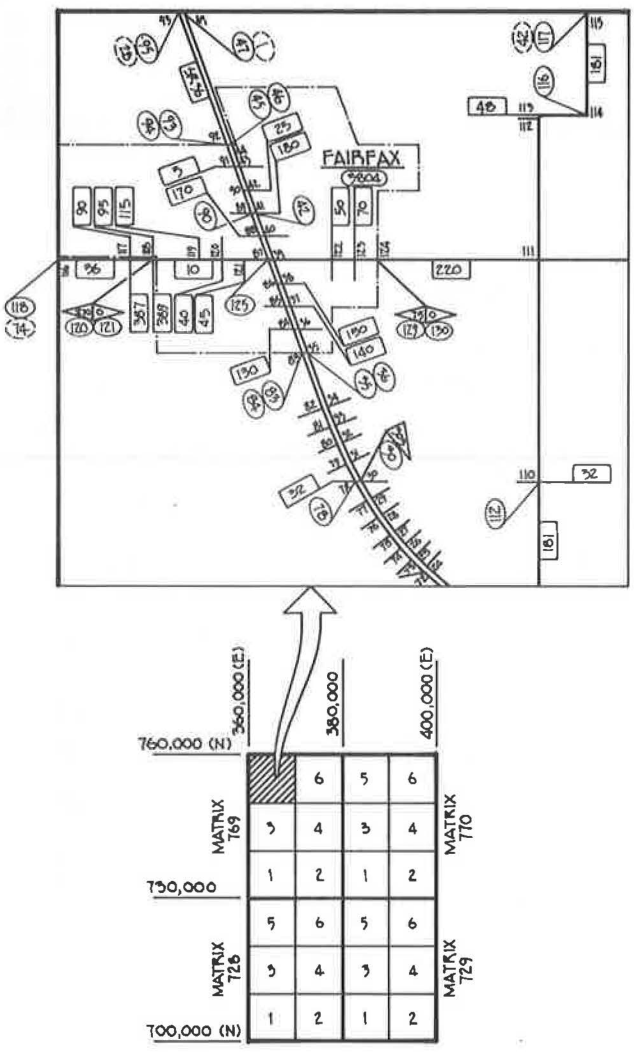


Figure 2. Sample matrix map.



tract the appropriate identification numbers for the road on which the accident occurred and the intersecting road, and code these numbers with the appropriate distance and travel direction information into a single record.

3. At the end of each day, all the coded accident-location records are processed through a series of programs that merge the new data into the existing location files and identify the reference intersection specified by the two roads coded for each accident. When the intersection is identified, its unique intersection number is automatically assigned to the accident-location record from the road index file, which identifies the reference intersection in the statewide frame of reference and specifies the appropriate entry point into the next level of accident-location processing.

4. Once a week, the new accident-location records that have been accumulated and partially processed are run through a final series of programs and data files for automatic computation of the X and Y coordinates for the accident-location records. Briefly, this process involves the use of the two-demensional road network file. The reference intersection number (automatically identified during daily processing) acts as a key and specifies the appropriate entry point into the statewide road network file. After locating the reference intersection, the INTRACS programs travel the appropriate direction and distance on the specified roadway through the road network file. Because the network includes points to describe the curves and other significant road characteristics, it is possible to simulate the true travel distance from the accident site to the reference intersection. Finally, the coordinate value for the accident location is automatically calculated from its relative position in the road network and entered onto the accident-location record.

ANNUAL (OR PERIODIC) ACCIDENT SUMMARIES

INTRACS is designed to process the accident-location master file with the road inventory file to determine three high-accident-location categories. These are

1. High-accident intersections,
2. High-accident sections, and
3. High-accident spots.

Once these locations are identified, all accidents occurring at one of them can be extracted from the accident-statistic master file and various detailed summaries of accidents can be prepared.

High-Accident Intersections

High-accident intersections can be determined on the basis of the number of accidents that occur or on the rate of accidents occurring when compared with the traffic volumes.

To determine the locations of intersections having high numbers of accidents, the system first computes the average number of accidents per intersection for a specified class of intersections (i.e., urban or rural). The number of accidents at each intersection is then compared to that of the average. Intersections at which the number of accidents exceeds the average number by a specified value are listed in an output report.

To determine locations having high rates of accidents, the system first computes the accident rate at each intersection by dividing the number of accidents by its approach-traffic volume and then computes the average rate for all intersections in the designated class. The accident rate at each intersection is then compared with that of the average. Intersections at which the rate exceeds the average rate by a specified value are listed in an output report.

Figure 3. Electronic digitizer.

Digitizer Table

Standard Cursor

Figure 4. INTRACS road network file format.

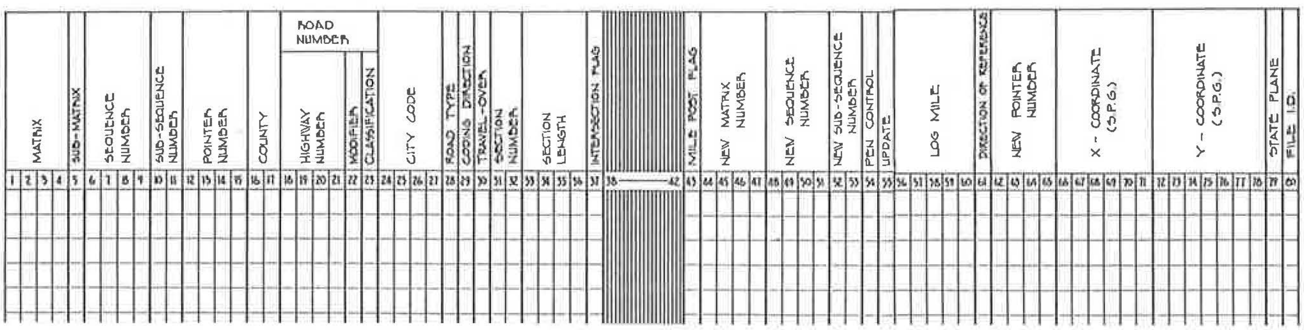


Figure 5. INTRACS road index file format.

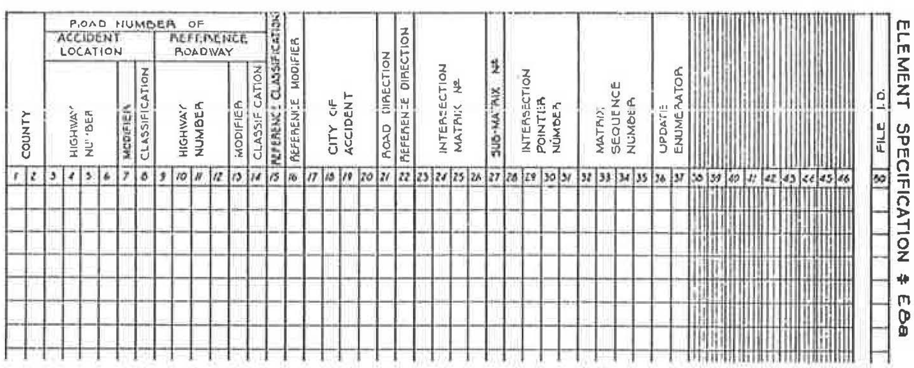
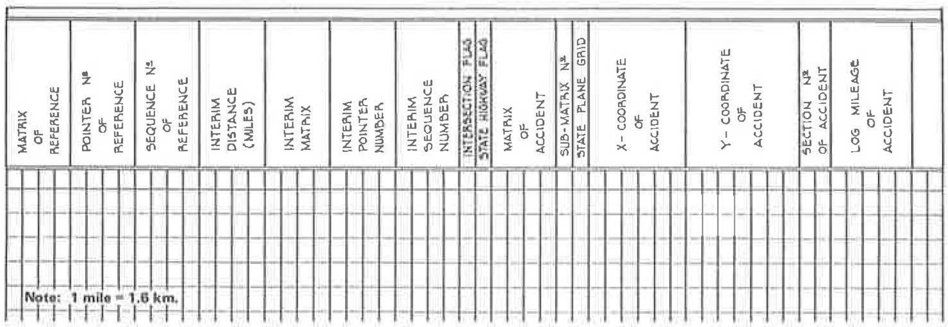


Figure 6. INTRACS accident-location master file.



High-Accident Sections

Sections are portions of continuous roadways between 4.8 and 12.8 km (3 to 8 miles) long. They may be stratified by five urban and five rural classifications. Continuous roadways are determined from the road network file, subdivided by the system into equal section lengths, and classified by the road inventory file.

High-accident sections may be determined on the basis of actual numbers of accidents or on the basis of the rate of accidents when compared to the vehicle kilometers of travel for each of the roadway classifications. As in the case of intersection locations, reports can be printed to describe the sections that exceed the average numbers or rates by specified amounts.

High-Accident Spots

Each accident appearing in the location file will be used in turn as the starting location for a road spot of specified length [such as 0.5 km (0.3 mile)]. By using the selected spot length, the statewide accident rate for the road classification under analysis, and the average daily traffic for the road section under analysis, the number of accidents occurring in each road spot is compared with the average or expected number. Those spots that have a significantly high-accident experience are reported in the order of the observed accident rate.

Summaries

After the high-accident intersections, sections, and spots are determined, all accidents occurring at each location can be extracted from the accident-statistic master file, and all roadway characteristics can be extracted from the roadway inventory file. A variety of summaries can relate the accident characteristics with the roadway, driver, vehicle, or environmental circumstances. Such summaries are useful for determining the most appropriate type of countermeasure that might be effective in reducing the frequency of accidents.

INTRACS techniques in the future may include the computer mapping of accident locations, roadway characteristics, traffic volumes, and street capacities for routes, corridors, or areas. All of these could be accomplished by using the six basic files.

SUMMARY

INTRACS represents a major statewide effort and is being developed to geographically locate accidents on road segments anywhere in the state. The system provides a procedure for analyzing accident rates and their relation to physical roadway conditions. The results will be used to identify critical accident locations and the conditions that cause accidents.

Because of its unique design, INTRACS provides a comprehensive system for efficient and meaningful analysis of coded accident information. Roadway sections, intersections, corridors, and geographic areas can be examined over any specified period of time for a complete accident history. Accidents can be identified by type, precise location or any of the other descriptive criteria included on individual accident report forms. Accident occurrence can also be correlated with roadway characteristics, jurisdiction, and federal-aid classification. INTRACS output can be in the form of printed summaries or computer-generated accident-spot maps.

A fundamental characteristic that sets the INTRACS system apart from other accident-record systems is the two-dimensional nature of its accident location and road files. Unique X and Y coordinates are assigned by electronic digitizer to every significant reference point along the federal-aid routes in the state. These coordinates specify the exact location of a given point within an established, statewide reference frame of interlocking matrices. The coordinates for accident locations are then determined by computer programs that use distances from the reference points.

The coordinates allow points having no common link other than their proximity to each other or to a specified location to be grouped for further analysis. For example, areas having excessively high-accident rates can be readily located by scanning the accident-location file for any instances of high-accident density. Accident rates can be automatically correlated with average daily traffic counts and other relevant roadway characteristics.

The coordinates for points that are coded into the INTRACS network are tied to a corresponding set of narrative files. These files contain key descriptive information for each particular point and connecting link, allowing a direct interface with existing statewide road inventory and accident-statistic files. The careful design of these files ensures maximum flexibility in accident analysis without needless duplication of the information already being maintained in separate file systems. Further, all files are designed to allow efficient updating, so that subsequent accident analyses can reflect the current status of a particular situation.

The INTRACS system can also be used by state and local governments for several other purposes. Additional information that can be coded to the same coordinate system and interrelated to the roadway locations established by the INTRACS project includes the following:

1. Vertical alignment of roads;
2. Utilities within the road right-of-way, e.g., water lines, sanitary sewers, electric lines, and telephone lines;
3. Right-of-way;
4. Adjacent land use;
5. Subsurface conditions determined from soil borings within the road right-of-way; and
6. Noise and air-quality data derived from field measurements or from theoretical computations by using roadway characteristics from data files.

The system is also flexible enough to incorporate geographic coding of the railroad network, major river systems, pipelines, and electrical transmission systems for the entire state.

An advantage of the program is the capability for local government agencies to define local data by using the same format. Identification of the locations of sanitary sewers, water courses, and storm drainage systems are among the data files that can be locally developed. The procedures are designed to permit local agency development of these kinds of data without the need for expensive electronic digitizing equipment. With this capability, local agencies can prepare their own data within the framework of the roadway system. As data files are developed, statewide summaries by county or other jurisdiction could be prepared as part of a normal state program of technical assistance to local governments.

Another capability of the system is the identification and coding of attributes and conditions of geographic areas (in contrast to the linear-system descriptions that characterize the initial development of the process). The matrix method of geographic coordination can be subdivided into smaller cell sizes, and cell attributes can be defined and coded for multiple purposes. Socioeconomic characteristics, bedrock and soil geology, ground cover, percolation, land use, climatology data, and other characteristics can be coded into matrix cells and the results used for county, regional, or statewide land-use capability analysis.

The ability to geographically relate linear systems to area conditions can provide data for both research and applied planning of many functions that concern federal, state, and local governments.

ACKNOWLEDGMENTS

The accident reporting system described in this report was prepared for the Indiana Department of Traffic Safety and Vehicle Inspection, in cooperation with the Indiana State Highway Commission, the Indiana State Police, the Indiana Department of Administration, and the U.S. Department of Transportation. We wish to acknowledge the contributions of the many staff members of Vogt, Sage, and Pflum Consultants for their collective thinking that has resulted in the detailed design and programming of INTRACS and their persistence and diligence in coding, editing, and processing the data files that are the basis of INTRACS.

The INTRACS working committee, comprised of state personnel representing the four agencies that will maintain and use the system, has offered constructive reviews, comments, and suggestions that have contributed to a better system.

Publication of this paper sponsored by Committee on Traffic Records.

Sampling Procedure Using Multistate Traffic Records to Select Accident and Exposure Data-Collection Sites

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This paper describes a sampling plan developed to select 80 field data-collection sites. At each of these locations, large-truck accident rates were to be measured and vehicle exposure was to be sampled simultaneously for 1 year. The problems to be addressed were (a) to stratify the sites in each state so that the accident experience developed would be representative of the state (to preclude selecting only high-accident locations) and (b) to devise a roadway typology whereby sites were consistent across states selected. Accidents are now being investigated at sites selected by this procedure in California, Maryland, Michigan, Nevada, Pennsylvania, and Texas.

This paper describes a sampling plan developed to obtain the accident rates (based on exposure) of large trucks. Truck exposure is the term used to describe the number of trucks currently in use and the annual number of kilometers these vehicles are driven. Fairly accurate information is available at the state and national levels as to the number of trucks registered through state licensing agencies each year. But, as one attempts to classify trucks into categories on the basis of such considerations as body type, number of axles, mass, and length, the available information becomes vague, especially in terms of truck combinations (where different trailer units can be combined with a particular tractor for different trips).

A great deal of information is available about truck accidents in general. The National Safety Council each year provides a broad estimate of trucks involved in motor-vehicle accidents in the United States and the distribution between single-unit and combination vehicles. Little or no information is available that identifies the relationship between truck accident frequency and truck size and mass.

Although exposure data are available, it is impossible to discuss accident rates by truck classifications, except in the most general terms. The data that are currently available do not indicate whether longer trucks or heavier trucks are over involved or under involved in accidents, based on their representation in the traffic population at the accident locations.

Although the methodology described here was developed to address truck accident rates (per million vehicle kilometers of exposure), the same technique could be used to obtain details about other types of vehicles such as automobiles, motorcycles, or buses.

A sampling technique has been developed for selecting 80 roadway segments at which large-truck accident and exposure data will be collected. These segments comprise approximately 1609 km (1000 miles) of highway throughout six participating states, e.g., California, Maryland, Michigan, Nevada, Pennsylvania, and Texas.

A typology was created to partition all roadways into six exclusive types. Two classification variables were used: road location (two levels, urban and rural) and roadway type (three levels, primary, secondary, and Interstate). Roadway type was nested within road location.

In each state, a multistage stratified random sampling of roadway segments was drawn within each roadway type. The distribution of large-truck accidents experienced was then plotted for those segments sampled. Potential data-collection sites were identified by using a two-way stratification method based on historic truck-accident distribution curves. The final sites were selected by a team of trained field crews after on-the-scene evaluation of the potential sites. These crews based their decisions on previously specified selection criteria (e.g., weight data and ability to collect exposure data). The logic of the site selection process is shown in Figure 1. Table 1 illustrates the final distribution of selected sites in the framework of the six states and two roadway classification variables.

SELECTION OF COOPERATING STATES

A literature review of the existing truck-related research and accident data was conducted at the beginning of the project (1). From this information, states in candidate areas of the country were selected on bases of annual truck exposure (distance), truck accidents, or state laws permitting extremes in truck size, mass, or length. The six states selected and the reasons why are given in Table 2. The first three states (California, Texas, and Pennsylvania) were selected because they represent more truck kilometers of exposure per year than any other state. Michigan was selected because it permits the heaviest truck payloads in the United States. Nevada was selected because it permits triples (tractor plus three articulated trailer units) to operate over a larger variety of roads than any other state. Maryland was selected to permit convenient pilot testing of the field data-collection techniques and to represent a state allowing approximately average masses and sizes of vehicles.

The decision to choose 80 sites was made at the beginning of the project and is based on the number of national accident-exposure descriptors. It was reasoned that this number of locations would provide adequate quantitative data for statistical analysis of the variables of interest and their numerous subcategories (i.e., truck classifications, sizes, and masses).

SAMPLING PROCEDURE

Roadway-Segment Sampling

Each state was divided into three to five nonoverlapping geographical regions. A sample (areas partitioned by

Figure 1. Site-selection procedure.

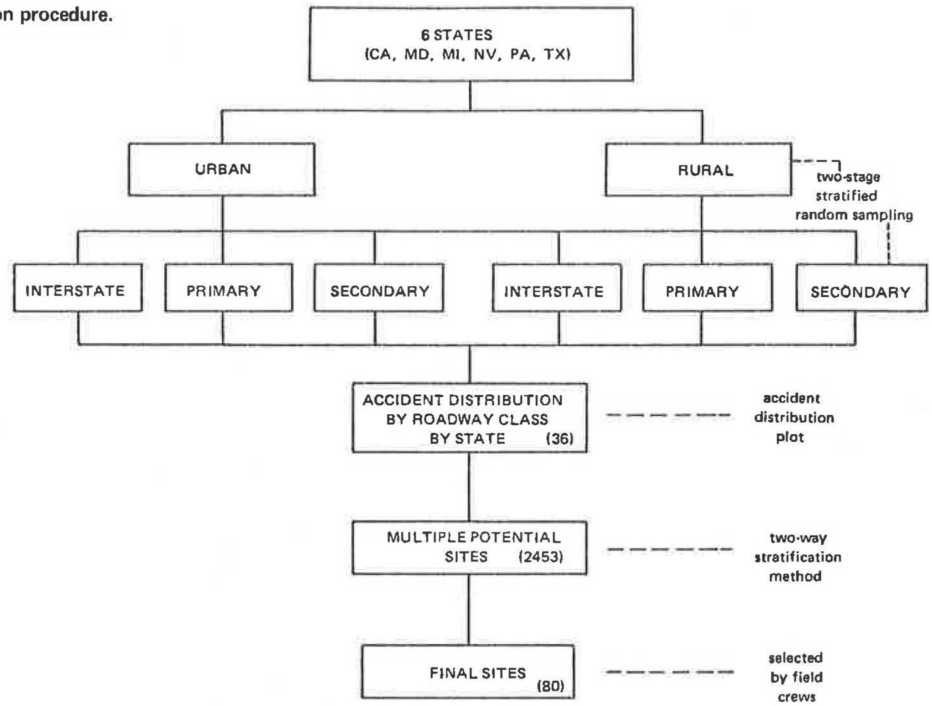


Table 1. Number of data-collection sites.

	No. of Sites						
Roadway Class	California	Maryland	Michigan	Nevada	Pennsylvania	Texas	Total
Rural							
Interstate	5	2	4	3	3	3	20
Primary	3	1	2	3	2	1	12
Secondary	3	1	2	2	2	2	12
Urban							
Interstate	5	2	4	2	3	4	20
Primary	2	1	2	1	1	1	8
Secondary	2	2	2	0	1	1	8
Total	20	9	16	11	12	12	80

Table 2. Vehicle characteristics in state participating in study.

	Rank		Max Truck Dimensions (m)			
State	Exposure[a]	No. of Accidents[b]	Length	Height	Width	Comments
California	1	7	20	4.3	2.54	Allows doubles
Texas	2	4	20	4.1	2.44	–
Pennsylvania	3	1	16.8	4.1	2.44	–
Michigan	5	12	20	4.1	2.44	Heaviest axle loading allowed
Maryland	–	–	20	4.1	2.44	Pilot test procedures
Nevada	–	–	32	4.1	2.59	Allows triples

Note: 1 m = 3.3 ft.

[a] 1974 Federal Highway Administration data for all trucks and all roads. [b] 1973 Bureau of Motor Carrier Safety.

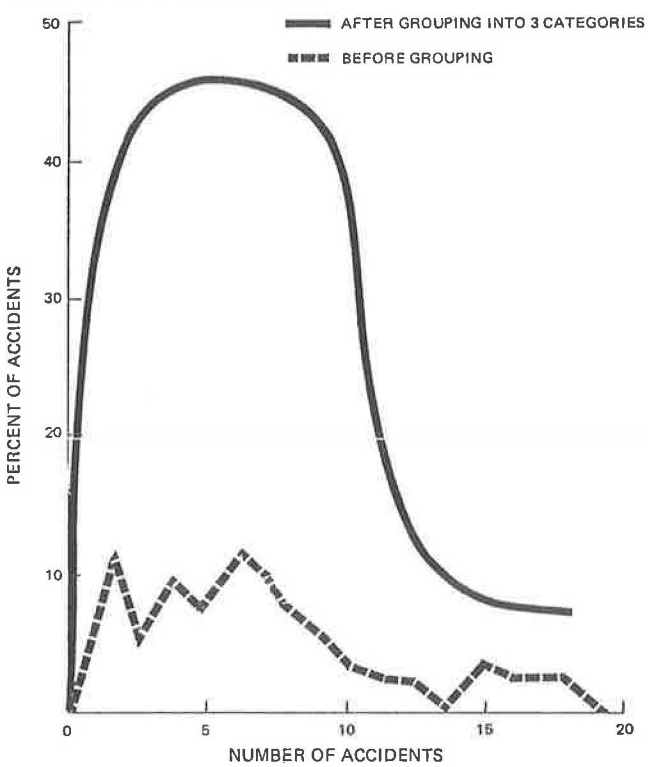
county or highway-district boundaries) was drawn from each. The drawing was made independently in each region (stratified random sampling). In California, for example, the sample was based on highway districts: Four districts—numbers 1, 3, 10, and 11—were sampled from among the 11.

Table 3. California rural Interstate-highway selection.

Highway District	Sample Area (counties)	Route[a]	Length (km)
1	5	None	–
3	11	A	145
		B	177
10	9	A	129
		B	48
		C	23
		D	26
11	3	A	32
		E	177
		F	32
All	28	6[b]	992[c]

Note: 1 km = 0.62 mile.
[a]Route numbers are not identified because the data collection in these areas is ongoing.
[b]Non-Interstate roadways.
[c]Sixty-two 16-km segments.

Figure 2. California large-truck accident distribution by 16-km (10-mile) segment of rural Interstate highways.



The next step was to identify the roadways to an initial limit of 10 to 20 in the sample area on the basis of their typology [i.e., urban versus rural and federal-aid Interstate (final) versus federal-aid primary versus federal-aid secondary (state)]. Although this task seems overwhelming, in no sample area was the number of roadways of a specific type (e.g., rural Interstate or urban primary) greater than nine. Table 3 illustrates the identification of rural Interstate highways in California.

Each roadway was divided into a number of segments. These were 16 km (10 miles) long for rural roadway categories, 4.8 km (3 miles) long for urban Interstates, and 3.2 km (2 miles) long for urban primary and secondary roadways. These lengths represent average distances between roadway exits where the average daily truck traffic remains constant.

Truck-Accident Distribution

Determining large (i.e., other than panel and pickup) truck-accident distributions by roadway classification was very time-consuming because it entailed counting the number of truck accidents in specific roadway segments. For each roadway classification, a 1974 truck-accident distribution was obtained from the proportion of those roadway segments in the sample having no truck accidents, one truck accident, two truck accidents, and so on. The site selection was primarily done on the basis of the accident distribution curves. These curves also permitted a direct comparison between the sites selected and the accident distribution for a specific class of roadway in a particular state. A large-truck accident distribution on the California rural Interstate highways sampled is shown in Figure 2. (Thirty-six of these distributions were plotted to display the six roadway types in each of the six states.) Such a distribution permits grouping all of the roadway segments into several accident categories, such as high, medium, and low. For California rural Interstate-highway segments, the following categories were derived:

1. Category 1 = low = 5 accidents/16-km (10-mile) highway segment,
2. Category 2 = medium = 6 to 10 accidents/16-km (10-mile) segment, and
3. Category 3 = high = more than 10 accidents/16-km (10-mile) segment.

Thus, in selecting the five rural Interstate-highway study sites allocated to California in Table 1, it was necessary to select from sixty-two 16-km (10-mile) highway segments within three accident categories and four geographical highway districts. A two-way stratification was used (2). (There were originally 2453 candidate sites from which 80 final study sites were selected.)

Table 4. Number and proportion of California rural Interstate segments in sample.

Accident Category	District 1 m_{ij}	District 1 P_{ij}	District 3 m_{ij}	District 3 P_{ij}	District 10 m_{ij}	District 10 P_{ij}	District 11 m_{ij}	District 11 P_{ij}	Total m_{ij}	Total P_{ij}
1	0	0.0	6	0.0968	3	0.0484	19	0.3065	28	0.4517
2	0	0.0	11	0.1774	7	0.1129	8	0.1290	26	0.4193
3	0	0.0	3	0.0484	4	0.0645	1	0.0161	8	0.1290
Total	0	0.0	20	0.3226	14	0.2258	28	0.4516	62	1.0000

Note: i = accident category (1, 2, or 3) and j = highway district (1, 3, 10, or 11).

Two-Way Stratification for Selecting Candidate Sites

In sampling the highway districts in California for rural Interstate study sites, sixty-two 16-km (10-mile) roadway segments were identified (Table 3). Table 4 represents the stratification of these 62 roadway segments into three accident categories and four geographic areas (highway districts). Thus, in district 3, there are 320 km (200 miles) of highway or 20 highway segments or potential sites. By using the 1974 truck-accident data, these 20 can be subdivided into 6 in category 1 (low), 11 in category 2 (medium), and 3 in category 3 (high). Similarly, the 14 segments in district 10 and the 28 segments in district 11 can be stratified by accident category. The number of segments is given by m_{ij} and the proportion of segments is given by P_{ij} ($P_{ij} = m_{ij}/62$).

The next procedure is to give each segment an approximately equal chance of selection and each accident category and highway district its proportional representation. In this instance, five study sites (n = 5) have been specified, and the numbers $n_{i.} = n\sum P_{ij}$ and $n_{.j} = n\sum P_{ij}$ are computed. These products are rounded to the nearest integers (with a further minor adjustment if required), so that both $n_{.j}$ (the total number of sites in the highway districts) and $n_{i.}$ (the total number of sites in the accident categories) add to n. The next step is to draw n = 5 cells with the probability $(n_{i.} \times n_{.j})/n^2$ for the ij th cell by constructing an n by n matrix. In row 1 of this matrix, one column is drawn at random. In row 2, one of the remaining columns is drawn at random, and so on. At the end, each row and column contains one unit. The results of one draw are indicated by X's in the table below.

Row (accident category)	Column (highway district) 1 (3)	2 (3)	3 (10)	4 (11)	5 (11)
1 (1)	–	–	–	X	–
2 (1)	–	–	–	–	X
3 (2)	–	X	–	–	–
4 (2)	X	–	–	–	–
5 (3)	–	–	X	–	–

Columns 1 and 2 were assigned to district 3 because $n_{.2} = 2$. Similarly, rows 1 and 2 were assigned to accident category 1 because $n_{1.} = 2$, and so on. This completes the allocation of the sample to the 12 cells. The three cells in district 1 were out of the draw because $n_{.1} = 0$. The allocation is given in more compact form below. (An alternative approach would be to convert P into ranges of integers and then select from a table of random numbers.)

Accident Category	District 1	3	10	11	Total
1	0	0	0	2	2
2	0	2	0	0	2
3	0	0	1	0	1
Total	0	2	1	2	5

The 62 potential sites have now been reduced to 34 potential sites. Specifically, the two sites representing the low accident category can now be selected from 19 potential sites in highway district 11, the two sites in the medium accident category can now be selected from 11 potential sites in highway district 3, and the one site in the high accident category can now be selected from 4 potential sites in highway district 3. The final sites were selected by the same crew that traveled to the six states and used a defined set of criteria.

Final Site Selection

There were nine primary criteria used in selecting the 80 sites. These were

1. Well-defined points of egress and entrance (control of exposure and accident data),
2. Vehicle volumes (confidence that vehicles traversed the entire segment),
3. Vehicle and truck mix (confidence that specific types of vehicles were consistent through the entire segment),
4. Truck-accident rates (high accident rates at selected sites within an accident category should be offset by low accident rates at the remaining sites to be selected within that category),
5. As long a segment as possible (given that the first three criteria are met),
6. Possible collection of exposure and speed data (field data collection by observers or cameras must be covert and not affect vehicle performance),
7. Possible collection of truck-mass exposure data (rest area, truck stop, or weighing station close enough to the site that there is high probability that the data collected will be directly applicable to the site under consideration),
8. Clear field of view and light source (to permit sampling of vehicle exposure both day and night), and
9. Cooperation of the local jurisdiction (it was necessary to have police and highway departments to assist in gathering the exposure data and to identify all large-truck accidents occurring within a 1-year period of time at each of the sites).

SUMMARY

This rather elaborate sampling procedure made possible the first large-scale, multistate, simultaneous field data collection of both accident and exposure data. The multistage stratified random sampling of roadway types will permit an analysis of large-truck accidents that are representative of the experiences of each of the six states that are cooperating in the study.

ACKNOWLEDGMENTS

This paper relates to one area of a study by BioTechnology, Inc., for the Federal Highway Administration. We wish to thank the individuals responsible for the traffic records of the states comprising the field study sites. We wish to acknowledge the efforts of Gerald R. Vallette of BioTechnology, who was in charge of the state coordination and site-selection activities and thank Wallace G. Berger of the U.S. Senate Staff (formerly of BioTechnology), and Julie Anna Fee, Martha Schwendeman, and Michael Freitas of the Federal Highway Administration for their suggestions. The views expressed in the paper are those of the authors and do not necessarily reflect the views or the policies of the Federal Highway Administration or the U.S. Department of Transportation.

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Filtering of Fatal-Accident Rates

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The relationship between the economy and national fatal-accident rates on a per-vehicle basis is analyzed. Although the relationship is obscured by the strong downward trend in the accident-rate data, there are consistencies apparent in the data. Accident rates historically (1949 to 1973) have decreased during recession periods and increased or changed in rate of decrease after each recession period. Of the specific economic measures studied, national unemployment rates showed the highest correlation (r = 0.86) with fatal-accident rates that were adjusted for the downward trend. Because the performance of the economy seems to have an effect on fatal-accident rates, it may be hazardous to compare fatal-accident data from one year to another without considering the economic conditions in the years compared.

Automobile accident rates or the number of highway-related deaths are often used in measuring the effectiveness of various vehicle and highway-system improvements. It seems imperative that factors other than the specific vehicle and highway-system changes affecting accidents and fatality levels should also be considered. For example, when comparing different model years of automobiles, data from the same calendar year must be treated with care because the kilometers driven per automobile, among other use factors, can vary with the age of the automobile (1). Comparing accident data where the ages of the automobiles are the same, but the calendar year of the data collection differs also can be hazardous, due to differences in the accident environment and in the factor that this paper will discuss, the economy.

A strong relation between the general performance of the economy and highway deaths has been suggested (1, 2). The data show that as economic performance improves, highway deaths increase. Various theories have been offered as explanations for this connection between highway mortality and economic prosperity. To date, no causes have been clearly identified.

ACCIDENT DATA

Fatal motor-vehicle accident counts given by the National Safety Council divided by the number of registered vehicles (the total of automobiles, buses, and trucks) given by the Federal Highway Administration were used as fatal-accident rates for this study. These accident rates may be more meaningful than fatal counts for automobile insurance companies and others concerned with per-vehicle measures of performance of the highway system.

The fatal-accident rates from 1949 to the present are shown in Figure 1. The overall trend of these data is depicted by the smooth curve drawn through the original data points.

The most striking feature of Figure 1 is the general downward trend in fatal-accident rates. This downward trend runs counter to population and vehicle trends. More specifically, exposure data, such as kilometers driven per vehicle, suggest an upward trend, because these have increased over the long term. However, some variations in kilometers per vehicle are reflected in the accident data. Factors that may have contributed to this reduction in the rate of fatal accidents include (a) the gradual phase in of improved vehicle and highway systems and (b) improved driving and safety performance.

The impact of the energy crisis on fatal-accident rates in 1974 can be clearly seen. The step-down in the trend line at 1974 reflects the incremental reduction in highway-fatality rates due to the establishment of the 88-km/h (55-mph) speed limits on major highways. The estimate of this effect of lower speed limits was derived from National Safety Council estimates of the effect on traffic deaths (3). This change, which affects all drivers and all vehicles, has had a powerful effect on automobile-fatality rates. With the maintenance of speed limits at this level, the lower overall rate should continue.

DATA REPRESENTING THE ECONOMY

Two types of data were used to represent the economy. The first was an indicator of the economy in general and consists of whether or not the nation was in a recession. The second was economic series, such as unemployment rates, that are thought to describe the economic conditions that directly affect the driving population.

General Economic Conditions: Recession Periods

Recessionary and nonrecessionary economic periods as delineated by the National Bureau of Economic Research (NBER) were used as indicators of the general economic condition of the country. An abbreviated description of the methods that NBER uses to determine recession periods appeared in the December 1, 1974, New York Times (4). A rough translation of the NBER's qualitative definition of a recession into a quantitative one is given in the article and listed below:

1. In terms of duration—declines in real gross national product (GNP) for two consecutive quarters and a decline in industrial production over a 6-month period;
2. In terms of depth—a 1.5 percent decline in real GNP, a 1.5 percent decline in nonagricultural employment, and a two-point rise in unemployment to a level of at least 6 percent; and
3. In terms of diffusion—a decline in nonagricultural employment in more than 75 percent of industries, as measured over 6-month spans, for 6 months or longer.

The recession periods delineated by NBER are shown as shaded areas in Figure 1.

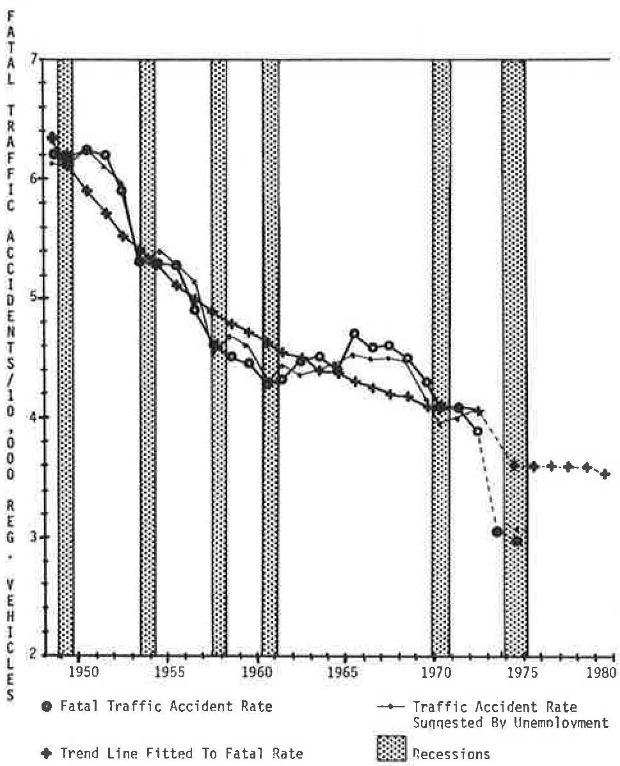
Specific Economic Series Chosen

The economic series were chosen to be used with a regression analysis. First, the series had to be representative of the economic factors that affect the driving population. Second, series with long-term trends were not considered because high correlations can be calculated that, due to the trend, are actually meaningless. Third, data for the series had to be available from 1949 to the present in a continuous manner.

Three types of economic well-being of the driving population are considered in this study: perceived, actual, and demonstrated. These three broad categories and the series chosen to represent each are shown below.

	Type of Series		
Type of Criterion	Representative of Economic Factors	No Long-Term Trend	Available from 1949 to Present
Perceived	Consumer sentiment	Consumer sentiment	—

Figure 1. Rates of fatal traffic accidents.



Type of Criterion	Type of Series: Representative of Economic Factors	No Long-Term Trend	Available from 1949 to Present
Actual	Unemployment, real wages, disposable income, and avg hours worked	Unemployment and avg hours worked	Unemployment and avg hours worked
Demonstrated	Consumption of goods, savings, kilometers driven, new automobiles purchased, and private housing		

[Consumer sentiment can be determined from the University of Michigan surveys (5) and unemployment data are available from the U.S. Department of Commerce (6).]

This table shows that most of the economic series chosen have long-term trends that are difficult to remove and thus fail the second criterion. Manipulations such as deflating the series and converting them to per capita measures do not remove the long-term upward trends in these series. These long-term upward trends are not represented in the frequency data. Of course, the upward pressures exerted by the economy may have been offset by the improvements in vehicles, highway systems, and driving performance.

The series that remain after eliminating those that fail one or more of the criteria are the unemployment rate and the average number of hours worked.

RELATIONSHIPS OF THE ECONOMIC AND FREQUENCY DATA

Unadjusted Accident Frequency

Figure 1 shows that there is a strong downward trend in the fatal-accident rate. This strong downward trend obscures many of the fluctuations of the accident frequency that are counter to it. However, there are regular fluctuations from the downward trend that can be isolated. The most consistent of these is a definite downward trend through each recession period. The second consistent fluctuation is a change in the rate of decline or actually an increase in the frequency after each recession.

No attempt was made to relate the fatal rates shown in Figure 1 to specific economic series. The main reason for this was the long-term downward trend in the data. It is not reasonable to assume that this downward trend has been generated by the economy because most economic measures actually suggest a long-term upward trend. Even kilometers driven per vehicle have increased over the period considered. Thus, improvement in safety per kilometer driven seems to dominate the factors affecting fatal-accident rates over the long term. However, significant downward fluctuations in the economic series from the long-term upward trend are represented in the accident frequencies as was suggested in the discussion of recessionary periods, since most economic series are affected in recessions.

Adjusted Accident Frequency

Because the long-term downward trend of the fatal-accident rate obscures the effects of the economy, an attempt was made to quantify or estimate the effects of the trend and remove it from the data. A smooth curve was fitted to the fatal-accident rate to represent the long-term trend, and although this curve cannot be described as an exact estimation of the downward trend, it is a plausible rough estimate. This estimate of the long-term downward trend accounts for 89 percent of the variance in the fatal-accident rate.

The long-term trend was then removed from the fatal-accident rate by subtracting the values represented by the fitted curve from the actual values. Linear regression was used to relate this detrended accident data to the specific economic series chosen. The relation of the unemployment rate with the detrended accident rate [correlation coefficient (r) = 0.86] is much better than that of the average number of hours worked with the detrended accident rate. The result of this part of the analysis is also shown in Figure 1. The estimated relation between the unemployment rate and the residual accident rate for 1949 to 1973 was used with the lowered trend line to estimate the point for 1975.

CONCLUSIONS

There seems to be a strong relation between the general economic performance and fatal-accident rates. Although the relationship is obscured by the strong downward trend in the accident-rate data, there are consistencies apparent in the data. Accident rates historically have decreased in recession periods and increased or changed in rate of decline after recession periods.

Of those specific economic measures studied, national unemployment rates showed the strongest relationship with fatal-accident rates, adjusted for the downward trend. As illustrated in Figure 1, the fitted rates closely follow the original fatal-accident rates. Because unemployment is an important part of the overall economic well-being of the country, the decrease and subsequent increase in accident rates through recession periods is also reflected in the estimated relationship between the unemployment and fatal-accident rates.

Because the performance of the economy seems to have an effect on accident rates, it may be hazardous to compare fatal-accident data from one year to another without also considering the economic conditions in the years compared.

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**Mr. Eshler was with Nationwide Insurance, Columbus, Ohio, when this research was performed.*

Analysis of Countywide Accident Data by Rate and Frequency

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A Highway Safety Program Standard (Identification and Surveillance of High Accident Locations) requires each state and local community to have an established procedure for the identification of high accident locations. The standard, however, specifies neither definite criteria nor procedures for the identification of such locations. Consequently, communities throughout the country use a variety of identification methods with varying degrees of success and accuracy. These range from the accident-frequency method to the accident-rate method and various combinations of them. The result of these procedures is the identification and selection of the most critical accident locations. A methodology for the analysis of large numbers of locations has been developed and implemented in Oakland County, Michigan, as part of a countywide comprehensive traffic engineering project. The methodology uses both accident-frequency and accident-rate data for each intersection and highway link to identify the most critical locations. The procedure stratifies the data from a number of intersections (or links) and assigns each location to a cell within a matrix that considers accident frequency on the horizontal axis and accident rate on the vertical axis. The locations contained in the cell corresponding to the highest frequency and the highest rate are identified as the most critical locations. Locations with a high frequency and a low rate or a high rate and a low frequency are considered less critical. A computer program was developed that determines the rate and frequency for all highway locations (intersections or links) being analyzed, assigns each location to the appropriate cell in the rate and frequency matrix, and then prepares reports indicating the locations contained in each cell and the pertinent data for each location. The rate and frequency analysis procedure was tested by using countywide accident data, as well as data from smaller political jurisdictions, and was an effective and valuable traffic-engineering tool.

Increased travel on our roads and highways is causing a corresponding increase in the number of accidents. However, when these numerical increases are compared with the higher travel loads, there has been a net decrease in accident rates (1). This decrease can be attributed, at least in part, to the positive effects of safety-improvement programs. Continued safety improvements require the comprehensive assessment of problem locations and subsequent corrective actions.

A Highway Safety Program Standard requires each state and local community to have an established procedure for identifying high-accident locations. Most communities identify such locations by considering either accident frequencies or accident rates and using assigned threshold values (2, 3). The use of a single indicator and an arbitrary threshold value, however, sometimes results in the selection of noncritical locations for improvements and may omit locations that are more critical.

STUDY OBJECTIVES

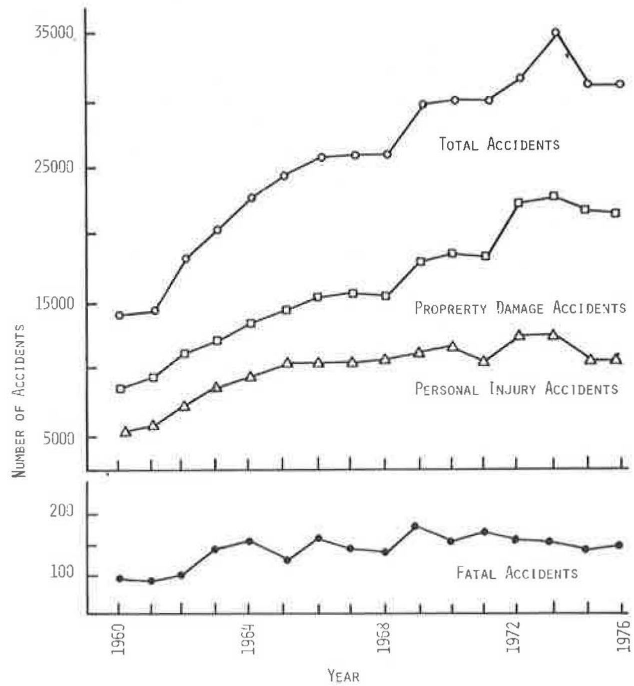
The object of this study was to develop a methodology that would stratify the highway locations in an area in a manner that would eliminate the possibility of selecting noncritical locations for remedial action. The basic steps in the countywide accident study were to

1. Develop a methodology that allows an analyst to establish the relative standing of all accident locations in a community;
2. Develop a computer program that can use the available accident data, determine the overall and by-type accident frequencies and rates, and generate a rate and frequency matrix indicating the relative standing of the intersection and highway-link locations in the county; and
3. Test the procedure with the Oakland County, Michigan, accident data to identify high-accident locations and to prove the validity of the system.

The frequency of accidents at an intersection or a link location is an important measure of safety conditions. A location, however, may have a low accident frequency and a very low traffic volume and thus a high accident rate, whereas another location may have a high accident frequency and a very high traffic volume and thus a low accident rate. It must then be determined which of the two locations is more critical.

Accident frequency is defined as the number of accidents at a location per year. Accident rate is defined (for intersection locations) as the number of accidents per million vehicles entering the intersection per year and (for links) as the number of accidents per million vehicle kilometers of travel per year.

Figure 1. Oakland County accident trends.



The study was conducted in Oakland County in southeastern Michigan. The county has an area of 2351.2 km^2 (907.8 miles^2) and had a 1975 population of 975 097. The trend of the overall accident frequency since 1960 has been to increase except in 1968, 1971, 1974, and 1975 (Table 1). The overall accident statistics, when plotted, indicate a leveling off in the numbers of fatal and personal-injury accidents (Figure 1).

ANALYSIS PROCEDURE

Defining high, moderate, and low accident locations is an essential prerequisite to any plan to reduce safety hazards on highways. The establishment of criteria for such categorization, however, varies in different communities. Therefore, this study attempted to develop an analysis methodology that could categorize accident locations by both their accident frequencies and rates. A community could then develop a priority scheme based on its available resources.

To identify high-hazard locations in the county on a basis of either accidents or accidents of specific types, a computer program was developed to determine the accident frequencies and rates for all locations and to assign each location to a position in the rate and frequency matrix.

This methodology is based on a simultaneous consideration of accident rates and frequencies by using a

Table 1. Countywide accident statistics.

	Accidents				Persons			Annual Percentage Change in
Year	Total	Property Damage	Injury	Fatal	Injured	Killed	Total	Total Accidents
1960	13 722	8 385	5 234	103	8 517	122	8 639	—
1961	13 947	8 194	5 656	97	9 327	108	9 435	1.6
1962	18 051	10 730	7 219	102	11 825	115	11 940	29.4
1963	20 251	11 854	8 252	145	13 654	163	13 817	12.2
1964	22 571	13 115	9 291	165	15 258	202	15 460	11.5
1965	24 472	14 260	10 076	136	16 359	164	16 523	8.4
1966	25 650	15 122	10 361	167	16 692	179	16 871	4.8
1967	25 814	15 648	10 021	146	16 289	165	16 454	0.6
1968	25 799	15 104	10 554	141	17 218	163	17 381	0
1969	29 414	17 958	11 275	181	18 165	201	18 366	14.0
1970	29 987	18 458	11 372	157	18 072	173	18 245	1.9
1971	29 433	18 720	10 541	172	16 284	189	16 473	1.8
1972	34 366	22 170	12 035	161	18 601	179	18 780	16.8
1973	35 020	22 681	12 180	159	18 426	186	18 612	1.9
1974	32 401	21 665	10 588	148	15 812	160	15 972	7.5
1975	32 415	21 583	10 679	153	16 117	161	16 278	0

Figure 2. Typical rate and frequency analysis matrix.

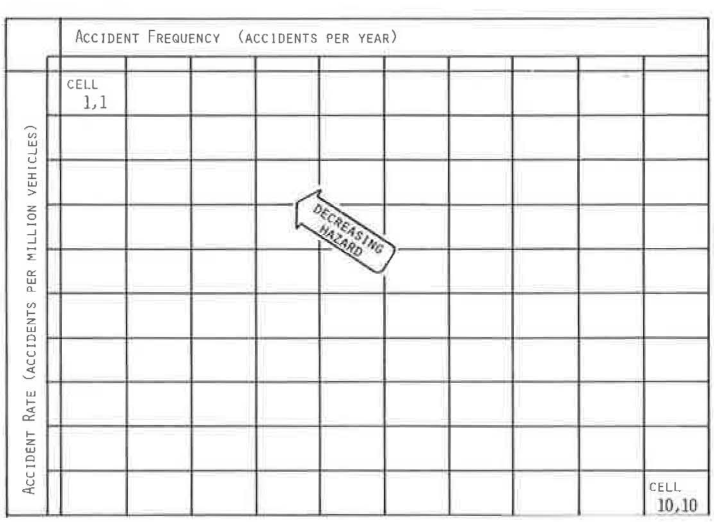
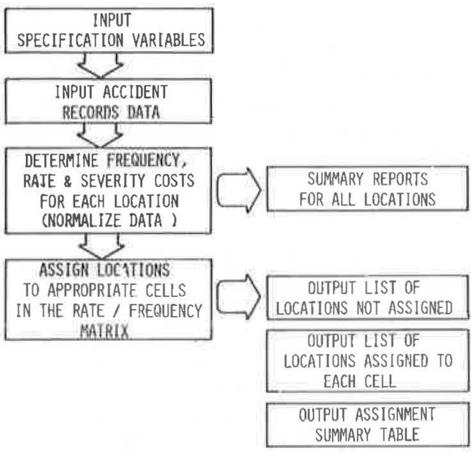


Figure 3. Macroscopic program flow chart.



matrix format (Figure 2) in which the horizontal axis of the matrix is divided into 10 increasing increments of annual accident frequency, and the vertical axis is divided into 10 increasing increments of accident rates. For roadway segments or links, the rate was based on accidents per million vehicle miles per year per mile of road; for intersections, the rate is based on accidents per million entering vehicles per year. (SI units are not given for the variables in this matrix because it was developed for use with U.S. customary units.)

The location of a cell in the matrix defines a certain level of hazard. The most hazardous intersections or links in the system are located in the lower right-hand cell of the matrix, i.e., cell (10, 10). Decreasing levels of hazard are represented by other cells in the matrix as one moves toward the upper left-hand corner, i.e., toward cell (1, 1).

The computer program uses accident-inventory data files to produce reports indicating the allocation of in-

Figure 4. Cell-assignment summary: 1973 intersection accident data file.

1973 OAKLAND COUNTY TRAFFIC ACCIDENT SUMMARY (ALL INTERSECTION ACCIDENTS)
RATE/FREQUENCY MATRIX CELL ASSIGNMENT TOTALS

ACCIDENT RATE	ACCIDENT FREQUENCY (ACCIDENTS/YEAR) 0- 4	5- 8	9- 12	13- 16	17- 20	21- 24	25- 28	29- 32	33- 36	37-150
0.0 - 0.59	119	39	5	2	0	0	0	0	0	0
0.60- 1.19	62	66	52	18	6	6	3	2	0	1
1.20- 1.79	22	40	33	22	14	8	6	8	2	6
1.80- 2.39	17	19	21	16	14	9	6	1	3	13
2.40- 2.99	4	9	17	18	5	6	8	1	9	21
3.00- 3.59	3	4	4	10	6	7	5	4	5	15
3.60- 4.19	1	3	6	2	3	5	2	2	1	13
4.20- 4.79	0	1	2	2	4	1	3	4	2	9
4.80- 5.39	1	3	1	2	0	2	3	0	0	10
5.40- 24.00	9	7	8	5	3	0	2	2	0	22

TOTAL INTERSECTIONS ASSIGNED 968

Figure 5. Intersection locations assigned to cell (10, 10): 1973 intersection accident data file.

1973 OAKLAND COUNTY TRAFFIC ACCIDENT SUMMARY (ALL INTERSECTION ACCIDENTS)

INTERSECTIONS ASSIGNED TO CELL 10 , 10 PAGE 105

INTER ID	ACCDNT	VOLUME	(DATE)	RATE	SEVERITY F	PI	PD	COST	CNTRL	INTERSECTION NAME	
38	45	20000	13/70	6.16	0	16	29	68320.00	1	E. WIDE TRACK	E. HURON
39	51	15000	13/70	9.32	0	9	42	50760.00	1	E. WIDE TRACK	UNIVERSITY
41	38	15000	13/70	6.94	0	20	18	76640.00	1	E. WIDE TRACK	SAGINAW
44	56	25000	13/70	6.14	0	13	43	64840.00	1	W. WIDE TRACK	W. HURON
122	49	24000	13/70	5.59	0	20	29	81920.00	1	STEPHENSON	THIRTEEN MILE
124	118	49258	5/71	6.56	0	60	58	231840.00	1	STEPHENSON	FOURTEEN MILE
126	46	12949	6/69	9.73	0	18	28	74640.00	1	ROCHESTER	WATTLES
132	69	25000	13/70	7.56	0	28	41	114880.00	1	ROCHESTER	AVON
173	43	9000	13/70	13.09	0	14	29	61520.00	1	EAST BLVD.	UNIVERSITY
306	84	38383	5/71	6.00	0	18	66	92880.00	1	CROOKS	BIG BEAVER
478	37	18046	11/70	5.62	0	16	21	64480.00	1	MIDDLEBELT	ELEVEN MILE
498	85	38174	1/74	6.10	0	27	58	119640.00	1	ORCHARD LAKE	MAPLE
507	50	24395	1/73	5.62	0	17	33	73640.00	1	ORCHARD LAKE	MIDDLEBELT
547	37	17743	4/71	5.71	0	15	22	61560.00	1	HALSTEAD	GRAND RIVER
658	71	34742	9/70	5.60	0	23	48	101240.00	1	M-59/HIGHLAND	CRESCENT LAKE
659	57	28913	9/70	5.40	2	22	33	254640.00	1	M-59/HIGHLAND	AIRPORT
674	50	20771	6/73	6.60	0	23	27	91160.00	1	M-59/HIGHLAND	MILFORD
727	50	24743	8/70	5.54	1	15	34	149320.00	1	GRAND RIVER	NOVI
765	51	18857	7/71	7.41	4	16	31	397280.00	1	TEN MILE	NOVI
815	40	20000	13/70	5.48	0	14	26	60080.00	1	AUBURN	EAST BLVD.
819	57	23000	13/70	6.79	0	25	32	100360.00	1	AUBURN	PADDOCK
942	59	19310	9/71	8.37	0	26	33	104240.00	1	LAPEER	DRAHNER

tersections or links to the various cells of the matrix on the basis of preselected frequency and rate increments.

A macroscopic flow diagram of the computer program is shown in Figure 3. The program first reads specification variables such as

1. The name of the accident data file (page header);
2. The type of accident to be analyzed, such as total or motor vehicle and parked vehicle; and
3. The increments of accident rate and frequency to be used.

The program then reads accident-record data from tapes for the time period being considered in the analysis. The accident-record data are summarized and normalized for each location, and a summary report of such items as the accident frequency, accident rate, and severity cost for each location is printed out. The program then assigns each location to the appropriate

Figure 6. Cell-assignment summary: 1974 intersection accident data file.

1974 OAKLAND COUNTY TRAFFIC ACCIDENT SUMMARY (ALL INTERSECTION ACCIDENTS)
RATE/FREQUENCY MATRIX CELL ASSIGNMENT TOTALS

ACCIDENT RATE	ACCIDENT FREQUENCY (ACCIDENTS/YEAR) 0- 4	5- 8	9- 12	13- 16	17- 20	21- 24	25- 28	29- 32	33- 36	37-150
0.0 - 0.59	119	36	6	2	0	0	0	0	0	0
0.60- 1.19	67	72	54	18	7	8	1	2	3	1
1.20- 1.79	30	35	39	26	20	9	8	5	6	3
1.80- 2.39	7	24	18	17	21	15	13	1	6	12
2.40- 2.99	5	5	11	8	10	9	7	7	6	21
3.00- 3.59	3	3	4	5	7	1	2	5	2	13
3.60- 4.19	5	4	3	4	4	2	4	4	0	9
4.20- 4.79	2	1	2	4	3	1	1	3	2	7
4.80- 5.39	1	3	3	1	1	1	1	0	0	6
5.40- 24.00	5	3	7	3	4	2	2	1	1	5

TOTAL INTERSECTIONS ASSIGNED 961

Figure 7. Intersection locations assigned to cell (10, 10): 1974 intersection accident data file.

1974 OAKLAND COUNTY TRAFFIC ACCIDENT SUMMARY (ALL INTERSECTION ACCIDENTS)

INTERSECTIONS ASSIGNED TO CELL 10 , 10 PAGE 105

INTER ID	ACCDNT	VOLUME	(DATE)	RATE	SEVERITY F	PI	PD	COST	CNTRL	INTERSECTION NAME	
124	107	49465	3/74	5.93	0	28	79	133120.00	1	STEPHENSON	FOURTEEN MILE
306	95	45963	3/75	5.66	0	27	68	124440.00	1	CROOKS	BIG BEAVER
674	46	20771	6/73	6.07	0	16	30	68800.00	1	M-59/HIGHLAND	MILFORD
765	42	18857	7/71	6.10	2	15	25	227000.00	1	TEN MILE	NOVI
942	56	19310	9/71	7.95	0	26	30	102800.00	1	LAPEER	DRAHNER

Figure 8. Cell-assignment summary: 1973 link accident data file.

1973 OAKLAND COUNTY TRAFFIC ACCIDENT SUMMARY (ALL LINK ACCIDENTS)

LINKS ASSIGNED TO CELL 10 , 10 PAGE 104

LINK ID	ACCIDENTS TOTAL	ACC/MI	VOLUME	(DATE)	RATE	SEVERITY F	PI	PD	COST	LNGTH	LINK NAME	
26.	134	134.00	19802	9/71	18.54	1	53	80	300600.00	1.0	JOHN R	10 MILE-11 MILE
60.	95	95.00	17000	13/72	15.31	0	33	62	141960.00	1.0	ROCHESTER	BIG BEAVER-WATTL
96.	99	99.00	11000	13/73	24.66	0	32	67	140960.00	1.0	LIVERNOIS/MAIN	14 MILE-MAPLE
119.	44	73.33	13094	10/72	15.34	0	12	32	56160.00	0.6	ROCHESTER	MAPLE-STEPHENSON
180.	71	101.43	17000	13/73	16.35	0	15	56	77880.00	0.7	ADAMS	WOODWARD-MAPLE
812.	123	123.00	20000	13/73	16.85	0	50	73	205040.00	1.0	9 MILE	JOHN R-DEQUINDRE
824.	34	48.57	6091	5/70	21.85	0	12	22	51360.00	0.7	10 MILE	HAGGERTY-GRAND R
862.	72	144.00	25000	13/72	15.78	0	31	41	125080.00	0.5	11 MILE	W MDSN HGHTS LMT
885.	65	65.00	9333	4/73	19.08	1	21	43	174040.00	1.0	12 MILE	FARMINGTON-ORCHA
892.	125	125.00	23483	4/73	14.58	0	29	96	144680.00	1.0	12 MILE	GREENFIELD-COOLI
968.	251	251.00	38462	8/73	17.88	1	98	152	488160.00	1.0	14 MILE	CAMPBELL-JOHN R
1117.	42	140.00	17412	9/73	22.03	0	13	29	58120.00	0.3	COOLEY LK	UNION LK-WILLIAM
1531.	144	160.00	26400	4/72	16.60	0	46	98	203440.00	0.9	M 59/HURON	TELEGRAPH-JOHNSO
1532.	112	160.00	21400	4/72	20.48	0	32	80	147200.00	0.7	M 59/HURON	JOHNSON-W WIDE T
1678.	13	65.00	9000	13/73	19.79	0	6	7	23760.00	0.2	LAFAYETTE	10 MILE-WOODWARD
1682.	28	46.67	5000	13/73	25.57	0	12	16	48480.00	0.6	FRANKLIN	S PNTC CTY LT-SO

cell in the rate and frequency matrix. The primary output is a report that lists all locations assigned to each cell and includes all the relevant information for each location. Locations that cannot be assigned because of missing data are indicated in a special report. Finally, the program summarizes the locations assigned to the rate and frequency matrix and the number of locations assigned to each cell.

The program was written in FORTRAN IV and has been implemented on an IBM 360-67 computer. It requires 130 kilobytes of central processing unit memory with data-storing capabilities on discs and magnetic tapes. An analysis of countywide accidents for 1973 and 1974 for all accidents in Oakland County required 1070 central processing unit s (this system included 1684 links and 1280 intersections).

Figure 9. Links assigned to cell (10, 10): 1973 link accident data file.

1973 OAKLAND COUNTY TRAFFIC ACCIDENT SUMMARY (ALL LINK ACCIDENTS)
RATE/FREQUENCY MATRIX CELL ASSIGNMENT TOTALS

ACCIDENT RATE	ACCIDENT FREQUENCY (ACCIDENTS/YEAR/MILE) 0.- 4.	5.- 8.	9.- 12.	13.- 16.	17.- 20.	21.- 24.	25.- 28.	29.- 32.	33.- 36.	37.-260.
0.0 - 1.59	101	12	6	5	6	3	1	0	2	0
1.60- 3.19	73	35	31	16	8	5	3	1	5	10
3.20- 4.79	62	26	17	32	13	8	7	4	2	19
4.80- 6.39	48	25	15	12	11	15	5	11	5	38
6.40- 7.99	24	14	10	8	6	5	5	9	3	48
8.00- 9.59	20	3	8	3	3	4	3	1	1	29
9.60- 11.19	19	2	1	1	2	1	1	0	1	8
11.20- 12.79	14	1	0	0	0	1	0	1	1	10
12.80- 14.39	16	3	3	1	0	0	0	0	1	8
14.40-200.00	122	11	1	1	5	1	1	1	0	16

TOTAL LINKS ASSIGNED 1158

Figure 10. Cell-assignment summary: 1974 link accident data file.

1974 OAKLAND COUNTY TRAFFIC ACCIDENT SUMMARY (ALL LINK ACCIDENTS)
RATE/FREQUENCY MATRIX CELL ASSIGNMENT TOTALS

ACCIDENT RATE	ACCIDENT FREQUENCY (ACCIDENTS/YEAR/MILE) 0.- 4.	5.- 8.	9.- 12.	13.- 16.	17.- 20.	21.- 24.	25.- 28.	29.- 32.	33.- 36.	37.-260.
0.0 - 1.59	129	19	10	5	5	4	1	3	1	3
1.60- 3.19	87	41	28	12	4	7	4	1	2	8
3.20- 4.79	65	37	20	26	17	10	11	6	5	22
4.80- 6.39	47	12	12	21	11	9	9	8	6	36
6.40- 7.99	28	8	6	3	6	7	4	4	5	36
8.00- 9.59	21	7	2	2	1	2	4	2	3	22
9.60- 11.19	15	2	3	4	2	0	2	0	0	16
11.20- 12.79	12	0	0	0	2	0	1	1	0	13
12.80- 14.39	14	1	2	0	2	0	0	0	1	4
14.40-200.00	134	13	4	3	1	2	3	0	0	7

TOTAL LINKS ASSIGNED 1201

Figure 11. Links assigned to cell (10, 10): 1974 link accident data file.

1974 OAKLAND COUNTY TRAFFIC ACCIDENT SUMMARY (ALL LINK ACCIDENTS)

LINKS ASSIGNED TO CELL 10 , 10 PAGE 103

LINK ID	ACCIDENTS TOTAL	ACC/MI	VOLUME	(DATE)	RATE	SEVERITY F	PI	PD	COST	LNGTH	LINK NAME	
60.	117	117.00	17000	13/72	18.86	0	36	81	161280.00	1.0	ROCHESTER	BIG BEAVER-WATTL
96.	77	77.00	11000	13/73	19.18	0	29	48	121640.00	1.0	LIVERNOIS/MAIN	14 MILE-MAPLE
824.	28	40.00	6091	5/70	17.99	0	9	19	39720.00	0.7	10 MILE	HAGGERTY-GRAND R
968.	232	232.00	38462	8/73	16.53	1	63	168	376840.00	1.0	14 MILE	CAMPBELL-JOHN R
1117.	52	173.33	17412	9/73	27.27	0	10	42	54160.00	0.3	COOLEY LK	UNION LK-WILLIAM
1532.	100	142.86	21400	4/72	18.29	0	32	68	141440.00	0.7	M 59/HURON	JOHNSON-W WIDE T
1682.	30	50.00	5000	13/73	27.40	0	7	23	34840.00	0.6	FRANKLIN	S PNTC CTY LT-SO

DATA ANALYSIS

The model was tested by analyzing all of the accident data for Oakland County for 1973 and 1974. Sample outputs are given in Figures 4 through 11.

Figure 4 shows the number of intersections assigned to each cell for 1973. Twenty-two intersections were assigned to cell (10, 10) (the lower right-hand corner of the matrix), which signifies the worst intersections when both rate and frequency of accidents are considered. This table also gives the increments of accident rate and frequency used in the assignment of intersections to the matrix.

Figure 5 shows the specific intersections assigned to cell (10, 10) of the matrix. The information provided by the computer program includes the following:

1. Intersection identification number;
2. Accident frequency (accidents per year);
3. Intersection traffic volume;
4. Date of intersection traffic volume (month and year), where month = 13 represents an estimated volume;
5. Accident rate (accidents per million vehicles per year);
6. Accident severity data—(a) number of accidents involving one or more fatalities (F), (b) number of accidents involving one or more personal injuries (PI), (c) number of accidents involving property damage only (PD), and (d) severity costs, based on National Safety Council figures [F = $82 000/fatal accident, PI = $3400/injury accident, and PD = $480/damage accident (all 1974 figures)];
7. Signal code—(a) 1 = traffic signal, (b) 2 = stop or yield, and (c) 3 = flasher signal; and
8. Intersection name.

The data provided in this output can also be used to rank intersections on the basis of accident-severity indexes.

The assignment results for the 1974 intersection accident data are shown in Figures 6 and 7. There were fewer intersections assigned to the matrix cell (10, 10). Because the same frequency and rate increments were used in 1973 and 1974, this indicates a general decrease in traffic accidents. This decrease can be attributed to reduced travel and the benefits resulting from safety-improvement projects.

Rate and frequency analysis was also performed on all roadway links in the Oakland County highway system. The figures showing the link-rating analysis are similar to those for the intersection analysis with the exception of the following differences in the link cell-assignment summaries:

1. Accidents are tabulated as total accidents per year per mile, which normalizes the effect of link length on the accident frequency, thus allowing comparisons between links, and
2. Link length rather than signal code is given.

Figures 8 and 9 show the link accident assignments and the list of links assigned to cell (10, 10) for the 1973 link accident data. Sixteen links were categorized in cell (10, 10). The corresponding assignments for the 1974 data are shown in Figures 10 and 11.

Similar rate and frequency analyses were also performed for various categories of accident types and roadway and environmental conditions. These analyses indicated the locations that are more critical with regard to specific problems that could be remedied by lighting, skid-resistant paving, and similar improvements.

STUDY OBSERVATIONS

The development of this rate and frequency analysis program showed that three important items influence its effectiveness. These are discussed below.

1. The accuracy of the volume data—the calculation of accident-rate statistics requires the input of traffic-volume data. The traffic-volume data available were often incomplete or obsolete. In many cases, the link or intersection traffic volumes were estimated or had been obtained from volume counts made several years earlier than the accident data. In other cases, no traffic-volume data had been recorded. The success of this form of analysis is highly dependent on the input of current measured traffic volumes.
2. Overlapping accident records—there was some overlap of accidents between the intersection and link rating analyses. The data file used allows an intersection to be examined within any defined radius from its center. The link data, however, are recorded from the centers of intersections; thus, a link may contain part of a major intersection. The use of merged accident files and a criterion [e.g., radius = 61 m (200 ft)] to separate intersection accidents from link accidents can solve this problem.
3. Selecting rate and frequency increments—the selection of the rate and frequency increments is important because they define the criterion assigning the intersections or links to the cells in the matrix. Changes in these increments can cause significant changes in the distribution of intersections and links to the matrix. Each agency using the rate and frequency matrix program may need to specify its own criteria for these increments. The selection of the rate and frequency increments should be such that the locations are scattered throughout the matrix. This allows identification of the differences among locations that vary in accident experience. Unequal increments of rates and frequencies may also be used to obtain a spread in location assignments to the rate and frequency matrix. These criteria for rate and frequency increments are treated as user-specified inputs to the computer model.

SUMMARY AND CONCLUSIONS

Rate-and-frequency analysis has been developed as a tool to assist traffic engineers in identifying critical accident locations in individual states and local communities. The computer program was developed as part of the Oakland County Comprehensive Traffic Engineering Project and can analyze accident inventory data and produce reports that define the allocation of accident locations in a community into the matrix. This analysis tool has been successfully tested with stratified accident data from Oakland County, Michigan.

This methodology has several important characteristics. The rate and frequency increments are based on user specifications, so as to meet the needs of individual communities. The associated computer program produces reports for various stratifications of accident data and user-specified criteria. The computer program does not make the decisions relative to priority ranking, but allows the community to make those decisions on the basis of its available resources. This method of analysis considers both accident frequencies and rates and is cost-effective. The computer use and data-input costs are insignificant when compared to manual methods of accident analysis such as the number and rate method.

It is essential to have accurate traffic-volume data to ensure the value and validity of this procedure. Current intersection and link volume counts are therefore a prerequisite to meaningful analysis.

ACKNOWLEDGMENTS

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Effectiveness of Selective Enforcement in Reducing Accidents in Metropolitan Toronto

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The enforcement of traffic laws is based on the belief that it induces greater driver compliance with the rules of the road, which leads to a reduction in the number of accidents. Conclusive empirical evidence substantiating this belief has, however, not previously been presented. The availability of computerized accident records for the Metropolitan Toronto Police Selective Enforcement program provided a unique opportunity to test whether increased enforcement was followed by a reduction in the number of accidents. By using accident records for 1800 locations over a period of 4 years, estimates of accident rates were obtained that accounted for a time trend and seasonal variations. The expected number of accidents so obtained was compared to the number of recorded accidents. Locations that received increased enforcement showed consistently fewer than the expected number of accidents. In the experiment, all important factors except increase in enforcement are randomized. Thus, unless there is some undetected causal factor, the reduction in accidents is statistically significant and can be attributed to the increased enforcement. If then, selective enforcement leads to a reduction in accidents, enforcement of traffic laws in general has the potential to reduce accidents. Therefore, it is important to deploy available enforcement resources to maximize their effect.

Primarily, the task of the police is to enforce the law. This being so, the effect of enforcement should be measured by the degree of compliance with the law. In more basic terms, however, the role of the traffic law and its enforcement is to induce patterns of behavior that make for safe conditions on the road. Consequently, the success or failure of the enforcement of the traffic law must be evaluated, in the final count, in terms of its effect on the occurrence of accidents.

Whether traffic-law enforcement has an effect on accident occurrence is at present largely a matter of belief. The absence of factual knowledge about effectiveness of enforcement is regrettable in view of the resources spent for this purpose. However, lack of reliable information on the effect of safety countermeasures is not confined to the field of law enforcement. Alcohol legislation, publicity campaigns, demerit point systems, vehicle inspection programs, and such are all costly countermeasures with essentially unproven effectiveness.

Why then, after decades of experience, are we still groping in the dark? Probably the most important objective impediment to the determination of the effectiveness of countermeasures is the difficulty of conducting controlled experiments. The conduct of a controlled experiment requires, in the present context, the existence of two groups of drivers that are identical in all respects (age, sex, education, experience, driving conditions, distances traveled, vehicles, and such), yet exposed to a significant difference in the variable whose effect is being investigated. Of course, occasions to structure such experiments in traffic safety are rare to nonexistent.

In 1973, Transport Canada conducted a study of the effect of enforcement (1) that was close to being a well-controlled experiment. At six of seven locations, various levels of enforcement were applied, with the remaining location serving as a control. The effect of enforcement on the number of violations was studied. During the course of this project we first learned about the selective-enforcement practice in Metropolitan Toronto. In Toronto, locations that have the dubious distinction of accumulating the largest number of accidents during a certain period of time are selected for increased enforcement. The existence of this process offered a unique opportunity to examine the effect of increased enforcement on the number of accidents in an experiment in which causal factors (which have been recognized as such) are either constant or else randomized.

SELECTIVE-ENFORCEMENT PROCEDURE AND ACCIDENT DATA BASE

Metropolitan Toronto is divided into five police districts. Each district receives periodically a list of the 20 street sections (intersections or midblock sections) on which the largest number of accidents occurred during the previous 28 d. This list will be referred to hereafter as the high-accident location (HAL) list, and the 28-d period will be described as the police reporting period (PRP).

The HAL list is posted in each district. The officers study it at the beginning of each shift and are requested to devote special enforcement attention to the street sections on the list. Thus, in every PRP, some locations in each district receive increased enforcement. Whether this increased enforcement effort is reflected in a reduction in the subsequent number of accidents is the central question in this report. An attempt will be made to answer the question on the basis of extensive statistical information.

For each reported accident in Metropolitan Toronto, a motor vehicle collision report is filled out. Much of the information on the form is subsequently coded, verified, and stored on magnetic tape. For this study, a copy of the magnetic tapes containing information on all accidents in the period January 1, 1970, to January 2, 1974, was obtained from the Records Bureau of the Metropolitan Toronto Police. From this extensive file, a smaller file with approximately 1800 street sections was generated. By using this reduced file, street sections within districts were ranked by number of accidents recorded in each PRP. The 20 street sections with the largest number of accidents in a PRP (ranks 1 to 20) replicated the actual HAL lists fairly accurately.

RESEARCH PROCEDURE

The object of this project was to determine whether increased enforcement results in accident reduction. In the context of the prevailing practice of selective enforcement in Toronto and the available information on accident occurrence, this object can be stated more precisely as follows: to determine whether, subsequent to the appearance of a street section on the HAL list, the number of accidents on that section is reduced.

Care had to be exercised in the selection of the research procedure to avoid some obvious and some less obvious pitfalls. It is well-known that the number of accidents occurring during a certain time period is subject to random fluctuations. Thus, even in the absence of any enforcement, some locations that are on the list one month will disappear from it during the next month and be replaced by others. The mere disappearance of a street section from the list is no indication of the success of enforcement.

A more insidious statistical trap may be encountered if one wishes to infer something about the effect of enforcement from the change in the number of accidents. It is true that, on the average, the number of accidents decreases after a location appears on the list. It is also true, however, that this phenomenon would be observed even without any change in the level of enforcement. To explain this paradox, consider the accident history of a certain intersection during six consecutive PRPs, as shown in the table below.

PRP	Recorded No. of Accidents	Rank in District
1	2	217
2	7	2
3	3	50
4	6	4
5	6	7
6	0	510

The right-hand column of this table gives the rank of the intersection in the district. Thus, during the first PRP, 216 street sections registered more accidents, and during the second PRP, only 1 street section experienced more accidents, and so on. The tendency for high rank to be associated with a higher than average number of accidents is clearly noticeable. (The average is 4.1 accidents/PRP; the numbers of accidents associated with high rank are 7, 6, and 6.) Consequently, the fact that following the appearance of a street section on the list, the number of accidents decreases may be merely due to the fact that when on the list, the number of accidents was unusually high.

To avoid these pitfalls, the study was structured into two phases. In the first phase, the expected number of accidents, obtained from time trends fitted to each street section and seasonal factors calculated for the entire metropolitan area, was estimated for each of 52 PRPs (4 years) for 1800 street sections. In the second phase, street sections that appeared on a list were identified. For those, the recorded accident experience subsequent to their appearance on the list was compared to the expected number of accidents calculated in the first phase. It is this juxtaposition of recorded versus expected that is used to draw conclusions about the effectiveness of increased enforcement.

The following two sections describe in some detail the two phases of this study.

ESTIMATION OF EXPECTED-ACCIDENT RATE

Table 1 lists the numbers of accidents occurring at the intersection of Eglinton Avenue and Don Mills Road during consecutive 28-d periods between January 1970 and January 1974. It is easy to see that the number of accidents varies widely from period to period. However, as the actual circumstances at the location (such as traffic flow, climate, and driver population) tend to change only gradually, one may hypothesize that the recorded number of accidents is merely a random fluctuation around a relatively stable average accident rate. The task here is to obtain estimates of the accident rate by using the concept that it varies continuously in time and also depends on the climatic season of the year.

After considerable experimentation it was found that the following parsimonious model adequately fits the accident data:

$$\bar{r}_{ij} = [A_j + B_j(i - 26.5)]\, X_{ik} \quad (1)$$

where

- $\bar{r}_{ij}$ = estimate of the (unknown) expected number of accidents (r_{ij}) for PRP i (i = 1, 2, . . . , 52) and location j (j = 1, 2, . . . , 1800);
- A_j = estimated seasonally uncorrected expected number of accidents at i = 26.5 for location j;
- B_j = change in the accident rate during one PRP at location j; and
- X_{ik} = multiplicative factor accounting for seasonal variations such as climate and traffic among PRPs, which is different for intersections (k = 1) and midblock locations (k = 2).

The determination of the accident rate estimates ($\bar{r}_{ij}$) involves then the estimation of 1800 values of A_j, 1800 values for B_j, and 2 × 52 = 104 values for X_{ik}.

The estimates of the values for the seasonal factors x_{ik} are shown in Figure 1. During the winter months the accident rate may increase 50 percent or more above its seasonally uncorrected level, whereas during the summer it hovers about 30 percent below its seasonally unadjusted rate.

To illustrate the use of Equation 1, estimates of the

Figure 1. Seasonal factors for intersection and midblock locations.

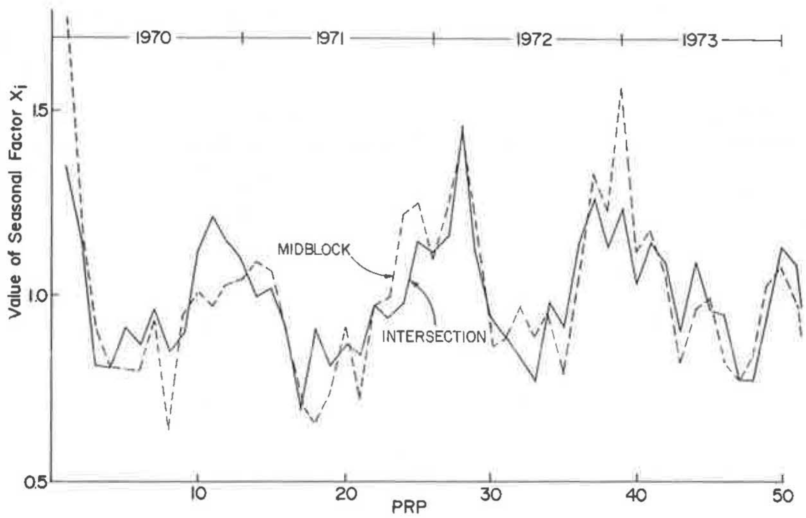
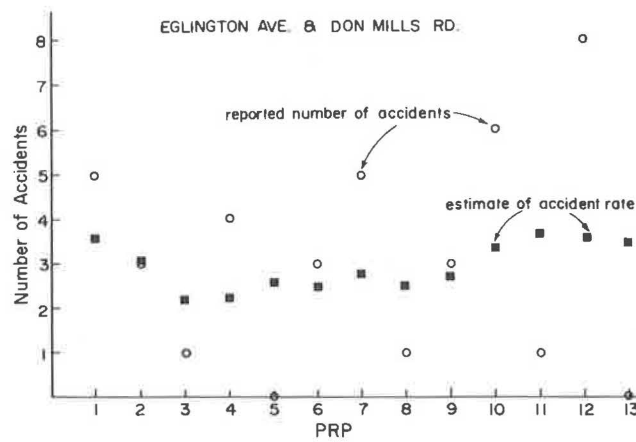


Table 1. Accidents at Eglington Avenue and Don Mills Road.

PRP	No. of Accidents	PRP	No. of Accidents	PRP	No. of Accidents
1	5	19	2	36	8
2	3	20	1	37	4
3	1	21	4	38	9
4	4	22	2	39	6
5	0	23	5	40	5
6	3	24	0	41	5
7	5	25	5	42	5
8	1	26	3	43	3
9	3	27	3	44	6
10	6	28	5	45	1
11	1	29	8	46	6
12	8	30	4	47	2
13	0	31	1	48	2
14	2	32	2	49	3
15	3	33	6	50	5
16	4	34	4	51	6
17	1	35	6	52	9
18	3				

Figure 2. Reported number of accidents versus estimated number of accidents.



expected number of accidents for the first 13 PRPs at the intersection of Eglinton Avenue and Don Mills Road were calculated by using A_j = 3.73 accidents, B_j = 0.0435 accidents/PRP, and the appropriate seasonal factors from Figure 1. These are shown together with the reported number of accidents in Figure 2.

It must be remembered that the squares in Figure 2 are estimates of the expected number of accidents, whereas the circles are random realizations. Thus, a closer correspondence between the two should not be expected. To illustrate, the expected value of a throw of a fair die is 3.5, whereas the random realizations vary from 1 to 6. Thus, a corresponding plot of 13 throws of a fair die would have squares at 3.5 and circles with equal likelihood at 1, 2, . . . , 6.

ACCIDENT REDUCTION SUBSEQUENT TO HIGH RANK

Estimates of the expected number of accidents obtained in this way proved to be sufficiently accurate (2) to proceed to the next phase. In the second phase, we examine whether, in the PRP following the appearance of a street section on the HAL list, the number of accidents on that section is on the average smaller than the expected number of accidents.

In each of the five districts, some street sections were high on the list for each of the 52 PRPs. For all but the last 5 of the 260 (5 × 52) instances, the recorded number of accidents in subsequent periods can be compared to the expected number as shown below.

Instance	No. of Accidents Recorded	No. of Accidents Expected
1	5	4.21
2	3	3.77
3	11	5.43
.	.	.
.	.	.
.	.	.
255	4	4.82
Total	992	997.00

In the first PRP after a street section is first on the list, there is a minute reduction (997 - 992 = 5) in the number of accidents. Similar comparisons for the second and third PRP after the street section is first on the list show reductions of 41.9 and 53.8 accidents respectively. Remembering that these reductions are relatively small and possibly a matter of chance fluctuations, it is well to specify what phenomena might be indicative of the effectiveness of selective enforcement in reducing accidents. First, one would expect that if a street section is on the list, then during subsequent PRPs, there should be fewer accidents occurring than would ordinarily be expected. Second, this effect should disappear in time if not reinforced. Third, if a street section was not on the list, there should be no observable reduction in the number of accidents.

Consider now Figure 3. The first point represents the 5.0 accidents saved during the first PRP after the street section attained rank 1 (first on the list). The second point is the sum of 5.0 and 41.9 and represents the accident savings during the two PRPs after attainment of rank 1. The third point is the sum of 5.0 + 41.9 + 53.8, and the subsequent points are calculated in the same way. It is fairly evident that the cumulative reduction in the number of accidents is consistent with the expectations. Namely, subsequent to a street section achieving high rank, fewer than the expected number of accidents occur on it. The effect lasts for a fairly

Figure 3. Cumulative reduction in number of accidents: rank 1.

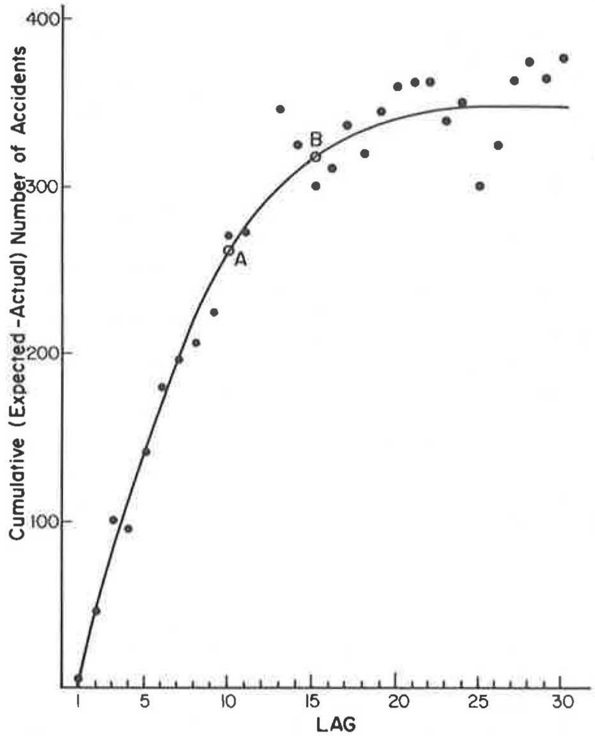


Figure 4. Cumulative reduction in number of accidents: ranks 1 to 10.

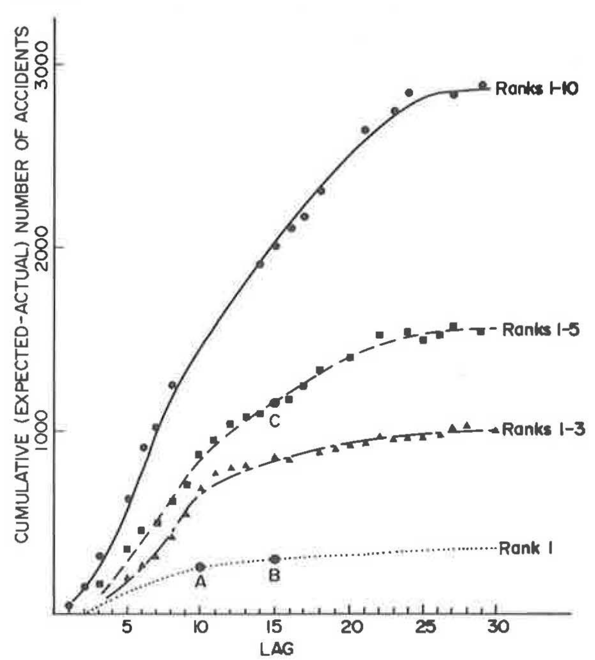


Figure 5. Cumulative reduction in number of accidents: ranks 101 to 105.

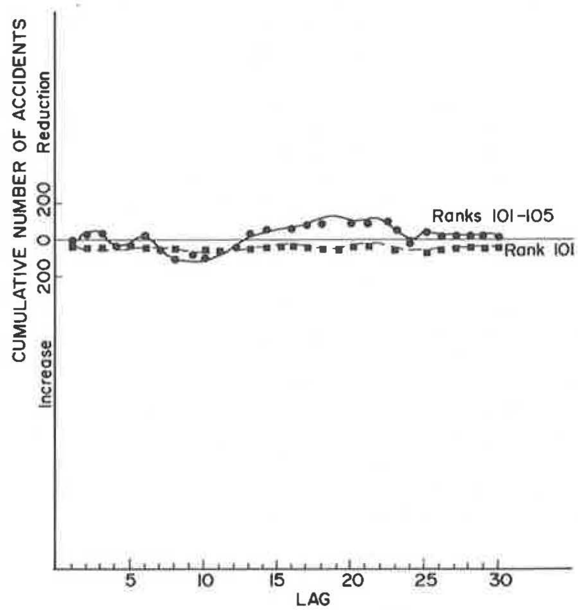
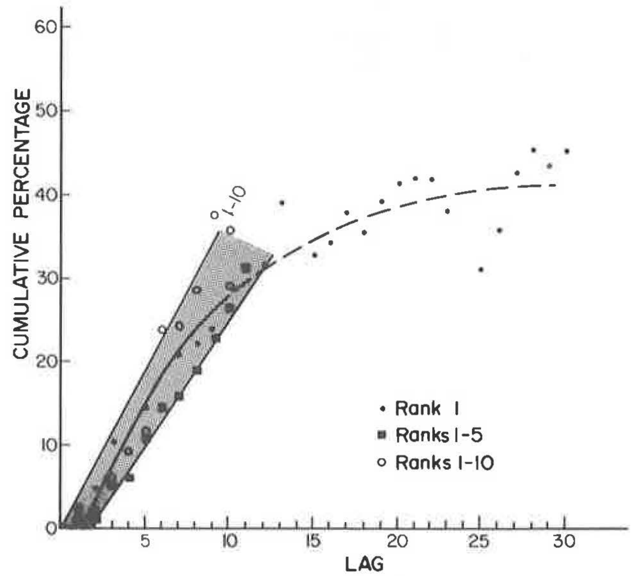


Table 2. Probability of type 1 error.

Rank	Lags	α	Rank	Lags	α
1	2	0.098	1 to 4	2, 3	0.100
1	2, 3	0.018	1 to 5	2, 3	0.041
1	2 to 4	0.055	1 to 6	2, 3	0.022
1	2 to 5	0.014	1 to 7	2, 3	0.017
1	2, 3	0.018	1 to 8	2, 3	0.027
1 to 2	2, 3	0.190	1 to 9	2, 3	0.011
1 to 3	2, 3	0.082	1 to 10	2, 3	0.010

Figure 6. Cumulative percentage reduction in number of accidents.



long period and gradually fades. The same phenomenon is shown in Figure 4, which also shows the cumulative reductions in accidents of the first 3, the first 5, and the first 10 locations on the list.

Figure 5 shows the change in number of accidents for street sections that were not on the list. As expected, no significant change is illustrated, which confirms that it is only high rank on the list that is followed by accident reduction.

In summary, the analysis confirms the anticipated effects. It remains to demonstrate that the observed phenomenon is unlikely to arise from mere chance fluctuations. To do so, the probability of the type 1 error (α) is listed in Table 2 for various combinations of rank and the period following its attainment. Thus, the probability of concluding that during the second PRP after the street section was first on the list, there are fewer accidents than expected, while actually there would be no change on the average, is 0.098. Table 2 shows that no matter what combination of rank and lag is considered, the chance of erroneously concluding that a reduction in accidents exists is small.

Finally, it is appropriate to show the accident reduction in relative rather than absolute numbers. The slope of the curve in Figure 6 is the rate at which the number of accidents is reduced. From the available data, scientifically supportable estimates of the percentage reduction in accidents cannot be obtained because of the reinforcement effect discussed below. However, the rate for a few PRPs after occurrence of high rank is reliable and is approximately 3 percent.

CONCLUSIONS AND DISCUSSION

Evaluation of the effectiveness of safety-oriented programs is difficult because of the practical obstacles to structuring scientifically defensible experiments. The practice of selective enforcement in Metropolitan Toronto offered a unique opportunity to examine the effectiveness of enforcement under conditions of relatively sound experimental design.

It was possible to show that, after a road section appears on the HAL list, a statistically significant reduction in the number of accidents occurs.

Two observations are in order: The first raises the question of whether this reduction in accidents can be attributed to selective enforcement. The second deals with the duration and magnitude of this effect.

Two phenomena occur after a road section appears on the list. Initially, the road section is exposed to increased enforcement. Subsequently, the number of accidents occurring is on the average less than would normally be expected. May we infer from these two phenomena that they are causally related? The answer is—yes, provided that no other causal factors have been overlooked. Unfortunately, the existence of possible external causal factors can never be rejected. It is possible, for example, that when enforcement is increased, some drivers will choose different routes for their travel. Nevertheless, those external causal factors we could think of represent somewhat speculative linkages. Our inclination is therefore to attribute the reduction in accidents to increased enforcement—the factor which motivated this examination in the first place.

The existence of an accident reduction that is attributed to increased enforcement is distinct from the question of the magnitude and duration of the effect. Figure 6 indicates a reduction of about 3 percent, but this number should be regarded with caution for the following reason. A location appearing on the list at some point in time may have been on the list several PRPs earlier and is likely to appear again. Thus, any accident reduction must be attributed to the entire history of increased enforcement rather than to a one-time occurrence. This reinforcement effect is particularly important when the reduction in number of accidents several PRPs after high rank is considered. Thus, the duration and magnitude of the effect of selective enforcement on accidents cannot be specified with any certainty. Because the reinforcement effect will probably be negligible for the first few PRPs after occurrence of high rank, some confidence can be placed in the magnitude of accident reduction in this range. The duration of the effect of selective enforcement is, however, less than might be inferred from the figures.

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Effects of the 88.5-km/h (55-mph) Speed Limit and Its Enforcement on Traffic Speeds and Accidents

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There have been many studies of the effect of the 88.5-km/h (55-mph) speed limit on vehicle speeds and accidents. Although several of these studies mention the need for enforcement to make the speed limit more effective, most do not present any enforcement data. This paper focuses on data from North Carolina, Mississippi, and Louisiana to show the probable role of enforcement. Time-series plots of speed, volume, and accident data for North Carolina are given for the period of 1973 and 1974. Time-series graphs of enforcement data for North Carolina, Mississippi, and Louisiana and Louisiana speed, volume, and accident data have been developed from the published quarterly and annual reports of the state police and highway agencies. The initial decrease in speeds caused by the energy crisis in the three states has been eroded in the past 2 years; except for Interstate highways, speeds have returned to precrisis levels. Of particular importance, however, are that speeds are now more uniform (standard deviations are lower and pace-group percentages have increased) and that very few vehicles are exceeding 105 km/h (65 mph). There are strong indications that the increased enforcement levels of 1974 to 1976 are responsible for maintaining the more uniform and safer speed levels. Louisiana data for 1974 and 1975, as compared with data for 1971 and 1972, show not only significantly fewer fatalities on the rural highways, but also large reductions in the percentages of all rural accidents and of rural fatal accidents for which excessive speed was cited as a contributing factor. A more detailed study of enforcement versus accident rate is said to be warranted.

The advent of the energy crisis in the fall of 1973 convinced U.S. motorists that driving at 88.5 km/h (55 mph) was a good idea. Even before the national 88.5-km/h (55-mph) speed-limit law was passed by Congress and adopted by the states, the average speeds on rural highways started to decrease.

Since that time, many public and private agencies on both national and state levels have made continuing studies to determine the effects of this traffic regulation. Late in 1974, Congress made the 88.5-km/h (55-mph) law permanent and required state-enforcement certification as a continuing prerequisite for the approval of federal-aid highway projects. In September 1975, the Federal Highway Administration (FHWA) issued new guidelines, and by mid-1976 all states were complying. The annual certification package requires quarterly speed surveys and a report of the total number of speeding citations issued.

The current Institute of Transportation Engineers (ITE) policy on the 88.5-km/h (55-mph) speed limit (27, p. 9), adopted August 18, 1975, in Baltimore states,

> It is the policy of the Institute of Transportation Engineers to recommend continuing investigation into the total effects of the 55-mph national speed limit. In the meantime, with the 55-mph speed limit in effect, the institute supports the concept that this limit should be uniformly and equitably enforced in all jurisdictions.

The object of the ITE committee dealing with this matter (27, p. 28) is defined,

> To determine the ramifications of the 55-mph speed limit through the assimilation of available data for review, analysis, and development of a platform of facts on which an institute position may be based.

The charge of the committee, then, was to provide a solid factual background and specific advice with which the ITE board of directors could develop and adopt an official ITE position on the 88.5-km/h (55-mph) speed limit.

LITERATURE REVIEW

Since the beginning of the energy crisis in 1973, there have been many studies of its effects [or of the effects of the 88.5-km/h (55-mph) speed limit] on traffic speeds, volumes, and accidents. Although several of these suggest the need for enforcement to make this speed limit more effective, most do not enumerate any enforcement data. This literature search is not an exhaustive one, but many of the most pertinent reports on the subject have been studied and are briefly reviewed here.

In addition to ITE, several other organizations such as the American Association of State Highway and Transportation Officials (AASHTO), the National Safety Council (NSC), and the Highway Users Federation (HUF) have studied the effects of the energy crisis and of the 88.5-km/h (55-mph) speed limit. The U.S. Department of Transportation through its monitoring programs has also analyzed the situation.

The initial AASHTO study (2) issued after the crisis had peaked, contained these findings and recommendations (somewhat abridged):

1. Speeds have been reduced 8 to 10 mph on rural freeways, 5 to 7 mph on rural conventional roads, and 5 to 7 mph on urban freeways.
2. In both rural and urban areas, speeds are now more uniform. In other words, more people are now driving closer to the average speed than they were before.
3. Even with these reductions in speed, there are still typically 65 percent of the drivers exceeding the 55-mph speed limit on rural freeways and 48 percent on urban freeways. Obviously, many drivers feel it is safe to drive faster than 55 mph.
4. However, there are about 50 percent fewer drivers exceeding 60 or 65 mph than there were in 1973.
5. Future observance of the 55-mph speed limit will be determined by driver attitude, level of enforcement, and fuel availability.
6. Fuel consumption has been reduced by the lower speeds. The fuel savings amount to approximately 3 billion gal annually.
7. In the first 6 months of 1974, approximately 6000 lives were saved. Approximately half of this reduction is the result of the reduced speeds and the more uniform speeds. The remainder of the saving in lives can be attributed primarily to reduced travel and improved driving habits.
8. It is the principal recommendation of this study that at such time that petroleum conservation is no longer a national problem, and when further federal legislation is being considered regarding the setting of maximum speed limits, the authority and responsibility for maximum speed limits be returned to the states with the strong recommendation that maximum speed limits remain at 55 mph. Exceptions should be considered only when engineering and traffic studies have shown that an increase in the speed limit would not result in speed characteristics appreciably different from those recorded during this study and when strong and compelling reasons for the increase in the speed limits exist.

AASHTO later released two follow-up studies. The first (3) showed trends in 1974 and the first 6 months of 1975. There was a steady increase in speeds after the first half of 1974 and also an increase in speed violations of 38 percent in the second half of 1974 and 25 percent in the first half of 1975, as compared to the first 6 months of 1974. The second update (4) gave statistical analyses of the trend lines for 1967 to 1973. The significant reductions in 1974 and 1975 deaths and injuries to below the trend line are credited to the 88.5-km/h (55-mph) speed limit. The downward trend line from 1967 to 1973 is attributed to safety improvements in vehicles, driver education, and roadways. AASHTO also noted that there has been a steady increase in average speeds since 1974, but that these speeds are still below 1973 levels and that the percentages of vehicles exceeding 97 and 105 km/h (60 and 65 mph) have not increased. The recommendations from this report include the following:

2. AASHTO should go on record as being strongly in favor of retention of the 55-mph speed limit.
3. Maximum efforts should be made by the states to enforce the 55-mph speed limit, and realistic speed monitoring be continued in all states.
4. Every effort should be made to inform and convince the public of the safety benefits of the 55-mph speed limit, with the emphasis on safety rather than on conservation.
5. AASHTO should continue supporting roadway, vehicle, and driver safety programs because these programs contribute a significant cumulative benefit in reducing traffic deaths and injuries.

Rankin (21) has compared speed, travel, accident, and fuel-use characteristics for 1973 and 1974 from data collected across the country. Early 1974 speed checks showed average speed decreases of up to 14.5 km/h (9 mph) on routes previously posted at 113 km/h (70 mph) or greater. However, soon after March 1974, the averages began to increase. The variation in speeds, as shown by the pace group, was also less during the energy crisis—a larger percentage of traffic was traveling in the same pace group, which provides a safer driving environment. Rankin also noted an increase in speeding enforcement in most states that "... must be recognized as a factor in changes in speed characteristics since January 1974." He reported on the decrease in travel and accidents in early 1974 and estimated a 7.5 percent saving in the average daily use of highway fuel in the first half of 1974. In a 1975 paper (22), Rankin added this observation:

In summary, the 55-mph limit has been an effective fuel-conservation measure, and it has contributed to the improvement in traffic safety that began in November 1973. Furthermore, it has focused increased amounts of public and news-media attention on our national traffic-safety problems. But in doing this, it has tended to develop a school of thought that the limit is a magic bullet to solve all traffic safety problems. The 55-mph limit is not a self-enforcing regulation. It apparently will require a large body of federal regulations that will impose additional costs of no small magnitude on state and local highway agencies. As a national regulation encompassed in a number of rules and requirements, it can inhibit the potential for the development of future speed-limit policies that promote fuel-use efficiency and traffic-safety operations, and yet most drivers accept it as reasonable.

The National Safety Council has issued two evaluations of the decrease in traffic deaths in 1974. The first (17) compared the data for the first 4 months of 1974 with those for the corresponding period in 1973. Of the total 24 percent decrease in fatalities, 11 was attributed to speed reduction, 5 was attributed to reduced travel, and the remainder was attributed to such factors as reduced automobile occupancy, less night driving, and greater use of safety belts. The second study (18) compared data for May to August 1973 with those for May to August 1974. It was concluded that most (10 percent) of the total 17 percent reduction in fatalities was attributable to the reduced travel speeds on the highway and that the remainder of the decrease was due to such factors as reduced travel, reduced average vehicle occupancy, and increased use of seat belts. This study also discusses other factors including traffic law enforcement: "Law enforcement in general, and enforcement of the 55-mph speed limit in particular, is important in helping to prevent accidents and deaths, but its contribution to the fatality reduction is difficult to isolate."

Another study on a national level was that of Schechter and Pfeffer (23), which was conducted by the Mitre Corporation for the National Science Foundation. This was a policy-assessment type of study, which is a multidimensional form of benefit-cost analysis applied to a given policy decision, and states that "... the design of future policies should reflect the lessons derived from an assessment of current policy." This study also reviews the historical development of the 88.5-km/h (55-mph) speed limit, presents the results of several other studies, and concludes,

A major cause of the gradual increase in the numbers of those violating the 55-mph speed limit is that there was no extensive ongoing national campaign to conserve motor fuel. Future policy decisions of this order must put strong emphasis on ways to induce citizens to cooperate, in addition to ways that depend on use of police powers.

Two older studies by federal highway analysts are relevant to this paper. In his classic 1964 report, Solomon (25) developed accident-involvement rates by dividing the number of accident-involved drivers by the related vehicle distances of travel. Cirillo (10) added to Solomon's work in 1968 and found that although the average speeds are about 11.3 km/h (7 mph) higher on Interstate highways than on two-lane roads, this system can better accommodate differences in vehicle speeds with much lower accident rates, except at the lowest speeds. This report also showed the results of an attempt to investigate the effect of the level of law enforcement on mean speed and accident involvement. No trend could easily be established between increases in warnings, arrests, or police patrols and the mean speed of travel or the accident-involvement rate on a study section. However, Cirillo mentioned difficulty in finding the exact kind of data needed and that further investigation would be undertaken in the future.

More recent federal studies have included an August 1975 National Highway Traffic Safety Administration (NHTSA) technical report (16), which concluded,

1. The greatest reduction in fatalities occurred on high-speed roads, the least occurred on roads unaffected by the new speed limit, and the relative reduction was twice as great on roads affected by the speed limit and
2. No accurate estimate can be made on the overall safety impact of the 55-mph speed limit, but there should be high confidence that a large portion of the reduction in fatalities is due to the direct or indirect benefits of the new 55-mph speed limit.

A related FHWA report by Page and others (20) states,

Highway fuel consumed in 1975 was 11.4 percent less than would have been expected based on 1962 to 1972 growth rates. Of this, it is estimated that 8.1 percent resulted from reduced travel. Estimates of the reduction due to the introduction of a higher proportion of more fuel-efficient vehicles in the total fleet since 1973 ranged from 0.6 to 2.8 percent depending on the method of calculation. The corresponding range for savings due to speed reduction was 0.8 to 2.9 percent.

Another 1974 U.S. Department of Transportation (U.S. DOT) study, that by Bishop and others (6), is the only one that mentions citations before and after the energy crisis. The numbers of citations issued during the months of July, August, and September in 1973 and in 1974 were obtained from 42 states that responded to the U.S. DOT survey and are compared below.

Year	Number of Citations	Increase (%)
1973	1 053 285	—
1974	1 765 840	67

These are apparently only citations issued for exceeding the 88.5-km/h (55-mph) speed limit (not other speed limits), although it is not clear from the report that this is the case. Citations were lower in only one state in 1974. The percentage increases in the other states varied between 1 and 361.

Burritt and others (8) have analyzed the relationships between accidents in 1974 and 1973 and the 88.5-km/h (55-mph) speed limit and concluded that "... the accident reduction experience on those sections of the Arizona State Highway System that were affected by the 88.5-km/h (55-mph) maximum speed limit almost solely accounted for the entire statewide reduction in fatal accidents." The total reduction for all the highways included was 48 percent. Regarding speed enforcement, they stated that "The total number of speeding citations in 1974 increased about 13 percent over 1973. It was not possible to isolate those speeding citations that were issued on the study area. However, it is reasonable to assume that the increase in citations occurred as a result of enforcing the 55-mph speed limit."

Estep and Smith (13) have reported on California's evaluation of the 88.5-km/h (55-mph) speed limit and its effects. After reviewing some national data, mostly from AASHTO (2), they found that the California data showed similar results, e.g.,

1. By December 1974, average speeds were still down by some 4.5 to 6.5 mph over 1972 levels,
2. Travel was down 2 percent, and
3. Fatalities were down by 18 percent overall, but on freeways where greatest speed changes occurred, reductions were about double that figure.

However, they reported modification of some trends late in 1974:

Since reductions in speeds have been mainly on state highways (most speed zones over 55 mph were previously located on state highways), it can be concluded that the effects of lower speeds have continued. On the other hand, the side effects of the energy crisis, such as improved driver attitudes, appear to have eroded since fatalities on local roads, where speeds changed little, have returned to 1973 levels.

They went on to criticize the need for certification of speed monitoring and enforcement:

Preliminary discussions with U.S. Department of Transportation seem to indicate that substantial state efforts will be required. It has been estimated that the cost of state speed surveys in California will be increased from $10 000 a year to as much as $200 000.

The position taken by California is that these requirements are unduly restrictive. California wholeheartedly supports the national 55-mph speed limit, but believes that a state's certification of compliance should be sufficient to guarantee the existence of necessary laws and their enforcement without the necessity for each state to make detailed certifications of compliance with federal regulations. The intrusion of the federal government into state law enforcement seems unnecessary, redundant, and inappropriate in these circumstances.

Their principal conclusion is,

There is no doubt that fatalities have decreased substantially since the 55-mph maximum speed limit was imposed and that a large part of the reduction is due to the slower and more uniform speeds. California data show that speeds have stabilized. There has been no significant change in average or 85th percentile speeds since August 1974. Fatality rates on California state highways have not increased in 1975 and have remained at the lower 1974 levels. The very substantial decreases in fatalities of 30 to 40 percent on the previously high-speed roads are too large to attribute in any major way to anything but the 55-mph speed limit.

Another California study by Chu and Nunn (9) isolated factors contributing to the decline in fatalities in early 1974. This study considered data for the first 6 months of 1974 and compared them with the previous 10-years experience. Least-square lines were used to establish trends for both the fatality rate (Y) and the vehicle miles of travel (VMT):

$$Y = 4.92 - 0.13X \tag{1}$$

$$VMT = 41.74 \times 2.23X \tag{2}$$

where X = year. (SI units are not given for the variables in this model because its operation requires that it be in U.S. customary units.) This permitted them to estimate that the expected number of fatalities for the first half of 1974 under normal conditions is 2303. The actual number was 1726, a saving of 577 lives (a 25 percent reduction). This decrease was attributed to reduced travel, the permanent daylight saving time, the reduction in driving speed, and other factors.

After showing through regression analysis that fatality levels are related to distances driven, they estimated that the reduction in fatalities due to reduced travel is equal to the 7.3 percent drop in VMT. The effect of daylight saving time was limited to the months of January, February, and March and was deduced from the changes in fatalities between the hours of 6 to 9 a.m. and 4 to 7 p.m. These data dramatically showed the effect that daylight saving was predicted to have, i.e., a sharply higher fatality rate during the morning rush hour and a sharply lower rate in the afternoon hour. It was estimated that a total of 47 lives were saved by this change (a 2 percent reduction).

To derive the effect of the reduced speeds, Chu and Nunn first deduced the effects of other factors by using the values determined by the National Safety Council and discussed above. Allowing for changes in automobile occupancy, travel patterns and routes, and increased seat-belt use, the net saving of lives was estimated to be 6 percent. Thus, 222 lives (a 10 percent reduction in fatalities) were saved by the reduced travel speeds, which is equivalent to 39 percent of the total fatality reduction.

An extensive study in Michigan reported by O'Day and others (19) compared 1974 and 1973 data for the January to May period. They found a 29 percent reduction in fatal accidents that could not be accounted for by the 7 percent reduction in driver exposure. Much was attributed to reduced crash severity because of reduced speeds on all categories of roads [-16 km/h (-10 mph) on Interstates, -8 km/h (-5 mph) on other U.S. and state trunklines, and -5 km/h (-3 mph) on county and local roads]. They observed a continuation of these reduced speeds and fatalities in the last half of 1974 that "... despite a return to normal traffic volumes and patterns, shows that the 88.5-km (55-mph) speed limit is effective in reducing fatalities when enforced." They noted that the 1974 enforcement was greatest on the Interstate highways, where a lower fatality reduction (-20 percent) was combined with the greatest speed reduction. The largest fatality reduction (-41 percent) occurred on non-Interstate-quality highways, where a relatively small decrease in average speeds [-8 km/h (-5 mph)] occurred. This led to two other conclusions:

1. Possibly there would still be a net gain in lives saved if speeds were allowed to rise slightly on Interstate highways, and available police resources were allocated to strict enforcement of the 88.5-km/h (55-mph) speed limit on non-Interstate-quality highways.

2. Speed limits even lower than 88.5 km/h (55 mph) on non-Interstate-quality highways, if strictly enforced, would result in even lower fatalities.

Figure 1. North Carolina automobile-speed trends: 1973 and 1974.

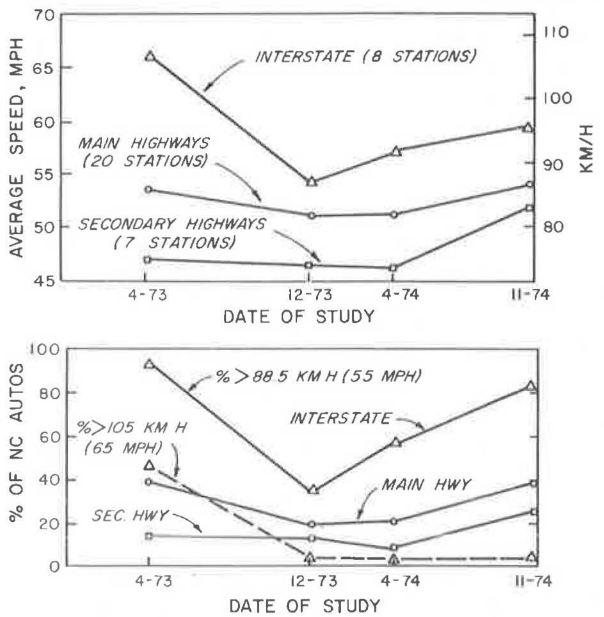


Figure 2. Quarterly North Carolina gasoline use and fatal accidents: 1973 and 1974.

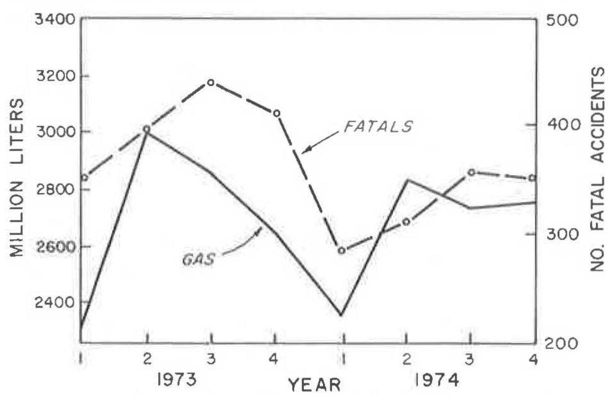
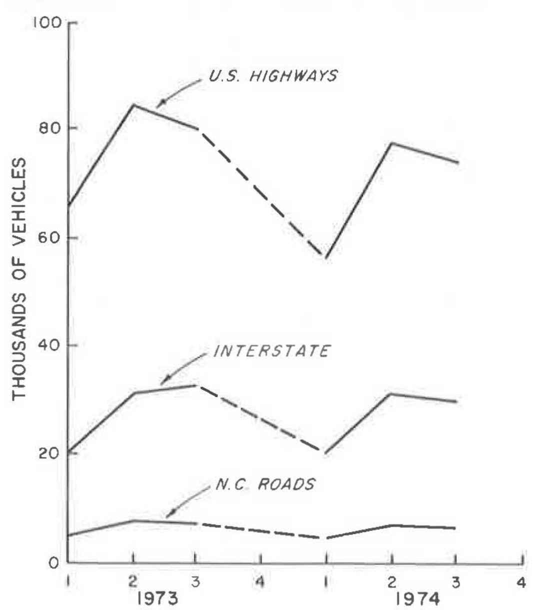


Figure 3. Average North Carolina traffic counts: 1973 and 1974.



Several other state-level studies have shown reductions of fatalities of similar magnitudes. These include those of Borg (7) of Indiana, Heckard and others (14) of Pennsylvania, and Agent (1) of Kentucky. Agent has stated that "Whereas traffic volume and other contributing factors may account for some of the decrease in accident rates since the beginning of the energy crisis, the lower travel speeds certainly stand out as the single most important reason why accident, fatality, and injury rates have decreased." Seila and Reinfurt (24) of North Carolina found a 21 percent fatality reduction, of which they attributed 5 (and possibly 10 to 15) to the 55-mph limit. In a related, but separate study by the Highway Safety Research Center of North Carolina, Council and others (11) found,

1. Following imposition of the lower limit on certain roadways, all sampled roadways experienced initial decreases in various measures of central tendency of speeds (e.g., means). These initial decreases were fully recovered by November 1974, except on Interstate highways.
2. When proportional changes in accidents are compared to proportional changes in counts and to predicted changes based on past research, accidents appear to have decreased significantly more than would be expected on all roadways except rural secondary roads, indicating the presence of causes other than volume decreases.

EVALUATIONS

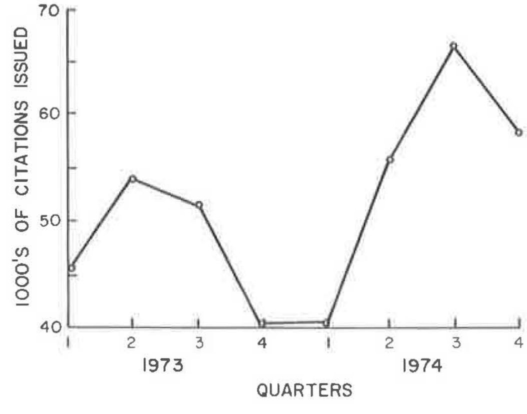
North Carolina

The 1973 and 1974 vehicle speed, traffic count, and fatal-accident patterns developed by Council and others (11) are summarized in Figures 1, 2, and 3. As discussed above, speeds decreased at the height of the energy crisis and then recovered substantially by November 1974. [The speeds of commercial vehicles generally are 1.6 to 5 km/h (1 to 3 mph) less than those of automobiles.] However, although the percentage of speeders increased in late 1974, the percentage of vehicles exceeding a speed of 105 km/h (65 mph) on Interstate highways was virtually zero.

Figure 2 shows the quarterly gasoline consumption (15) for North Carolina in 1973 and 1974. Figure 4 shows the overall state-police enforcement activity in 1973 and 1974. It should be noted that very similar patterns exist for gasoline use, fatal accidents, traffic counts, and total speeding citations. The increase in fatalities throughout 1974 is similar to the recovery in speed on all highways.

Beginning late in the second quarter of 1974, the North Carolina Highway Patrol greatly increased their speed-enforcement activity. At the peak of this crackdown, citations for speeding increased by 31 percent

Figure 4. North Carolina speeding citations: 1973 and 1974.



over the previous year. Although this activity did not prevent overall speed increases in the latter part of 1974, it could be responsible for preventing most drivers from exceeding speeds of 105 km/h (65 mph) and for causing less variance in traffic speeds. These conditions provide a safer highway and contribute to the lower fatality level maintained throughout 1974.

The North Carolina data have also been monitored in 1975 and 1976. All speed characteristics were reduced somewhat in 1975, with the average speeds on all classes of roads down about 3.2 km/h (2 mph). However, 1976 reports show increases in average speeds of up to 5 km/h (3 mph) over 1975 levels. The percentage of North Carolina automobiles exceeding the speed limit now exceeds 90 percent on rural Interstate routes, and the percentage of North Carolina automobiles exceeding 105 km/h (65 mph) has increased to 9.5 percent (21 percent of the tractor trailers observed). In 1975, speeding citations increased 20 percent over 1974; for the first 6 months of 1976, speeding enforcement increased another 12 percent over 1975, but in the summer of 1976, it decreased by 21 percent over 1975, which may have led to increases in speed.

Figure 5. Mississippi average speeds: 1973 to 1976.

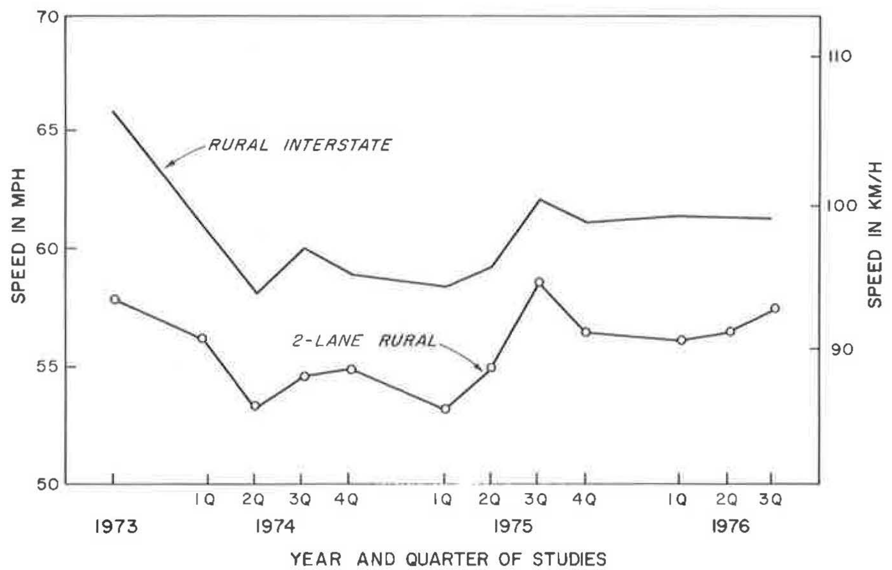
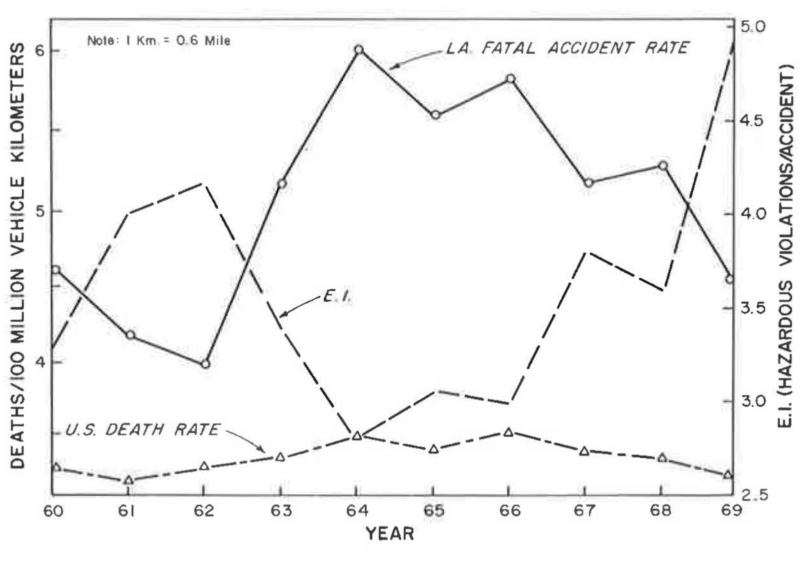


Table 1. Speed characteristics on Mississippi rural Interstate highways: 1973 to 1976.

Speed Characteristic	1973	1974	1975	1976
Avg, km/h	105.4	95.8	98.6	98.5
85th percentile, km/h	112.6	104.6	106.4	105.4
Percentage of vehicles having speeds >88.5 km/h	87.7	66.3	83.0	83.0
Percentage of vehicles having speeds >104.6 km/h	44.5	10.3	19.0	18.0
Standard deviation, km/h	12.6	10.9	8.9	8.5
Speed of pace group, km/h	100.6 to 116.7	84.5 to 100.6	88.5 to 104.6	88.5 to 104.6
Percentage of vehicles in pace group	45.4	57.1	65.0	65.0

Note: 1 km/h = 0.62 mph.

Figure 6. Louisiana death rate versus enforcement index: 1960 to 1969.



Mississippi

The Mississippi Highway Department had been conducting statewide speed studies before the energy crisis so that it was possible to study trends for the past 4 years in that state. Figure 5 shows the quarterly average speed trends for 1974 to 1976 and compares them with the 1973 speeds.

As in most other states, after the initial decrease of speeds in early 1974, speeds increased somewhat, but not to the precrisis levels. Characteristics of interest of speeds measured on rural Interstate highways are shown in Table 1. Traffic fatalities and speed enforcement as reported by the Mississippi Highway Patrol are shown below.

Year	Fatalities	Speeding Citations
1972	922	95 177
1973	883	134 751
1974	643	186 720
1975	612	212 416
1976	677	177 250

Enforcement more than doubled in the postcrisis years as compared to the last precrisis year (1972); however, some slippage occurred in 1976 and, at the same time, fatalities increased. The death rate in Mississippi decreased from 4.3/km (7.0/mile) in 1972 to 2.7/km (4.3/mile) in 1975, and travel increased 8 percent in that period. Surely, the reduced speeds and the increased enforcement have been effective in this state.

Louisiana

Figure 6 shows the apparent interaction of enforcement and the fatal-accident rate in Louisiana during the 1960s. Through the middle of this period, Louisiana was in the unenviable position of leading the nation with its traffic-

Figure 7. Louisiana death rate versus enforcement index: 1971 to 1976.

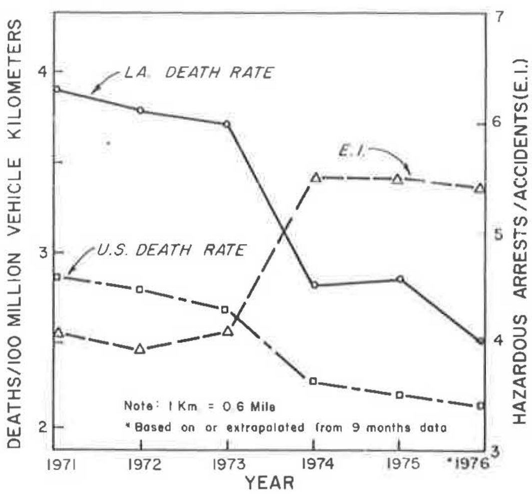


Figure 8. Louisiana enforcement: 1972 to 1976.

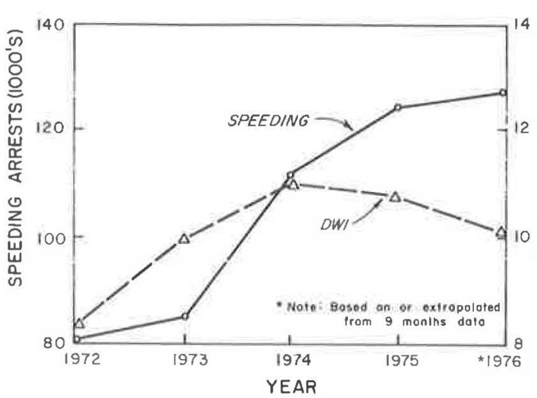


Figure 9. Louisiana rural speed studies: 1974 to 1976.

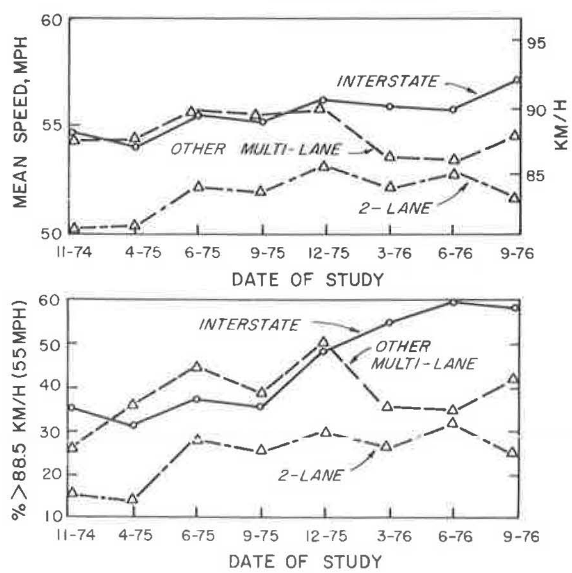
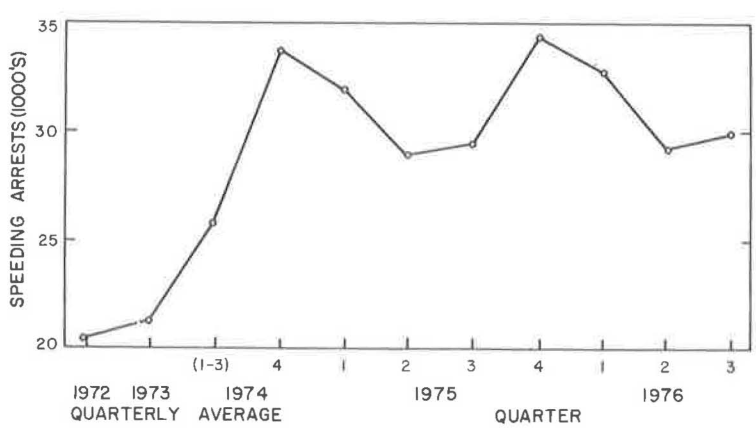


Figure 10. Quarterly Louisiana speed arrests: 1972 to 1976.



death rate approaching 6/100 million vehicle km (10/100 million vehicle miles) driven. Although no regression analysis has been made to incorporate other factors that might contribute to accidents, a very strong relationship appears in Figure 6. The increase in enforcement in 1969 was due to a planned crackdown under a new department head.

In 1970, accident records were in transition as a new uniform reporting form was being introduced. Since 1971, the Louisiana State Police has issued monthly urban and rural breakdowns of accident data, and accident rates are based on the combined total. However, in a separate troop-activity report, accident totals that are only those that occur within the troop jurisdiction are reported. Enforcement indexes consider this total, rather than statewide totals. Trends for the past 5 years are shown in Figures 7 and 8.

Once again, the increased enforcement brought about by the energy crisis and the 88.5-km/h (55-mph) speed limit appears to have had a marked effect. However, without more involved analysis it would be difficult to assess the part played by speeding-restriction enforcement. Figure 8 shows an increased driving-while-intoxicated enforcement. The exact effects of other factors, such as reduced travel and safer vehices, are not known. However, an inspection of motor-fuel consumption trends for Louisiana and typical traffic-volume trends at stations where quarterly speed studies have been conducted showed that reduced travel may have been less of a factor than in many other areas of the country. The total fuel used in 1974 was only about 2 percent less than that used in 1973 and volumes at the monitoring stations did not decrease, in fact some were slightly higher. Fuel consumption in the third quarter of 1976 is increased 13 percent over the same period in 1973.

Neither the Louisiana State Police nor the Louisiana Department of Highways had an established speed-measuring program before the energy crisis. The director of the department of highways issued an order on January 18, 1974, and informed the district attorneys of this action on January 22, 1974. All 88.5-km/h (55-mph) speed-limit signs were in place by March 1974. Late in August 1974, the Louisiana State Police Superintendent requested a small study by the state police in the Baton Rouge region. This study, conducted mostly on Interstate or other four-lane divided highways, showed that 45 to 70 percent of all vehicles were exceeding the 88.5-km/h (55-mph) speed limit with over 30 percent exceeding 97 km/h (60 mph) and up to 10 percent at two sites exceeding 113 km/h (70 mph). A crackdown began shortly thereafter and, as shown in Figure 8, speed enforcement has continued at a high level through 1975 and 1976.

Late in 1974, the Louisiana Department of Highways began regular speed studies at 12 locations around the state in response to directives of the Federal Highway Administration. Speed measurements began 3 months after the state police survey and were made in each quarter of 1975. In 1976, the study was extended to cover 28 locations. Figure 9 summarizes the characteristics derived from these studies, and Figure 10 summarizes the speed-enforcement levels by quarters for comparison with the speed data.

Speeds at rural stations on the Interstate and other divided multilane highways have increased slightly or remained relatively constant through the 2-year study period with an overall mean speed slightly above 88.5 km/h (55 mph) for both groups. The percentage of vehicles exceeding 88.5 km/h (55 mph) has varied considerably, but generally has increased from 30 to 60 percent on Interstate highways, which is still lower than that observed in August 1974. For these same stations, the percentage of vehicles exceeding 97 km/h (60 mph) has been 15 percent or less, and no more than 4 percent have exceeded 105 km/h (65 mph). On the other hand, two-lane highways have experienced a 3.2-km/h (2-mph) increase in mean speed [84 km/h (52 mph)], and the percentage of vehicles exceeding 88.5 km/h (55 mph) has nearly doubled (to 25 percent).

Speed-enforcement levels have reached peaks (in the 4th quarters of both 1974 and 1975) that exceed the pre-energy-crisis (1972 to 1973) efforts by 62 percent. State police officials have indicated that initially much of the increased effort was on the Interstate and other divided highways. This has probably helped to stabilize speed patterns on multilane divided highways, but meanwhile some slippage has occurred on the more dangerous two-lane highways. (Sixty-six percent of all rural accidents in 1973, 1974, and 1975 occurred on two-lane roads: This included 77, 80, and 81 percent of the 1973, 1974, and 1975 rural fatal accidents respectively.) More selective enforcement to combat this trend has now been instituted.

ITE ENFORCEMENT SURVEY

An ITE committee has surveyed state police officials regarding the 88.5-km/h (55-mph) speed limit and obtained data representing a good cross section of the entire country. In general, it was found that no more person power had been assigned to speed enforcement and that the chances of speeders being apprehended were only fair. Most agencies use moving radar as their principal enforcement tool and most unofficially allow tolerances of 10 to 16 km/h (6 to 10 mph). However, most officials emphasize that the individual police officer should use his discretion, but should arrest for any clear-cut violation.

State police managements generally (about 80 percent) favor the 88.5-km/h (55-mph) law and believe that it is enforceable, but only about 60 percent of them feel that most of their officers favor the law. Generally, most think that their data show that the 88.5-km/h (55-mph) speed limit saves lives. Their concern is that the public does not totally accept the need for or the benefit of 88.5-km/h (55-mph) speeds, which makes their job more difficult. However, a Georgia public-opinion survey showed that three-fourths of the 900 people asked favor the 88.5-km/h (55-mph) speed limit because it saves lives. Apparently their public relations effort was getting results, which is what most officials said was most needed.

A footnote to this study is the report of the Louisiana representatives at the December 7 to 9, 1976, meeting in Nashville, sponsored by the National Highway Traffic Safety Administration and International Association of Chiefs of Police. This meeting, at which 17 jurisdictions in the southeastern United States were represented, concluded that the 88.5-km/h (55-mph) speed limit is unenforceable. Police representatives claim that enforcement on the Interstate has diverted traffic to two-lane parallel roads and that this has caused fatalities to increase in 1976. (National Safety Council data for the first 9 months show a 2 percent increase in fatalities.) Incidents of police being harassed were also reported. Public relations representatives say that they cannot cajole the public on this matter any more.

The police in some states are also contending with new state laws that render convictions for violations of the 88.5-km/h (55-mph) speed limit trivial; e.g., only nominal fines, such as $5 or 10, and no points assessed for speeds up to the previous speed limit, i.e., 113 km/h (70 mph). A 1975 appeals court decision in Louisiana voided a lower court conviction under the state's relatively new multiple-offender law. The violator had had seven speeding tickets in 3 years: All but one had been issued on Interstate highways for driving about 113 km/h (70 mph) in clear weather, no accidents were involved, and the fines had been paid without a court appearance. The court held that this was not a serious disregard of traffic laws.

The police are concerned that the federal government will require more enforcement on the Interstates and divert them from more needed enforcement elsewhere. They believe that some agency other than the police should be used to convince the public to abide by the 88.5-km/h (55-mph) law to conserve energy. The consensus of the group meeting at Nashville was that the speed limit should be increased on the Interstate highways to 97 or 105 km/h (60 to 65 mph) [or possibly 100 km/h (62 mph), which is a nice round number].

DISCUSSION OF FINDINGS

The national 88.5-km/h (55-mph) speed limit was introduced as an energy-conservation measure in late 1973. With the initial decrease in overall highway speeds and travel, modest fuel savings of 5 to 10 percent were obtained. Since the latter part of 1974, these gains have been reduced, and fuel savings today are probably no more than 2 or 3 percent.

However, a generally unanticipated (although not unexplainable) windfall of this energy-conservation policy has been the saving of lives on the highways. In late 1975, 1.5 years past the peak of the crisis, almost all states were still experiencing fewer traffic deaths than in 1973, even though the vehicle kilometers of travel exceeded both 1974 and 1973 levels. In view of this result, federal authorities reaffirmed the 88.5-km/h (55-mph) speed limit as a national policy.

There appears to be adequate evidence to support the role that enforcement plays in maintaining speeds at a safer level. During the height of the energy crisis, people were very conscious of the shortage of gasoline and responded to the perceived real need to conserve it. Once the need to conserve eroded in people's minds, increased enforcement has served to retain much of what had been gained. Unfortunately much of this effort appears to have been concentrated on the safest highways, the Interstate system. The suggestions of O'Day and others (19) make sense. More effort concentrated on the two-lane undivided highways would probably have a greater effect. On the other hand, there may be some spillover in driving habits from the heavily enforced Interstate sections to the relatively unenforced two-lane roads.

However, recent research (12) has shown that speed enforcement has little carry-over effect beyond the point of enforcement activity. The overall speed characteristics on the highway studied agreed with those of other two-lane roads as reported by Council and others (11): On these roads, the 85th percentile speed was generally a little less than 97 km/h (60 mph) away from enforcement influences. This study (12) also showed that unless speed monitoring stations are careful to avoid the appearance of enforcement activity, the speeds observed will be 10 to 13 km/h (6 to 8 mph) below normal levels.

This observation has been confirmed in the past year in driving Interstate and multilane highways in Louisiana. Generally, a vehicle driving I-10 and I-12 out of Baton Rouge at very close to 97 km/h (60 mph), will be passed by almost twice as many vehicles as it passes in an 80-km (50-mile) stretch. This indicates an average speed at least 5 km/h (3 mph) higher than that indicated by state monitoring reports. Some spot speed studies at monitoring stations from a concealed position essentially determined that this was the case, although one study on I-10 produced a mean only 0.8 km/h (0.5 mph) higher than reported in the state quarterly study.

The presence of increasing numbers of citizen's band (CB) radio-equipped vehicles on the highways raises the question of whether or not enforcement of the 88.5-km/h (55-mph) speed limit is being impaired. Limited observations on rural Interstate highways in Louisiana show that about 15 to 20 percent of all vehicles are so equipped, but Louisiana state police officials do not feel that their enforcement effort is being undermined. The Baton Rouge area troop commander told a reporter (5) in June 1976, that "They are slowing people down, and that's what we want to do—not just write tickets. And, despite the 'smoke' warnings on CB radio, troopers in the eight-parish area are still writing 3000 tickets/month." One trooper indicated that the ratio between trucks and automobiles getting speeding tickets is about the same as before and just as many vehicles with CB radios get tickets as do those without them. With so much talk on CB radios today, it is possible for a driver with one to miss a smoke warning.

One of the most discontented with the 88.5-km/h (55-mph) speed limit is the independent trucker with a CB radio. Some are most vocal and abusive to police, but they do not represent the total trucking industry. Both the Louisiana Motor Transport Association and the American Trucking Associations are firmly in support of the 88.5-km/h (55-mph) speed limit. Initially both opposed the law, but in learning to live with it, they found that they were able to reschedule runs satisfactorily and still save money in fuel, maintenance, and insurance costs.

The other problem in enforcement work is the proportion of traffic activity devoted to speed enforcement. Witheford (26) reported in 1970 on a survey of state and city police agencies regarding speed enforcement policies and practices. He noted that about 25 percent of all traffic activity was speed enforcement and, that in many jurisdictions, at least 50 percent of all hazardous citations were for speeding. (Louisiana data for 1972 to 1975 showed 65 to 70 percent of hazardous moving violations to be for the speeding.) Witheford also noted that while there was no unanimity in what the proportion of activity should be, 45 percent of state agencies suggested that it should be increased and none suggested that it be decreased. However, as he points out, there may be merit in reevaluating priorities and possibly redirecting efforts toward other causes of accidents.

In 1974 and 1975, excessive speed was cited on Louisiana State Police accident reports in only 3.8 percent of all rural accidents and 12.5 percent of all rural fatal accidents; in 1971 and 1972, it was cited in 8.0 and 16.85 percent respectively. Obviously the 88.5-km/h (55-mph) speed limit and its enforcement has had an appreciable effect.

CONCLUSIONS

As a result of this study, the following may be concluded:

1. The 88.5-km/h (55-mph) speed limit has definitely altered the average speed and the speed variation on all classes of highways. Average speeds were reduced in early 1974 by as much as 16 km/h (10 mph), but gradual increases have occurred ever since. The percentage of vehicles exceeding 105 km/h (65 mph) is less than 10, and speed variability is significantly less, leading to lower fatality rates.
2. Travel decreased in early 1974, but by late 1974

and ever since, it has been growing at almost precrisis rates.

3. Fuel savings as a result of the 88.5-km/h (55-mph) speed limit are very modest (probably no more than 1 to 3 percent).

4. The saving of 9000 to 9500 lives in 1974, 1975, and 1976 is in large measure due to factors brought about by the energy crisis. In early 1974, the changes in travel habits and the reduced vehicle speeds contributed equally to this reduction. Since then, speed reductions have been the dominant factor with one estimate indicating that 60 percent of the death-rate reduction is due to the 88.5-km/h (55-mph) speed limit.

5. Speed enforcement increased in late 1974 and has been maintained at a high level in most jurisdictions. However, police agencies believe that because a majority of the public does not now favor the law, it is becoming increasingly less enforceable, particularly on Interstate highways.

RECOMMENDATIONS

Basic Policy

The national 88.5-km/h (55-mph) speed limit was passed on the basis of energy conservation needs and was reaffirmed in late 1975 on the bases of a modest fuel savings and a substantial reduction in highway fatalities. The policy question to be resolved is this: Should it be retained more on a safety basis than as an energy conservation tool, should it be retained on equal bases of safety and energy conservation, or should it be repealed?

How can we repeal this law in good conscience? The facts are overwhelming; The reduced speeds have probably been responsible for saving almost 15 000 lives in the past 3 years. The purpose of ITE states that its members should "... contribute toward meeting human needs for mobility and safety..." Are we losing that much mobility for the sake of safety in retaining a blanket 88.5-km/h (55-mph) law? I do not think so!

Public Relations

Police officials are being harassed for enforcing an unpopular law. Yet in Georgia, where there has been a thorough public relations job, three-fourths of 900 people surveyed support the 88.5-km/h (55-mph) speed limit. The police should not be the sole enforcers of an energy policy, but they have an equal concern with transportation engineers in promoting safety on our highways. NHTSA should assist the states in developing a public relations campaign to sell the 88.5-km/h (55-mph) limit on a safety basis as well as on an energy conservation matter. Give the public the real facts and tell them why the limit works. There have been a number of recent papers suggesting that the limit is a safety myth, but a hard look at the data with meaningful analyses will show that substantial benefits exist.

Evaluation of Enforcement's Role

A more detailed study of the interaction of speed enforcement and accidents is warranted. Rather than working from various gross data tabulations, a more integrated study is recommended:

1. Regular speed monitoring on a scientific sampling basis in which conditions of measurement, such as time and weather, are comparable should be conducted throughout the state on all classes of highways.

2. If possible, spot speed stations should be at or near permanent traffic-counting stations and both sets of data should be classified as to type of vehicle. Speed measuring devices should be concealed to provide the most accurate speed data possible.

3. Accident data should be studied along the same routes as speeds and counts are obtained.

4. Speed enforcement records should be collected and should include a careful note of the location, the road type, and the direction, time, weather, and pertinent vehicle and driver descriptions. Data as to prosecution and adjudication of these citations should also be obtained.

5. Regression analyses should be conducted to determine the real contribution of speed enforcement to the control of speed and the reduction of accidents.

Possible National Experiment

To detect the elasticity in the safety benefits, some states might be allowed to raise speed limits to 100 km/h (60 mph) on Interstate and other fully controlled-access facilities. This would be permitted only after each designated state could certify to record keeping that would permit NHTSA and FHWA to monitor the effects on fuel consumption and accidents.

1. Such monitoring should also include two other elements: correlation with enforcement activity and both speed and enforcement monitoring on two-lane roads to identify spillover effects.

2. After one or two years of monitoring, the data should be evaluated and a decision made as to further experiments. If no detrimental effect on highway safety has occurred and no energy crisis has been proclaimed, speeds on the Interstates might be increased to 105 km/h (65 mph) and another period of evaluation follow.

3. If another energy crisis occurs and a stringent conservation policy is launched, these trial speed limits should be one measure. Furthermore, the degree of cutback should be commensurate with the intensity of the crisis; i.e., speeds below 88.5 km/h (55 mph) may be essential and desirable.

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Relationship of the Color of the Highway Centerline Stripe to the Accident Rate in Arizona

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The problem considered in this study was that of the effect of changing the color of the centerline stripe from white to yellow on the accident rate on undivided, two-lane, two-way highways in Arizona. Only sections of roadway that had remained essentially unchanged (except for the color of the centerline stripe) for a period of 1 year before and 1 year after the color change were studied. Accident data on 74 sections of roadway, totaling 4587 km (2867 miles), were analyzed and statistically tested for differences between the accident rate with white centerlines and the accident rate with yellow centerlines under various road surface and light conditions. Of the eight accident-rate categories tested, the following four showed a significant increase: (a) the dawn or dusk accident rate, (b) the dawn or dusk accident rate during periods of wet pavement or poor visibility, (c) the nighttime accident rate during periods of wet pavement or poor visibility, and (d) the overall accident rate during periods of wet pavement or poor visibility. The following other four categories tested showed no significant change: (a) the nighttime accident rate, (b) the daytime accident rate, (c) the daytime accident rate during periods of wet pavement or poor visibility, and (d) the overall accident rate under all conditions combined. These data indicate that the currently used yellow centerline stripes are inferior to the previously employed white centerline stripes.

The most recent edition of the Manual on Uniform Traffic Control Devices, published in 1971, requires that all centerline markings on two-lane, two-way highways be yellow rather than the white previously in use. The expressed intent of this requirement is to further a new concept whereby the color difference between the markings of two-way and divided highways enables the motorist to be immediately aware of the danger of opposing traffic on seeing a yellow line. The lane markings remain white to eliminate any possible confusion.

The new centerline standard has an easily perceived safety objective. There can be no argument with its purpose; however, the questions to be asked are (a) has the desired result been achieved and (b) have any adverse conditions been created?

Some officials of the Arizona Highway Department have voiced an unsubstantiated belief that yellow striping may not be as visible as white striping, particularly in bad weather and at night. The purpose of this study is to provide a statistical basis for accepting or rejecting this belief. If it is true, the striping color change should have led to a higher accident rate.

The problem considered, then, is that of the relationship between the change of the color of the centerline stripe from white to yellow and the accident rate on undivided, two-lane, two-way highways in Arizona. Implied within this statement are the following subfactors that should be considered in evaluating the overall problem:

1. Did the dawn or dusk accident rate change significantly?
2. Did the nighttime accident rate change significantly?
3. Did the daytime accident rate change significantly?
4. Did the rate of accidents attributed to wet pavement or to poor visibility caused by bad weather conditions change significantly?
5. Did the overall accident rate change significantly?

HYPOTHESES EVALUATED

The following null hypotheses, based on the above subfactors, were tested:

1. The dawn or dusk accident rate before the color of the centerline stripe was changed is less than or equal to the dawn or dusk accident rate after the color was changed.
2. The nighttime accident rate before the color of the centerline stripe was changed is less than or equal to the nighttime accident rate after the color was changed.
3. The daytime accident rate before the color of the centerline stripe was changed is less than or equal to the daytime accident rate after the color was changed.
4. The rate of accidents attributed to wet pavement or to poor visibility caused by weather before the color of the centerline stripe was changed is less than or equal to the rate of accidents attributed to wet pavement or to poor visibility caused by weather after the color was changed.
5. The overall accident rate before the color of the centerline stripe was changed is less than or equal to the overall accident rate after the color was changed.

SCOPE AND LIMITATIONS

This study covers only undivided, two-lane, two-way highways of the Arizona State Highway System. The study was confined to the 12 months before and the 12 months after the striping change was accomplished. To eliminate the possible effects of the 1973 fuel shortage and the lowering of the maximum speed limit to 88.5 km (55 mph) in 1974, statistics on accidents and traffic volumes observed after September 30, 1973, were not considered. The reduction in vehicular travel due to the fuel shortage was first noticeable in October 1973 (1). An adequate sample size was provided by the use of the 24-month period of accident data.

Any portions of a highway undergoing changes in configuration other than changing the color of the centerline stripe—such as widening the shoulders, changing the roadway width, or adding lanes—during the time of the study were not included.

The validity of the findings in this study are limited by the accuracy of the data supplied by the various state agencies. Errors in accident data can result from the fact that the investigating police officer often must use judgment in filling out the accident report.

Many statistics and other information of interest to the traffic engineer are based on the unsubstantiated statements of accident victims or the value judgments and recollections of the investigating officer. Nevertheless, the shortcomings associated with accident reports should not discredit them as a useful research tool. The errors in the reports can be expected to be consistent from year to year, thus permitting reasonably accurate comparisons between years.

REVIEW OF RELATED RESEARCH AND LITERATURE

Many articles and studies concerning accidents and accident rates as related to traffic volumes, elements of the roadway cross section, lane lines, roadside obstructions, and roadway surface were reviewed. The findings and comments from a few of these are given below. (The Arizona Department of Transportation computer input to the Transportation Research Information Service failed to find any literature relating accidents to the centerline stripe.)

However, Stieg (2) has made the following comment on the visibility of white versus yellow centerlines:

> The yellow traffic line has an unfortunate tendency to disappear just when it is needed most.
>
> The specified yellow color is generally believed to be highly visible, a belief that appears to have been substantiated by Air Force research which placed this color high on its list of those that provide easy recognition in the air for flying aircraft, and high visibility on the ground for downed fliers. These findings, however, are related to chromatic contrast against blue sky and green grass or other vegetation, in bright sunlight. These are definitely not the conditions that prevail on our highways during the dusk-to-dawn period of highest fatal accident density....
>
> The increased use of yellow markings on our highways has not taken into consideration the very real deficiencies of standard highway yellow as a visible warning device.
>
> The normal human eye does not perceive the color as quickly as it does white because of its low reflectance, which derives from (a) low refractive index .... Furthermore, the normal dark-adapted human eye sees even less under critical twilight conditions.
>
> The abnormal human eye, due either to congenital defects, or to those imparted by disease or by the use of alcohol, tobacco or drugs, may not perceive yellow as a color at all.

The causes of accidents are many and varied. Johnson (3), reporting on the findings of a research team, stated, "Among the 68 subjects studied, 289 contributing factors were identified—an average of 4.3 factors/case." (A factor was defined as any circumstance connected with a traffic accident without which the accident could not have occurred.)

The vehicle driver is undoubtedly the most important single component of the driving process and also the most difficult to understand and control [Conger (4)]. Numerous studies have attempted to isolate the human traits that are apparent in individuals involved in accidents. Although certain psychological traits, such as aggressiveness, intolerance, and resentment of authority are apparent in chronic traffic violators and accident repeaters, one study concluded that it would be difficult if not impossible to use human characteristics as reliable predictors of accident involvement [Goldstein (5)].

The roadway has been shown to have little direct causal relationship to automobile accidents. Michaels (6) reported, "in only 5 percent of accidents do observable characteristics of the highway play a significant causal role." Although the direct causal relationship may be low, the roadway undoubtedly influences the accident rate because the highway can require mental and physical responses beyond the abilities of the driver. The best evidence of such influences is the low-accident rates on modern, well-designed, fully access-controlled highways as compared with the accident rates on older, less expensive roadways [Burch (7)].

The traditional method of measuring exposure to highway traffic accidents is vehicle distances driven. Stewart (8) wrote that the vehicle distance rate of exposure involves three assumptions: (a) all driving involves some exposure to accident hazards, (b) the exposure to accident hazards is proportional to the distance driven, and (c) the degree of exposure is the same for all drivers. Since vehicle distances are the unit of exposure used in this study, Stewart's assumptions are also used.

RESEARCH DESIGN

To obtain statistically accurate data for use in answering the questions, the research design was subdivided into five major areas: establishment of the time frame of the study, delineation of the study area, analysis of the accident data, derivation of the traffic volumes, and determination of the statistical methods to be used.

Establishing the Time Frame

The dates when the centerline colors were changed by the Arizona Highway Department on all state and U.S. routes were obtained from the Weekly Striping Reports of the Arizona Highway Department (9). While most routes were changed in the first 4 months of 1972, the entire system was not completely changed until August 1, 1972.

The time frames for the before-and-after accident data were that the before period would be all of 1971 and the after period would be from September 1, 1972, through August 31, 1973. The selection of these time periods permitted all roads to have yellow centerlines for at least 1 month before the accident data analysis for the after period. Terminating the after period on August 31, 1973, eliminated any effects that the program of edge-lining two-lane roads might have had on the accident rate because this program was not begun until November 1973. This also eliminated any effects of the 1973 fuel shortage or the 1974 speed-limit reduction.

The study, then, covers 32 months: 12 months with white centerlines, 7 months changeover, 1 month to allow drivers to become accustomed to the yellow centerlines, and 12 months with yellow centerlines.

Delineating the Study Area

All roadway sections were eliminated from the study area that (a) had more than two lanes, (b) were divided, (c) were less than 8 km (5 miles) long, (d) went through major urban areas, or (e) had any configuration change other than that of the color of the centerline stripe.

Sections of roadway less than 8 km (5 miles) in length were eliminated because it was believed that there would be insufficient exposure and therefore a relatively small number of accidents. The section would then be insensitive to changes in the accident rate.

Urban sections of roadway were eliminated from the study area because (a) the responsibility for pavement striping varied from area to area, (b) the striping patterns often changed daily, and (c) the presence of many other variables would make it difficult to isolate the effect of the color of the centerline stripe.

The determination of the configuration changes that took place during the time frame of the study was accomplished with the assistance of the Arizona Department of Transportation and by examination of its Complete Project Numbering Reference. A letter was then sent to each of the seven Arizona Department of Transportation District Engineers to verify that the remaining sections of roadway had remained unchanged throughout the 32-month time period under investigation. Three additional sections of roadway were eliminated from the study area as a result of the responses received.

To preserve a meaningful sample size, no attempt was made to eliminate the numerous sections of roadway affected by the frequent alterations of passing zones.

After all of the criteria were applied to the two-lane, two-way routes in the Arizona State Highway System, 74 sections of roadway totaling 4587 km (2867 miles) remained to be studied. These sections represent approximately 74 percent of the total length of two-lane, two-way routes available in Arizona.

Each of the 74 sections was arbitrarily given a study-section number for ease in referencing.

Analyzing the Accident Data

Although an accident may have many contributing causal factors, traffic engineers generally agree that three classes of accidents—(a) head-on collisions, (b) sideswiping collisions, and (c) vehicles running off the roadway—can be reduced by the installation of pavement centerlines. Other factors can and do contribute to these accident types, but the pavement centerline is considered as a major contributory factor in only these three types of accidents (10). Thus, these types of accidents are considered as related accidents for the purpose of this study, and they were the only types used.

Accident data for the study area were obtained from the Arizona Department of Transportation for the before-and-after time periods. Over 5200 accident summaries were examined, categorized, and tabulated by study-section number, accident type, roadway-surface condition, and light condition at the time of the accident.

Accidents that involved hitting an animal or some mechanical failure of the vehicle were categorized separately. Accidents that occurred when it was snowing, raining, blowing dust, or when the pavement was wet were tabulated into a separate category entitled wet or poor visibility.

Deriving the Traffic Volumes

Traffic volumes in terms of the average daily traffic (ADT) were calculated from the data given by the Arizona Highway Department (11).

The before time period was all of calendar year 1971, and the calculations of ADT for the 74 sections came directly from the 1971 data. However, because the ADT counts ceased to be published on a monthly basis in 1971 and the after time period included the last 4 months of 1972 and the first 8 months of 1973, an estimate was made of the ADTs for that time period.

A check of monthly volumes as a percentage of yearly totals showed that the last 4 months of 1971 accounted for 31 percent of the total yearly volume, which agrees closely with the results of Burritt and Moghrabi for 1973. It was then assumed that the monthly traffic-volume percentages had remained fairly constant for the years 1971 through 1973, and the estimated ADT for the after time period was calculated by taking 31 percent of the 1972 traffic volume for each study section and adding to this 69 percent of the 1973 traffic volume for each study section.

The following calculation of the ADT study section 1, US-60 from milepost 30.00 to milepost 70.00 is typical. The traffic count data are available from the Log of the Arizona Highway System (12) as shown below (1 km = 0.62 mile).

Road Section	Length (km)	Annual Avg 24-h Traffic 1971	1972	1973
From I-10 to Ariz-72	29.18	6406	7084	3030
From Ariz-72 to Maricopa County Line	39.82	6662	7367	4070

In general, the ADTs are calculated as follows:

$$ADT = \Sigma(\text{road-section length})\ (\text{ADT for that road section})/\Sigma(\text{road-section length}) \quad (1)$$

For the before period, ADT = [(29.18 × 6404) + (39.82 × 6662)]/(29.18 + 39.82) = 6554 vehicles/d, and for the after period, ADT = (0.31 × 1972 ADT) + (0.69 ×1973 ADT); i.e., ADT = {0.31 [(29.18 ×7084) + (39.82 ×7367)]/(29.18 + 39.82)}+ {0.69 [(29.18 ×3030) + (39.82 × 4076)]/(29.18 + 39.82)} = 4751 vehicles/d.

STATISTICAL ANALYSES OF THE ACCIDENT RATES

The hypotheses to be tested were stated in a manner requiring a determination of whether the accident rate under various conditions changed significantly. It was necessary, therefore, to calculate several categories of accident rates for each of the 74 sections of roadway with the white centerlines in use and with the yellow centerlines in use.

Because the roadway sections comprising the sample were essentially identical except for the color of the centerline stripe, the statistical analysis required involves paired observations. If the difference between the sample variances is large or if it is otherwise unreasonable to treat the population variances as being equal, one method that can be used for significance testing is the paired-sample t-test. This test does not require an assumption of equal population variances; it applies two random samples of the same size, which need not be independent. When n pairs of such observations are selected from two nonnormal populations, for large n ($n > 30$), the distribution of the mean of the differences is approximately normal, and tests of hypotheses concerning the means may be carried out by using the statistic

$$T = (\overline{D} - d_0)\ (n)^{1/2}/S_d \quad (2)$$

where

$\overline{D}$ = mean of the differences of n pairs of observations,
d_0 = value to which the difference of the two sample means is being compared,
S_d = standard deviation of the differences of n pairs of observations,
n = number of paired observations in the sample, and
$\nu = n - 1$ = number of degrees of freedom.

There were 74 paired observations. By using a level of significance of 0.05, the critical region was found to be $T > t_{\alpha,\nu} t_{0.05,73} = 1.645$.

The table below shows the actual changes in the related accident rates for the conditions tested.

Condition	Change (no. of study sections) Decrease	None	Increase
Light			
Dawn or dusk	23	21	30
Nighttime	39	5	30
Daytime	38	2	34
Wet pavement or poor visibility			
Dawn or dusk	6	53	15
Nighttime	20	28	26
Daytime	25	26	23
Overall	23	17	34
Combined	34	2	38

Table 1 gives the magnitudes of the before-and-after rates, the differences, and the significances for all 74 sections of roadway.

Of the eight accident-rate categories tested, four showed no change in the accident rate with the yellow centerline stripes in use, and four showed an increased accident rate with the yellow centerline stripes in use. The four categories showing no change were the nighttime related accident rate, the daytime related accident rate, the daytime related accident rate during periods of wet pavement or poor visibility, and the overall related accident rate under all conditions combined. The four categories showing an increase were the dawn or dusk related accident rate, the dawn or dusk related accident rate during periods of wet pavement or poor visibility, the nighttime related accident rate during periods of wet pavement or poor visibility, and the overall related accident rate during periods of wet pavement or poor visibility.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The results of the eight statistical tests performed do not provide a clear-cut answer to the relationship between the color of the centerline stripe and the accident rate in Arizona. In general, the data seem to indicate that the yellow markings have had a detrimental effect on the related accident rate. Four of the related-accident-rate tests showed no change, and four showed a significant increase in the related accident rate.

As work on this project progressed and conclusions were drawn, a number of questions were raised for which no answers were evident. Many of these questions could be solved only by additional, and often specific, studies that were beyond the scope of this project.

The following eight conclusions refer to the specifically named accident rate with yellow centerlines in use at the 5 percent level of significance:

1. The dawn or dusk accident rate increased significantly.
2. The dawn or dusk accident rate under conditions of wet pavement or poor visibility caused by bad weather increased significantly.
3. The nighttime accident rate under conditions of wet pavement or poor visibility caused by bad weather increased significantly.
4. The overall accident rate under conditions of wet pavement or poor visibility caused by bad weather increased significantly.
5. The nighttime accident rate showed no significant change.
6. The daytime accident rate showed no significant change.
7. The daytime accident rate under conditions of wet pavement or poor visibility caused by bad weather showed no significant change.
8. The overall accident rate under combined conditions of dawn or dusk, nighttime, daytime, and wet pavement or poor visibility caused by bad weather showed no significant change.

If a true evaluation of the white versus yellow centerline accident rate comparisons is to be made, it must be assumed that the proportions of the traffic volumes for each light condition to the ADT volumes remained fairly constant from year to year. Although no data are available on traffic volumes by time periods within a given day, it can be reasonably assumed that these proportions did in fact remain constant. The same assump-

Table 1. Average accident rates per hundred million vehicle miles.

Condition	Related Accident Rates			Significant at $\alpha = 0.05$
	White	Yellow	Difference	
Light				
Dawn or dusk	5.65	8.14	2.49	Yes
Nighttime	41.58	40.19	-1.39	No
Daytime	45.31	39.23	-6.08	No
Wet pavement or poor visibility				
Dawn or dusk	0.65	1.55	0.90	Yes
Nighttime	3.28	8.10	4.82	Yes
Daytime	8.13	8.00	-0.13	No
Overall	12.04	17.77	5.73	Yes
Combined	92.64	87.55	-5.09	No

Note: Discrepancies in totals are due to rounding of actual accident rates.

tion regarding the proportions of traffic volumes during periods of wet pavement or poor visibility caused by bad weather is not as easily made. Did the number of hours, or even days, when such weather conditions prevailed remain the same for the before and after time periods? Did the volumes of traffic using the roads under such conditions remain constant throughout the entire time period of the study? The data required to provide answers to these questions are not available. If the after time period contained many more days with conditions of wet pavement or poor visibility than did the before period, the increase in the dawn or dusk, nighttime, and overall accident rates (under conditions of wet pavement or poor visibility) stated previously in conclusions 2, 3, and 4 respectively cannot be attributed solely to the changed color of the centerline.

Even though this argument cannot be answered satisfactorily with the data available, the overall conclusion of this study is that the significant increases in the dawn or dusk accident rate, the dawn or dusk accident rate under conditions of wet pavement or poor visibility, the nighttime accident rate under conditions of wet pavement or poor visibility, and the overall accident rate under conditions of wet pavement or poor visibility indicate that the currently used yellow centerline stripe is inferior to the previously used white centerline stripe.

Most research to date on the relationship of accidents to traffic volume has dealt with all accidents and with total traffic. It would be much more useful to relate accident rates by time of day and hourly traffic volumes. Because accident summaries carry notations of the time of day and the day of year, they could be used directly to evaluate hourly, daily, and seasonal variations in rates. Continuous traffic-count stations are now in use, and a study could be initiated to explore the possibility of coordinating these continuous traffic counts with the time of accident so that accident rates could be calculated on an hourly basis. These data, then, would be valuable in evaluating specific situations and in determining the merit of specific improvements.

There is also a need for more comprehensive information in terms of increased weather-bureau data. If data relating the temperature and road conditions on specific sections of readway could be recorded for future use, accident rates for poor weather conditions could be made more meaningful.

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Abridgment

Dial-in Freeway-Traffic Information System

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To provide travel information to the driver before he or she leaves his or her home or office, a telephone dial-in service was developed. The service was installed as a part of the Dallas Corridor Study, a research and demonstration project concerned with instrumentation, surveillance, and control of urban freeway and arterial facilities (1). The city of Dallas provided funding for the installation and monthly charges, and the design, operating procedures, and evaluation were developed by Texas Transportation Institute under a research contract with the U.S. Department of Transportation. The system was operated for approximately 18 months before it was terminated because of lack of use by the driving public. A detailed documentation of the system is given in the project reports (1, 2).

OPERATING STRATEGIES AND PROCEDURES

The principal object of the dial-in information service was to give drivers accurate, current information to aid them in the pretrip planning phase of an intracity trip. Depending on the amount of information to be given at any one time, callers could receive locations of incidents, suggested alternate routes, current nonincident operating conditions, or a combination of these. In the absence of an incident or of changing conditions, the message was updated at least every 10 min during peak hours and every 30 min during off-peak hours.

Up to 5 (originally 10) callers could receive the message at any one time. The system was capable of handling up to 20 lines without additional equipment. Callers entering in midmessage received a repeat of the total message. After a caller had received one complete message, the mechanism disconnected that call, freeing the line for another caller.

The system imposed a maximum message length that could be adjusted from 10 to 60 s. Messages exceeding the maximum were voided, edited, and rerecorded. When messages were less than the maximum, the current message length was automatically adjusted so that there was no dead time on the recording.

Information Sources

Information that might be of use to drivers using the North Central Expressway was secured from sources that included a closed-circuit television system for incident detection and operating conditions, the police radio scanner for incident location, a real-time computer printout (1, 3) for operating conditions, real-time computer incident monitoring (4) for incidents, and reports from field units for operating conditions and incidents.

Design of Message Formats

To design message formats and to put the available information in priority order within the limited message time, a human-factors study (5) was made to determine the requirements of urban freeway motorists in the Dallas area. The study involved survey questionnaires administered to 303 motorists employed in seven firms in the central business district.

This questionnaire was designed to establish the degree of interest in the service and to develop design and operational criteria for the messages. Seventy-five percent of the respondents stated that they would use such a service. Their greatest interest was in information about the location and degree of congestion, alternate routes, the reason for congestion, and whether or not a lane was blocked. On bases of the survey results, other studies (6), and day-to-day operational experience in the control center, a set of messages for various traffic situations and other design criteria were specified.

The message formats for various operating conditions during the morning peak periods are given below. If there are no incident messages, the following conditions are reported:

1. At (time), North Central traffic inbound is {moving well [>56 km/h (35 mph)], moderately congested [48 to 56 km/h (30 to 35 mph)], congested [32 to 47 km/h (20 to 30 mph)], or heavily congested [<32 km/h (20 mph)]} between (LBJ, Loop 12, or Mockingbird) and (Loop 12, Mockingbird or downtown).
2. Traffic outbound is {moving well [>64 km/h (40 mph)], moderately congested [48 to 63 km/h (30 to 40 mph)], congested [32 to 47 km/h (20 to 30 mph)], or heavily congested [<32 km/h (<20 mph)]} between (downtown, Mockingbird, or Loop 12) and (Mockingbird, Loop 12, or LBJ).
3. No lane blockages are reported.

If there are incident messages in the peak direction, the following conditions are reported:

1. At (time), there is (an unidentified blockage, a stalled automobile, an accident, or spilled debris) on North Central inbound at (location).
2. Traffic is backed up to (location).
3. Inbound traffic is moving well south of (location).
4. An alternate route is advisable.
5. Traffic outbound is {moving well [>64 km/h (40 mph)], moderately congested [48 to 63 km/h (30 to 40 mph)], congested [32 to 47 km/h (20 to 30 mph)], or heavily congested [<32 km/h (<20 mph)]} between (downtown, Mockingbird, or Loop 12) and (Mockingbird, Loop 12, or LBJ).

Off-peak messages were similar, but with the speed levels slightly higher. These formats served to guide the operators in the type and order of information to be given, so that consistency for various conditions would be maintained. Departure from the prescribed format was necessary from time to time to adequately describe special situations, such as weather conditions or police enforcement activity. Information of lower priority (the higher numbers above) was eliminated as necessary to keep the message within the time constraints.

SYSTEM COMPONENTS

The dial-in system hardware had five primary components:

1. The recording and monitoring instrument, which had the outward appearance of a conventional dial telephone with push buttons for six lines, was the mechanism for recording and checking messages. The six push buttons allowed for dictating and checking messages and indicated when there was an incoming call.
2. A three-position switch was used to select the message that would be output to the caller. Placing the switch in the left or right position caused the message recorded on channel 1 or 2 respectively to be output. Placing the switch in the center position caused incoming calls to be unanswered, although they continued to ring and would receive the message when the switch was moved.
3. A handset was provided to override the recorded message, so that callers receiving a current operating message could be informed that an update was being made. This was necessary because moving the channel selector from one channel to another cut off current callers.
4. A digital readout recorded cumulatively the number of calls received. Pulling a small plunger reset the meter to zero, so that the number of calls received each day could be determined.
5. A recording and playback unit was provided for each of the two channels. These units required no direct operation or adjustment by the operator.

PUBLICITY

To adequately publicize the availability of the service and to obtain a basis for evaluation, several methods of advertising the dial-in service were used. Because the degree to which the system might be used was not known, not all of these methods were used initially. This was due to the fear that overloading the system with callers, many of whom would be curiosity callers outside the service area, would cause some legitimate callers to receive busy signals and discourage them from trying again. The sequence used was (a) to provide mail notification to a control group (303) selected from the questionnaire respondents, (b) to publicize the system in the news media, (c) to mail information to major downtown buildings, (d) to include mail notification in some water bills sent to areas whose residents might logically use the service, and (e) to mail information to a sample of motorists who might use North Central (as determined from a license-plate survey). In some of these publicity efforts, evaluation data were also sought.

EVALUATION

Although approximately 75 percent of the control group indicated that they would use such a service, experience has shown that what drivers say they will do in the abstract and what they do in actuality may differ. Therefore, it was essential to have a positive, mechanical count of the number of calls received per day as well as to secure comments from a sample of those actually using the service.

Evaluation of the effectiveness of the dial-in system, therefore, was accomplished by two methods. First, the daily count of the number of callers was recorded and second, an attempt was made to contact and elicit comments from actual users of the system.

Number of Calls Received

Daily records of calls received were kept by the control-center personnel. On the first day of operation, 3315 calls were received. This was a result of the extensive coverage in the news media and certainly included a large number of curiosity callers. A record of the calls showed that the number declined steadily to about 115/d by the end of the first month. The average number of calls received during the first year of operation was 83/d, but the number of calls received on any single day was as low as 30.

It is difficult to make an absolute comparison of the operation from one day to the next because of the highly variable nature of the operating conditions and characteristics. Accidents may go undetected; rain may be falling in a residential area and not on the freeway; and the variability of driver schedules due to holidays, illness, or vacations is a factor. However, it was possible to make a relative comparison from one day to the next by realizing that the absolute change may be affected by any one of several unknown or unmeasurable factors. A trend or indicator is evident from such comparisons.

Publicity

The initial coverage in the news media had the greatest effect on the number of calls received. However, the number of calls decreased decidedly after the initial surge. Direct mailings to drivers had the next greatest effect. For example, the water-bill mailings increased the load as much as tenfold. A lesser, but measurable, effect was the mailing to drivers who might use North Central (as determined by their license plates). About 500 notices were mailed, and less than 5 percent were returned as undeliverable. Comparing the Thursday and Friday a month before with the Thursday and Friday after the mailing showed that calls approximately doubled (from 49 to 106), but in another month dropped to their previous range. Mailings to office building managers had no discernible effect on the number of calls.

Accidents

Accidents classified as minor had little effect on the number of calls received. Although accidents of both minor and major natures were reported over commercial radio, reports of the more spectacular accidents, such as automobiles on fire or overturned in the roadway, seemed to spur additional calls. For example, on May 4, 1976, it was widely reported on commercial radio that a multiple automobile accident had occurred, and three vehicles were on fire. The number of calls tripled from the previous day. (Some of these could have been repeats from those who, on learning of the accident, called for updated information.) However, on October 16, a minor accident was reported, and there were fewer calls than on the same day of the previous week and the same number as on the following day. Increases in the number of calls of 29 to 155 percent were recorded on days of major accidents.

Weather

As with accidents, less severe weather conditions had little or no effect on calls received. However, severe weather (lightning or heavy rain) reported on radio and TV alerts generated more calls. There were increases in calls from the same day of the previous week of 20 to 110 percent.

Time of Day Versus Day of Week Profile

Calls received during the first year of operation were categorized as to day and time. There was no particular pattern for day of the week, except that approximately 12 percent more calls then the average were received on Fridays. More calls were received in the afternoon peak period, except on Fridays when more calls were received in the off-peak period (afternoon), possibly indicating that more drivers were leaving work early for the weekend. Overall, 29 percent of calls were received in the 6:45 to 9:00 a.m. peak period, 30 percent in the 9:00 a.m. to 4:00 p.m. off-peak period, and 41 percent in the 4:00 to 6:15 p.m. peak period.

Questionnaire Evaluation

To evaluate the dial-in service and obtain some insight into its positive and negative aspects, an evaluation questionnaire was developed. Because it was not possible to know the identity of callers, several approaches to obtaining evaluations by users of the system were attempted. These questionnaires were sent to the design control group, to tenants of office buildings on the North Central Expressway, and to a sample of drivers using it as determined from license plates.

There were only 103 returns from about 700 direct mailings. Of these, 42 percent indicated that they had used the service. Fifty-eight percent said that they had not, although all those receiving the questionnaire had also received information on the system, including its purpose, the telephone number to call, and a request to try the service. When asked why they had not used the system, 34 percent indicated that they did not know about it or forgot about it. Twenty-three percent stated that they did not need it. Sixteen percent indicated that they felt conditions would change between the call and their arrival at the freeway, 14 percent said that North Central was the only route available, and 5 percent used commercial radio.

Of drivers using the system, 36 percent indicated that they used it less than in the first week of operation. Reasons given were (a) forgot or did not know the number (50 percent), (b) the time lag between information and freeway arrival (25 percent), (c) not helpful (17 percent), and (d) use automobile radio (8 percent).

Of the users of the service, 72 percent did not indicate a need for additional information, 9 percent indicated the need for a delay estimate, 7 percent wanted more detail, and 5 percent wanted the time of the report.

The system was described as always accurate by 29 percent of the users, usually accurate by 51 percent, seldom accurate by 15 percent, and never accurate by 5 percent. Only 18 percent of the respondents actually indicated the specific inaccuracies, 12 percent of these being that the conditions had changed between the call and the freeway arrival.

The respondents were also asked what conditions induced infrequent callers to use the service when they did. Of these, 36 percent used it when in a hurry, 23 percent used it when the weather might affect traffic operation, 14 percent used it when traffic was observed (as from an office window) to be backed up, and the remainder used it for miscellaneous reasons.

SUMMARY AND CONCLUSIONS

1. General public apathy toward the pretrip dial-in traffic information service was demonstrated by both the number of calls received daily and the response to direct mail questionnaires. Despite the fact that those receiving the survey questionnaires were among the group receiving information on the service, over half had not even tried it.

2. An average of 83 calls/d were received during the first year of operation; some days there were as few as 30.

3. The primary reason given for not using the service was that the respondent did not know about it or forgot about it, despite the fact that all of them had received at least one letter describing the service and in many cases a stick-on label with the service number printed on it.

4. The next most frequent reason for not using the service was that conditions would change between the call and the time of the driver's arrival at the freeway.

5. Eighty percent of the questionnaire respondents described the information as either always or usually accurate, and 95 percent described the 30-s message as about the right length.

6. Direct mail publicity was the most effective means of increasing the number of calls, but any increases were temporary.

7. The dial-in traffic information service did not sustain an acceptable level of use.

8. Although it was not substantiated totally in the data, it appeared that routine nature of messages on nonincident days caused callers to lose interest in the service and discontinue calling. However, unusual weather or accidents appeared to remind some drivers that the service was available.

9. If a dial-in service is offered, it should be in conjunction with other information-dissemination modes to eliminate the time-lag problem cited by questionnaire respondents.

10. Much human-factors research has been directed toward the driver or user of information systems. Such research should also be directed toward those who operate the system to determine techniques for sustaining interest and attention where much of the operation may be of a routine or repetitive nature.

ACKNOWLEDGMENT

This research was developed within the Dallas Corridor Study, which was conducted by the Texas Transportation Institute for the Federal Highway Administration in cooperation with the city of Dallas. The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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Bulb-Loss Effects on Message Readability of Motorist-Information Matrix Signs

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This study addresses the question of the amount of bulb loss that can be tolerated in an electronic motorist-information sign before the message becomes illegible, misunderstood, or misinterpreted. A representative group of traffic-descriptor and advisory words and route numerals were displayed on a real-time matrix sign. Selected percentages (10 to 50) of bulbs were failed in a random pattern, and slides were taken of the resulting displays. These slides were shown to subjects who were instructed to respond by writing the word if it was legible. From these data, specifications for 85th and 95th percentile correct comprehension were determined for both familiar and unfamiliar motorists.

The object of motorist-information systems, whether audio, visual, static, or dynamic, is to transfer meaningful messages to the motoring public. These messages usually pertain to various tasks associated with vehicular maneuvers and may include information on route guidance, traffic conditions, or hazard warning. In displaying information by electronic variable-matrix signs, the legibility of the words displayed is the critical first step in the message transfer. A designated portion of motorists must be able to effectively read the words shown. If the display fails in this capacity, then it is useless, and message transfer cannot be achieved.

In the operational setting of an electronic display, one or more matrix bulbs in the sign may be lost, but drivers still be required to read the sign before it is deemed necessary that the bulbs be replaced. Manufacturers of these signs recommend that bulb replacement is warranted from a public-credibility standpoint at a level of failure of approximately 10 percent. No published information is available relating bulb failure in electronic matrix signs to message readability. Specifically, in traffic engineering, the criteria for bulb-replacement specifications have followed the lead of the sign manufacturers. Credibility has been the primary control. This study is an evaluation of the experimental question, "How high is the percentage of bulbs that can be lost before a message is misunderstood or misinterpreted?" The emphasis is on the measurement of human comprehension of traffic-condition and advisement words or route numerals of various lengths as displayed on a variable-matrix sign with various degrees of bulb loss.

RESEARCH METHODOLOGY

General Approach

The research approach selected for evaluating the effects of bulb loss in electronic matrix signs on message legibility consisted of laboratory testing by using visual simulations. Slides (35-mm) of a full-scale, trailer-mounted matrix sign were used to increase the fidelity and realism of the laboratory study.

A trailer-mounted matrix sign obtained from an electronics firm in Texas was used in the laboratory studies. The sign was composed of a 7 by 60 array of 25-W bulbs, 0.46 m (1.5 ft) high by 3.7 m (12 ft) long. Any message or symbol not exceeding about 10 characters on a single line could be displayed. Normally, a character was 5 bulbs wide. The sign was programmed by punched paper tape. Characters were formed by one vertical column of bulbs at a time; i.e., each column of holes on the tape corresponds to a column on the sign. The punched tape, therefore, is a replica of the characters that are displayed on the sign.

The laboratory study needed to be as real-world as possible, but experimentation with a large number of human subjects required expediation also. The mediamaster laboratory on the Texas A&M University campus is an excellent facility for experiments of this nature. The laboratory has remotely controlled environmental testing and evaluation capabilities for approximately 20 subjects.

The slide presentations were projected onto an opaque wall screen by the rear-projection method. Taped voice instructions and the slides were synchronized by a multichannel control system located in the projection room. The laboratory's subject-response evaluation capabilities were not used because written responses were required.

The subjects tested were selected from among residents of Bryan and College Station, Texas. The demographic characteristics of the 226 subjects were stratified as to age, sex, education, and distance driven per year as shown in Table 1. The characteristics of the population pool were formulated carefully to be representative of the national driving public (1).

Experimental Design

The physical dimensions of the single-line lamp-matrix sign used imposed an upper limit on word length of 10 characters. Four-character words were chosen as the lower limit. Words of fewer characters are generally prepositions, conjunctions, and adjectives and were not considered, as the interest in this study was primarily with one and two-word combinations. Five different sets of highway situation or advisement words were chosen for each word length. The words chosen were to be representative of those currently used in practice on the electronic matrix signs employed for traffic control and advisement (2). Thus, the independent variable was length of word and varied from 4 to 10 characters. Five different route numerals were also chosen, for a total of 40 words and numerals [(5 x 7) + (5 = 40)]. These words and numerals were subsequently divided into two groups or sets of 20 each (Table 2).

The individual word or numeral was presented statically on the electronic matrix sign with the various degrees of bulb failure simulated. Initial observations indicated that virtually no words or numerals were legible beyond a 50 percent bulb loss if they had not been shown previously at a lesser degree of bulb loss. For analysis purposes, all words or numerals were categorized as being exhibited to a driver in a familiar or an unfamiliar state. An unfamiliar word was defined as a word that had not been recognized and read at a lesser degree of bulb loss; a familiar word was the opposite. Five equal increments of bulb loss, ranging from 10 to 50 percent inclusive, were established.

As there is no real-world pattern to bulb loss, random bulb failure was simulated. A chart was plotted duplicating the actual 7 by 60 matrix on the sign, and by using column and row assignment within the matrix, bulb failures were generated from random-number tables until 42 positions (10 percent of 420 bulbs) had been selected. The corresponding bulbs were turned off by unscrewing. Each word or numeral was then displayed on the sign, and 16-mm slides were made. The same procedures were repeated for all percentages of bulb loss.

The slides of the highway situation or advisement words and the route numerals at the designated degrees of bulb failure were arranged randomly in two groups, A and B. Each group was then arranged into two series of presentations; one group in which the percentage of bulbs lost increased from 10 to 50 and the other in which the percentage of bulbs lost decreased from 50 to 10. Increasing bulb loss was assumed to represent the situation experienced by a familiar driver (a commuter or daily trip maker) when the word or numeral is first seen clearly legible and then gradually degraded over time until recognition is not possible. Decreasing bulb loss was designed to test unfamiliar drivers (tourists or infrequent trip makers) viewing the sign for the first time. Each series was measured separately to obtain the performance of both familiar and unfamiliar drivers. By averaging the ascending and descending series according to the psychophysical method of limits, it was also possible to offset errors of anticipation with errors of perserveration and obtain an average value that was best representative of driver recognition. The complete experimental design is summarized below.

Characteristic	Description
Independent variables	Characters per word and size of matrix (random), location of bulb failure (random), percentage of bulb failure in 10 percent increments
Criterion variables	Percentage of correct responses
Controlled conditions	Type of presentation (single word flash), presentation rate (3 s/word), response rate (10 s/word)
Statistical design	93 subjects, seven word lengths (4 to 10 characters/word) and one number length (4 characters—letters and numbers), 40 words/study, five levels of bulb failure per word (10 to 50 percent)

Experimental Administration

The subjects were tested in the media-master laboratory. All subjects were residents of Bryan or College Station and drawn from the population pool described in Table 1. The total number of subjects tested was 93; the groups viewing each order of slide presentation in both the familiar and unfamiliar states were approximately equal.

Each group of subjects was administered 100 words: 20 for each level of bulb loss. The words were given in a different random order at each bulb-loss level. From one to five subjects were tested at any given time. Taped voice instructions were played to the subjects, and an example slide was displayed onto the opaque wall screen by using the rear-projection method. Each word or numeral, with a given bulb loss, was projected on the screen for 3 s. (This time is a reasonable approximation of the visual exposure a driver would have on approaching a sign of standard legibility design at a normal operating speed.) The slide was then removed from the screen, and the subjects were given 10 s to completely and legibly write the word or numeral if such was discernible. This was ample time for a written response. Typical slides at various percentages of bulb loss are shown in Figures 1 to 10.

RESULTS

The criteria of correct response to bulb loss was that the subject must completely and exactly reproduce the word or numeral displayed; i.e., an incorrect response, or error, was recorded if the subject either omitted the word (numeral) completely or the reproduction was incorrect. The percentage-correct response for a given word length and percentage of bulb loss was calculated by using the formula, $[1 - (E/N)] \times 100$ percent, where E = total of errors (either omission or incorrect reproduction) and N = number of words presented at the designated bulb loss and word length.

Each group of words and numerals was analyzed for the ascending series and for the descending series series of percentages of bulbs lost. During the data reduction process, the two series were analyzed separately, representing the familiar and unfamiliar motorist conditions, and also evaluated in total. The percentages of bulbs lost versus the percentage-correct response versus the word lengths are summarized in Table 3.

Figures 11, 12, and 13 present plots of the percentage-correct responses versus the percentage of bulbs lost as a function of word length for the familiar, the unfamiliar, and the average motorist state respectively. The unfamiliar driver state represents the worst condition. The 85th and 95th percentile levels of correct response shown on these figures represent criteria commonly used in traffic-engineering practice as bases for design recommendations.

These data indicate the following:

Table 1. Demographic data of laboratory test subjects.

Characteristic	Percentage of Population	Characteristic	Percentage of Population
Sex		Junior high school grade	
Male	70.3	7	4.5
Female	29.7	8	7.2
Age, years		9	11.7
18 to 24	11.7	High school grade	
25 to 34	24.4	10	11.7
35 to 44	19.8	11	12.6
45 to 54	29.7	12	37.8
55 to 64	13.5	Years of college	
>64	2.7	1	19
Educational level		2	2.7
Elementary school grade		3	1.8
1	0	4	0
2	0.9	Kilometers driven per year	
3	0	0 to 16 100	42.6
4	0.9	16 100 to 32 200	42.6
5	3.6	>32 200	14.8
6	3.6		

Note: 1 km = 0.62 mile.

Table 2. Words used in bulb-loss study.

No. of Characters	Group A	Group B
4	Slow, toll, road	Lane, exit
5	Truck, route	Alert, wreck, merge
6	Bypass, access, reduce	Bridge, median
7	Blocked, traffic	Freeway, stalled, vehicle
8	Accident, entrance, pavement	Downtown, junction
9	Condition, alternate	Diversion, hazardous, collision
10	Congestion, expressway, visibility	Restricted, prohibited
Numerals	I-415, US-23	HWY-6, I-270, US-39

Figure 1. Four-character word at 10 percent bulb failure.

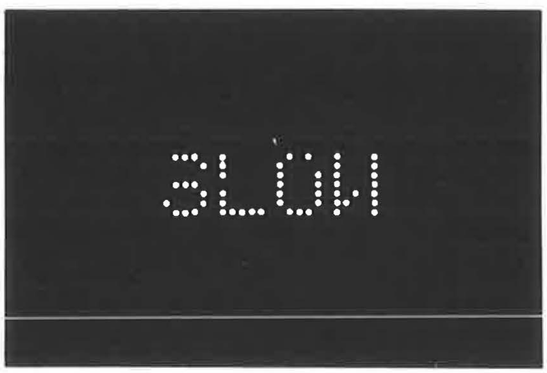


Figure 2. Four-character word at 50 percent bulb failure.

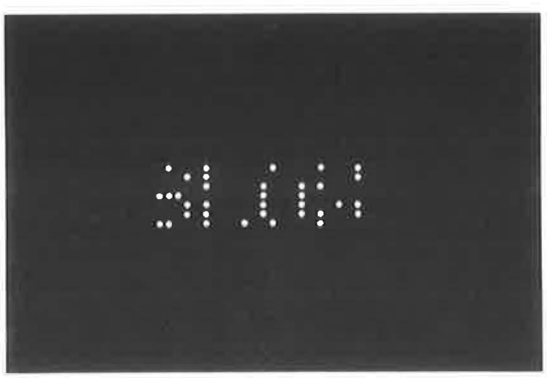


Figure 3. Six-character word at 10 percent bulb failure.

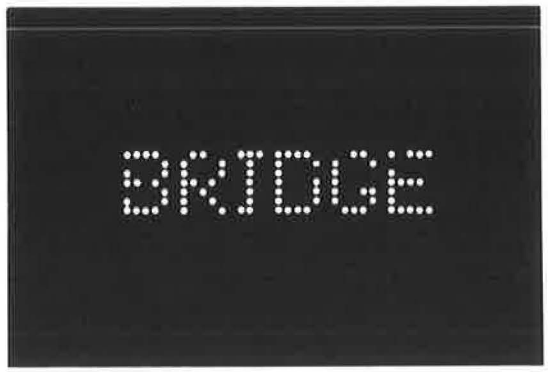


Figure 4. Six-character word at 50 percent bulb failure.

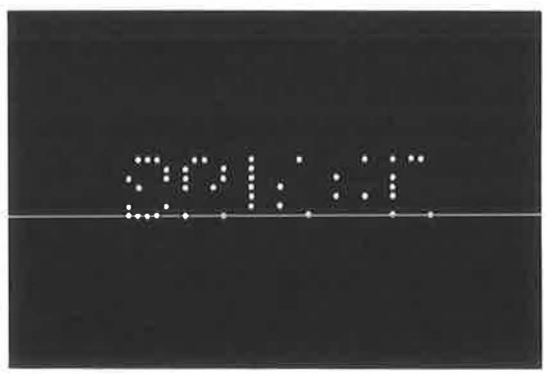
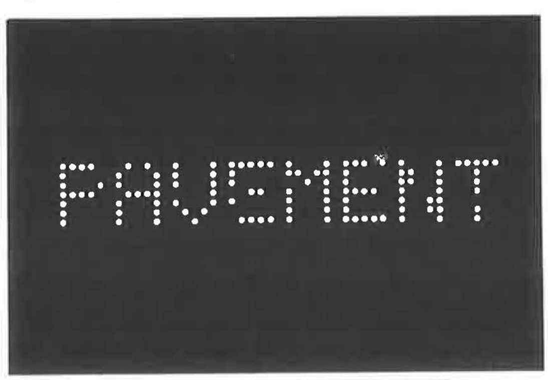


Figure 5. Eight-character word at 10 percent bulb failure.



1. At all levels of bulb loss, the unfamiliar state resulted in poorer recognition than the familiar state. This was expected because the familiar subject had previously seen the words at lower loss levels and, hence, needed fewer parts of the words to recognize them at higher levels of bulb loss.

2. The length of the word had no systematic relationship to the percentage-correct response for the familiar state (Figure 11), but for the unfamiliar state, the longer words were somewhat more difficult to recognize than the shorter ones (Figure 12).

At first the relationship between word length and performances seemed to be inconsistent with other studies of word recognition that indicate that words having a larger number of characters can be read at a higher

Figure 6. Eight-character word at 50 percent bulb failure.

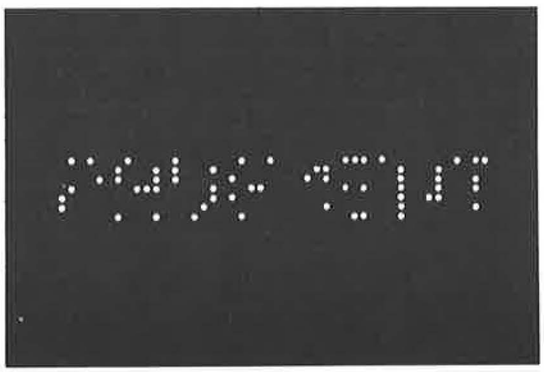


Figure 7. Ten-character word at 10 percent bulb failure.

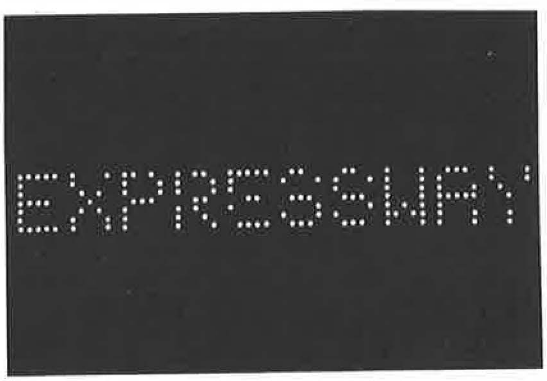


Figure 8. Ten-character word at 50 percent bulb failure.

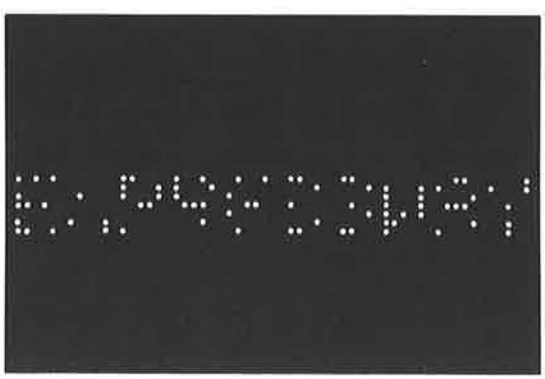


Figure 9. Route numeral at 10 percent bulb failure.

Figure 10. Route numeral at 50 percent bulb failure.

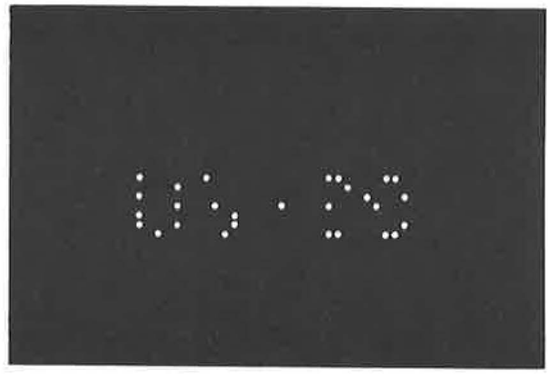


Table 3. Percentage of bulb loss versus percentage of correct responses versus word length.

Characters per Word	Bulb-Loss Percentage	Motorist Condition Familiar	Motorist Condition Unfamiliar	Avg
4	10	99	96	96
	20	98	91	94
	30	97	79	88
	40	91	51	69
	50	80	29	54
5	10	100	97	99
	20	99	92	96
	30	98	77	87
	40	92	37	61
	50	79	10	42
6	10	98	94	96
	20	98	78	88
	30	96	57	76
	40	91	29	59
	50	79	13	46
7	10	100	94	97
	20	99	89	94
	30	98	82	90
	40	93	63	76
	50	83	28	47
8	10	98	93	95
	20	96	80	84
	30	93	65	78
	40	86	38	62
	50	78	9	44
9	10	97	88	91
	20	96	70	84
	30	95	50	74
	40	88	26	54
	50	82	7	40
10	10	99	92	95
	20	98	78	88
	30	95	59	77
	40	85	34	55
	50	78	12	49
Numerals	10	100	94	97
	20	97	90	93
	30	96	70	82
	40	84	40	60
	50	59	8	35

percentage of degradation than can words having fewer characters. For example, affirmative is more easily recognized than yes. The better recognition of shorter words here may be due to their higher frequency of occurrence in the traffic vocabulary.

The percentages of bulb loss associated with the 85th and 95th percentile criterion performance levels are summarized in Table 4.

Many different viewpoints can be taken in arriving at conclusions in this study. For the freeway commuter or the familiar driver, bulb losses of approximately 45 and 30 percent respectively, corresponding to the 85th and 95th percentile design levels, are tolerable before deterioration reaches a point where legibility is a problem. Of course, poor appearance and possible loss of credibility may justify bulb replacement before this level of loss develops.

Figure 11. Bulb loss versus correct response as a function of word length in a familiar motorist state.

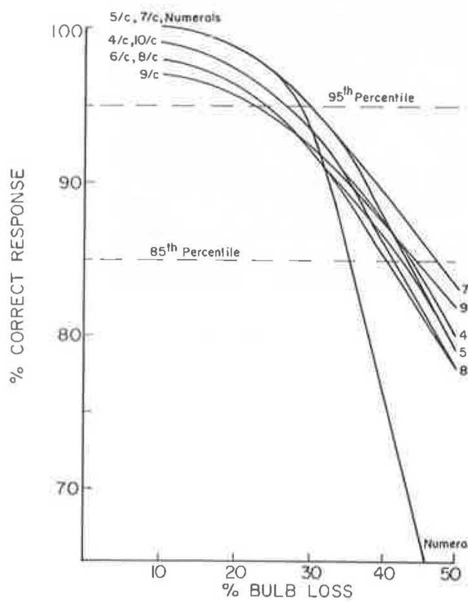
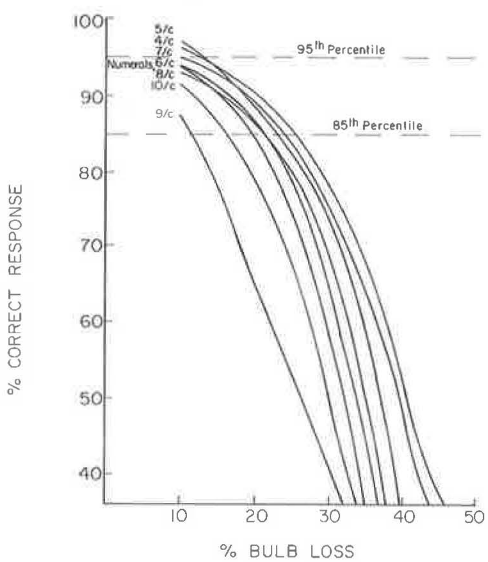


Figure 12. Bulb loss versus correct response as a function of word length in an unfamiliar motorist state.



However, for the unfamiliar motorist, the tolerable bulb-failure percentages are approximately 20 and 10 percent for the 85th and 95th percentile design levels. These loss percentages are consistent with the appearance criterion and the manufacturer's suggested bulb-replacement specification of 10 percent loss. The dependence of the unfamiliar driver on dynamic signing information is also an argument in favor of the 10 percent criteria. The tolerable bulb-loss percentages for the average-motorist state [approximately 30 percent (the 85th percentile) and 15 percent (the 95th percentile)] maybe more representative of the normal stratification of familiar and unfamiliar motorists in the driving public. However, at the 85th percentile design levels, the appearance is questionable; thus, bulb loss should not exceed 10 percent if both sign readability and credibility are to be maintained.

Most dynamic motorist-information systems display messages involving two-word combinations on one line, and this must also be taken into consideration. A message may consist of two words of different lengths for which different percentages of bulb loss are tolerable. The poorest performance measured by recognition of a word of a specified character length is the critical factor in the message transfer. For example, as shown in Table 4, for the familiar state, route numeral performance, from a standpoint of bulb failure versus legibility, was 36 percent at the 85th percentile design level, and nine-character words performed at 23 percent for

Figure 13. Bulb loss versus correct response as a function of word length in an average motorist state.

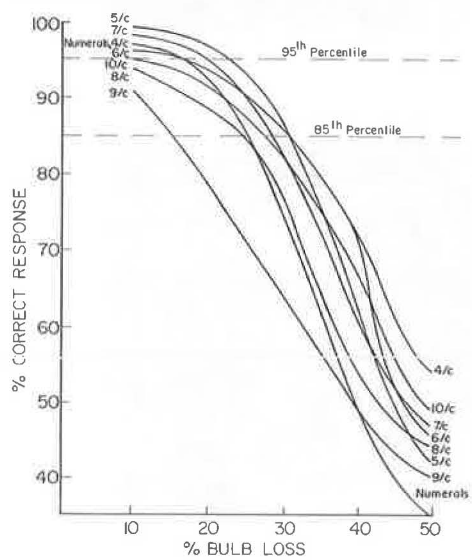


Table 4. Percentage of bulb loss associated with 85th and 95th percentile criterion performances as function of word length.

No. of Characters	Bulb-Loss Percentage					
	Familiar		Unfamiliar		Avg	
	85th	95th	85th	95th	85th	95th
4	45	28	23	11	31	17
5	44	31	21	12	32	21
6	43	25	20	8	31	17
7	49	31	21	10	30	20
8	41	25	20	6[a]	25	6[a]
9	46	23[a]	10[a]	8	16[a]	7
10	42	28	15	7	28	10
Numerals	36[a]	31	18	8	26	17
Avg	44	28	18	8	28	14

[a]Maximum bulb loss tolerable for criterion performance regardless of length.

the 95th percentile design level. The corresponding lowest bulb-loss percentages were 10 and 6 percent by nine and eight-character words respectively for the unfamiliar state and 16 and 6 percent also by nine and eight-character words respectively for the average state. These performances should be considered in bulb replacement for multiword messages.

Route numerals pose special problems of concern with degradation and legibility. For an average state, unsatisfactory performance is exhibited for the 85th percentile correct-response level beyond a bulb loss of approximately 20 percent and for the 95th percentile level beyond a bulb loss of approximately 10 percent. This indicates that the tolerable bulb-loss criteria for both legibility and appearance of route numerals are closely related. Special bulb specifications should be considered when using messages with route numerals. Numbers are harder to recognize than words because there is no sequential redundancy, i.e., knowing one number does not help a driver to anticipate the next, but the verbal language does permit filling in missing or distorted letters.

CONCLUSIONS AND RECOMMENDATIONS

Several conclusions and recommendations concerning the effects of bulb loss on the legibility of words, route numerals, and the messages displayed on electronic variable-matrix signs are suggested by the results of this study. Some are as follows:

1. For 85 or 95 percent of traffic-related words to be correctly read, the percentage of bulb failures must not be greater than that shown below.

Motorist State	Correct-Response Criteria 95	85
Unfamiliar	8	18
Average	14	28
Familiar	28	44

2. Bulb-replacement criteria for a specified level of legibility performance vary with the motorist state.
3. At the 85th percentile performance criterion, for both familiar and unfamiliar-motorist states, bulb replacement will probably be controlled by appearance (e.g., 10 percent bulb loss) rather than by legibility. The matrix sign may be legible at a level of bulb loss at which the overall appearance is unacceptable.
4. Only in the unfamiliar state and at the 95th percentile does the bulb-replacement criterion approach that designated by sign manufacturers (approximately 10 percent).
5. Messages with route numbers are read with difficulty at bulb failures beyond approximately 15 percent. Special considerations are advised for route numeral bulb replacement specifications.

In summary, it is emphasized that the manufacturer's specifications for bulb replacement should be adhered to beyond a 10 percent failure rate. There is also a need to further evaluate the results of this study and how they relate to real-world situations. On-site testing and a study of the legibility performance of three-character words and multiword combinations are justified.

ACKNOWLEDGMENT

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Abridgment

Survey of Motorist Route-Selection Criteria

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Other research and surveys have focused on the types of traffic descriptors motorists prefer (1, 2, 3) and the specific techniques for displaying such information in real-time.

It is also necessary to ask the motorist directly certain questions about his or her typical driving habits—the routes taken and the reasons for selecting these routes when he or she is familiar with other routes. The daily commuter makes a route-choice decision in traveling to and from work, and the intercity traveler makes a route-choice decision in passing through major cities or in traveling to destinations within the city. It was hypothesized that the reasons for selecting typical routes would be similar to the reasons for selecting alternative routes in incident-type situations. The driver's hierarchy of route-choice criteria would be used in either situation.

If the information drivers need most in making a route-choice decision were available, it would then be feasible to determine whether such information was measurable and how it might be best displayed to the motorist.

METHOD

Motorist Samples

A sample of 202 drivers from the central business district of Dallas was selected to respond to the work-trip questionnaire. This sample consisted of daily commuters; they were 56 percent male and 44 percent female and had a median education of 14 years, a median age of 25 to 44 years, and a median driving experience of 11 to 20 years.

Another sample of 215 drivers was interviewed at rest stops on an Interstate leading into Houston. They were not asked personal information, nor was this a criterion in their selection. Of them, 123 reported a destination within the city and 92 a destination beyond the city. Thirty-five percent of those having a destination within the city and 76 percent of the through motorists were unfamiliar with the city.

Questionnaire Description

The format of the two questionnaires was similar, but the individual questions were necessarily different.

The rest-stop subjects were asked to describe the route they planned to take, whether they knew of other routes, and specifically why they had chosen the route they had previously described. They were also asked why they had not taken a familiar alternative route. A second series of questions related to what they would do in a situation in which they learned over the radio that traffic was stop-and-go ahead, because of an incident, and the reasons for their actions. They were also asked what information they would like to know in advance about the route they had chosen. These drivers were given a mail-in portion of the questionnaire that asked for recall of a time when a traffic jam had inconvenienced them. The questions were similar to those on the first questionnaire, except that the answers were based on actual experiences.

The work-trip questionnaire was given to the commuters through the personnel departments of their employers. The employers were two life insurance companies, a gas company, an electric company, a telephone company, an oil company, and the county offices.

The commuters were asked to describe the routes they regularly took to work and home, the alternative routes, and the reasons for their choice of route. The second portion of the questionnaire was analogous to the mail-in questionnaire for the rest-stop drivers. The questions related to their reasons for selecting a particular alternative route, if they did so, or why they decided to wait out a traffic jam. To determine the importance of the information they had just given about the alternative route, they were asked how the existence of advance information would have influenced their route-choice decision.

RESULTS AND DISCUSSION

Rest-Stop Survey

The reasons for their route choice given by drivers with destinations within and beyond the city are given below.

Reason	Percentage of Drivers	
	Within City	Beyond City
For choosing present route		
Convenience	45	50
Direct, short	23	13
Faster	20	21
Less congested	5	5
Other	7	11
For rejecting alternative route		
Takes longer	46	44
Less direct	42	44
More congested	3	4
Other	9	8

There were few differences in the reasons given for taking their present route or for not taking a known alternative route. The usual ones were that the present route was more convenient, direct, or faster, while the alternative route took longer and was less direct.

The major information about the route ahead sought was route guidance (33 percent), the level of congestion (17 percent), and the locations of congestion, accidents, and maintenance (13 percent).

The two destination groups were fairly consistent in their reactions to a radio advisory of an incident ahead, as shown below.

Action	Percentage of Drivers		
	Within City	Beyond City	Total
Divert around incident	77	65	72
Continue	13	21	16
Wait and continue	7	13	9
Depends on delay	3	1	2

Collectively, 72 percent said they would divert around the incident. Only 16 percent would continue, and 9 percent would wait it out. The major reasons given for either continuing or diverting are summarized below.

Reason	Percentage of Drivers
To continue	
Unfamiliar with area	66
Type of alternative facility disliked	9
Time not a factor	7
Other	18
To divert	
Avoid congestion	48
Save time	27
Avoid delay	20
Other	5

The major reason for continuing was a lack of familiarity with the area. The major reasons for diverting were to avoid congestion and delay and to save time.

Both those diverting and those continuing were asked what information about the alternative route they would like before they got on it. Of those continuing, 30 percent were mainly concerned about where to exit and reenter the Interstate, and 44 percent of those diverting were concerned about adequate route guidance.

Mail-in Survey

Thirty-three percent of those asked to complete an additional questionnaire returned their forms. The survey focused on a freeway or Interstate incident they could recall in which a traffic jam had inconvenienced them.

The actions taken in these incidents are summarized below.

Action	Percentage of Drivers
Diverted (took another route)	9
Continued	49
Waited and continued	42
Other	0

These values can be compared to the 72 percent who had previously stated that they would divert. The major reasons given for continuing were that the alternative route would not save time (23 percent) and that they were unfamiliar with the alternative routes available (20 percent). The types of information desired by these drivers before deciding to continue were the locations of the diversion routes (27 percent) and the level of congestion ahead (16 percent).

Commuter Survey

The 202 commuters from the central business district were asked to describe the route they regularly took to work. This requirement was mainly to make them focus on a particular route. The reasons these commuters gave for taking their present routes to work and homeward are given below and compared with the reasons given by rest-stop drivers for their route choice.

	Percentage of Drivers		
	Commuters		Rest-Stop
Reason	To Work	To Home	Drivers
Fastest route	23	24	20
Fewest stops	14	8	3
Convenience and accessibility	12	6	46
Shortest, most direct	22	14	20
Less traffic	8	19	5
Good traffic flow	5	10	0
Other	16	19	7

The major factors of speed, directness, and convenience are comparable, but the commuters had more different reasons, and convenience and accessibility were mentioned much less often. Sixty percent of the commuters had taken one or more alternative routes to work, and 74 percent of these had done so during the previous month. These drivers were asked to detail two alternative routes and the reasons for their route choice. The principal reasons were lighter traffic (29 percent), change of scenery (15 percent), and the need to make specific stops (13 percent).

The second series of questions related to the route taken homeward. Thirty-seven percent always or often took a homeward route different from the route to work, and 60 percent sometimes took a different route home. The major reasons and percentages of drivers taking these alternative routes were very similar to those taking an alternative route to work.

Like the rest-stop drivers, the commuters were asked to recall an incident situation that had inconvenienced them. The percentages taking various courses of action are given below and compared with the actions taken by the rest-stop drivers.

	Percentage of Drivers	
Action	Commuters	Rest-Stop Drivers
Divert	27	9
Continue	45	49
Wait and continue	24	42
Other	4	0

About the same percentages elected to continue on the route, but three times as many commuters diverted, and about half as many waited it out. The options for diverting may be more numerous for commuters driving in a metropolitan area than they are for drivers on an Interstate or freeway. Slightly fewer of the commuters (40 percent as opposed to 52 percent of the rest-stop drivers) said they would still have stayed on the original route even if they had known in advance of the traffic jam. Again, this may be due to the larger number of route options available to the commuter.

The reasons given by those who elected to divert and by those who elected to continue are given below.

Reason	Percentage of Drivers
For diverting	
Better traffic flow	35
Less traffic	25
Convenient to get on	18
Directness, shorter	8
Followed others	4
Other	10
For continuing	
Faster even with incident	50
No way to get off	28
No alternative route	12
Alternative more congested	3
Other	7

Those diverting thought that the diversion route would be less congested and traffic would be faster, while those not diverting believed, as did the rest-stop drivers, that the freeway was still the fastest route. Drivers needed assurance that they would be saving time by diverting.

Of those remaining on the primary route, 77 percent were satisfied, but 49 percent would have liked additional information on the length of the delay and traffic conditions. Fifty-five percent of those staying believed they would have diverted if they had had that information.

SUMMARY AND CONCLUSIONS

1. The criteria for taking alternative routes are fairly consistent both among motorists and by the same motorist at different times. The commonalities in the reasons given for selecting routes suggest that a message system could satisfy the needs of a great majority by presenting traffic information and positive route guidance.
2. The unfamiliar motorist was more concerned than the familiar motorist with route guidance and distrusted being diverted into unfamiliar territory.
3. At least 50 percent of those electing to continue through incident-related congestion would have diverted if they had had additional information.
4. While 72 percent of drivers said they would divert on hearing an incident advisory, few could recall instances of actually doing so. One reason for this may be lack of adequate information on where diversion routes are and how to get to them.
5. Drivers are not committed to a single route. Typical route-choice decisions, as well as incident-related decisions, are dictated by driver expectations regarding comparative traffic conditions on the routes.

Real-time signing and the radio are among the means of presenting to drivers the kinds of information they require. The public must be taught that the system is credible, so as to develop confidence in the information displayed. Present driving habits in both typical and route-diversion situations are based largely on previous driving experiences and not on current information.

The driver can be induced to divert if given timely information needed to make the correct decision.

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Motorist-Aid System on a Rural Freeway: The Illinois Experience

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The state of Illinois has installed an experimental motorist-aid telephone system along 221 km (138 miles) of I-80 between Rock Island and Joliet. The system consists of 302 roadside terminals in pairs, one telephone in each direction of travel, at approximately 1.6-km (1-mile) intervals. Before and after studies were conducted to evaluate the effectiveness of the system in terms of system use, response time, convenience, reliability, and costs. The sources for these data were stopped-vehicle surveys, state police assistance-rendered reports, service-unit assistance-rendered reports, a public-opinion survey, and a motorist-aid system-use survey. The major findings were that (a) approximately 24 percent of all I-80 aid candidates are using the motorist-aid system, (b) the average time between incident occurrence and police notification is reduced from 15.5 min in the before period to 12.8 min in the after period and to 9.6 min when the aid telephones were used, and (c) the cost-effectiveness of the system, considering accident reduction and time saved only, is in the 0.6 to 0.7 range for the total investment.

The state of Illinois has installed an experimental motorist-aid telephone system along 221 km (138 miles) of I-80 between I-74 (Rock Island) and Ill-43 (Joliet). The system consists of 302 roadside terminals in pairs, one telephone in each direction of travel, at approximately 1.6-km (1-mile) intervals. The Illinois Department of Transportation (IDOT) owned system is a two-way voice carrier, hard-wire (25 pairs) installation, operated through the state police headquarters near Joliet (police district 5) and Rock Island (police District 7). Toll-free calls from motorists requiring assistance are answered by a police desk sergeant, who either dispatches the necessary services or provides the required information.

The primary goals of the system, as defined in a 1968 feasibility study (1), were

1. To provide aid in an efficient manner to the motorist in need,
2. To minimize the hazard caused by the motorist in distress, and
3. To keep traffic flowing.

The secondary goals, which have varying degrees of importance, were

1. To maximize the service quality,
2. To maximize the extent and quality of upstream warnings of hazards,
3. To maximize the use of existing and planned resources,
4. To minimize the system obsolescence, and
5. To provide for the collection of adequate statistical operative data to analyze and evaluate the performance of the system and ensure legal backup for each incident in case of motorist suit.

SYSTEM EVALUATION

In the evaluation program, the pertinent measures of effectiveness were defined and placed in three categories—system use, response time, and convenience. The evaluation consisted of before and after studies related to the costs of the system and the measures of effectiveness (2, 3).

The measures of effectiveness related to system use were

1. The system-utilization ratio, i.e., the ratio of the number of system activations by aid candidates to the total number of aid candidates;
2. The system-efficiency ratio, i.e., the ratio of the number of successful motorist aids to the total number of aid candidates; and
3. The system-success ratio, i.e., the ratio of the number of successful motorist aids to the number of system-aid activations.

In the before study, an activation was defined as a stop of an aid candidate on or alongside the road. In the after study, an activation was defined as the attempt of a motorist to convey a need for aid through the communication terminal. An aid candidate was defined as a stopped motorist who needed assistance from one of the services provided by the motorist-aid system (such as the police, medical, fire, mechanical, or information services).

The measures of effectiveness related to the response-time category were detection and need-definition times, the time to scene, the time on scene, and the time to aid center or base.

The measures of effectiveness related to convenience were (a) ability to provide precise need definition, (b) safety (primary and secondary accidents), and (c) the opinions of aid candidates regarding system performance.

The studies and sources of data for the evaluation of the system included (a) stopped-vehicle surveys (which measured system use and response time), (b) state police assistance-rendered reports (which measured response time), (c) service units assistance-rendered reports (which measured response time and system use), (d) I-80 accident reports (which measured response time, system use, and convenience), (e) a public-opinion survey (which measured convenience, system use, and response time), and (f) a motorist-aid system-use survey (which measured system use).

Stopped-Vehicle Surveys

Two before (September 1969 and March 1970) and one after (August 1973) stopped-vehicle surveys were conducted, each for 24 h/d for a week, on a 14.5-km (9-mile) section of I-80. In the two before studies, 857 and 438 vehicles respectively were spotted stopped; in the after study, the number of stopped vehicles observed was 861. The means of the duration of stops were 13.4 and 13.7 min for the before studies and 12.6 min for the after study. However, statistical analysis could not establish a significant difference.

The percentages of stopped drivers that could be considered aid candidates because of their apparent reason for stopping were approximately 12 and 14 for the two before studies and 25 for the after study. The system-use measures of effectiveness for the 36 observed cases of aid-telephone use during the after stopped-vehicle surveys are given below.

Ratio	Value
System utilization	0.17
System success	0.67
System efficiency	0.11

The rate of aid-candidate stops per vehicle kilometer of travel was 1 stop/16 340 vehicle·km (1 stop/8600 vehicle miles). [This rate is significantly higher than the rate of 1 stop/32 000 vehicle·km (1 stop/20 000 vehicle miles) advocated by previous studies.] Because of the small sample (0.5 percent of the total travel), the latter rate was used hereafter.

State Police Assistance-Rendered Reports

In the before study (August 1969 to October 1971), 3040 assist reports were collected (117 assists/month). In the after study (April 1973 to April 1974), 729 assist reports were obtained (61 assists/month). The reduction in the number of reported assists could be attributed to the following effects: the shift from giving directional information by police patrol to giving it through the motorist-aid system, the fading enthusiasm of the police in filling the assist forms, and the reduction in total travel due to the energy shortage.

In district 5, the police patrol was nine officers and nine vehicles during the before study and seven officers and seven vehicles during the after study. In district 7, the patrol level was increased from six officers and six vehicles to nine of each. These changes were made due to organizational changes in the police districts.

The average motorist waiting time for field assists increased from 13.4 min during the before period to 20.5 min in the after period. The average police on-scene time increased from 22.3 min during the before study to 30.2 min during the after study. Both of these increases can be attributed in part to the elimination of most of the short-time field assists, such as information aid, from the after sample.

Part of the after study period fell within the period of the energy shortage and the reduced (20 percent) speed limit (January to April 1974). If the motorist waiting time is adjusted for this speed-limit reduction, the difference between the before and after values for the corresponding patrol levels could have been an increase of nearly 3.5 min.

Service-Unit Assistance-Rendered Reports

In the before study (December 1969 to May 1972), a total of 521 assist forms were received. Three service units (6 percent of the submitting units and 1.2 percent of the contacted units) were responsible for the return of 73.7 percent of them. These service units operated over 41.3 percent of the length of the study section.

In the after study (April 1973 to June 1974), 320 assist forms were returned, of which 82 percent were sent by three service units operating over 37.4 percent of the study section. The averages for the time to scene, time on scene, and time to aid center or base differed significantly in the before and after study, as shown below:

Time	Before (min)	After (min)	Change (%)
To scene	20.9	16.4	21.5
On scene	23.4	17.4	25.6
To aid center or base	27.7	19.0	31.4

The differences in the time to scene and time to aid center or base are quite significant, especially when the effect of the speed-limit reduction is also considered. The time to scene and the time on scene for ambulances and fire units were not significantly different in the before and after studies. The vehicle-service assists reported in the after study involved aid-telephone notification for 70 percent of the sample.

The same two service units accounted for 60 and 70 percent of the reports in the before and after study periods respectively. This prevents analyzing the contribution of the optimal service-coordination capability of the telephone system and suggests that other factors could be responsible for the significant differences in the time to scene and the time to aid center or base.

The significant reduction in the time on scene during the after study could also be related to a reduction in the percentage of assists by service vehicles patrolling the road. Such a decrease could reduce the probability of prolonging the time on scene, if the service vehicle is not fully equipped to handle the disability.

I-80 Accident Analyses

Of the 752 yearly accidents reported in the before study period (August 1969 to May 1972), 71 were of the secondary type, and of the 723 yearly accidents in the after study period (April 1973 to April 1974), 27 were of the secondary type. The reduction in the number of secondary accidents far exceeds the 23 percent (4) expected from the reduced travel and speed during the gasoline shortage and thereafter.

In addition, this apparent reduction more than offsets the 13 accidents involving aid telephone poles. However, because of the small sample sizes, no conclusions as to a statistically significant effect of the motorist-aid system on the reduction in secondary accidents can be made.

In the case of accidents, the motorist-aid system was used to notify the police in 46 percent of the cases. For all I-80 accidents, the aid-telephone system-use measures of effectiveness are given below.

Ratio	Value
System utilization	0.46
System success	1.00
System efficiency	0.46

The average time to notify the police was reduced from 15.5 min in the before study period to 12.8 min (9.6 min when the aid telephone was used, with 72 percent of such calls made by passing motorists) in the after study period and was found to be statistically significant. The effects of the motorist-aid system on the recovery of the ill and of accident victims could not be determined because it was impossible to obtain the necessary data from the various health agencies. However, the reduction in time to notify the police by an average of 2.7 min could only have had positive effects.

Public-Opinion Survey

In the before study (December 1969 to May 1972), approximately 1700 questionnaires were distributed by the police when assisting, but only 231 (15 percent) were returned. In the after study (April 1973 to April 1974), only 88 questionnaires, out of an unknown number distributed, were returned.

In general, the after respondents were aware (93 percent) of the I-80 motorist-aid telephone system and favored (63 percent) its expansion. Nearly half (49 percent) of the respondents had used the system. More than 90 percent of the respondents found the 1.6-km (1-mile) spacing between the aid telephones about right.

After the installation of the system, nearly 89 percent of the respondents were not unduly delayed in being detected, compared to approximately 76 percent before the installation. Nearly 70 percent of the respondents in the before study were not unduly delayed in receiving service, compared to approximately 90 percent in the after study.

Motorist-Aid System Use

There were 17 689 activations registered on the audio tapes from motorist-aid calls between April 1973 and April 1974. This represented nearly 85 percent of the estimated 20 846 system activations during that period.

The activations were classified into five categories: incident-first call (no previous calls), duplicate call [previous call(s) regarding the incident], return call by police (aid arrangement or additional information), maintenance call, and others (bad connections, prank calls, and false calls). Table 1 gives the breakdown of the system activations and shows that 65 percent of the activations were incident related.

The primary reasons for use of the aid telephone and the related types of action by the dispatcher are given in Table 2. The major reasons were vehicle disability (63.3 percent), information (26.5 percent), and accidents (4.0 percent).

Dispatcher actions in cases of disability included sending a service vehicle (60 percent), placing a call to a local contact (18 percent), giving information as to availability of service (12 percent), and sending a police patrol (8 percent). For information calls, information was given directly (84 percent), police were sent to help (15 percent), and the dispatcher made a call elsewhere for information (0.4 percent). For accident calls ambulances were sent (8.1 percent), and police were sent (81.4 percent). For fires, five units were sent (40 percent), and police were sent (47.7 percent).

Further analysis showed that aid-telephone calls are made by the stopped-vehicle occupants (78 percent), passing motorists (15 percent), police patrols (4 percent), and others (3 percent). Of the vehicle occupants who made calls, 81 percent drove to the telephone terminal, 18 percent walked, and 1 percent received a ride to the nearest telephone. In addition, 3.5 percent of all calls were made from telephones located opposite the direction of travel for the reported incident.

Calculations based on a rate of one aid-candidate stop for every 32 000 vehicle•km (20 000 vehicle miles)

Table 1. Recorded and estimated system activations.

System Activation	Recorded	Estimated	Percentage
Incident-first call	8 646	10 191	48.9
Duplicate call	1 985	2 339	11.2
Return call by police	877	1 033	4.9
Maintenance call	2 883	3 397	16.3
Others	3 298	3 886	18.7
Total	17 689	20 846	100.0

Table 2. Reasons for use of aid telephone and related dispatcher actions.

		Dispatcher Actions (percentage of action by category)								
Reason	Percentage of Calls	Gave Information	Sent Police	Sent Fire Unit	Sent Ambulance	Sent Tow Truck	Sent Service Unit	Placed Telephone Call	Other	Total
Vehicle disability	63.3	11.5	8.2	—	—	10.8	49.3	18.0	2.2	100
Fire	0.7	3.1	47.7	40.0	—	1.5	—	3.1	4.6	100
Accident	4.0	1.2	81.4	0.6	8.1	4.1	1.7	0.6	2.3	100
Illness	0.4	26.5	61.8	—	2.9	—	—	5.9	2.9	100
Automobile in ditch	2.7	1.7	59.5	—	0.4	34.2	0.8	2.1	1.3	100
Make telephone call	1.6	4.4	0.7	—	—	—	—	35.3	59.6	100
Information	26.5	83.8	14.7	—	—	—	—	0.4	1.1	100
Other	0.8	2.9	52.2	—	—	1.5	2.9	4.3	36.2	100
Percentage of total calls	100.0	29.8	15.0	0.3	0.3	7.9	31.3	12.2	3.2	100

of travel and nearly 1.45 billion vehicle·km (846 million vehicle miles) of travel during the after study period give an estimate of 42 300 aid candidates stopped along I-80. This gives the following overall system-use measures of effectiveness:

Ratio	Value
System utilization	0.24
System efficiency	0.23
System success	0.98

Communication-System Reliability

Data on failure of the system hardware were collected for the period from mid-April 1973 to mid-April 1974. The 1501 equipment malfunctions were due to circuitry failure (96.4 percent), vandalism (2.1 percent), cable cuts (0.5 percent), and accidents (1.1 percent). A major cause for circuitry failure was lighting, which was later rectified by circuit modification.

The expected number of daily failures was 4.1, with a mean time between failures of approximately 6 h. The probability of system availability at any particular time was 0.93 with 7 percent of the telephone terminals out of order at any particular time.

System Evaluation: Summary

There were several difficulties in conducting a statistically sound evaluation of the motorist-aid system. The foremost was the energy crisis that prevailed during the latter part of the after study period (January 1974 to April 1974). The crisis affected the availability and quality of service on the one hand and the total travel and travel time on the other. No restructure of the study to enable the evaluation of these effects and their impact on the effectiveness of the motorist-aid system was possible. However, an adjustment factor was introduced to reduce these effects.

During the study period, an organizational change took place in districts 5 and 7 of the state police. These changes, however, were not necessarily to reflect the operation of the motorist-aid system, and thus the full impact of the system on the level of police patrolling could not be established.

The data-collection task was very involved and required the cooperation of the motoring public and many public and private agencies. However, the length of the study (5 years) definitely affected the enthusiasm of the participating agencies, as evidenced by the relatively small data samples. In summary, the following values of system-use measures of effectiveness and response times are considered to represent the before and after situations:

Measure of Effectiveness	Before	After
System-utilization ratio	–	0.24
System-efficiency ratio	–	0.23
System-success ratio	–	0.98
Time to detect an incident, min	15.5	12.5
Time to scene, min	20.2	16.6
Time on scene, min	23.1	17.8
Time to aid center or base, min	31.7	25.4

BENEFITS AND COSTS

Determining the overall benefits due to the motorist-aid telephone system involves tangible and intangible benefits of which the relative importance and value are often difficult to determine.

The tangible measures of effectiveness or benefits considered in the analysis included the following: aid-candidate involvement time in an incident, number of secondary accidents, number of accidents involving telephones, level of police patrol, system-utilization ratio, system-efficiency ratio, and public acceptance. The intangible measures of effectiveness included the following: value of the system to Illinois Department of Transportation, value of the system to the state police, value of the system to national and state policies regarding aiding motorists on rural freeways, and quality of the service of assisting agencies.

Table 3 gives the before and after values for the tangible measures of effectiveness. As with any before and after study, the differences in values cannot be precisely attributed to the effects of the system in question. However, in this case, if it were assumed that the changes were fully caused by the aid telephones, and furthermore, that 1 h of time was worth \$4.00, then the time saving per incident would be approximately \$1.00 for every vehicle occupant. Since 9935 out of 10 102 aid candidates actually received aid, if vehicle occupancy is 1.8, the time saved due to the system is worth nearly \$17 883.

There are several estimates of the losses involved with fatal, injury producing, and damage producing accidents. The National Safety Council estimate (1972) is as follows (5):

Accident	Loss (\$)
Fatal	82 000
Injury	3 400
Damage	480

If the difference in the number of secondary accidents after adjusting for the energy-crisis factor had been due to the availability of the motorist-aid system, then the yearly saving would have been approximately \$140 000 (1972), including the loss due to the accidents involving the aid telephone (3 injuries and 10 damages).

Assigning monetary values to human life and limb can also be approached from the standpoint of the lost individual income in future years and other factors and result in extremely large benefits for even one serious incident. In such cases, any apparent reduction in fatal accidents or injuries can be expanded into substantial monetary benefits.

The yearly costs of highway patrol personnel and vehicle operation were approximately \$526 000 in the before study period and approximately \$782 000 in the after period. This represents an increased cost of nearly \$255 000/year, which the state police attributed to factors other than the telephone system.

To estimate the cost of the motorist-aid telephone system, per aided call, annual system costs were computed based on a system life of 10 years (1973 to 1983), an 8 percent interest rate, and an 8 percent inflation rate. For simplicity in the analysis, it was assumed that all costs involved in the program development and implementation were invested at the initial point in time. The total annual costs for the first 2 years considered the maintenance cost as part of the system implementation phase. For the remaining 8 years of the life of the system, an average maintenance cost based on a 1975 base cost of \$140 000 and an 8 percent inflation rate were used. These costs, however, exclude system construction and maintenance supervision. Table 4 presents the system cost analysis.

The cost of the system per aided call, or the subsidy per aided call, could be evaluated with respect to two investment situations: development and installation of the I-80 system or continuing operation of the I-80 system beyond 1976.

Before proceeding with the analysis, it is necessary to estimate the average number of aided calls per year for the first 2 and for the remaining 8 years of the economic life of the system. A ratio of 7.3 aided calls/million vehicle•km (11.7/million vehicle miles) was found based on 1973 and 1974 data. If it is assumed that the annual increase in traffic will be 4 percent and that the above ratio will remain constant throughout the economic life of the system, the average numbers of aided calls per year for the first 2 and the remaining 8 years are estimated to be 10 000 and 12 500 respectively. If aided calls are further classified into critical calls and noncritical ones, where critical calls are those due to disability, accident, fire, or an automobile in a ditch, then according to Table 2, the critical calls were 71.1 percent of the aided calls. The projected critical calls for the first 2 and the remaining 8 years are then estimated to be 7181 and 8887 respectively.

In the first investment situation, the costs per aided call and per aided critical call during the first 2 years (1973 to 1975) were estimated to be approximately $27 and $37 respectively. For the remaining 8 years, the average costs per aided call and per aided critical call were estimated to be approximately $37 and $52 respectively.

In the second investment situation, the costs per aided call and per aided critical call would be approximately $15 and $21 respectively.

If the differences in the values of the measures of effectiveness (time saved and reduced accidents) are considered to be results of the availability of the system only, subtracting their monetary value (adjusted for inflation) from the annual system cost gives a cost per aided call of approximately $10 for the first 2 years of operation (1973 to 1975). When the average maintenance cost and the ever-increasing monetary value of saved time and reduced accidents are considered, the average benefit-cost ratio during the remaining life of the system should be approximately 2 to 1, and when the total investment and the above benefits are considered, the benefit-cost ratio is in the range of 0.6 to 0.7.

Table 3. Summary of measures of effectiveness.

Measure	Before	After	Change (%)
Aid-candidate involvement time in incident, min			
Ends on scene	58.8	46.9	20
Ends at aid center	90.5	72.3	20
Number of secondary accidents/year	71	27	50[a, b]
Severity of secondary accidents			
Fatal (personal)	2; 1[a]	0	1[a, b]
Injury (personal)	32; 25[a]	4	84[a, b]
Damage	37; 28[a]	23	19[a, b]
Number of accidents involving telephone poles	0	13[c]	13
Level of police patrol (officers and vehicles)			
District 5	9 and 9	7 and 7[d]	22
District 7	6 and 6	9 and 9[d]	50
System-utilization ratio	—	0.24	—
System-efficiency ratio	—	0.23	—
System-success ratio	—	0.98	—

[a] Adjusted for energy shortage and impact of speed-limit reduction.
[b] Sample too small for statistical significance.
[c] Three injury accidents and 10 damage accidents.
[d] Changes in police patrol level due to organizational changes.

Table 4. Estimated costs of motorist-aid system.

Item	Total Cost ($)	Annual Cost ($)
Program development (feasibility study, program administration, evaluation)	240 300	49 766
System implementation (design, purchase, installation, training, and maintenance for first 2 years)	1 055 300	218 552
Total annual cost (first 2 years)	—	268 318
System operations [maintenance (based on 1975)]	—	190 400
Total annual cost (last 8 years)	—	458 718

SUMMARY OF FINDINGS

1. More than 10 000 motorists/year seek aid through the I-80 aid telephone system.
2. Approximately 24 percent of all I-80 aid candidates use the motorist-aid system.
3. Approximately 98 percent of the aid candidates who call successfully receive aid.
4. Approximately 23 percent of the aid candidates on the facility are successfully aided by the motorist-aid system.
5. Approximately 46 percent of the I-80 accidents are reported through the aid telephones, with 72 percent of such calls made by passing motorists.
6. The average time between incident occurrence and police notification was reduced from 15.5 to 12.8 min in the after period and to 9.6 min when the aid telephones were used.
7. The primary reasons for use of the aid telephone were vehicle disability (63.3 percent), information request (26.5 percent), and accident (4.0 percent).
8. The primary dispatcher actions were sending tow trucks or other service units (39.2 percent), providing information (29.8 percent), and sending a police vehicle (15.0 percent).
9. Calls from aid telephones are made by stopped-vehicle occupants (78 percent), passing motorists (15 percent), police patrols (4 percent), and others (3 percent).
10. Of the vehicle occupants making calls, 81 percent drove to the terminal, 18 percent walked, and 1 percent received a ride to the nearest telephone.
11. The telephone system operates at 93 percent reliability, because 7 percent of the telephones are out of service at any particular time.
12. The opinion of a sample of telephone users is favorable and indicates recognition of reduced travel delays when compared with that of a before sample.
13. The after study period showed reduced incident response times of 20 percent and reduced secondary accidents of 50 percent.
14. During the after study period, the system telephone poles were involved in 13 accidents.
15. When the total investment is considered, the motorist-aid system costs per aided call and per aided critical call for the first 2 years of operation are approximately $27 and $37 respectively.
16. When the total investment is considered, the expected costs per aided call and per aided critical call for the remaining system life (8 years) are approximately $37 and $52 respectively.
17. When only the operating costs are considered, the expected costs per aided call and per aided critical call for the remaining 8 years of the economic life of the system are approximately $15 and $21 respectively.
18. Analysis of the effectiveness of the system indicates that if the adjusted reduction in secondary accidents is wholly attributed to the availability of the aid telephone system, then the expected benefit-to-cost ratio for the remaining economic life of the system, considering accident reduction and time saved only, is approximately twice the average maintenance cost or in the 0.6 to 0.7 range for the total investment.

Table 5. I-80 and I-87 motorist-aid systems.

Item	I-80	I-87
Type of system	Two-way communication; buried cable; call-back feature	Two-way communication; buried cable; no call-back feature
Length, km	221	287
Number of telephones	302	712
Avg spacing of telephones, km	1.4	0.8
Number of control consoles	2	5
Total travel, billion vehicle·km	1.36 (1973)	1.15 (1969)
System-use ratio	0.24[a] (1973)	0.71[b] (1968)
Number of accidents	723 (1973)	488 (1968)
System cost, $	1 055 300[c] (1973)	692 234 (1968)
System cost per telephone, $	3494	974
Annual maintenance cost, $	85 000 (1975)	137 500 (year unknown)
Annual maintenance cost per telephone, $	281	193
Maintenance agency	Private contractor	Telephone company
Benefit-cost ratio	0.6 to 0.7[d]	0.10[d]
Cost per aided call, $	31[e]; 30[f]	19[g]

Note: 1 km = 0.62 mile.

[a] Based on one aid-candidate stop/32 000 vehicle·km (1 stop/20 000 vehicle miles).
[b] Based on expanded stopped-vehicle survey.
[c] Includes maintenance cost for 2 years.
[d] Benefits might not be comparable.
[e] Based on 10-year economic life (interest rate 8 percent, inflation rate 8 percent).
[f] Based on 20-year economic life (interest rate 8 percent, inflation rate 8 percent).
[g] Based on 20-year economic life (interest and inflation rates and whether included unknown).

CONCLUSIONS AND RECOMMENDATIONS

At the outset of this project, the need for a cost-effective operation was not a critical issue because of the low probability of achieving such a positive ratio in a rural environment. However, the secondary goals, which involved optimization of certain system functions, included the desire for an optimal allocation of resources.

While the study results indicate favorable trends toward achieving these goals, the use and value of the aid telephone system to the various parties and issues involved—the motoring public, the state police, the Illinois Department of Transportation, and national and state policies on implementing motorist-aid systems on rural freeways—vary in degree and importance.

Definitely, to the motoring public, the use and value of the system are quite high. Aid candidates were able to reduce the time to notify a service agency of their need by nearly 6 min, and the overall average reduction in time involved with an incident was approximately 15 min. This reduced the hazard caused by the motorist in distress as expressed in a reduced number of secondary accidents during the after study period. Also, the system helps to instill a sense of safety and security in the driver who knows that if something happens, help can be reached.

The use of the system to the state police could not be fully evaluated because of the reorganization within the police districts having jurisdiction over the study section. However, they have recently said that, while they did not encourage the original installation of the emergency call service on I-80, it is now very important because the patrols are organized to fit this type of operation, and if the telephones were removed, a far heavier concentration of patrols would be required. This, of course, indicates that the police consider the system as an integral part of the service and use it to their satisfaction.

The major function of the Illinois Department of Transportation, as of any other department of transportation, is to provide for a safe and efficient movement of people and goods. The availability of the motorist-aid system definitely aids in fulfilling this function. In an economy with dwindling financial resources, the investment in services to the motoring public contributing to these resources should be based on statewide priorities. In the case of the I-80 motorist-aid system, where the contribution to the resources is not through its use but through the use of the highway facility itself, the low benefit-cost ratio of the system, ranging between 0.6 and 0.7, is a crucial issue.

Any decision about the future of the system or the installation of a new and similar one should consider, among other things, the following: (a) public relations, (b) the degree of use of the system by the motoring public, (c) traffic safety, (d) reduction of the cost of the system by the reduction of its size, and improvement of its reliability while maintaining an acceptable level of service, and (e) citizens band (CB) radios.

To improve the rating of the system among other systems or projects competing for funds, it is necessary to improve its benefit-cost ratio. This can be done by increasing the benefits, reducing the cost (maintenance), or both.

The study findings indicate that, at most, 24 percent of the aid candidates used the system, and 23 percent of them successfully received aid. According to a suggested guideline (1), the latter percentage indicates a marginally effective system. An increase in public awareness of the motorist-aid system services could increase the use of the system, which would yield higher benefits.

Nearly 83 percent of those who used the system drove to the terminal, which suggests that a greater spacing of terminals could achieve a similar system-use ratio for a smaller system maintenance cost. The spacing could be even greater at the vicinity of interchanges where access to aid is less remote. The effect of greater spacing on the time saved by the motorist should not be drastic if, for instance, the spacing were increased to 3.2 km (2 miles).

As to national and state policies on implementing motorist-aid systems on rural freeways, conclusions about some technical aspects of such a system could be made. The two-way voice communication system with call-back features proves to be very effective and has an advantage over other communication systems, because it enables relay of full information and needs in both directions and return calls to the aid candidate if more information is necessary.

As to the implementation of such a system on similar facilities in Illinois, the issue of the low benefit-cost ratio emerges as a critical one, although some significant intangible factors are involved. However, when the motorist-aid system on I-80 in Illinois is compared with the one on I-87 in New York (6), the I-80 system appears to compare favorably with the one on I-87, even though the installation and maintenance costs per telephone are higher for the Illinois system, and its use is approximately one-third of that in New York. A major factor in considering the implementation of future motorist-aid systems in Illinois should be the ability to bring the installation and maintenance costs to more attractive levels.

Because of the findings of this study and the increased use of CB radios, it is recommended that a feasibility study to incorporate CB radios into a motorist-aid system on I-80 should be conducted. However, to improve the benefit-cost ratio of the existing I-80 motorist-aid system, the following should be undertaken:

1. Develop and implement a public information program to increase the awareness of the motoring public to the motorist-aid system and its service capabilities;
2. Study and improve the system circuitry to increase its reliability and reduce the maintenance costs; and
3. Analyze and implement lower cost maintenance procedures, and make changes in the configuration of the

system to reduce maintenance requirements.

DISCLAIMER

The contents of this paper reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein.

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