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Contents

Methodology for Ranking Roadside Hazard Correction Programs

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This paper describes the development and use of a computerized system to facilitate the prioritizing of roadside fixed-object treatments. Developed for the Traffic Engineering Branch of the North Carolina Division of Highways, the system is designed to perform economic analyses of various fixed-object improvements on an areawide, or roadway segment, basis, for example, determining the effect of removing all trees within 9 m (30 ft) of the edge of pavement on rural, two-lane, secondary roads in the piedmont area of North Carolina. Developed inputs for the system include: (a) frequency and severity of the most affectable accidents for each given hazard-treatment combination, (b) expected reductions in fatal, injury, and property damage only accidents associated with implementation of the treatment, and (c) initial, maintenance, and repair costs over the service life of each treatment. System outputs include predicted accident savings, the net discounted present value and benefit-cost ratio for each candidate fixed-object treatment, and a priority ranking based on comparisons of net present value. Initial runs using the system indicated that the use of transition guardrail at hazardous bridge ends and tree removal in certain locations in North Carolina appear promising. System developmental efforts also reemphasized the continuing presence of a serious national problem—the lack of sound information concerning effectiveness levels for fixed-object countermeasures.

In recent years, more attention has been given to highway programs that are designed to make the roadside environment safer and, consequently, to lessen the severity of crashes associated with off-the-road hazards. Since funding for such programs is limited, developing cost-effective approaches to the problem is essential.

In an attempt to provide highway administrators and engineers with an economical tool to facilitate the prioritization of roadside fixed-object treatments, a computerized system was developed by the University of North Carolina Highway Safety Research Center (HSRC) for the Traffic Engineering Branch of the North Carolina Division of Highways (DOH). An accompanying user's manual was developed as an aid to engineers and computer programmers using the system.

An economic analysis of various roadside safety improvements on an areawide basis included a determination of the frequency and severity of the most affectable accidents for each treatment based on North Carolina accident data. In addition, the expected reductions in fatal, injury, and property damage only (PDO) accidents associated with the implementation of the treatment were analyzed. Benefits were developed based on accident savings by assigning dollar costs to fatal, injury, and PDO accidents. Improvement cost components included initial, maintenance, and repair costs over the service life of each treatment. The Net Discounted Present Value (NDPV) for each hazard-treatment combination was determined through economic analysis, and a priority ranking was developed based on comparisons of net present value. For alternatives with different service lives, the equivalent annual cash flow was calculated.

The system producing the priority ranking of roadside improvement programs was developed to analyze areawide improvements rather than spot improvements on which most existing fixed-object programs focus. Programs aimed at fixed-object spot locations are based on the assumption that a given hazard will be struck with a high enough frequency to be detected. Unfortunately, this is rarely the case. Rather than a specific hazard's (e.g., an identifiable tree) being struck numerous times, the roadside hazard problem evolves from the fact that a number of different hazards, perhaps of the same type, are struck numerous times. Any given hazard is struck with very low frequency, usually less than once per year. Hence, there is a need for a methodology to rank roadside fixed-object correction programs on an areawide basis.

The areawide approach attempts to identify hazards along an expanded spot that includes roadway segments on more than one route. What will be identified in this procedure is a given hazard with an appropriate treatment for a given type of roadway segment.

This methodology will allow the user to perform the economic analysis for a particular hazard-treatment combination for any expanded spot ranging from a statewide area to a much smaller area. The variables defining a specific area include the following:

1. Location (urban or rural);
2. Area in the state (coastal plain, piedmont, mountain);
3. Highway type (Interstate, U.S., state, secondary road, city street);
4. Number of lanes (two lanes, four or more lanes undivided, four or more lanes divided—for rural areas only);
5. Highway character (intersection, nonintersection);
6. Highway features (tangent section, curve section); and
7. Median width—0.3-3.6 m (1-12 ft), 3.9-9 m (13-30 ft), 9.3-18 m (31-60 ft), over 18.3 m (over 61 ft).

The first two columns of Table 1 list the roadside hazards and treatments examined for the analysis program that was developed. For example, the design methodology will allow one to analyze a combination such as a program aimed at removing all trees from the roadside on all curved, nonintersection segments of two-lane, North Carolina highways in the rural regions of the coastal plain. The benefits from this particular combination could then be compared to the benefits from any other hazard-treatment-segment combination that is defined.

METHODOLOGY

The basic research design used in this study is an extension of a system employed in an earlier one by Council and Hunter (1) and performed for the Motor Vehicle Manufacturers Association of the United States, Incorporated (MVMA). The present study, however, deals only with fixed-object accidents and related countermeasures rather than roadway safety countermeasures of all types. Figure 1 is a schematic representation of the basic tasks leading to the priority ranking of fixed-object improvement programs.

Determination of Accident Reduction Factors

Calculating the accident reduction factors was, perhaps, the most important input to the economic analysis phase. First, a literature review of fixed-object countermeasure evaluations was conducted. Many of the reports, unfortunately, had poor study designs, particularly before and after designs with no control groups. It was concluded from this literature search that more and better-conducted evaluative studies dealing with fixed-object improvement should be performed and published.

Another data source that provided limited information was the file of before and after studies compiled by the Traffic Engineering Branch of the North Carolina Division of Highways. It contained approximately 400 improvement studies on subjects such as delineation, channelization, and signal installation, but few pertaining to roadside fixed-object treatments.

Twelve state highway departments were contacted for

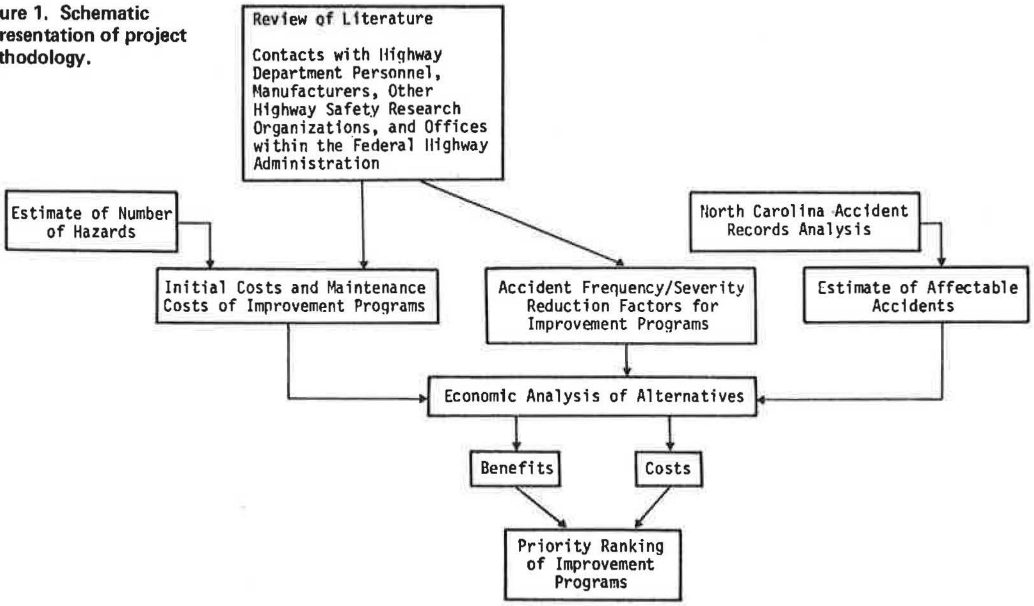
Table 1. Summary of hazard-treatment information.

Hazard	Treatment	% Reduction[a]			Cost ($)			Service Life (years)	Comment
		Fatal	Injury	PDO	Initial	Maintenance	Repair		
Utility poles	Breakaway	30	-1	0	36/pole	0	250/pole	10	Rural intersection, non-intersection
		30	-1	0	36/pole	0	550/pole	10	Urban intersection, non-intersection
		30	-1	0	36/pole	0	250/pole	10	Rural intersection
		30	-1	0	36/pole	0	550/pole	10	Urban intersection
	Relocate 9 m from edge of pavement	32	-1.7	0	375/pole	0	200/pole	20	Rural non-intersection
		32	-1.7	0	375/pole	0	500/pole	20	Urban non-intersection
		32	-1.7	0	375/pole	0	200/pole	20	Rural intersection
		32	-1.7	0	375/pole	0	500/pole	20	Urban intersection
	Remove	38	-1.5	0	930/pole	0	0	20	Rural non-intersection: cost/pole includes $11/m to bury cable at pole spacing of 75 m
		38	-1.5	0	1600/pole	0	0	20	Urban non-intersecting: cost/pole includes $20/m to bury cable at pole spacing of 75 m
		38	-1.5	0	435/pole	0	0	20	Rural intersection: cost/pole includes $11/m to bury cable for 90 m of cable required
		38	-1.5	0	850/pole	0	0	20	Urban intersection: cost/pole includes $20/m to bury cable for 150 m of cable required
Trees	Remove	50	25	-20	30/tree	0	0	10	Rural and urban (without removal of stump)
		50	25	-20	60/tree	0	0	10	Rural and urban (with removal of stump)
Exposed bridge rail ends	Transition guardrail	55	20	-50	1950/end	0	400/hit	15	Rural and urban, 2 lanes with 30 m total of approach or trail guardrail per end
		55	20	-50	5550/end	0	400/hit	15	Rural and urban, 4-lane (divided and undivided), 120 m of guardrail/exposed bridge end
Substandard bridge rail	Improved rail (three beam)	15	5	-3	83/m	0	50/hit	20	Rural and urban
Underpasses (bridge piers)	Concrete median barrier with end treatment	60	40	-150	12 100/site	0	350/hit	20	Rural and urban, 4-lane divided, median piers
		60	40	-150	6000/site	0	350/hit	20	Rural and urban, 2-lane, 4-lane undivided, shoulder piers
	Attenuators:								
	Water-filled cushion	75	60	-300	24 000/site	0	500/hit	10	Rural and urban, 4-lane divided, median piers
		75	60	-300	24 000/site	0	500/hit	10	Rural and urban, 2-lane, shoulder piers
		75	60	-300	12 000/site	0	500/hit	10	Rural and urban, 4-lane undivided, shoulder piers
	Sand-filled cell	75	60	-300	10 000/site	0	800/hit	10	Rural and urban, 4-lane divided, median piers
		75	60	-300	10 000/site	0	800/hit	10	Rural and urban, 2-lane, shoulder piers
		75	60	-300	5000/site	0	800/hit	10	Rural and urban, 4-lane undivided, shoulder piers
	Steel barrels	75	60	-300	17 000/site	0	700/hit	10	Rural and urban, 4-lane divided, median piers
		75	60	-300	17 000/site	0	700/hit	10	Rural and urban, 2-lane, shoulder piers
		75	60	-300	8500/site	0	700/hit	10	Rural and urban, 4-lane, undivided, shoulder piers
Rigid signs or supports									
Small sign	Breakaway	70	25	-12	70/sign	0	100/sign	5	Rural and urban
Large metal support	Breakaway	60	20	-20	300/pole	0	150/sign	10	Rural and urban
Large metal support	Relocate behind guardrail	55	30	-5	125/sign	0	100/sign	10	Rural and urban (assumes no guardrail cost)
All supports combined	Breakaway	68	24	-14	100/sign	0	110/sign	5	Rural and urban
Guardrail ends	Breakaway cable terminal	55	25	-15	350/end	0	350/end	15	Rural and urban, median and shoulder
	Turned down Texas terminal	55	25	-15	300/end	0	300/end	15	Rural and urban, median and shoulder
Median-involved accidents									
Narrow median	Concrete median barrier	90	10	-10	66 000/km (67/m)	0	0	20	Rural and urban; median width, 0.3-3.6 m
		85	5	-25	66 000/km	0	0	20	Rural and urban; median width, 3.9-9 m
Wider median	Double-faced guardrail	75	2	-28	49 500/km	0	500/hit	15	Rural and urban; median width, 0.3-3.6 m
		85	5	-30	49 500/km	0	500/hit	15	Rural and urban; median width, 3.9-9 m
		85	5	-30	49 500/km	0	500/hit	15	Rural and urban; median width, 9.3-18 m

Note: 1 m = 3.3 ft; 1 km = 0.6 mile.

[a] Minus sign indicates an increase in the proportion of accidents.

Figure 1. Schematic representation of project methodology.



any available information. Some states furnished reports in the form of aggregated before and after studies, and a few provided specific studies of fixed-object improvements. Several offices within the Federal Highway Administration (FHWA) were contacted, including the Office of Research, which provided useful information concerning both ongoing research and completed, but unpublished, research.

Based on these data sources, the final estimates of accident reduction factors were developed. Again, it was concluded that very little evaluation data exist for these roadside fixed-object programs. For treatment categories where a number of studies existed, the accident reduction factors were compared, and more weight was given to those with sound study designs. Most of the final composite reductions, or increases, were compared to a series of estimates developed by FHWA research engineers under a contract that seeks to prioritize targets for future research and development (2). The accident reduction figures, therefore, are the best current estimates of effect and should be systematically updated to reflect results of new research.

Determination of Initial and Maintenance Costs for Improvement Programs

Other necessary inputs to the economic analysis system are the initial treatment costs and maintenance costs. The literature review provided some cost data (3), but the major part of the cost data was supplied by state highway departments, research organizations, and manufacturers of safety equipment. Once this information was obtained, all cost figures were compared with current North Carolina costs. Follow-up meetings with field maintenance personnel provided data useful in developing average repair costs per crash for several hazard-treatment categories.

After compilation of all available accident reduction and cost data, a list of appropriate treatments and accompanying costs for each hazard was developed (see Table 1).

Estimation of Affectable Accidents

In analyzing any improvement program it is essential to determine the frequency of accidents that could be reasonably expected to be related to that improvement program. For example, if one is considering placing transition sections of guardrail around unprotected bridge ends, then the affectable accidents are those involvements where an untreated bridge end was struck.

For deriving estimates of affectable accidents, the most useful data source would be one in which accident data are merged with roadway geometric characteristics. Although such a data base is currently being developed in North Carolina, it did not exist for this project. Because of this, four different data files had to be merged to obtain estimates of annual proportions of affectable accidents for each roadside hazard.

The process followed in developing estimates of affectable accidents may be summarized as follows:

1. A composite estimate of the accident proportion for each hazard by highway segment (e.g., proportion of total statewide accidents involving utility poles on rural, U.S., two-lane tangent sections) was developed based on 3 years of accident data (1973-1975).
2. An estimated number of total North Carolina accidents for 1979, the base year used in all subsequent analyses, was developed from trends in past accident data (using a 6 percent incremental factor, a total of 164 889 accidents for 1979 was estimated).
3. The treatment-by-treatment composite proportions were multiplied by the 1979 totals to derive affectable frequencies of accidents for each hazard-treatment combination (these frequencies were used in all subsequent economic analyses).

In determining affectable accidents for this study, only single-vehicle accidents were considered. When a fixed object is struck in multivehicle collisions, there is no way of accurately determining when injury occurs, i.e., during the vehicle-to-vehicle crash or the subsequent vehicle-to-fixed-object collision. Thus, an injury or death occurring in a multivehicle collision may or may not be affected by treating a fixed object.

The restriction of affectable accidents to those involving only single vehicles, of course, will cause the final economic analysis outputs to be somewhat conservative. Thus, when interpreting the final results (and in subsequent use of the developed computerized system), the reader should be aware that programs shown to pay off would, in reality, pay off at a slightly higher rate, and those programs close to the breakeven point (i.e., a slightly negative NDPV) might be cost beneficial.

As indicated here, development of the composite estimates of these affectable accident proportions was a multistaged effort. First, the 1973-1975 North Carolina Accident Tapes were analyzed to develop tabulations of single-vehicle accident frequencies according to (a) fixed object struck, (b) geographical area, (c) rural or urban location, (d) highway type, and (e) accident severity. Second, because of the need for more specific information concerning point of impact in bridge-related crashes (i.e., bridge rail, bridge end) and in guardrail crashes (i.e., guardrail proper versus guardrail end), the accident sketches and narratives from the 1974 and 1975 accident report hard copies were manually examined. Third, because information concerning whether a fixed-object crash occurred on a curve or tangent section did not exist on the 1973-1975 data set, 1971-1972 data (where such a variable did exist) were used to form the same tabulations (e.g., area, urban/rural, highway types), but with the additional curve/tangent breakdown. This 1971-1972 information was then used to distribute the 1973-1975 accident data by curve versus tangent sections, assuming that the earlier curve/tangent accident proportions were applicable to the later years. This was done for all fixed-object categories except underpasses, bridges, and guardrails, where preliminary tabulations indicated that further expansion was impractical.

Finally, in order to partition the data by number of lanes, an additional tape containing data for North Carolina rural primary highways was developed and analyzed to further distribute the data into the categories of two lanes (2), four or more lanes undivided (4U), and four or more lanes divided (4D).

Thus, 3 years of single-vehicle accident data were distributed by roadway segment, the proportion of total accidents, and an accident severity distribution comprised of the proportions of fatal, injury, and property damage only (PDO) accidents for a particular fixed object. For example, the following table is based on data for fixed objects (trees) and roadway segment (rural, coastal plain area, Interstate, 4D, tangent):

Item	1973	1974	1975
Accident severity proportion:			
Fatal	0.000	0.068	0.127
Injury	0.434	0.308	0.404
PDO	0.566	0.625	0.469
Overall proportion	0.000 100 387	0.000 107 000	0.000 106 371

From these three estimates, the following composite estimate was formed:

Accident Severity	Overall Proportion
Fatal = 0.080 Injury = 0.325 PDO = 0.595	0.000 107 000

As noted earlier, 1979 was chosen as a base year since no additional fixed-object treatment programs could be implemented before then. Based on past accident trends, a total of 164 889 accidents were predicted for that year. Thus, to obtain the total number of affectable accidents for the hazard/roadway segment in the above example, the composite overall estimate is multiplied by 164 889. Then the total number of affectable accidents is multiplied by the composite accident severity proportions to provide the distribution of injuries for this hazard/roadway segment. In the computerized system, these overall accident and injury proportions are stored as internal data.

Estimate of Hazards

The final major component in this overall analysis methodology is the number of hazardous fixed objects beside the roadway. In order for the developed methodology to be implemented, frequency counts had to be developed for each of the ten categories of hazards shown in Table 1 and subdivided by location, area of the state, roadway type, number of lanes, roadway feature (e.g., curve, tangent), and roadway character (e.g., intersection, nonintersection).

Data concerning hazardous fixed objects were developed from two basic sources. First, where retrievable data existed, DOH computer files were analyzed to determine the necessary frequencies. Computerized information was available for hazardous bridge components (i.e., bridge ends, bridge rails, and bridge piers), and for hazardous medians on divided highways. Where such DOH data files did not exist, the basic source of information was a 1974 Traffic Engineering Branch report entitled Roadside Fixed Object Hazards Inventory (4). In this study, frequencies of eight classes of roadside fixed objects were developed from samples collected on different roadway segments in 17 North Carolina counties. In each sampling area, actual counts of hazardous obstacles were made in a windshield survey. Technicians conducting the inventory were instructed on what was to be considered hazardous in all cases. The data from these samples were expanded in the original study to provide estimates of the fixed-object frequencies for the entire state. In this study, data concerning guardrail ends, signs and luminaires, trees, and utility poles were extracted.

These estimates of hazards per kilometer (grouped by location, highway type, and number of lanes) were further examined in order to determine where obvious sample size-related inconsistencies appeared either between highway types, between number of lanes within highway types, or between rural and urban areas. These inconsistencies were then corrected based on two general assumptions concerning (a) the similarity of certain roadway types (e.g., 4D U.S. and 4D North Carolina routes are basically new sections of roadways), and (b) observation of trends within a given highway type when shifting from one roadway class to a higher order roadway class (i.e., the trend from U.S. 2-lane to 4U to 4D segments should be similar to the trend from North Carolina 2-lane to 4U to 4D). The estimates of hazards per kilometer were then converted to total frequencies per segment for each of the roadway segments by multiplying by the number of kilometers in each segment file.

It should be noted that estimated hazard frequencies for the three areas of the state were calculated by multiplying these average estimates of hazards per kilometer by the total kilometers for the different areas (coastal plain, piedmont, mountains). Thus, the underlying assumption was that the same number of hazards per kilometer would be found in all of the three areas across the state. This critical assumption had to be made because of the lack of other area-specific data.

The estimates of hazardous utility poles were further subcategorized into intersection and nonintersection sites based on the distribution of intersections within each location, area, highway type, and lane configuration and on assumptions concerning the average number of poles per intersection. The estimates of utility poles, trees, and signs were further subcategorized by whether the hazard was located on a tangent or curve section, based on independent DOH estimates of the percent of total roadway that are curves within each roadway segment type.

Information concerning the number of hazardous bridge rail ends, hazardous bridge rails, and hazardous bridge piers was developed using data from an existing bridge and structures file containing information about all structures on primary and secondary roadways. First, computer runs were made in order to determine the number of bridges and the number of sets of median and shoulder bridge piers categorized by the necessary roadway segment descriptors. Based on these bridge and pier frequencies, the number of possible hazardous bridge ends and piers and the number of meters of possible hazardous bridge rails were calculated.

Next, factors representing the proportions of these possible hazards that are truly hazardous bridge ends, rails, and piers were then estimated based on the percentage of roadway kilometers built to lower standards within each area, highway type, and number of lanes. These percentages were developed from construction and reconstruction dates, segment improvement dates, and inputs from DOH engineers. The proportions were then multiplied by the possible frequencies to generate the final frequencies of hazardous ends, piers, and railing lengths.

Finally, in the analysis of cross-median accidents where a median barrier might be an appropriate treatment, the required estimate of hazardous median sections was based on a count of the number of kilometers of median by roadway type, area, location, and number of lanes from an existing roadway characteristics file. This information was further subdivided by grouping medians into widths of 0.3-3.6 m (1-12 ft), 3.9-9 m (13-30 ft), 9.3-18 m (31-60 ft), and over 18.3 m (over 61 ft). Final estimates of unprotected (hazardous) median lengths in each of these categories were calculated by deleting those sections (especially Interstate segments) where barriers currently exist and by a slight modification to account for short sections now protected by barriers around bridge piers.

In summary, this methodology was used to estimate the number of hazards for each of the roadway segments to be analyzed. The validity of the estimates is dependent on both the adequacy of the sample used to develop the Roadside Fixed Object Hazards Inventory and the viability of the assumptions used.

ECONOMIC ANALYSIS METHODOLOGY FOR EVALUATING POTENTIAL IMPROVEMENTS

When considering the economic evaluation of various highway safety improvements, calculations involving costs, benefits, cost-effectiveness, or some combination of these are generally considered. In an attempt to provide administrators concerned with engineering improvements with a better tool for deciding how to allocate resources, the National Cooperative Highway Research Program (NCHRP) developed Methods for Evaluating Highway Safety Improvements (5). However, this report discusses several economic techniques without necessarily recommending one technique over others, although the benefit/cost ratio is recommended in the user's guide. It should also be noted that this NCHRP report has generated some comment concerning the ranking of alternatives (6).

Alternative Methods

One criticism is that it is basically unsound to rank competing alternatives on the basis of a calculated benefit/cost (B/C) ratio (6). The placement of certain costs, such as maintenance or repair costs, in either the numerator or denominator of the B/C ratio can affect the calculation in such a way as to alter any subsequent ranking based on B/C ratio (6, 7, 8). Indeed, it would appear that the numerator-denominator issue has spawned considerable debate, without a definite resolution of the issue.

Many references recommend the use of the net present worth or NDPV technique for ranking of alternatives. The NDPV method calculates the algebraic difference in the present worths of both outward cash flows (costs) and inward cash flows (benefits or incomes). The alternative with the greater NDPV is identified as the one with the greater economy. The NDPV technique was used to rank alternatives in this study, and the following specific rules were formulated:

1. For each investment in a particular safety measure, compute the service life of the project the NDPV of the measure, including capital and maintenance costs and accident benefits, using appropriate discount rates.
2. If the choice is between accepting or rejecting the investment, accept if the NDPV is greater than zero and reject if the NDPV is less than zero.
3. When comparing alternative investments, each having an NDPV greater than zero, where only one can be selected, accept the alternative for which the present value is greatest. If the time periods (service lives) encompassed by the alternative investments are not comparable, convert the two investments into average annual cash flows. Accept the alternative with the largest annual cash flow.

Due to its popularity, the B/C ratio was also developed for each alternative, with repair costs per crash subtracted from the calculated accident benefits in the numerator part of the ratio. This was done after discussions with North Carolina Division of Highways (DOH) Traffic Engineering Branch personnel indicated that, for most of the fixed-object crash-related repairs, the associated costs more closely represented a negative benefit. The denominator part of the ratio includes initial costs and periodic maintenance costs.

Other Considerations

In the performance of an economic analysis technique, numerous input data are involved. Some of the more important variables used are described here:

1. Discount rate. Based on long-term borrowing for roadway construction, a value of 6 percent was chosen.
2. Inflation rate. An inflation factor designed to reflect the increasing costs of accidents and treatments with time was included as a basic input variable. Since inflation seems to vary widely over time, average inflation rates have been estimated that correspond to three basic lives of 5, 10, and 20 years, as shown below:

Service Life (years)	Estimated Average Inflation Rate (%)	Inflation Factor
5	6.7	1.067
10	5.7	1.057
20	4.7	1.047

The appropriate inflation factor is applied to the maintenance costs, repair costs, and accidents costs in the economic analysis.

Recognizing the difficulty in predicting future inflation rates, the NCHRP report (5) recommends that no inflation factor be used in a highway economic study. However, after discussions with personnel in the Transportation Engineering Branch of the North Carolina DOH, it was decided that the above inflation factors would be used in developing the priority ranking, since they currently use similar inflation factors in other studies. Appropriate values may be input at any time the system is used in the future.

3. Service life. For the improvements used in this project, 20 years was the maximum value used (values for specific treatments are shown in Table 1).

4. Salvage values. It was felt that the use of salvage values would have a minimal effect on the outcome of the fixed-object improvements analyzed. Thus, zero salvage values were used in all cases.

5. Accident growth factor. An annual growth rate of 4 percent for untreated accidents was input into the analysis system. This growth rate was estimated by the North Carolina Division of Highways; it represents the approximate increase in yearly traffic volume. The internal computation algorithms assume that accidents are directly proportional to change in yearly traffic volume (or vehicle kilometers). This growth rate is also assumed to be constant over the service life of the project.

6. Starting year. Starting year is a basic input to the economic analysis and represents the year in which the treatment is implemented (i.e., the year preceding the initial benefit accumulation). The starting year (or year zero) for the development of the priority ranking presented in the Results section of this paper is 1979. Thus, accident benefits would first accrue in 1980.

7. Accident costs. In this analysis, benefits are derived from accident savings. Thus, costs must be associated with fatal, injury, and PDO accidents. To some, this notion of assigning costs to lives and injuries is totally unacceptable. To others, it is a necessary ingredient in the economic analysis of highway safety improvements. The concept has been used for many years by the Transportation Engineering Branch in its internal analyses.

Estimates of these accident costs vary widely, but the basis for the costs used in this study is a 1974 study by Barrett entitled Crashes and Costs: Societal Losses in North Carolina Motor Vehicle Accidents (9). Using a methodology similar to that employed by the National Safety Council, Barrett developed these costs in in 1973 dollars: fatality, $84 400; nonfatal injury, $5350; and PDO crash, $325. Expanding these numbers from an occupant to an accident base and applying the change in the consumer price index, these costs were updated from the end of 1973 in 1976 dollars with these results: fatal accident, $133 637; injury accident, $10 946; and PDO, $743.

These costs are internal inputs in the basic system. To inflate these 1976 costs to 1979 figures, an average annual inflation rate of 6.7 percent was used by the system. The computerized system expands 1976 costs to appropriate starting year dollars automatically, with the average inflation rate dependent on the length of time between 1976 and the starting year.

Computerized System

A major project goal was the development of a computerized system that would perform the economic analysis by combining all the inputs depicted in Figure 1, the schematic representation of the project methodology. Thus, the accident frequency/severity reduction factors, the estimate of affectable accidents, the estimate of hazard occurrence, the cost data, the linkage of the affectable accidents with the proper reduction factor, and the economic analysis of the alternatives are all computerized in the developed system.

The economic analysis component of the system may be activated for any hazard/treatment/roadway segment combination or combinations (i.e., any row or rows of an internal matrix) by submitting certain required user input cards. For example, one may be interested in determining the NDPV and the B/C ratio for the removal of trees within 9 m (30 ft) of the edge of pavement for the following roadway segment:

Area	Rural or Urban	Highway Type	No. of Lanes	Curve or Tangent
1	Rural	N.C.	2	Tangent

The information pertinent to the economic analysis (i.e., the accident, hazard, and treatment data) would be linked, the economic analysis portion of the system would be activated, and two output tables would be developed containing values for the predicted annual accident reductions, the NDPV, the B/C ratio, and the annual benefits.

In addition to the analysis of any number of individual hazard/treatment/segment combinations, the computerized system also contains an additional subroutine that was developed to allow users to collapse row combinations. The example presented here has been concerned with removal of hazardous trees on roadway segments defined as follows:

Area 1 Rural N.C. 2-lanes Tangent

This row collapse subroutine would allow the user to sum over certain roadway segment identifiers. For example,

Area (1 + 2) Rural (U.S. + N.C.) 2-lanes Tangent

could be studied in a subsequent economic analysis. In this example, areas 1 and 2 and U.S. and North Carolina highway types are combined for rural, 2-lane, tangent roadway sections. This feature provides the user with much flexibility.

RESULTS

Economic analyses for 942 basic hazard/treatment/segment combinations were performed. Less than one-third of this total, or 279 rows, had a positive NDPV.

The results of the ten top-ranked fixed-object improvement programs, based on NDPV, are presented in Table 2. As indicated earlier, the basic input variables included (a) a starting year of 1979, (b) 164 889 predicted accidents in 1979, (c) a discount rate of 6 percent, and (d) a traffic growth rate of 4 percent.

It is instructive to note that the top ten treatment programs in Table 2 are all concerned with either bridge ends, cross-median involvements, or trees. These top ten programs, however, have a combined total cost of approximately $61 million. The program shown to have the largest payoff was the use of transition guardrail at hazardous bridge ends for a rural, Interstate, 4-lane divided roadway in the piedmont section of North Carolina. The annual benefits for this program amount to $4.7 million, and the B/C rate is 80.54. The cost of

Table 2. Summary of 10 top-ranked, fixed-object improvement programs based on NDPV.

Rank	Hazard	Treatment	Rural or Urban	Area	Highway Type	Annual Benefit ($)	Benefit/ Cost Ratio	Treatment Cost ($)
1	Bridge ends	Transition guardrail	Rural	2	Interstate, 4-lane divided	4 717 396	80.84	599 400
2	Cross-median accidents	Concrete median barrier	Rural	2	Interstate, 4-lane divided	3 392 460	5.76	8 390 975
3	Bridge ends	Transition guardrail	Rural	2	N.C., 2-lane	3 296 543	15.32	2 326 350
4	Cross-median accidents	Double-faced guardrail	Rural	2	Interstate, 4-lane divided	2 493 450	5.00	6 293 231
5	Cross-median accidents	Double-faced guardrail	Rural	1	U.S., 4-lane divided	1 649 800	3.14	7 805 159
6	Cross-median accidents	Double-faced guardrail	Rural	1	N.C., 4-lane divided	1 495 312	8.50	2 014 055
7	Bridge ends	Transition guardrail	Rural	1	Interstate, 4-lane divided	1 138 157	61.95	188 700
8	Trees	Removal	Urban	2	City street	1 131 649	2.76	5 071 800
9	Trees	Removal	Rural	2	N.C., 2-lane	1 025 099	5.68	1 726 800
10	Trees	Removal	Rural	2	Secondary road, 2-lane	978 562	1.29	26 607 060

Note: N.C. = North Carolina route.

this treatment for this roadway segment is approximately $600 000.

Other interesting findings were gained from the examination of other row-by-row results for the specific treatment classes (many of which are not shown in Table 2). The transition guardrail for bridge ends pays off for practically all rural locations, but for only two Interstate locations in urban areas. Improved bridge rails, which could become a high priority item with FHWA in the near future, do not pay off on any roadway segment. This treatment, however, is relatively expensive.

The breakaway cable terminal (BCT) for shoulder guardrail ends appears to be most effective for rural locations in area 3, the mountainous area. The Texas twist end treatment, which was inserted for comparative purposes, exhibits similar characteristics. For median guardrail ends, both the BCT and Texas twist treatments pay off on almost all rural divided roadways.

The breakaway sign support treatment pays off on practically all rural roadway segments and quite a few of the urban segments. The same is true for the tree removal treatments, both with and without stump removed.

For unprotected shoulder bridge piers, the concrete median barrier (CMB) with guardrail treatment pays off better in coastal plain/rural locations and piedmont/urban locations than elsewhere. The three attenuator treatments for the shoulder bridge piers do not pay off nearly as well. For the unprotected median piers, both the CMB and attenuator treatments tend to pay off on rural U.S. and North Carolina roadways in both the coastal plain and the piedmont areas.

Breakaway utility poles pay off for many rural U.S. and North Carolina roadway segments in nonmountainous areas. Removing and relocating utility poles follow the same trend but do not pay off in nearly as many cases.

Finally, in terms of cross-median accidents, both the CMB and double-faced guardrail pay off for a number of rural/coastal plain and piedmont segments. The mountainous area does not show results as favorable because most of the Interstate system in area 3 already has the CMB in place.

Collapsing Results Within Treatments

Although the creation of a priority ranking such as the one discussed here is informative, it was felt that further comparisons of treatments would be helpful. Table 3 presents the results of implementing all treatments statewide (e.g., collapsing across areas, highway types, number of lanes) for rural locations. Similar information was developed for urban locations.

For rural locations, using transition guardrail at hazardous bridge ends is again the top-ranked program. Removing trees is the second-ranked program, while use of double-faced median barrier is third. Making rigid support posts break away appears to be quite effective also.

To try to further clarify these rural results, the benefits for each specific treatment within all highway types were examined. An example of the results is shown in Table 4. Transition guardrail for bridge ends pays off on all highway types except secondary roads, but is also very expensive (approximately $15.2 million for Interstate, U.S., and North Carolina routes). The Interstate routes have the highest payoff.

Tree removal (leaving ground-level stumps) pays off across all road types, but the costs are again extreme (almost $1 billion, including $79 million on secondary roads). The results indicate that U.S. and North Carolina routes should have priority. Double-faced median barrier is most effective on Interstate routes. Making rigid sign and luminaire supports break away also pays off across all highway types, with North Carolina routes appearing to have priority.

For the urban locations, only five treatments pay off. The two top programs are removal of trees with stumps and removal of trees without stumps. Transition guardrail for bridge ends, breakaway supports, and CMB for shoulder bridge piers follow in order. Tree removal (without stump) pays off on both Interstates and city

Table 3. Annual benefits, benefit/cost ratios, and costs for rural statewide treatment programs.

Rank	Hazard	Treatment	Annual Benefit ($)	Benefit/ Cost Ratio	Treatment Cost ($)
1	Bridge ends	Transition guardrail	10 041 539	3.14	47 507 249
2	Trees	Removal	8 417 187	1.67	99 113 460
3	Cross-median accidents	Double-faced guardrail	3 686 870	1.30	95 371 847
4	Cross-median accidents	Concrete median barrier	3 240 984	1.66	57 436 895
5	Signs and luminaires	Breakaway	1 715 087	8.49	1 125 900
6	Guardrail end-median	Texas twist treatment	389 293	12.02	357 000
7	Guardrail end-median	Breakaway cable terminal	381 764	10.26	416 500
8	Bridge piers-median	Concrete median barrier and guardrail	344 270	2.67	2 424 000
9	Bridge piers-shoulder	Concrete median barrier and guardrail	302 779	1.65	5 466 000
10	Guardrail end-shoulder	Texas twist treatment	179 777	1.63	2 892 000
11	Bridge piers-median	Sand-filled cells	153 597	1.60	2 020 000
12	Guardrail end-shoulder	Breakaway cable terminal	127 970	1.30	3 374 000

Table 4. Annual benefits, benefit/cost ratios, and costs for rural statewide treatment programs by highway type.

Hazard	Treatment	Highway Type	Annual Benefit ($)	Benefit/ Cost Ratio	Treatment Cost ($)
Bridge ends	Transition guardrail	Interstate	6 472 400	37.49	1 792 650
		U.S.	1 221 785	3.17	5 689 500
		N.C.	3 258 093	5.30	7 657 050
		S.R.	-910 738	0.72	32 368 050
Trees	Removal	Interstate	334 524	145.17	18 300
		U.S.	3 127 921	6.71	4 318 290
		N.C.	3 280 957	2.67	15 429 420
		S.R.	1 673 786	1.17	79 347 450
Cross-median accidents	Double-faced guardrail	Interstate	2 979 142	1.85	35 335 872
		U.S.	-344 510	0.94	54 218 736
		N.C.	1 052 239	2.83	5 817 240
		S.R.	-	-	-
Cross-median accidents	Concrete median barrier	Interstate	3 263 570	3.22	17 278 272
		U.S.	277 198	1.07	36 685 440
		N.C.	-249 783	0.15	3 473 184
		S.R.	-	-	-
Signs	Breakaway	Interstate	46 865	2.53	151 100
		U.S.	407 847	7.72	298 400
		N.C.	656 889	15.45	223 500
		S.R.	603 486	7.55	452 900

Note: U.S. = U.S. route; N.C. = North Carolina route; S.R. = Secondary Road.

streets. This reflects the large number of hazardous trees on city streets. Tree removal, including the stump, follows the same trend. The costs for these tree removal treatments, however, are enormous.

Bridge end transition guardrail pays off only on Interstate routes. No bridge end hazard estimates were available on city streets. Breakaway supports pay off on all highway types except on city streets, with the Interstate system receiving priority. Protecting shoulder bridge piers with CMB also pays off on all routes except city streets, with Interstate and U.S. routes having priority.

DISCUSSION AND RECOMMENDATIONS

This study was performed to respond to several specific needs in North Carolina, one of which is the development of a technique to deploy fixed-object improvement funds in a cost-effective manner. In the past, requisite data and system development have been lacking to formally tie the process together. The project thus represents the first effort at linking the necessary ingredients of such a system. As such, the system is not without flaws, and various improvements should be considered both in North Carolina and in other states developing a similar system. In addition, project efforts have pointed out a continuing need on the national level.

The most needed extension to the current system would be the incorporation of linear or dynamic programming algorithms for budget allocation purposes (10, 11). The development of a priority ranking provides the highway administrator with a rational tool for comparing alternatives; but when budget constraints are introduced, use of the ranking alone to formulate the budget package will not guarantee the global maximization of benefits. When constraints are such that programs become financially mutually exclusive, many combinations of budget packages may have to be examined—if the administrator is concerned with overall benefit maximization. Linear or dynamic programming packages have been developed to deal with such problems in other areas and a similar application should be considered here.

There is also a continuing need for examination of the effectiveness, cost, and injury factors that are the bases for the system, perhaps in some form of sensitivity analysis. The values used reflect the consensus of personnel of the DOH's Transportation Engineering Branch and of the HSRC as to the most rational current values for variables such as discount rate, rate of traffic growth, inflation rate, and accident and treatment costs. Changes in these input variables could obviously have a considerable effect on any ranking scheme.

In addition to the sensitivity analysis, some periodic consideration should be given to the possible addition of other costs into the system, such as the cost of time, vehicle operating costs, and pollution effects. Some of these variables, as related to the system output, could become more significant in the future.

Although cost factors may well continue to vary, the fact that such a sensitivity analysis is needed for the effectiveness factors—the fact that the estimates of effectiveness are not more specifically defined—is a major roadway safety issue. There is a continuing and very serious need for more well-designed effectiveness evaluations of fixed-object treatments. As can be seen from the literature review, there is a scarcity of good evaluations concerning fixed-object improvement programs. Where such evaluations exist, they generally are the before and after type with no control group; thus, they are subject to accident fluctuations, regression to the mean, and other artifacts. As projects concerned with fixed-object improvements become implemented across the nation, the Traffic Engineering Branch—perhaps in conjunction with the roadway design branch of each state—should evaluate the effects of the programs as thoroughly as possible and incorporate sound results into the developed system.

The only solution to such problems is to try to carefully build the evaluation process into the project—a planning sequence that can ensure proper evaluation designs (often including control groups or locations) and the proper statistical tests.

When an evaluation is completed, it is very important that the knowledge gained be transmitted to others in the highway safety field, including other state highway departments, research organizations, and federal organizations. It is apparent that the publication of technical information is a rather low priority item in most highway departments, but there is an urgent need for dissemination of the results of evaluative efforts by these agencies.

Thus, a system has been developed to aid engineers in making decisions about fixed-object correction programs. As with most other tools needed by states, the system is dependent on both in-state and national input variables. Solutions to the problems, which have been reemphasized here, should be of top priority for both the engineers and the researchers who work on roadside safety.

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Evaluation of Highway Safety Projects Using Quality-Control Technique

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Highway improvement projects are generally aimed at alleviating highway deficiencies related to traffic flow, congestion, and safety. Although significant effort is expended in developing and implementing the most appropriate countermeasures for specific deficiencies, not enough work is undertaken by highway agencies to evaluate the impact of such improvements. The evaluation of implemented projects is critical in determining future courses of action for the agencies regarding specific countermeasures related to individual problems. Although statistical methods of analysis using Poisson and chi-square distributions have been in existence, they are neither suitable for locations with very low accident frequency nor responsive to local conditions or standards. This paper offers an alternative procedure—quality-control technique—that overcomes the shortcomings of the other methods and offers the advantages of performing parametric comparisons by facility type or improvement type utilizing various measures of effectiveness. This procedure can also be adapted for identification of safety deficient locations. Parametric control charts required for this procedure can be readily prepared by computer or manual methods from existing data for various facility types.

Increased highway travel during the past decade has resulted in increasing numbers of accidents and fatalities. However, due to higher traffic volumes on the highways, the accident rate is not increasing (1). Recent emphasis on various highway safety programs is believed to have contributed to decreasing the rate of highway accidents and fatalities. Decisions on whether to continue, delete, or improve various highway safety programs depend on the ability to measure their individual effectiveness. While overall program evaluations are done at the state and federal levels, the evaluation of specific projects and treatments at the local level is often neglected. Hence, program evaluation is often subjective and based on limited data.

A comprehensive traffic engineering project was initiated in Oakland County, Michigan, to assess the current status of traffic engineering activities and to develop and implement appropriate projects for the promotion and improvement of traffic engineering activities to reduce the safety deficiencies. As a part of the project, a need was established indicating that a simplified and practical methodology for the evaluation of highway safety projects is necessary. Furthermore, this methodology must be in a suitable format to encourage increased usage by the traffic engineering personnel in the county.

This paper presents the evaluation methodology developed as a part of the comprehensive traffic engineering project and demonstrates its applicability by performing a typical highway safety project evaluation. That part of the evaluation methodology, which is reported in this paper, relates to the parametric comparison of highway accident experiences.

EXISTING PARAMETRIC TEST PROCEDURES

Determining the significance of highway improvements requires the evaluation of the effect of specific projects or treatments on accident experience, other measures of effectiveness, or both. A small change in accident experience can be called a matter of chance, whereas a large reduction is generally attributable to the specific improvement.

There are currently two basic methods of testing the significance of a change: the Poisson and the chi-square tests of significance. The first test involves measuring the change in accident experiences and comparing it with a set of Poisson significance curves developed for a specific range of confidence intervals (2). A change greater than the minimum percent change necessary for the corresponding accident frequency at a given level of confidence limit is interpreted as a significant improvement. The tests of means and the distributions are described as conservative and liberal measures of significance respectively (see Figure 1). For example, if the intersection point of the number of before accidents at the study site and percent reduction during the post-improvement period is above the top curve, it can be stated that the null hypothesis can be rejected at the given level of confidence. In this case, the null hypothesis is that there is no difference between the pre- and post-improvement accident experiences. When accident data for a specific project fall between the two curves (conservative and liberal), the significance of the improvement is not conclusively demonstrated; more data are necessary to obtain a more specific conclusion.

The chi-square test is similar to the Poisson test in that two curves are used to represent the limiting conditions (Figure 2). The liberal curve is based on the Poisson distribution and minimizes the probability of judging a reduction as nonsignificant when in fact it is really significant. The conservative curve is based on the chi-square distribution and serves to minimize the probability of defining a reduction as significant when the opposite is true (3).

Figure 1. Poisson curves for test of significance in accident reduction.

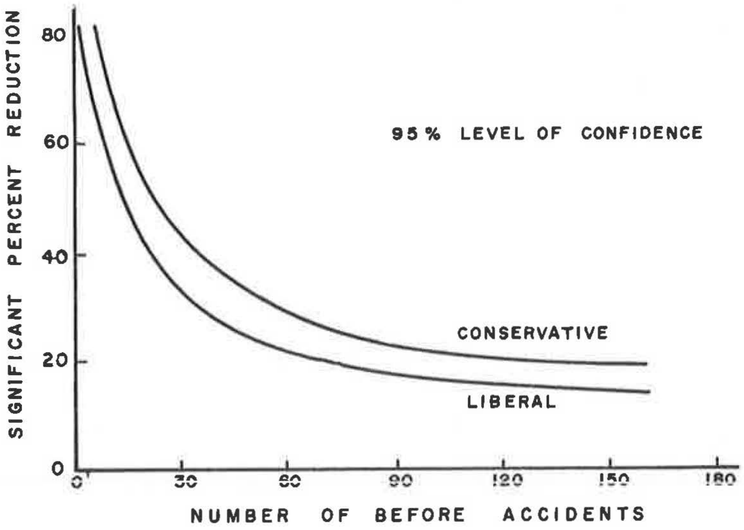
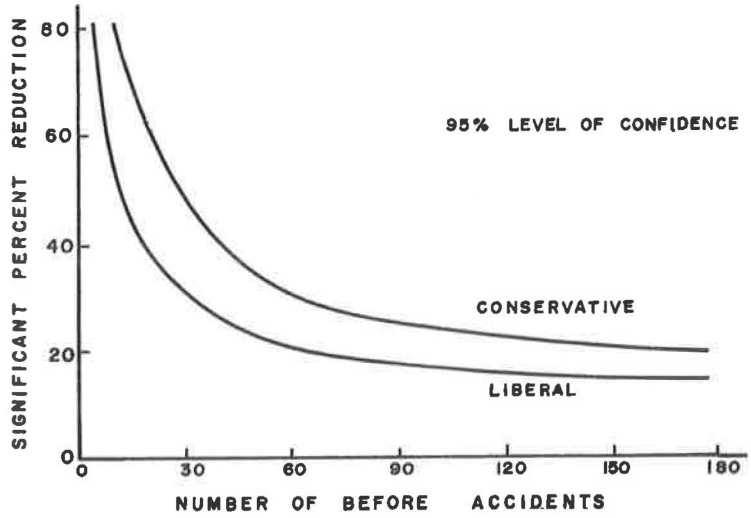


Figure 2. Chi square curves for tests of significance in accident reduction.



These two techniques can provide an adequate method of testing the significance of a safety improvement when the magnitude of a pre-improvement accident frequency is sufficiently high. As the accident frequency decreases, a higher accident reduction percentage is necessary to attribute the accident reduction to the specific improvement. This point can be demonstrated by using significance curves shown in Figure 2 (4). Suppose that a safety improvement were performed at a location where the preproject accident data indicated an average of 10 collisions per year. Looking at the significance curves, we can observe that the improvement must reduce accidents to three or four per year before it can be called statistically significant. Thus, a very high reduction in accidents is required to show a statistically significant change resulting from the improvement.

Classical quality-control theory has been applied to manufacturing processes in the past. In the field of highway safety, a similar approach has been used in the identification of hazardous locations. Jorgenson (2) has presented the rate quality-control method as one method for the identification of hazardous locations.

The methodology used in the evaluation procedure presented in this paper uses similar quality-control theory. This procedure involves determining accident experience averages and upper confidence limits for groups of similar highway locations at selected levels of confidence. The upper confidence limit (UCL) of group i is defined as

$$UCL_i = \overline{X}_i + Z\sqrt{\sigma_i^2} \qquad (1)$$

where

$\overline{X}_i$ = average frequency of accidents for group i,
σ_i^2 = variance of accident frequency in the same group i, and
Z = constant used to define selected confidence level.

The similarity in highway locations can be dependent on several variables. In this study the number of lanes and demand volumes—i.e., average daily traffic (ADT)—were used to classify the highway locations. The selection of classification variable increments depends on sample size and ability of the independent variables to explain the variability in the dependent variable, in this case, accident experience.

The highway locations within each category (number of lanes and demand) that fall above the upper confidence limit line are defined as abnormal or out of control when compared with its group. Such abnormal sites are candidates for improvements. If a location indicates a pre-improvement accident frequency falling into the abnormal category and post-improvement accident frequency under the upper confidence limit, it would indicate that the applied treatment was successful in bringing the site from out of control to within control. Thus, it can be concluded that the treatment was effective in alleviating the accident problem.

Groups of highway locations will range from low to high accident frequencies and from low to high traffic volumes. Each group has its own mean and variance from which upper confidence limits are determined. Therefore, evaluation of a site that has very low accident frequency and also has very low traffic volume can be out of control within its own group and, as a consequence of safety treatment, can be within control after improvement.

The resulting increases in traffic volume from an improvement may change the group to which a location is classified, but it is still possible to determine whether or not it is within control by using a different quality-control chart.

For example, Figure 3 shows hypothetical confidence bands for four-legged unsignalized intersections with two lanes on each approach. The horizontal axis indicates increasing groups of approach traffic volumes. The vertical axis represents total accident frequency, which will be the measure of effectiveness in this sample. The upper limits of the band, Y_3 - Y_4, Y_7 - Y_8, and Y_{11} - Y_{12}, represent 95 percent confidence limits for the distribution of accident frequencies observed in the various volume groups. The total accident frequency at the test site before the safety improvement is indicated by point Z_1. Consider that the post-implementation accident experience results in a shift in total accident frequency to Z_2 or Z_3. The movement of the site from Z_1 to Z_2 indicates the site was out of control before the safety improvement and is in control after improvement; however, the location remained in the same group of traffic volumes. Similarly, consider that point Z_1 shifted to Z_3. This shift indicates only a minor reduction in total accident frequency. However, it indicates that the location is in control in a different volume group; thus, the reduction can be considered statistically significant at the 95 percent level of confidence.

By employing this technique, it is possible to evaluate the change in accident experience resulting from improvements and to compare the improved facility with similar locations. This, coupled with the technique's ability to measure the improvements on low as well as high frequency locations, provides a valuable tool in the overall highway safety evaluation strategy.

STUDY AREA

Oakland County is located in southeastern Michigan. The county has 39 cities and villages and 22 townships; it is one of the most rapidly growing counties in the Detroit metropolitan area. It has a population of over 900 000 and an area of 2408 km² (867 miles²) with approximately 7500 km (4500 miles) of highway network.

A computerized accident record system has been established for the county that analyzes a preselected set of links and intersections on an annual basis for accident frequency, accident rate, and accident type. The accident rate is computed in customary units to reflect accidents per million vehicle-miles for roadway sections and accidents per million vehicles for intersections.

There were 1205 links in the system that experienced one or more accidents in 1975. These links vary from two-lane roadways to freeway links. The overall ranking of these links on the basis of accident frequency

Figure 3. Hypothetical confidence bands for unsignalized intersections.

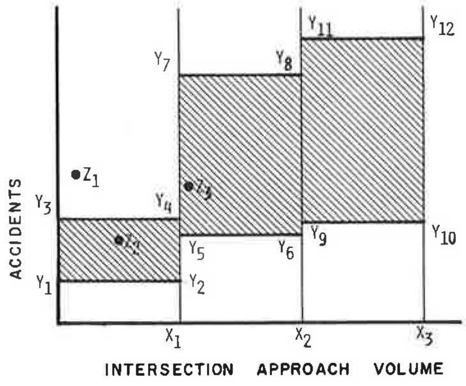


Table 1. Accident characteristics for various link types.

		Maximum			Minimum			Mean			Standard Deviation		
Roadway Link Type	No. of Links in Group	Accident Frequency	Accident Frequency/ Mile	Accident Rate/ MVM	Accident Frequency	Accident Frequency/ Mile	Accident Rate/ MVM	Accident Frequency	Accident Frequency/ Mile	Accident Rate/ MVM	Accident Frequency	Accident Frequency/ Mile	Accident Rate/ MVM
Freeway	41	65	60	3.57	3	3	0.41	22.1	17.1	1.31	13.8	12.2	0.67
6 or more lanes	39	177	188	12.56	16	17.8	1.03	84.9	80.5	4.7	38.2	36.8	2.5
5 lanes	46	146	146	17.12	2	2	1.72	49.9	45.8	5.7	36.0	31.0	3.23
4 lanes	119	242	143.33	29.39	2	1.2	0.15	42.8	37.4	5.5	40.2	31.0	4.4
2-lane, 2-way	919	126	115	277.17	1.0	0.33	0.20	13.52	12.03	10.24	18.45	16.8	16.2

Table 2. Accident characteristics for 2-lane, 2-way facilities.

		Mean			Standard Deviation		
Demand Level (ADT)	No. of Links in Sample	Accident Frequency	Accident Frequency/ Mile	Accident Rate/ MVM	Accident Frequency	Accident Frequency/ Mile	Accident Rate/ MVM
0-4 000	495	4.1	3.16	14.5	4.94	3.68	20.9
4 001-8 000	140	13.4	11.3	5.4	8.2	6.98	3.36
8 001-12 000	129	19.2	17.6	5.0	14.89	12.23	3.3
12 001-16 000	62	27.36	25.44	5.07	16.05	13.98	2.74
16 001-20 000	48	40.77	36.1	5.63	24.12	17.87	2.87
20 001-24 000	23	50.27	49.24	6.17	20.02	19.48	2.57
24 001-28 000	22	66.19	63.45	5.82	28.36	26.2	2.63

or rate does not necessarily reflect their hazardousness relative to their characteristics. It was recognized that the number of lanes in the links represents a significant distinguishing feature that may influence differences in accident experience.

Objectives and Procedure

The objectives of this study were:

1. Determine whether or not there is significant difference in accident patterns between various types of links, e.g., two-lane, four-lane, five-lane, and freeway;
2. Develop quality-control charts so that highway link locations which are abnormal in terms of accident experience can be recognized; and
3. Test whether the quality-control charts can be used in the evaluation of safety projects.

In order to accomplish the above objectives, an analysis of the available accident data for the county was performed. The analysis consisted of a two-step procedure. First, all 1205 links were stratified according to the number of lanes and types of facilities, which yielded the following groups:

Type of Links	Number in Group	Type of Links	Number in Group
Freeway	41	5-lane	46
6 or more lanes for highways without access control	39	4-lane	119
		3-lane	1
		2-lane	919
		Unknown	40

The "unknown" category means an absence of lane number information in the data file. The three-lane category was eliminated from further analysis due to insufficient data points.

The accident experience of each group was statistically analyzed to determine the maximum value, minimum value, mean, and standard deviation. In each case, the various measures of accident experience were analyzed (i.e., accident frequency, accident frequency per mile, accident rate). The results of this analysis are shown in Table 1. The resulting data indicate that there is a substantial difference in mean accident frequencies and mean accident rates between the link types: freeway links have the lowest accident rates, and two-lane roadway links have the highest accident rate.

In the second step, the data files for two-lane roadway facilities were then segregated on the basis of traffic demand (ADT) data in order to study the variations of accident experience as a function of traffic demand. Several different increments of demand were used to substratify the two-lane, two-way facilities. Table 2 presents data classified using 4000 ADT as the demand increment for two-lane, two-way roadways only. These data clearly show that there is a steady increase in mean accident frequency for increased ADT.

The upper limits of the various demand groups were computed using standard statistical tables for 80 percent, 84.13 percent (1 standard deviation), 90 percent, and 95 percent confidence levels. These limits of the confidence level were then determined by using standard (Z) one-tailed distribution values from statistical tables. They indicate that a particular link will be under the upper limit of its appropriate category, the percent time indicated by the confidence level. The selection of higher confidence levels will mean more stringent criteria for identifying a specific location as critical.

Results

The two-lane roadways were segregated by demand groups. The mean frequency lines and the upper confidence limit lines were generated for all groups of demand, and then appropriate quality-control graphs were prepared (Figures 4-7).

Figure 5 presents the mean frequencies and one standard deviation line for various volume groups. Figures 4, 6, and 7 show 80 percent, 90 percent, and 95 percent confidence levels respectively. They represent increasingly stringent criteria for finding statistically significant results from safety projects.

These charts can be used to determine the hazardousness of a location. A location plotted on the appropriate chart falling above the mean value line may indicate a somewhat abnormal accident experience, since its accident experience is above the mean experience of the group. Those values falling above the confidence limit lines would indicate locations that are critical or out of control.

In an evaluation study, if it is found that a location was out of control before the treatment was applied and comes under control either in the same volume group or in a different volume group, then safety improvement has been achieved. This type of quality-control chart can be developed for various categories of accidents and can be used to test specific evaluation objectives.

The quality-control charts shown here (Figures 4-7) are for a highway network in a specific area (Oakland County, Michigan). The same charts may not be applicable in other areas. Therefore, quality-control charts may have to be developed for a specific area on the basis of existing areawide accident experience before they can be used for evaluating highway safety projects in the area.

CASE STUDY

In order to demonstrate the use of the quality-control procedure in the evaluation of a highway safety project, an improvement site was selected for evaluation. The site chosen was a 3.2-km (2-mile) stretch of two-lane roadway that was outmoded due to the land use development and resulting increased traffic demand and high accident experience. In an attempt to alleviate the congestion problem and reduce the accident experience, the

Figure 4. Quality-control graph for confidence level 80 percent.

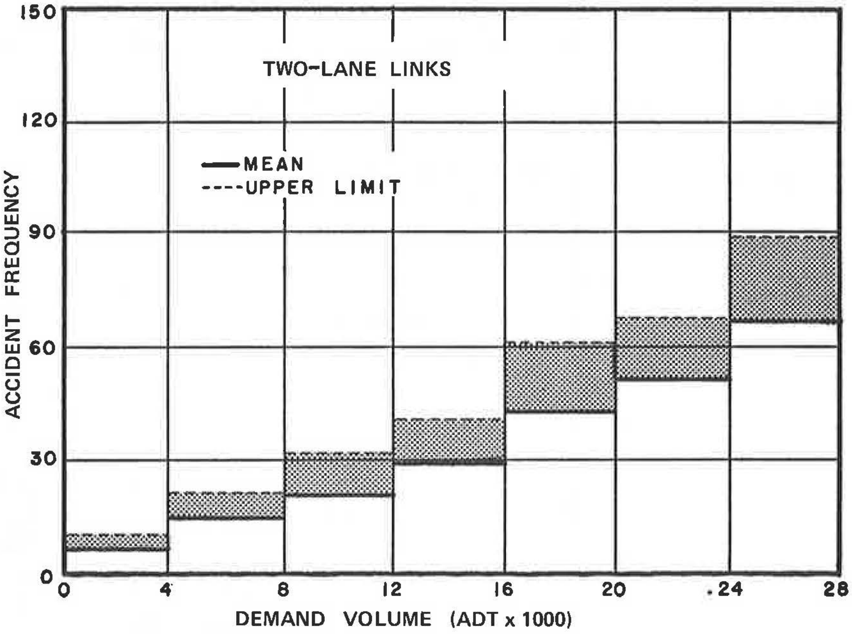


Figure 5. Quality-control graph for confidence level 84.13 percent.

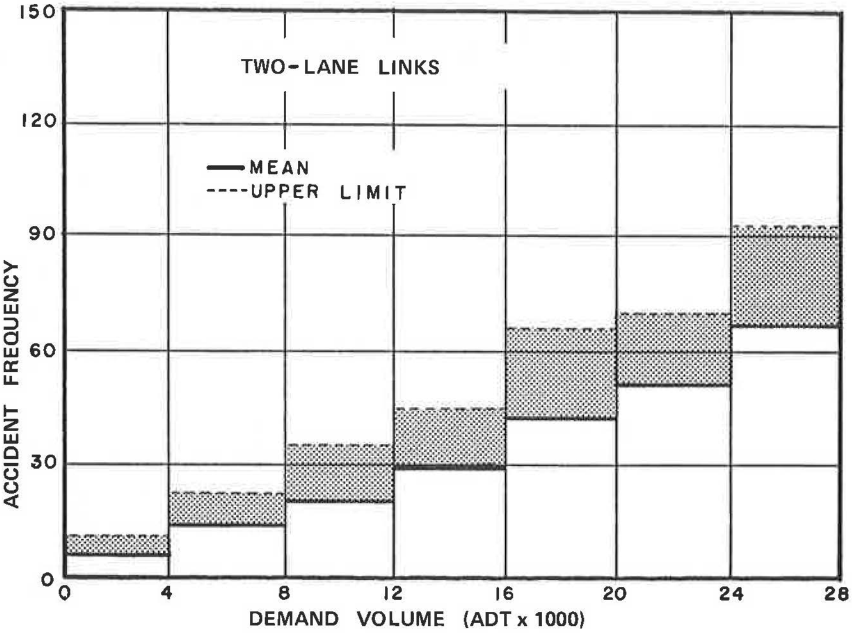


Figure 6. Quality-control graph for confidence level 90 percent.

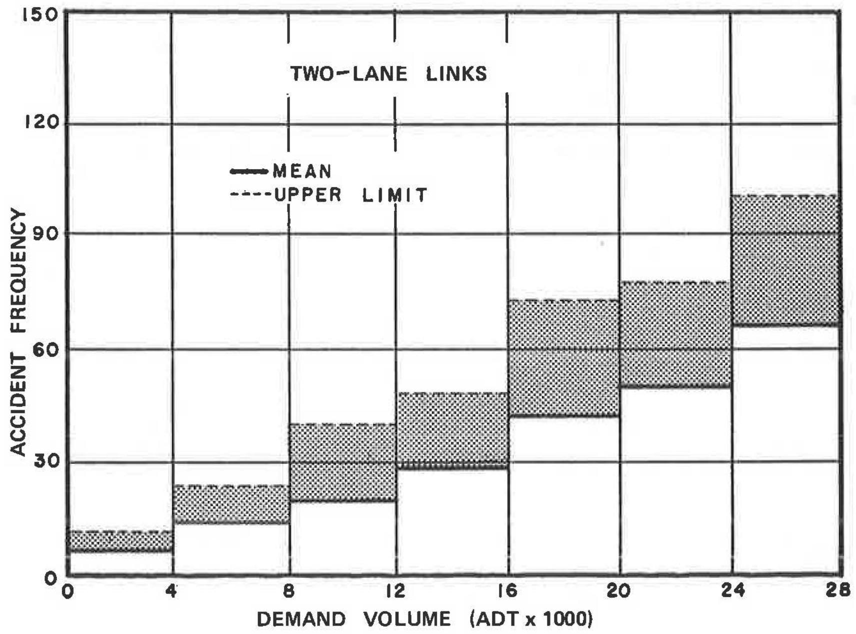
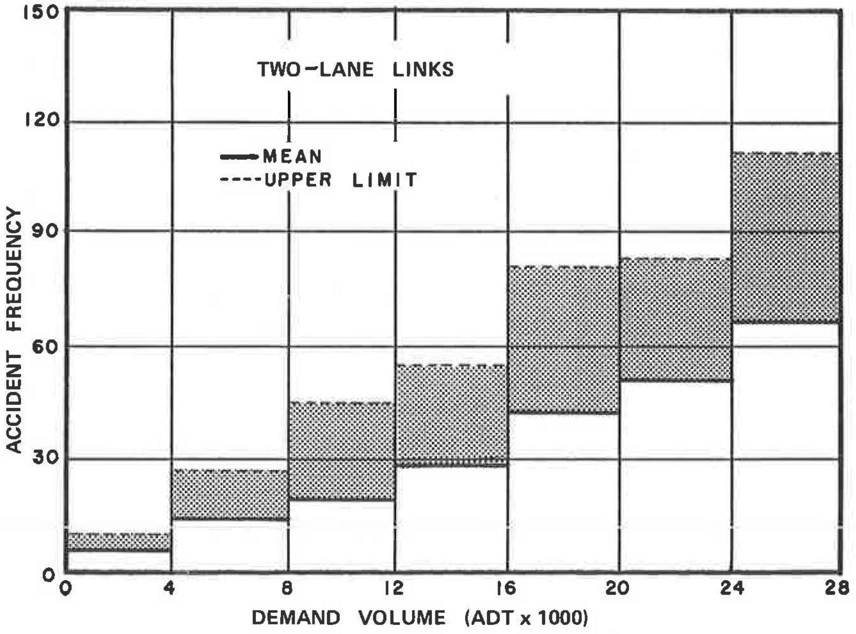


Figure 7. Quality-control graph for confidence level 95 percent.



roadway was widened to a four-lane facility. The volume and accident data available for this study were as follows:

	Traffic Volumes			
Link	Pre-Project		Post-Project	
Number	1973	1974	1975	1976
1	12 000	14 000	25 000	27 000
2	13 000	15 000	26 000	29 000

The accident experience in the above locations was as follows:

	Traffic Accidents (yearly)			
Link	Pre-Project		Post-Project	
Number	1973	1974	1975	1976
1	54	44	55	47
2	79	65	64	50

Averages for use in the evaluation study were computed as:

Pre-Project Data	Post-Project Data
Link 1 Volume = 13 000 ADT	Link 1 Volume = 26 000 ADT
Accident Frequency = 49	Accident Frequency = 51
Link 2 Volume = 14 000 ADT	Link 2 Volume = 27 500 ADT
Accident Frequency = 72	Accident Frequency = 57

When the pre-project data are plotted on the quality-control graph pertaining to the 95 percent confidence level (Figure 8), it can be seen that link 2 was out of control. The improvement to four lanes resulted in a change in volume and accident experience. Since the link is now a four-lane facility, a different quality-control graph (Figure 9) must be used for post-project evaluation. When these data are plotted on Figure 9, it can be readily seen that the post-accident experience is below the mean accident frequency for the appropriate

Figure 8. Case study application of quality control graph (2-lane, 2-way facility).

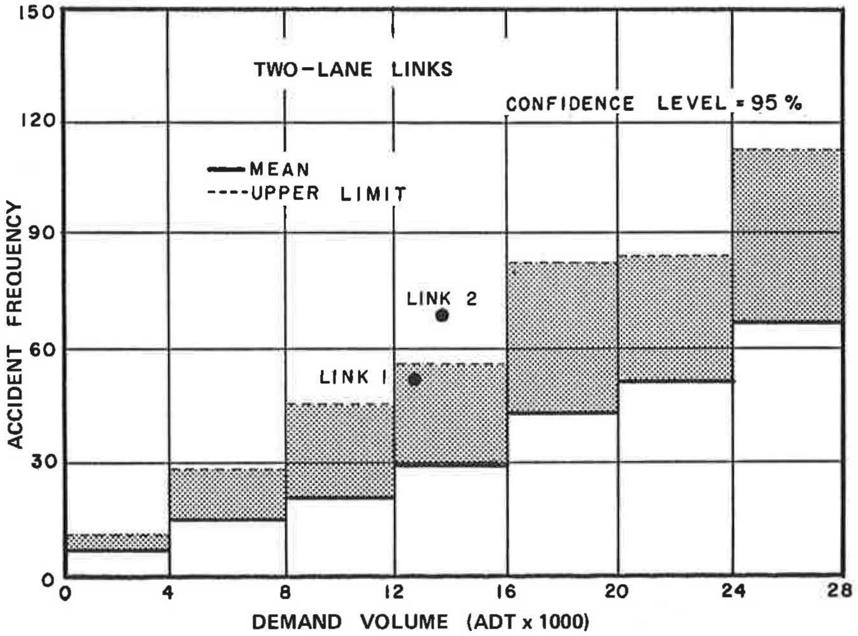
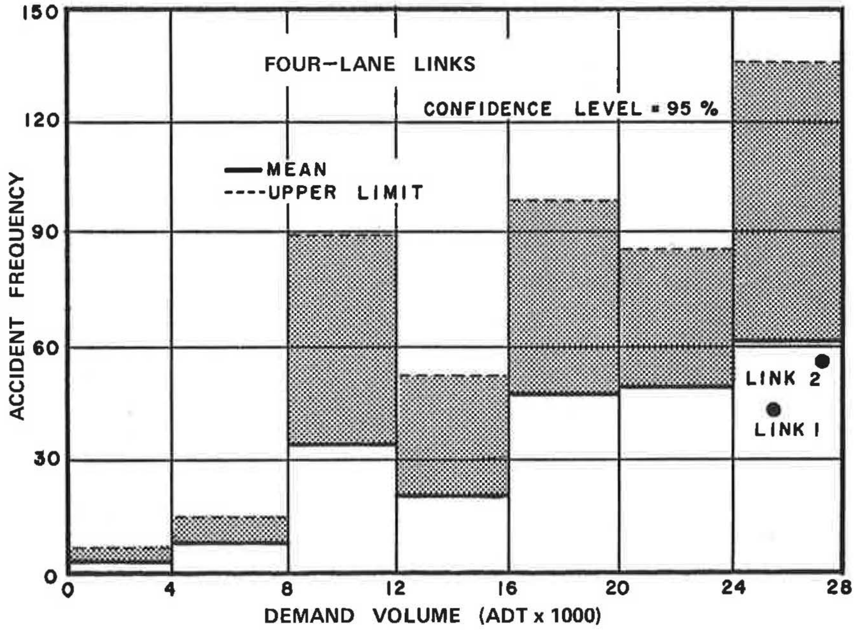


Figure 9. Case study application of quality control graph (4-lane, 2-way facility).



volume group; therefore, it can be concluded that the improvement has had a significant impact on the accident experience.

CONCLUSIONS

The quality-control technique yields a method of determining the statistical significance of safety improvement projects that is not only responsive to low accident frequencies but is also representative of local conditions and standards. The necessary quality-control charts are easily generated using available data for specific areas. The development of appropriate quality-control charts for various facilities and accident types will allow the evaluation of various highway safety improvements.

The study indicated that there is considerable difference in accident experience between types of highway facilities, such as freeway, two-lane, four-lane, five-lane, and six-lane. The data also indicated that the accident experiences change with a change in traffic volume.

Quality-control charts may be developed for various levels of traffic demand for all types of roadway, if there are sufficient data points available. The choice of traffic volume increments should be made by analyzing various grouping schemes and observing the accident distribution characteristics. The quality-control charts can be used to identify specific highway locations as abnormal or critical, depending on their location with respect to the confidence bands.

The example cited demonstrates that it is possible to use quality-control charts for evaluating a highway safety improvement or project. It provides a way to evaluate highway safety projects that involve low accident frequencies, since the procedure only recognizes out-of-control and in-control situations. It also assists the evaluators in determining whether significant improvements have taken place.

ACKNOWLEDGMENT

The findings in this report are a result of a study performed under a federal grant received by the Traffic Improvement Association of Oakland County, Michigan, in cooperation with the Michigan Office of Highway Safety Planning and the Federal Highway Administration, U.S. Department of Transportation. We wish to express our gratitude to the sponsoring agencies. The opinions, findings, and conclusions in this publication are ours and not necessarily those of the state of Michigan or the U.S. Department of Transportation, Federal Highway Administration.

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Michigan Dimensional Accident Surveillance (MIDAS) Model: Progress Report

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The Michigan Dimensional Accident Surveilance Model is being developed by the Michigan Department of State Highways and Transportation. The model aims to objectively analyze the entire roadway system (not just locations with the worst accident histories), to select candidate locations for upgrading that are the most sensitive to correction, and to choose sets of the most likely cost-effective corrective measures. This paper introduces the procedures; reports on progress, accomplishments, and shortcomings to date; and stimulates related interest and development elsewhere. The model may be visualized as grouping all roadway segments with identical predetermined physical and accident characteristics into one cell of a multicell array. Subsequent statistical analysis, cost estimating, and accident predictions assess probable impacts on transforming all sites from one cell type to another. Data sources are several master tapes of accident reports, road features inventory files, and a traffic volume file. The identification of segments having a statistically significant number of accidents and the determination of logical countermeasures work well. The prediction of expected accidents for each corrective action at present lacks precision and requires additional work.

The Michigan Department of State Highways and Transportation has maintained computerized accident report data since 1963. Candidate locations for possible spot safety improvements were selected, in rank order, by total accidents and accident rates for 0.3-km (0.2-mile) roadway segments. Threshold values were used to control the size of the listing. The same locations tend to appear year after year. Feasible corrective treatments are eventually exhausted. Yet engineering attention is still given, although lower ranked candidate sites may not be investigated due to limitations of time, personnel, and funding.

MODEL DEVELOPMENT

A desire to identify sites with correctable accident patterns (independent of the number of total accidents) initiated the development of an accident analysis system—the Michigan Dimensional Accident Surveillance (MIDAS) model. The guiding objectives for model development are to

1. Greatly expand knowledge by including as much pertinent information as possible in the analysis;
2. Analyze objectively the entire roadway system, not just locations with poor accident histories;
3. Optimize injury avoidance;
4. Select candidate locations that are the most sensitive to correction and select sets of corrective measures that are likely to be the most cost effective; and
5. Provide a managerial tool to test policy.

The model consists of three stages: (a) locating all sites with statistically significant injury accident patterns, (b) investigating all feasible countermeasures, and (c) optimizing expenditures based on cost effectiveness. Due to spatial limitations, this paper will primarily address the progress in developing stage 1.

The principal concept of stage 1 is to aggregate roadway segments with similar physical and environmental characteristics into one cell of a multicell array, with the array containing all conditions in the universe. The dimensions and principal variables are

1. Geometry—number of lanes, horizontal alignment, vertical alignment;
2. Environment—roadside development, day/night, wet/dry, intersection/midblock, operational controls;
3. Cross section—lane width, shoulder width, curb type; and
4. Accident—accident characteristics.

From these variables, it is mathematically possible to create 514 080 data sets. Most of the conditions do not exist; approximately 20 000 cells contain real-world data.

The model uses several data files. Accident data for each year are obtained from accident master tapes. Files of accident data are created for each of the department's nine districts for the years 1971 through 1975 plus the cumulative five-year period. Geometric and environmental files are created for each of the nine districts. The state highway and transportation department's photolog provided most of the data, thus limiting the precision of some variables. Another file set contains traffic volumes with hourly and 24-hour summaries. The vehicular counts are available for approximately every 4 km (2½ miles) in the system. There are three file sets containing volume conversion factors by year, month, and day of the week. Remaining files contain modified highway capacity factors derived from the TRB Highway Capacity Manual. A file set with English description of the routes, crossroads, local governmental agencies, and counties is available.

STAGE 1 PROCEDURES

The procedures in stage 1 for identifying statistically significant accident patterns consist of several computer programs. The principal computer program simultaneously reads eight file sets. The model steps down the trunkline system in 0.3-km (0.2-mile) segments. Reading precoded characteristics at segment midpoints, it determines such factors as basic laneage, lane width, shoulder width, and horizontal and vertical alignment. It then ascertains the number and type of injury and fatal accidents that occurred in a given segment. For each discovered accident, the model also calculates segment roadway capacity and checks upstream and downstream for the nearest recorded traffic volumes. It factors both volumes to estimate hourly volume at the time of the accident. The volume-to-capacity ratio is then calculated for the recorded hour of the accident. After this process is completed for midblock segments, it is repeated for intersections. Only injury and fatal accidents (without discriminating) are analyzed. This alleviates a difficulty of inconsistent reporting of property damage accidents between rural and urban areas and promotes a desire to emphasize injury-avoidance improvement projects.

Cells are created by assigning X, Y, Z, and N subscripts (geometry, environment, accident, and cross section) to each segment and subsequently sorting the data by ascending order of the subscripts. The data in each cell are tested for a goodness-of-fit to a Poisson distribution; a mean, variance, and upper limit are calculated. Figures 1 and 2 are cell outputs from the X, Y, Z, and N array. There is also a procedure for the interactive aggregating of variables allowing one to analyze several million combinations of variables and aggregations of variables with an output similar to Figures 1 and 2.

Figure 1 illustrates a cell containing all segments that have these characteristics: eight lanes divided, tangent alignment, urban development, nonsignalized intersections, no auxiliary turn lanes, right-angle injury accidents, 39-m (12-ft) lanes with curb and gutter. There are 205 intersections with similar characteristics with a mean of 1.17 right-angle injury accidents in 5 years. Of the total sample, 120 had no right-angle accidents; two had 19 right-angle accidents each (significant at the 99 percent level). At the bottom of the histogram, English descriptions of sites with significantly large frequencies—called outliers—are provided. Outliers are easily identified and have a different perspective when viewed with like locations as opposed to a singular high accident listing.

Figure 2 is similar to Figure 1 and is an example of a cell with a much larger sample size—1258 sites—and represents all injury accidents per site in lieu of a spe-

Figure 1. Illustration of a cell containing all segments that have certain characteristics such as eight lanes divided and tangent alignment.

```
  X= 33  8LANE DIVIDED TANGENT                          *
  Y=  2  URBAN NO SIGNAL/NO TURN                        *
  Z=  2  RIGHT ANGLE ACCIDENTS                          *
  N= 11  12FT LANES WITH CURB                           *
*****************************************************

  AVG=     1.17
  UCL=     6.56
  N=      205

                  NUMBER  OF  LOCATIONS
             1         2         3         4         5         6
ACC*123456789012345678901234567890123456789012345678901234567890123
  0*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX 120
  1*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  2*XXXXXXXXXXXXXXX
  3*XXXXXXXXXXXXXX
  4*XXX
  5*X
  6*XXX
  7*
  8*
  9*0
 10*
 11*
 12*
 13*00
 14*
 15*
 16*0
 17*
 18*
 19*00

CSECT   MP  ACC   ROUTE        XROAD/MIDBLOCK          LOCAL GOV'T COUNTY

82081 18.60   9 M-153          AT KEILWORTH AVENUE     DEARBORN CY.WAYNE CO.
82081 19.12  19 M-153          AT BINGHAM STREET       DEARBORN CY.WAYNE CO.
82141  0.09  16 M-102          AT ONTAGO STREET        SOUTHFIELD CWAYNE CO.
82141  1.15  19 M-102          AT CENTRALIA STREET     SOUTHFIELD CWAYNE CO.
82141  4.30  13 M-102          AT WESTMORELAND STREE STH/DET CITYWAYNE CO.
82144  2.61  13 M-102          AT I-94 FREEWAY         E.DET. CITY WAYNE CO.
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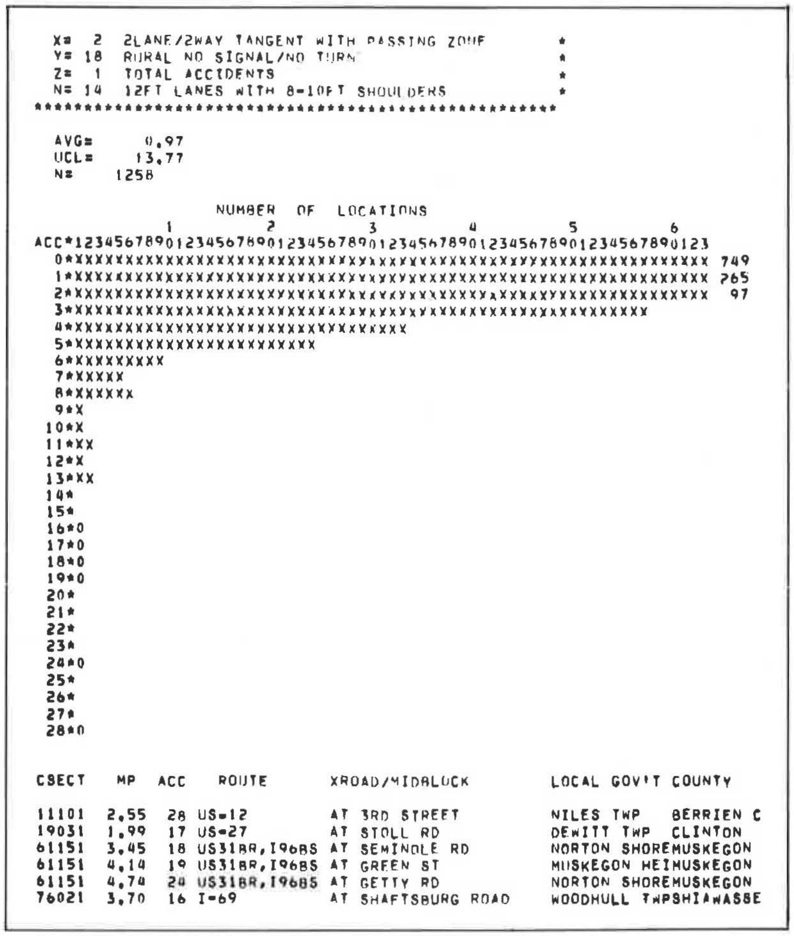

Figure 2. Illustration of a cell with a large sample size (1258 sites), representing all injury accidents per site in lieu of a specific accident pattern.

```
  X=  2  2LANE/2WAY TANGENT WITH PASSING ZONE         *
  Y= 18  RURAL NO SIGNAL/NO TURN                      *
  Z=  1  TOTAL ACCIDENTS                              *
  N= 14  12FT LANES WITH 8-10FT SHOULDERS             *
*****************************************************

  AVG=      0.97
  UCL=     13.77
  N=     1258

                     NUMBER  OF  LOCATIONS
             1         2         3         4         5         6
ACC*123456789012345678901234567890123456789012345678901234567890123
  0*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX 749
  1*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX 265
  2*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX  97
  3*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  4*XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  5*XXXXXXXXXXXXXXXXXXXXXXXX
  6*XXXXXXXXX
  7*XXXXX
  8*XXXXXX
  9*X
 10*X
 11*XX
 12*X
 13*XX
 14*
 15*
 16*0
 17*0
 18*0
 19*0
 20*
 21*
 22*
 23*
 24*0
 25*
 26*
 27*
 28*0

CSECT   MP  ACC   ROUTE        XROAD/MIDBLOCK          LOCAL GOV'T COUNTY

11101  2.55  28 US-12          AT 3RD STREET           NILES TWP   BERRIEN C
19031  1.99  17 US-27          AT STOLL RD             DEWITT TWP  CLINTON
61151  3.45  18 US31BR,I96BS   AT SEMINOLE RD          NORTON SHOREMUSKEGON
61151  4.14  19 US31BR,I96BS   AT GREEN ST             MUSKEGON HEIMUSKEGON
61151  4.74  24 US31BR,I96BS   AT GETTY RD             NORTON SHOREMUSKEGON
76021  3.70  16 I-69           AT SHAFTSBURG ROAD      WOODHULL TWPSHIAWASSE
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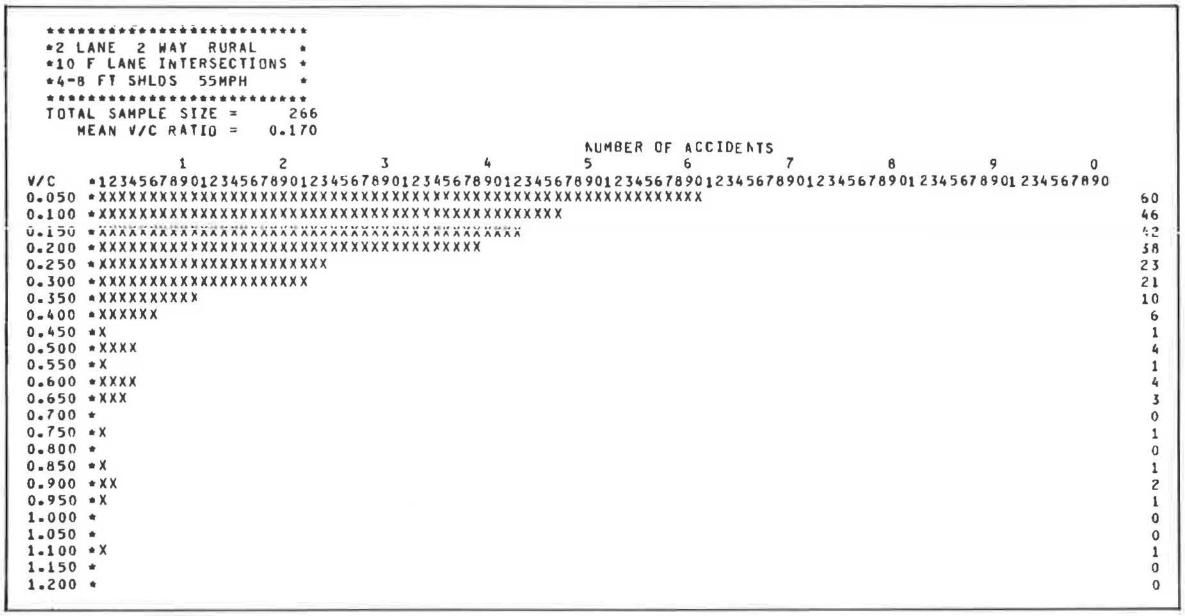
Figure 3. Graphic output of data for 1 year (1975) of accidents and the noted cell conditions.



```
    ***************************
    *2 LANE  2 WAY  RURAL     *
    *10 F LANE INTERSECTIONS  *
    *4-8 FT SHLDS  55MPH      *
    ***************************
    TOTAL SAMPLE SIZE =      266
       MEAN V/C RATIO =    0.170
                                                       NUMBER OF ACCIDENTS
                1         2         3         4         5         6         7         8         9         0
V/C   *1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
0.050 *XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX                                          60
0.100 *XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX                                                        46
0.150 *XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX                                                            42
0.200 *XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX                                                                38
0.250 *XXXXXXXXXXXXXXXXXXXXXXX                                                                               23
0.300 *XXXXXXXXXXXXXXXXXXXXX                                                                                 21
0.350 *XXXXXXXXXX                                                                                            10
0.400 *XXXXXX                                                                                                 6
0.450 *X                                                                                                      1
0.500 *XXXX                                                                                                   4
0.550 *X                                                                                                      1
0.600 *XXXX                                                                                                   4
0.650 *XXX                                                                                                    3
0.700 *                                                                                                       0
0.750 *X                                                                                                      1
0.800 *                                                                                                       0
0.850 *X                                                                                                      1
0.900 *XX                                                                                                     2
0.950 *X                                                                                                      1
1.000 *                                                                                                       0
1.050 *                                                                                                       0
1.100 *X                                                                                                      1
1.150 *                                                                                                       0
1.200 *                                                                                                       0
```

cific accident pattern. The process for identifying outliers relies on statistical significance and dispersion from the cell mean (measured by the number of standard deviations) and is relatively insensitive to the accident pattern, sample size, or magnitude of accidents frequency. Earlier a procedure was described for estimating the volume-to-capacity ratio for the recorded hour of the accident. Figure 3 is a graphical output of the data for 1 year (1975) of accidents and the noted cell conditions.

OTHER STAGES

Stage 2 involves the analysis of each outlier with a significantly high concentration of accidents. Logical countermeasures are identified by increments—e.g., widen lane from 33.3 m to 36.3 m (10-11 ft), add left-turn lane, right-turn lane, and signalization—with each incremental change being cost estimated. This is accomplished by having the outlier float through a decision tree. The resistance to each change (moving from one mode to another) is measured by an estimated cost. The expected change in accidents is estimated for each countermeasure, including the do-nothing alternative. The cost of each countermeasure is divided by the anticipated reduction in accidents, producing a cost-effectiveness index for each proposal. The status of stage 2 is a preliminary working program for identifying and estimating the cost of countermeasures. Present accident predictive procedures are not satisfactory, and more comprehensive accident predictive algorithms are being developed.

Stage 3 is the model optimization process. The objective is to maximize expected returns within budget and management policy constraints. Theoretical procedures have been explored but will not be implemented until the completion of stage 2. Action is under way to accelerate the completion of the model, its validation, and expansion to access sources of data heretofore unobtainable.

ACKNOWLEDGMENTS

Several engineers and technicians, who labored in developing and editing the base data and subsequent software, deserve much credit. Special consideration is due Donald E. Orne, Traffic and Safety Division, for his substantial contribution in formulating the concepts and processes of the model.

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Accident Characteristics Before, During, and After Safety Upgrading Projects on Ohio's Rural Interstate System

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In 1973, minor safety upgrading projects were conducted at 21 locations on the rural Interstate system of Ohio, involving 618 km (384 miles) of freeways. In 1972, the accident rate per million vehicle kilometers (MVKM) on these 618 km was 112.9 accidents/161 MVKM (112.9/100 million vehicle miles). In 1974, the accident rate dropped to 77.9 accidents/161 MVKM. To account for the possible effect of the introduction of the reduced speed limit in 1974, accident rates were also compared on 246 km (153 miles) of the rural Interstate system not subjected to safety improvement. The difference in proportional reduction in accident rates is statistically significant and favors the 21 study sites. The accident rates increased to 120.8 accidents/161 MVKM during the 1973 safety upgrading construction program. However, only 151 accidents were positively identified from traffic crash reports and construction diaries as construction related. These 151 accidents were studied in detail. Observed patterns included: (a) rear-end (61) and single vehicle, fixed-object (56) accidents were the most frequent; (b) 34 accidents occurred in the relatively short taper area; (c) the proportion of the lane taper accidents at night and at dawn or dusk was high; (d) the proportion of construction object accidents at night was high; (e) the proportion of tractor-trailer and bus accidents at night was high; (f) excess speed was listed in 88 cases as a contributing factor, while road defects or construction or traffic control were listed only in 15 cases. Some suggestions are being made regarding traffic control at work zones.

INTRODUCTION

The implementation of the Interstate highway system began in 1956 with the passage of the historic Highway Revenue Act and Federal-Aid Highway Act. The Interstate system is now about 90 percent completed. However, once a facility is constructed, it requires continuing attention to operation and maintenance.

Naturally, all highways will deteriorate in time at a rate determined by the traffic and environmental conditions. Resurfacing and other corrective measures are required to maintain the original design standards and the corresponding efficiency and level of safety.

Since the original design standards for freeways were developed, research, as well as experience gained from operating freeways, has taught us much about the relationship between design standards and performance. To eliminate safety hazards unwittingly built into our freeways, a 90 percent federally-supported Interstate Highway Safety Upgrading Program was begun.

For administrative purposes, safety improvement projects on the Interstate highways are classified as either major or minor upgrading. Major improvements are cost-intensive projects that are usually expected to reduce accidents. Minor improvements are low-cost projects and are usually expected to reduce the severity of accidents, mostly through reduction of roadside hazards.

Ohio's Interstate Highway Safety Upgrading Program was implemented in the early 1970s. It was rather puzzling to find, therefore, in the course of a previous study, that accident rates in Ohio actually exceeded projected trends during the first few years of the 1970s.

It is clear that safety upgrading projects differ from most new construction projects in that traffic must flow uninterrupted while work is in progress. This, of course, presents potential hazards to construction workers and through traffic alike. This realization led to the theory that safety upgrading projects may be responsible, at

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Mr. Migletz was a graduate student at Ohio State University at the time this study was conducted.

least partially, for the apparent increase in accident rates. That is, although these projects can be expected to ultimately decrease the accident rates on a roadway, they might be responsible for some increase of accidents during construction. If this is true, efforts should be taken to minimize the problem, since major emphasis has now shifted from new construction to maintenance and safety upgrading of the existing road network.

Study Objectives and Scope

This research project had three objectives:

1. Determine if accident rates in fact increased significantly during safety upgrading construction;
2. Determine if safety upgrading projects were successful in ultimately reducing the severity of accidents; and
3. Analyze construction-related accidents to determine if accident patterns can be related to elements usually present in work zones, and, based on the results, make suggestions which may reduce potential hazards in work zones.

A total of 21 minor safety upgrading projects on the rural Interstate highway system of Ohio were investigated. They mainly involved sign and lighting supports, guardrails, energy absorption barriers, drainage, and improved skid resistance. The 21 projects involved upgrading of some 618 km (384 miles) at a cost of $20 million, and most were completed during 1973. This study was conducted between November 1975 and May 1977.

Special Problem

The 55-mph speed limit, aimed at conserving fuel, was signed into law on January 2, 1974, and became effective nationwide on March 3, 1974. On Ohio's rural Interstate highways, the 1973 mean speeds and 85th percentile speeds were 102.9 km/h (63.9 mph) and 114.8 km/h (71.3 mph), respectively. The corresponding speeds in 1974 were 92.3 km/h (57.3 mph) and 99.4 km/h (61.7 mph). It is generally accepted that the reduced speed limit favorably affected accident rates. The implication for this project is that the routine comparison of accident statistics for the Before-Construction, During-Construction, and After-Construction time periods would be nonconclusive, since speed characteristics changed significantly in 1974.

It was, therefore, necessary to select 13 control sites, totaling 246 km (153 miles). These control sites were similar to the 21 study sites in terms of design standards and traffic volumes, but, of course, no safety upgradings were performed during the study period.

Sources of Accident Data

From the Ohio Department of Transportation's computerized data storage system, the number of fatal, nonfatal, and property-damage-only accidents could be obtained for any segment of the roadway for a given time period. Traffic crash reports prepared by the Ohio State Highway Patrol are stored on 16-mm microfilm by accident case number and were also available for review.

Records of the 2948 accidents that occurred on the 21 study sites during safety upgrading were investigated. Construction-related accidents were identified by reviewing the sketches and reading the accident descriptions prepared by the highway patrol. In construction-related accidents, the diagrams usually included sketches of temporary traffic control devices and location of construction equipment and construction material. The narrative description mentioned the construction zone. A total of 151 accidents were thus identified as definitely construction related.

Traffic volumes were also available for the 21 projects and for the 13 control sites. It was, therefore, possible to compute accident rates, expressed as accidents per million vehicle kilometers. Table 1 lists accidents, travel, and accident rates. For the during-construction period, accident statistics are given in two ways: by excluding construction-related accidents, denoted (w.o.), and by including construction-related accidents, denoted (with).

The field districts of the Ohio Department of Transportation, which conducted safety upgrading construction projects, were asked by operation and traffic engineers to submit the following information:

1. Date work started,
2. Day-by-day description of work in progress,
3. Location of work in progress,
4. Lane or shoulder closure for work in progress,
5. Any material or equipment stored within 9 m (30 ft) of pavement,
6. Any accidents involving contractor's equipment,
7. Any evidence of accidents occurring during the night that were not on state highway patrol reports,
8. Any evidence that accidents were related to contractor's traffic control (any complaints about unsafe traffic control method), and
9. Date work zone opened to traffic.

Responses were received for all 21 projects. Many of the responses also contained suggestions for improving traffic control procedures. These suggestions provided the rationale for the recommendations presented in this paper.

BEFORE- VERSUS DURING-CONSTRUCTION ACCIDENT RATES

The first objective of this study was to determine if accident rates in fact increased significantly during safety upgrading construction. For each of the 21 study sites, the number of accidents and the vehicle kilometers were determined for the construction period (X_D, M_B).

Before- and During-Construction accident rates (λ_B, λ_D) were computed from the ratio of the total number of accidents and total vehicle kilometers on the 618 km (384 miles) of rural Interstate highways included in this study, and expressed as accidents per 161 million vehicle kilometers (accidents per 100 million vehicle miles).

It is assumed that X has a Poisson distribution with parameter $\lambda M = \mu$. The F-test was then applied to the null hypothesis: $\lambda_B = \lambda_D$. The test statistics, $F^* = [X_D/(X_B + 1)] (M_B/M_D)$, are compared with $F_{1-\alpha}$ where the

Table 1. Accident statistics for construction and control projects.

	No. of Accidents				Accident Rates/161 MVKM		
Project	Total	Fatal	Non-fatal	Per 161 MVKM	Total	Fatal	Non-fatal
Construction							
Before	2551	34	1345	22.604	112.9	1.5	59.5
During (without)[a]	2797	36	1438	24.399	114.6	1.5	58.9
During (with)[b]	2948	39	1487	24.399	120.8	1.6	60.9
After	1819	14	734	23.347	77.9	0.6	31.4
Control							
Before	1031	15	369	10.271	100.4	1.5	35.9
After	823	5	259	9.905	83.1	0.5	26.1

[a] Construction-related accidents excluded.

[b] Construction-related accidents included.

degrees of freedom are $\nu_1 = 2(X_B + 1)$ and $\nu_2 = 2X_D$ and α is the significance level. For the one-sided, upper-tail test, the $F_{1-\alpha}$ was computed from $\log_{10} F_{1-\alpha}(\nu_1, \nu_2) \simeq a/(h - b)^{1/2} - cg$

where

$$h = 2\nu_1\nu_2/(\nu_1 + \nu_2),$$
$$g = (\nu_2 - \nu_1)/\nu_1\nu_2,$$

and a, b, and c are constants obtained from statistical tables. The null hypothesis is to be rejected in favor of the alternative, $\lambda_D > \lambda_B$, if $F^* > F_{1-\alpha}$.

The α significance level represents the probability of rejecting a true hypothesis. No specific α was preselected in this study; rather, the statistic $\underline{\alpha}$ was determined for each test. The $\underline{\alpha}$ is the lowest significance level that would lead to the rejection of the null hypothesis. It is customary in traffic engineering studies to work with $\alpha = 0.05$ or $\alpha = 0.10$.

Total accidents, fatal accidents, and injury accident rates were compared. The results of the test are as follows:

Time Period and Factor	Total	Fatal	Injury
During			
λ_D	120.8	1.6	60.9
Before			
λ_B	112.9	1.5	59.5
F*	1.070	1.032	1.024
ν_1	5104	70	2692
ν_2	5896	78	2974
$\underline{\alpha}$	$0.005 < \underline{\alpha} < 0.01$	$0.25 < \underline{\alpha} < 0.50$	$0.25 < \underline{\alpha} < 0.50$

The test indicates we can reject the null hypothesis that the total accident rates before and during construction were the same, with a 0.5 to 1 percent chance that we are rejecting a true hypothesis. The test on the fatal and injury accidents, however, does not result in a convincing argument against rejecting the null hypothesis. We interpreted the results of the statistical tests to mean that, although accidents during the construction period increased, the increase in the more serious (fatal and injury) accidents is not statistically significant.

BEFORE- VERSUS AFTER-CONSTRUCTION ACCIDENT RATES

The second objective of this study was to determine if safety upgrading projects were successful in ultimately reducing the severity of accidents.

Minor safety upgrading projects, investigated in this study, are typically designed to reduce the severity of accidents. But their effectiveness is difficult to test because of the reduced 55-mph speed limit introduced in March 1974. To bypass the problem, 13 control sites were selected, and proportional changes in before and after accident rates were compared with changes on the 21 improved roadways.

Table 2. Details of statistical tests, before versus after accidents.

Project	Total	Fatal	Nonfatal
Construction			
Before accidents (X_{B1})	2551	34	1345
After accidents (X_{A1})	1819	14	734
Sum of accidents (N_1)	4370	48	2079
ΔP_1	0.168	0.417	0.294
Control			
Before accidents (X_{B2})	1031	15	369
After accidents (X_{A2})	823	5	259
Sum of accidents (N_2)	1854	20	628
ΔP_2	0.112	0.500	0.175
P	0.151 3	0.4414	0.266 4
Z*	5.638 3	-0.6280	5.911 6
$\underline{\alpha}$	$\underline{\alpha} < 0.000\,01$	$0.70 < \underline{\alpha} < 0.75$	$\underline{\alpha} < 0.000\,01$

As can be expected, accident rates (λ_c) at the control sites were lower in 1972 than accident rates (λ_s) on the 21 sites scheduled for safety improvements. The difference is statistically significant for total accidents and injury accidents, as shown below by the results of the two-sided F-tests:

1972 Rates/ Factor	Total	Fatal	Injury
Study sites			
λ_s	112.9	1.5	59.5
Control sites			
λ_c	100.4	1.5	35.9
F*	1.123		1.652
ν_1	2064		740
ν_2	5102		2690
$\underline{\alpha}$	$0.001 < \underline{\alpha} < 0.001$		$\underline{\alpha} < 0.001$

The years 1972 and 1974 were used as before and after periods, although some of the safety upgrading projects extended into 1974. The 1974 accident rates and the results of the two-sided F-test are shown below:

1974 Rates/ Factor	Total	Fatal	Injury
Study sites			
λ_s	77.9	0.6	31.4
Control sites			
λ_c	83.1	0.5	26.1
F*	0.937	0.990	1.198
ν_1	1648	12	520
ν_2	3638	28	1468
$\underline{\alpha}$	$0.10 < \underline{\alpha} < 0.20$	$0.50 < \underline{\alpha}$	$0.01 < \underline{\alpha} < 0.02$

In 1974, on the study sections, where safety upgrading projects were completed before 1974 (or, in a few cases, during 1974), total accident rates were lower than on the control sites. The difference is small, however. Fatal accident rates are about the same, and injury accident rates are still higher on the study projects. It is clear that accident rates improved at the study sites, relative to the control roadways. It is also quite clear, however, that accident rates improved from 1972 to 1974 on the control sites, too, although no safety upgrading projects were conducted there. It is necessary, therefore, to test statistically the difference between the proportionate improvements.

The one-sided upper-tail test was based on the statistic, $Z^* = \Delta P_1 - \Delta P_2/\sqrt{P(1 - P)(1/N_1 + 1/N_2)}$. The null hypothesis $H_0{:}\Delta P_1 = \Delta P_2$ was rejected and $H_2{:}\Delta P_1 > \Delta P_2$ was accepted, if $Z^* > Z_{1-\alpha}$. Cumulative normal distribution tables provide the $Z_{1-\alpha}$ values. The details of the test are given in Table 2. The proportionate difference in the reduction of fatal accidents is not statistically significant, but the reduction in total accident rates and injury accident rates is significant at the $\underline{\alpha} > 0.000\,01$ level.

Thus, it was concluded that safety upgrading projects were effective in reducing injury accidents as well as total accident rates.

ANALYSIS OF CONSTRUCTION-RELATED ACCIDENTS

The third objective of the study was to analyze construction-related accidents to determine if accident patterns can be related to elements usually present in work zones, and based on the results, to make suggestions which may reduce potential hazards in work zones.

Selected Categories

Fairly detailed information was available on the 151 construction accidents. The following 11 categories were selected with the expectation that they would provide the framework for the identification of some informative accident patterns.

1. Accident severity: fatal, nonfatal, property damage only;
2. Type of accident: head-on, rear-end, sideswipe, improper merge, single-vehicle fixed-object, single vehicle run off road, pedestrian, construction only, other;
3. Location of accident: beginning of construction zone, lane taper, lane closure, construction area, median opening, ramp;
4. Construction object involved: construction machinery, drums, other traffic control devices, none;
5. Time of day: daylight, dawn or dusk, night;
6. Weather: no adverse weather conditions, rain, snow, fog, other;
7. Road conditions: dry, wet, snow or ice, mud or sand, other;
8. Vehicle type at fault: passenger car, pickup or recreational vehicle, tractor-trailer or bus, motorcycle;
9. Probable cause of accident: traffic control, driver, vehicle;
10. Contributing circumstances: excess speed, failure to yield, following too closely, drinking, driver preoccupation, improper passing, drove off roadway, defective vehicle, road defects, construction, traffic control, other, none; and
11. Traffic control procedures: traffic officer only, single-lane closure, multiple-lane closure, all lanes closed, shoulder closure, no closure, officer and single-lane closure, officer and multiple-lane closure, officer and all lanes closed, officer and shoulder closure, flagman.

The size of the data set did not permit any complex statistical analysis. Instead, 21 pair combinations were tested by means of difference-in-proportion tests. The comparisons and the results are presented next.

Combinations of Accident Categories

The following combinations were used in this study:

1. Accident severity versus type of accident, location of accident, construction objects involved, time of day, vehicle type at fault, traffic control procedures;
2. Type of accident versus location of accident, construction objects involved, time of day, vehicle type at fault, traffic control procedures;
3. Location of accident versus construction objects involved, time of day, vehicle type at fault;
4. Construction object involved versus time of day, vehicle type at fault, traffic control procedures;
5. Time of day versus vehicle type at fault, traffic control procedures;
6. Weather versus road conditions; and
7. Vehicle type at fault versus traffic control procedures.

The highlights of conclusions based on the tests are summarized here, organized by the 11 categories listed earlier in this paper. Detailed results of all tests are available from the authors.

Accident Severity

Accident severity was measured by the proportion of accidents resulting in injury or fatality. The proportions were as follows:

Type	Construction Accidents	All Accidents
Fatal accidents	3 (1.99%)	39 (1.32%)
Injury accidents	49 (32.45%)	1487 (50.44%)
Property damage only	99 (64.56%)	1422 (48.24%)

At the 21 study sites, construction-related accidents were less severe than all accidents. Of the 25 accidents that occurred in construction activity areas (where work was actually performed), one was fatal and 12 others resulted in injuries. This is significantly higher than the corresponding proportion of all accidents. Accidents involving construction objects (67) were less severe than other construction-related accidents. Accidents involving construction machinery (11) were more severe than accidents involving other construction objects, such as drums (45) or other traffic control devices (11). Accidents during the daylight hours (102) were more severe than those occurring at night (39) or at dawn and dusk (5). (Time of day information was not available for 5 accidents.) Accidents where pickup and recreational vehicles were at fault (16) were more severe than other accidents. Accident severity could not be related to traffic control procedures, e.g., lane closure or shoulder closure.

Type of Accident

The following types of accidents were observed: rear-end, 61 (40.40 percent); sideswipe, 15 (9.93 percent); improper merge, 7 (4.64 percent); single-vehicle fixed-object, 56 (37.09 percent); single vehicle run off road, 10 (6.62 percent); and other, 2 (1.32 percent). There was a difference in distribution of accident types at different locations within the work zone (see Table 3). Most of the single-vehicle, fixed-object accidents involved construction objects (see Table 4). There was a difference in the distribution of accident types during different times of the day: While most rear-end (53) and sideswipe (13) accidents occurred during daylight, all other types of accidents were evenly distributed between day and night. There was no difference in the distribution of accident types when vehicle types at fault or traffic control procedures were considered.

Location of Accidents

The construction zone, which might be several kilometers long, consists of specific sections, as listed under category 3 (see Selected Categories). The beginning of a construction area starts with the first set of advance warning signs. The lane taper area is the transition area where the normal roadway is altered laterally by channelizing devices. The lane closure area starts at the end of the taper and continues through the marked construction zone, but does not include the next category, the construction area. This is the actual site of the activities, which may move during the day within the lane closure area. The distribution of the accidents by location is as follows: beginning of zone, 24 (15.9 percent); lane taper, 34 (22.5 percent); lane closure, 59 (39.1 percent); construction area, 25 (16.6 percent); median opening, 4 (2.6 percent); and ramp, 5 (3.3 percent). Of the 11 construction machinery accidents, 6 occurred at the construction area and 3 at median openings. Of the 45 drum and 11 other traffic control de-

Table 3. Type of accident versus location of accident.

	Location						
Type	Construction Zone (beginning)	Lane Taper	Lane Closure	Construction Area	Median Opening	Ramp	Total
Rear end	14	8	30	6	3	0	61
Sideswipe	2	6	3	3	0	1	15
Improper merge	0	5	0	2	0	0	7
Single vehicle, fixed-object	7	15	22	9	1	2	56
Single vehicle, run off road	1	0	3	4	0	2	10
Other	0	0	1	1	0	0	2
Total	24	34	59	25	4	5	151
≸ of total	15.9	22.5	39.1	16.5	2.6	3.3	100

Table 4. Type of accident versus construction equipment involved.

	Construction Equipment				
Type	Construction Machinery	Drums	Other Traffic Control Devices	None	Total
Rear end	5	3	0	53	61
Sideswipe	3	1	2	9	15
Improper merge	1	5	0	1	7
Single vehicle, fixed-object	2	34	8	12	56
Single vehicle, run off road	0	2	1	7	10
Other	0	0	0	2	2
Total	11	45	11	84	151
≸ of total	7.3	29.8	7.3	55.6	100

vice accidents, 21 occurred in the relatively short taper area, 26 in the lane closure area, and only 3 in the construction area. The proportion of the 34 lane taper accidents occurring at night and at dusk (20) was significantly greater than the proportion of all other accidents occurring at the same time. The proportion of the tractor-trailer and bus accidents at the taper was significantly greater than accidents at all other locations involving the same type of vehicles.

Construction Equipment Involvement

The proportion of construction object (drum) accidents at night was significantly greater than the proportion of daylight construction object accidents. However, no construction machinery was hit at night or at dawn or dusk.

Time of Day

The distribution of accidents by time of day differed for different vehicle types at fault. The proportion of tractor-trailer and bus-caused accidents at night and dawn or dusk was greater than the proportion for other vehicles.

Weather

Accidents during adverse weather conditions included 15 during rain, 5 during fog, and 3 other. There were no snow-related accidents. No statistically significant patterns were discovered.

Road Condition

A total of 21 accidents occurred on wet roadway, matching closely the weather category. No other patterns related to pavement condition were discovered.

Vehicle Type at Fault

Vehicle type at fault categories were tested against traffic control procedures. No differences in distribution were found.

Probable Cause of Accident

The state highway patrol reports listed the driver as the probable cause of accident in 130 cases, the vehicle in 12 cases, and traffic control on 5 occasions.

Contributing Circumstances

The data obtained from the accident reports are given here. No statistical tests were performed. Excess speed was the most significant of the contributing circumstances noted. The contributing circumstances were excess speed, 88; failure to yield, 10; following too closely, 15; drinking, 5; driver preoccupation, 16; improper passing, 7; drove off roadway, 9; defective vehicle, 12; road defects, 4; construction, 8; traffic control, 3; other, 24; and none, 6.

Traffic Control Procedures

Only a few accident reports noted the presence of traffic officers or flagmen. Single-lane closure accounted for 124 of the reported accidents. There were 21 accidents where no part of the roadway was closed, and 6 accidents occurred when the shoulder was closed. No attempt was made to perform statistical analysis.

SUGGESTIONS REGARDING TRAFFIC CONTROL AT WORK ZONES

The procedures listed below and prescribed in the Manual of Uniform Traffic Control Devices are recommended given careful consideration of specific local conditions:

1. Expected proportions of large vehicles seem to be involved in more severe accidents and in more nighttime accidents.
2. Nighttime accidents are especially concentrated in the taper area. The review of channelizing devices for effectiveness at night is suggested. Signs should be well illuminated by headlights of all types of vehicles.
3. Excess speed was identified as the one single dominating contributing circumstance in accidents. The effectiveness of speed reduction signs should not be assumed.
4. Accidents are more severe in the construction activity area. Screening should be considered, if high speeds are to be maintained.
5. If traffic is expected to back up occasionally be-

yond the usual warning signs, additional warning signs should inform drivers about the cause of the problem.

6. Traffic control plans should be prepared by knowledgeable personnel. If geometric design standards or high volumes appear to indicate problems, past records of accident history should be studied for possible clues. The sites studied in this research did not have very bad accident problems, but all sites were on the rural Interstate system, which usually has low accident rates. On lower standard roads or in urban areas, the problems were more serious.

These suggestions are based on our interpretation of a relatively small set of accident data and on comments received from construction engineers during the data collection phase. More research is clearly needed.

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Ride Quality Criteria of Multifactor Environments

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A comprehensive ride quality model that accounts for the effects of multifrequency and multiaxis vibration inputs as well as the interactive effects of noise and vibration upon passenger discomfort is under development. The model development has been based upon extensive experimental studies utilizing a realistic multi-degree-of-freedom laboratory simulator located at the Langley Research Center, Hampton, Virginia. This paper briefly describes the basic elements of the ride quality model; presents summary data relating to human discomfort response to vertical, lateral, and roll vibrations; and concludes with a description of the results of an initial study of human response to combined noise and vibration stimuli. Results of studies involving vibration stimuli alone are presented in terms of sets of equal discomfort curves for each of the previously mentioned axes of vibration. In addition, a set of noise-vibration criteria curves are included based upon the concept of additivity of the discomfort components due to noise and to vibration. This assumption is shown to be valid for the restricted range of stimuli used in this study.

Passenger comfort within existing as well as future transportation systems is strongly dependent on environmental factors such as vibration, noise, temperature, and pressure. These factors can act to degrade vehicle ride quality and hence passenger acceptance of a particular transportation system. For example, the introduction of advanced transportation systems such as short-takeoff and landing (STOL) aircraft, civil helicopters, and high-speed surface vehicles is expected to be accompanied by more severe levels of vibration and noise than most currently operating systems. The increased levels of these environmental factors are likely to produce additional decrements in ride quality and, therefore, further reductions in passenger acceptance. Consequently, a definite need exists for a valid ride quality model that can be readily used by system designers to estimate the trade-offs between passenger acceptance (or comfort) and the degree of complexity of vehicle ride control systems required to achieve a specified level of comfort. To be useful, such a model should be applicable to any transportation system and should account for both multiaxis and multifrequency vibratory inputs as well as the interactive effects, if any, of noise and vibration. The uses of such a model would be to predict passenger acceptance of any noise-vibration environment, to determine the specific components of the noise or vibration environment or both that most affect passenger discomfort, and to serve as a diagnostic tool in providing a "fix" to a ride quality problem by knowing how much reduction in noise or vibration characteristics or both is required to achieve acceptability.

Numerous studies in the area of human subjective response to whole-body vertical vibration have been conducted (see 1-5). An excellent summary and critical review of a larger number of studies conducted prior to 1970 is given in Hanes (6). Unfortunately, as Hanes points out, the results of these studies show very little agreement with one another. Many of the criteria curves or recommended levels of vibration proposed by various investigators differ by as much as one or two orders of magnitude. Many reasons have been offered for such disparities in results, and these reasons are summarized as being attributable to poor experimental design, the multifactor nature of actual ride environments, use of inadequate adjective rating scales, subject populations used, and a lack of a fundamental understanding of the empirical laws governing human discomfort response to vibration (7).

A systematic and comprehensive effort to develop a general predictive model of passenger discomfort to combined noise and vibration that is free of the above limitations has been under way at the Langley Research Center, Hampton, Virginia. The National Aeronautics and Space Administration (NASA) model (7) recognizes that passenger discomfort results from the interrelationships of many factors of which vibration and noise are the most important. The NASA model approach involves the experimental determination of the basic psychophysical relationships governing human discomfort response to complex vibration and noise stimuli acting singly or in combination. The NASA concept involves the derivation of a scale of vibration discomfort and then inclusion of the effects of noise and other variables in the form of scale correction factors. Various investigations resulting from NASA efforts have been reported (see 8-17). The NASA model studies, however, have not yet accounted for the effect of noise and its possible interactions with the various parameters of vibration such as vibration frequency and amplitude. This paper summarizes the results of experimental studies of passenger response to single axis vertical, lateral, and roll vibrations and presents the results of a study directed toward the extension of the NASA ride quality model to the more general case of predicting passenger discomfort response to a combined noise and vibration environment.

APPARATUS

The experimental apparatus used in these studies is a unique laboratory simulator called the Passenger Ride Quality Apparatus (PRQA). The PRQA is located at the Langley Research Center and has been described in detail in Clevenson and Leatherwood (18). It is a three-degree-of-freedom simulator configured to resemble the interior of a modern jet transport (see Figure 1). Up to six subjects can be simultaneously exposed to field- or laboratory-generated noise and vibration inputs covering the range of frequencies and amplitudes known to affect passenger comfort. Approximately 2000 subjects have been used on the PRQA as part of the NASA Ride Quality Model Development Program.

METHOD

The results presented in this paper are derived from several different studies conducted at the Langley Research Center as part of a program for the development of a ride quality model. The methodology used in the various studies will be discussed in general terms in this paper, and the reader can refer to the designated references in order to obtain details of a particular experimental method.

Figure 1. A view of Passenger Ride Quality Apparatus (PRQA), a laboratory simulator located at Langley Research Center, Hampton, Virginia.

The methodological approach used to develop a family of equal discomfort contours for vertical vibration consisted of a sequence of three studies, employing a method of constant stimuli in the first study and magnitude estimation procedures in the remaining two studies (13). The sequence of studies for this axis used a total of 186 paid subjects (118 female, 68 male). The first study, using the method of constant stimuli, determined the acceleration level at each frequency (1 to 30 Hz) that produced identical values of discomfort. The second study, using magnitude estimates of discomfort as a function of acceleration level at each frequency, generated a family of equal discomfort curves. The third study, also employing magnitude estimation procedures, determined how different frequency components within the vertical axis summate or mask or both to produce the total discomfort response to a ride. The end result of these three studies was the development of a complete model for vertical vibration that accounts for within-axis frequency masking.

Equal discomfort curves and frequency masking for lateral and roll vibration were obtained in a manner similar to that described here for vertical vibration. The only difference in methodology involved the use of the method of constant stimuli to determine equality between vertical axis vibrations and both lateral and roll vibrations. This was necessary in order that the magnitude estimates of discomfort measured within any of the three axes would have similar meaning relative to the total discomfort scale. In other words, identical discomfort ratings of vibrations in each of the three axes would correspond to identical values of subjective discomfort. A total of 84 subjects were used in the lateral vibration study, and 96 subjects were used in the roll vibration study.

The study of the effects of combined noise and vibration used a total of 48 subjects and a magnitude estimation procedure to obtain subjective evaluations of discomfort. Each subject (six subjects concurrently) was required to provide magnitude estimations of successive comparison-ride segments relative to a standard-ride segment assigned the numerical value of 100. The comparison-ride segments consisted of vertical vibrations, either sinusoidal or random, and octave band random noise. The sinusoidal vibrations were at a frequency of 5 Hz, and the random vibrations had a center frequency of 5 Hz and a 5-Hz bandwidth. Root mean square (rms) acceleration levels varied from 0.02 to 0.130 g for both types of vibration stimuli. The octave band random noise was centered at 500 or 2000 Hz and was presented at ambient [$\approx$65 dB(A)], 75, 85, and 95 dB(A). The standard-ride segment was always sinusoidal in nature and was applied at a level of 0.074 g_{rms} in the ambient noise condition. The comparison-ride segments were factorial combinations of the noise and vibrations described above. The experimental design is shown in Figure 2.

RESULTS AND DISCUSSION

Vertical Axis Constant Discomfort Curves

A family of constant discomfort curves for vertical sinusoidal vibration was developed using the methods described in the preceding section. These curves are presented in Figure 3, which shows the peak and root mean square acceleration levels at each frequency (from 1 to 30 Hz) required to produce constant specified levels of discomfort. For example, the curve labeled "1" is defined as the DISC = 1 curve and corresponds to the threshold of discomfort. The acceleration levels of the curve can be considered as defining the boundary at which the subjective evaluations of ride quality change from one of comfort to one of discomfort. The curves noted by the numbers 2, 3, 4, and so on (DISC = 2, 3, 4, and so on) bear a direct ratio relationship to the threshold curve. That is, the DISC = 2 curve provides twice the discomfort of the DISC = 1 curve; the DISC = 4 curve corresponds to twice the discomfort of the DISC = 2 curve and four times that of the DISC = 1 curve. Thus, discomfort is a continuous function of vibration acceleration level at each frequency with the result that various levels of discomfort within each frequency can be readily discriminated. This is particularly pertinent to the development of ride quality criteria, since quantification of the basic psychophysical relationship between perceived discomfort and level of vibration stimuli will allow system designers to reliably estimate the trade-offs between passenger comfort and the ride environment for transportation vehicles. The equal discomfort curves in Figure 3 also display sharp dips at a frequency of 5 to 6 Hz, indicating these frequencies to be the most crucial with respect to ride quality judgments. This is to be expected, since these frequencies correspond to the major whole-body resonances of the human body. Absent from these curves are dips in the 10- to 15-Hz frequency region where local head and neck resonances of the human body have been shown to occur. The reason such effects were not observed in this series of studies was the use of actual cushioned aircraft seats (tourist class) that effectively reduced transmission of floor vibrations to the seated subjects at frequencies greater than 9 Hz. A point of interest regarding Figure 3 is the fact that the increment in floor acceleration required to produce a specified increase in discomfort (doubling of discomfort, for example) at low frequencies is much less than that required at the higher frequencies. This is attributable in part to reduced human sensitivity to vibration at the higher frequencies and also to the effect of the seat transfer function. In any event, vibration frequencies greater than approximately 15 Hz are felt to be relatively unimportant to ride quality for transportation vehicles operating within realistic ride environments. The downturn of the DISC = 1 and DISC = 2 curves of Figure 3 at frequencies greater than 25 Hz is probably due to increased cabin noise levels resulting from harmonic exitation of the cabin structure at the higher frequencies. Such continuous excitation would not normally be present in an actual operational transportation system.

Vertical Frequency Masking and Summation

The equal discomfort curves discussed above were developed by exposing passenger subjects to a series of

Figure 2. Experimental design of combined noise-vibration study.

VIBRATION		NOISE LEVEL, dB(A)						
		AMBIENT	75		85		95	
			Octave Center Frequency					
Type	g_{rms}	--- --	500	2K	500	2K	500	2K
SINUSOIDAL 5 Hz	0.020							
	0.042							
	0.064							
	0.085							
	0.106							
	0.130							
RANDOM 5 Hz	0.020							
	0.042							
	0.064							
	0.085							
	0.106							
	0.130							

Figure 3. Vertical equal discomfort curves.

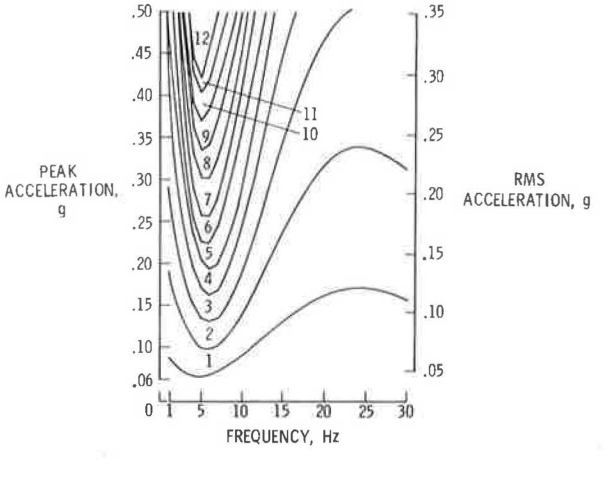


Figure 4. Vertical masking factor as a function of rms vertical acceleration and vibration bandwidth.

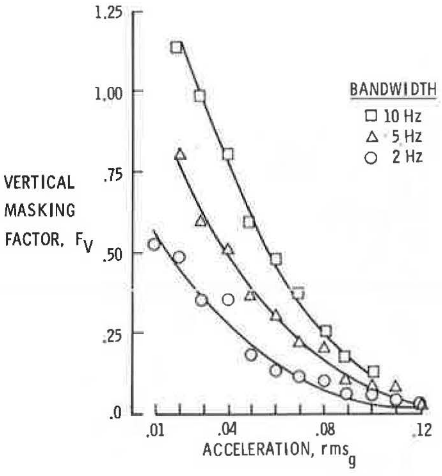
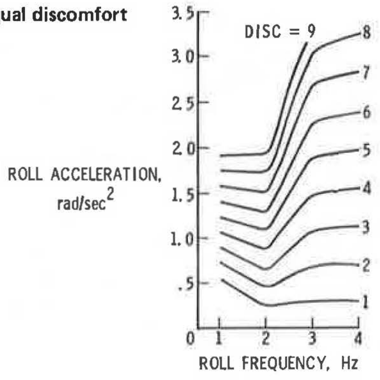


Figure 5. Roll equal discomfort curves.



discrete vibration stimuli, each of which was characterized by specific frequency and acceleration components. Thus, these curves are strictly applicable to the case of single frequency, vertical sinusoidal excitation. The logical question arises as to how to determine passenger subjective discomfort response in the presence of multiple frequency excitation. The results of an experimental study directed toward answering this question for vertical vibrations are presented in Figure 4. This figure presents the vertical frequency masking factor, F_v, as a function of root mean square floor acceleration and the bandwidth of the input vibration. To gain a proper understanding and interpretation of the data presented in Figure 4, it is useful to first consider the basis upon which the masking factor was determined. It was assumed that the masking phenomenon for vertical vibration can be represented by the following equation:

$$DISC_{TOTAL} = DISC_{MAX} + F_V (\Sigma DISC - DISC_{MAX}) \qquad (1)$$

Equation 1 is similar to that developed by Stevens (19) to calculate the loudness of complex noise. The terms in Equation 1 are defined as follows:

$DISC_{TOTAL}$ = Total perceived discomfort of an arbitrary ride spectrum composed of 30 contiguous frequency bands, each of which has a 1 Hz bandwidth.

$DISC_{MAX}$ = Contribution to the total perceived discomfort by the 1 Hz frequency band that produces maximum discomfort—determined by use of equal discomfort data.

$\Sigma DISC$ = Summation of the contributions to the total perceived discomfort produced by each of the 1 Hz frequency bands.

F_v = Vertical frequency masking factor.

The masking factor, F_v, is a measure of the degree of additivity (or nonadditivity) of individual frequency components in relation to the total discomfort response. If F_v approaches unity, then the total discomfort response ($DISC_{TOTAL}$) is given by the summation of the individual discomfort components within each frequency band (additive effect); consequently, no frequency masking is present. If F_v approaches 0, then the total discomfort response is given by the particular 1-Hz bandwidth of vibration that produces the maximum discomfort component. In this case, the contributions to discomfort made by the remaining frequency bands is completely masked. If F_v becomes negative, then an antagonistic interaction between the separate frequency components is present with the result that the rated discomfort will be less than the discomfort produced by the dominant frequency component. In Figure 4, the masking factor is seen to be a function of the bandwidth of vibration and the rms acceleration level within a bandwidth. No systematic trends for F occurred as a function of center frequency for any of the bandwidths. Recalling that small values of vertical masking factor, F_v, correspond to a high degree of masking whereas large values of F_v indicate little masking, it is seen that within a particular bandwidth the amount of frequency masking increases substantially with increasing levels of rms acceleration. This means that the separate frequency components of discomfort become less additive as rms acceleration increases. Furthermore, the amount of frequency masking decreases for increasing bandwidth of vibration. Both of these results are consistent with what would be expected to occur based upon purely physical considerations. For example, within a specified bandwidth the increase in masking with increasing rms acceleration level results from the fact that the contribution to total discomfort of the dominant frequency component (i.e., $DISC_{MAX}$) becomes disproportionately larger than the contribution to total discomfort of the remaining component frequencies.

The main point to be made with regard to these results is that the presence (or lack) of frequency masking for vertical vibrations is a function of both bandwidth and overall rms amplitude of the vibration. Hence, development of ride quality criteria should account for these factors. In a practical sense, a knowledge of frequency masking would allow for more accurate diagnosis of the source of ride quality problems and would enable system designers to more effectively select and apply ride control techniques for the improvement of vehicle ride quality.

Roll Equal Discomfort Curves

Constant discomfort curves for roll vibration are presented in Figure 5. The range of frequency (1 to 4 Hz) and roll acceleration level (0 to 2.0 rad/s^2) covered in Figure 5 are considered representative of those that may be encountered in realistic transportation systems. Each curve of the figure indicates the level of roll acceleration that is required at each sinusoidal frequency to produce constant levels of discomfort. These curves show that the lower frequencies result in the greatest discomfort. At these lower frequencies (1 to 2 Hz), large relative motions of the body, head, and trunk occur, and this probably accounts for the increased discomfort. It should also be noted that, for the range of roll acceleration studied, the maximum level of discomfort obtained was 9 discomfort units (DISC = 9) as compared to 12 discomfort units (DISC = 12) for vertical vibration.

Roll Frequency Masking and Summation

Masking information for the roll axis of vibration was obtained from tests in which passenger subjects were exposed to random roll vibrations of various amplitudes within a frequency bandwidth ranging from 0.5 to 4.5 Hz. The resulting masking data are presented in Figure 6 in terms of the roll frequency masking factor, F_R, as a function of root mean square roll acceleration level. These data indicate that values of the roll masking factor are much smaller than those obtained for the vertical masking condition and, furthermore, tend to become increasingly negative as roll acceleration level increases. At the smaller values of roll acceleration (less than 0.40 rad/s^2) used, the roll masking factor is approximately zero, indicating that the subjective response is dominated by the particular frequency component that produces the most discomfort. In other words, the separate frequency components of discomfort do not add, and subjective discomfort can be predicted from knowledge of the maximum discomfort component alone. Negative values of the roll masking factor, however, indicate that increases of roll acceleration level (greater than 0.40 rad/s^2) result in an antagonistic-subtractive interaction between the discomfort produced by separate frequency components. In a sense, this result may be thought of as a case of reverse or reciprocal masking between discomfort components. In this case, the subjective discomfort reported by subjects is less than the discomfort that would be produced by the dominant frequency component acting singly. Thus, predictions of subjective response to roll vibrations that do not account for this antagonistic interaction would tend to overestimate subjective discomfort at the higher roll acceleration levels.

Lateral Equal Discomfort Curves

The equal discomfort curves for lateral (side-to-side) vibrations are presented in Figure 7. These curves cover a frequency range of 1 to 10 Hz, because lateral vibration frequencies in excess of 10 Hz occur relatively infrequently in transportation vehicles and, hence, are considered to be of minor importance to ride quality. These curves indicate that human subjects are most sensitive to lateral vibration occurring at a frequency of 2 Hz with the sensitivity decreasing for frequencies both above and below this value. For the larger levels of discomfort, the sharp upward slope of the curves supports the previous assumption that the higher lateral frequencies are relatively unimportant to ride quality.

Lateral Frequency Masking and Summation

The masking data for the lateral axis of vibration are shown in Figure 8 in terms of the lateral frequency masking factor as a function of root mean square lateral acceleration for several bandwidths of lateral vibration. The data presented in Figure 8 were averaged over lateral vibration center frequency since center frequency had only a minimal effect upon discomfort responses. It is readily apparent that the frequency masking phenomena for the lateral axis differ from the vertical masking results in several important respects. One of the most obvious differences is the fact that lateral frequency masking factors are considerably smaller than those obtained for vertical masking and, most importantly, the 2-Hz bandwidth condition gives masking factors that are negative over the entire range of lateral accelerations investigated. This implies that the effects of individual frequency components within a 2-Hz bandwidth are subtractive, i.e., the total discomfort response to the frequencies contained within the band is less than the discomfort produced by the dominant individual frequency component.

The data for the 5- and 10-Hz bandwidth conditions indicate that lateral accelerations greater than approximately 0.085 g_{rms} result in lateral masking factors that approach zero. This implies that frequency components within a random vibration frequency band do not add, and, therefore, the discomfort response is attributable to the dominant frequency component alone. For lateral accelerations of less than 0.085 g_{rms}, the discomfort responses due to individual frequency components become slightly additive as indicated by the small positive values for the lateral masking factor (recall that F = 1 corresponds to perfect additivity). The overall conclusion to be made from the results of the lateral frequency masking study is that the contributions to discomfort of the individual frequencies within the larger bandwidths (5 and 10 Hz) are, at most, only slightly additive. This means that for these bandwidths the major contributor to discomfort will be the particular frequency that, if acting alone, would produce the most discomfort. For the 2-Hz bandwidth vibrations, however, the effects of the individual frequency components upon total discomfort response are subtractive. The exact mechanism accounting for this antagonistic-subtractive effect of reverse-reciprocal masking is not clear at the present time.

Combined Noise and Vibration

The results of the study of the effects of combined noise and vibration on passenger discomfort were analyzed by computing an analysis of variance based on the de-

Figure 6. Roll masking factor as a function of rms roll acceleration.

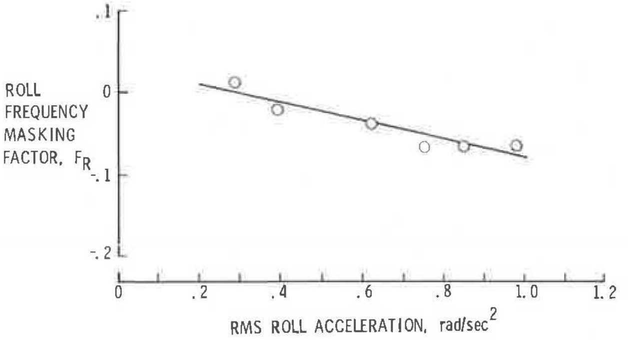


Figure 7. Lateral equal discomfort curves.

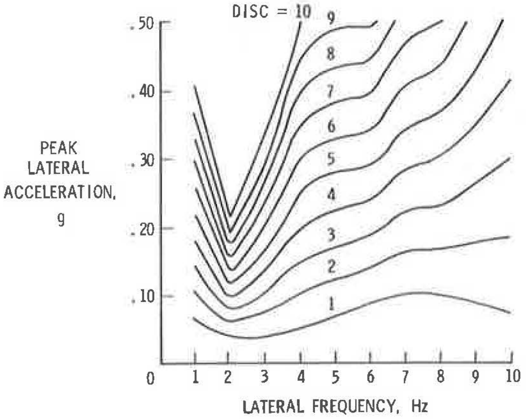


Figure 8. Lateral masking factor as a function of rms lateral acceleration and bandwidth of vibration.

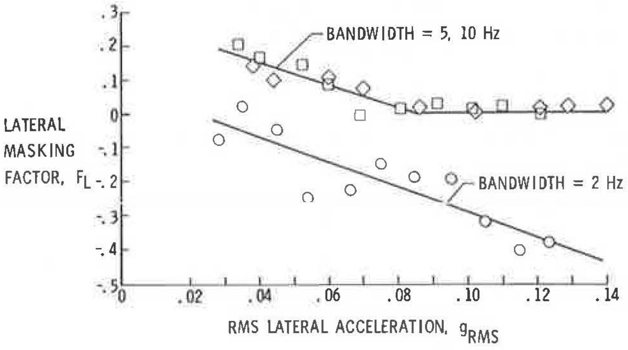
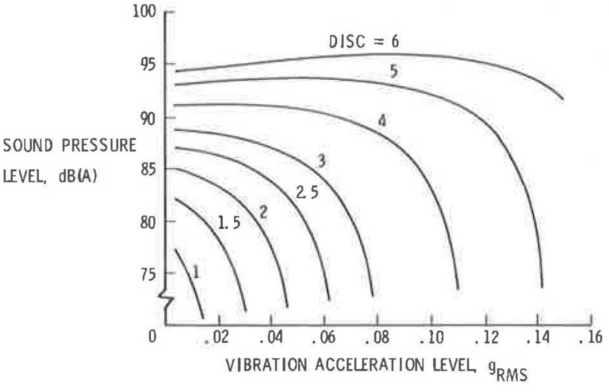


Figure 9. Noise-vibration criteria curves.



sign of Figure 1 (see 20). The analysis of variance (2 × 6 × 3 × 2) consisted of factorial combinations of two types of vibration (random or sinusoidal with each applied at six levels of acceleration: 0.020, 0.042, 0.064, 0.085, 0.106, and 0.130 g_{rms}) and of two different noise octave bands (500 and 2000 Hz center frequencies) presented at one of three noise levels [75, 85, 95 dB(A)]. There were repeated measures on all factors. A summary of the analysis of variance is presented in Table 1. All main effects (except for vibration type) and most double and triple interactions were significant. This implies that knowledge of all four factors is required in order to adequately assess passenger discomfort within the combined environment. Further analysis (Tukey test for additivity) of the interaction, however, indicated that the significant interactions may be an artifact of the analysis of overall reactions due largely to the fact that two different psychophysical laws are embedded in the overall discomfort responses, namely, a linear law for vibration discomfort and a power law for noise discomfort. This concept is discussed in the following section.

NOISE DISCOMFORT MODELING

The experimental design in Figure 1 provided the means for extending the NASA Ride Quality Model to incorporate a discomfort scale correction factor for noise, since the subjects were exposed to the same vibrations both with and without noise. Thus, the discomfort attributable to noise could be represented as the difference in discomfort between a ride with and without noise. The relationship would be given by the following formula:

$$DISC_N = DISC_{N+V} - DISC_V \qquad (2)$$

where

$DISC_N$ = discomfort due to noise only,

$DISC_{N+V}$ = discomfort due to combined noise and vibration, and

$DISC_V$ = discomfort due to vibration only.

Table 1. Summary of analysis of variance for overall discomfort responses.

Source	Sum of Squares	df	Mean Square	F
T Vibration Type	1.10×10^5	1	1.10×10^5	0.68
Error (SXT)				
A Acceleration Level, g_{rms}	609.67	5	121.93	72.62[a]
Error (SXA)				
D Noise Level, dB(A)	837.01	2	418.51	93.89[a]
Error (SXD)				
F Octave Bands	210.94	1	210.94	60.81[a]
Error (SXF)				
S Subjects	1472.19	47	31.32	-
TXA Interaction	9.90	5	1.98	4.15[a]
Error (SXTXA)				
TXD Interaction	2.77	2	1.38	2.58
Error (SXTXD)				
AXD Interaction	35.92	10	3.59	9.18[a]
Error (SXAXD)				
TXF Interaction	1.76	1	1.76	5.54[a]
Error (SXTXF)				
AXF Interaction	9.91	5	1.98	6.27[a]
Error (SXAXF)				
DXF Interaction	179.68	2	89.84	39.96[a]
Error (SXDXF)				
TXAXD Interaction	7.01	10	0.70	1.84[a]
Error (SXTXAXD)				
TXAXF Interaction	0.85	5	0.17	0.39
Error (SXTXAXF)				
TXDXF Interaction	0.68	2	0.34	0.78
Error (SXTXDXF)				
AXDXF Interaction	13.60	10	1.36	3.63[a]
Error (SXAXDXF)				
TXAXDXF Interaction	4.22	10	0.42	1.05
Error (SXTXAXDXF)				

[a] $p < 0.05$.

Equation 2 is valid only if noise and vibration do not interact, i.e., if their separate effects are additive. As noted earlier in this paper, the analysis of variance of the overall discomfort responses indicated that all interactions were significant. It was also suggested that these interactions may be an artifact of the linear analysis of overall discomfort responses and that two psychophysical relationships may be embedded in the overall discomfort responses. Consequently, two additional analyses of variance were computed based upon (a) noise discomfort responses, obtained from Equation 1, and (b) the logarithm of the noise discomfort responses. Computation of these analyses of variance allowed the determination of the degree of interaction (nonadditivity) of noise and vibration associated with the noise discomfort responses. That is, the assumption of additivity implicit in Equation 2 was tested for a linear and a power law relationship between noise discomfort and noise level. The analyses of variance were for factorial (6 × 3) combinations of vibration (6 levels) and noise (3 levels) with the noise discomfort responses averaged across octave bands. Results are summarized in Table 2. The results in Table 2 indicate a significant interaction of noise and vibration for the linear noise discomfort responses but not for logarithms of these same responses. Thus, the use of logarithmic transformation of noise discomfort responses removed the interaction of noise and vibration. The implication of this fact is that separate but successive noise and vibration criteria may be sufficient for the prediction of ride quality in the combined environment whenever the noise and vibration spectral characteristics are limited, i.e., noise energy, vibration energy, or both are concentrated within single octave bands, discrete frequencies, or both.

A tentative noise-vibration criterion based upon the additivity concept discussed in the preceding section is presented in Figure 9. This figure shows a set of constant overall discomfort curves for the combined noise and vibration environment. These curves were generated from the psychophysical functions relating noise discomfort and vibration discomfort to the physical levels of each stimulus (see 20 for details). The individual curves in Figure 9 indicate the noise level [dB(A)] and vertical vibration acceleration level (g_{rms}) required

Table 2. Summary of analyses of variance for both linear and logarithmic values of noise discomfort responses.

		Linear			Logarithmic		
Source	Degrees of Freedom	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
A Vibration Level	5	2.1602			0.5041		
B Noise Level	2	21.6025			3.9180		
AXB Interaction	10	1.0096			0.1949		
Nonadditivity	1	0.8858	0.8858	64.1884[a]	0.0003	0.0003	0.0139
Balance	9	0.1238	0.0138		0.1946	0.0216	

[a] $p < 0.05$.

to produce constant amounts of overall discomfort for the noise and vibrations of the present study. Discomfort levels range from a value of 1 (DISC = 1), corresponding to discomfort threshold, to a value of 7 (DISC = 7), corresponding to a high level of subjective discomfort. Several important facts and implications of criteria curves such as those in Figure 9 should be noted. These include: (a) the curves supply a single source of information for determining the overall discomfort due to combined noise and vibration, (b) trade-offs between noise and vibration in terms of subjective discomfort can be made, and (c) for noise levels greater than 95 dB(A), the discomfort is relatively unaffected by vibration acceleration level. The reader should note, however, that these statements apply strictly to the factors and factor levels used in this study.

CONCLUSIONS

This paper has presented a summary of the results of experimental studies of passenger discomfort response to single-axis vertical, lateral, and roll vibrations as well as passenger discomfort response to combined noise and vertical vibration. The important facts and implications of this research are summarized below:

1. A family of constant discomfort curves with a direct ratio relationship to one another was generated for vertical sinusoidal vibration. These curves were anchored at the discomfort threshold for vertical vibration.

2. Discomfort is a continuous and readily discriminable function of vibration acceleration level within each frequency of vibration. Quantification of the basic psychophysical relationship between perceived discomfort and vibration stimulus levels provides a very useful tool for determining trade-offs between passenger comfort and ride environment.

3. Vertical vibration frequencies greater than approximately 15 Hz are considered relatively unimportant to ride quality for transportation vehicles operating within realistic ride environments. This is due in large part to the attenuation of vertical vibration by the cushioned seats.

4. The presence (or lack) of frequency masking for vertical vibrations is a function of both bandwidth and overall rms amplitude of the vibration. Thus, the effect of frequency masking should be accounted for in the development of ride quality criteria, since a knowledge of this effect would allow for more accurate prediction, diagnosis, or both of ride quality problems.

5. A family of constant discomfort curves for roll vibration was developed. These curves were anchored at the discomfort threshold for roll vibration.

6. The roll masking data indicated that estimates of human discomfort response to random roll vibrations applied at levels less than or equal to approximately 0.40 rad/s^2 (rms) can be made from knowledge of the single roll frequency component that contributes the largest amount of discomfort. For roll acceleration levels greater than 0.40 rad/s^2 (rms), the separate frequency components of discomfort interact in an antagonistic sense. As a result, estimates of discomfort response that do not account for this antagonistic interaction would tend to overestimate subjective discomfort to the higher levels of roll vibration.

7. A family of constant discomfort curves (anchored at threshold of discomfort) was produced for lateral vibrations.

8. The frequency masking factor for the lateral axis was also found to be a function of both the bandwidth of vibration and the overall rms acceleration level. Furthermore, the relative values of the lateral masking factor were generally much smaller than the values of the vertical masking factor for corresponding bandwidths and acceleration levels. This meant that the discomfort values produced by individual frequency components contained within a lateral vibration spectrum were less additive than the discomfort components contained within a similar vertical vibration spectrum; i.e., for random lateral vibrations a single frequency component of the vibration spectrum is the dominant determiner of the subjective response to that spectrum. Consequently, it is important to account for these effects in the assessment of ride quality within transportation systems having substantial lateral ride motions.

9. Passenger discomfort responses to the combined noise and vibration stimuli used in this study were shown to be additive if a logarithmic transformation of noise discomfort responses was performed. This implies that separate but successive noise and vibration criteria may be sufficient for the prediction of ride quality in the combined environment when the spectrum characteristics of the noise and vibration are relatively uncomplicated, i.e., concentrated within single octave bands or discrete frequencies.

10. A tentative set of noise-vibration criteria curves (constant comfort) based upon the stimulus parameters of this study were generated. These criteria curves provide a single source of information for determining the overall discomfort due to combined noise and vibration as well as the trade-offs between the two stimulus factors in terms of passenger discomfort.

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Resource Impacts of Alternative Automobile Design Technologies

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Automobile production and operation consume energy, materials, capital, and labor resources. Alternative automobile design concepts are examined in terms of their aggregate resource impacts. A computer-based model was developed for generating the resource requirements of alternative automobile technologies. The model goes beyond previous tools in its scope, level of impact disaggregation, and flexibility. It projects the annual energy, materials, capital, and labor requirements of the passenger automobile fleet through the year 2000. The methodology integrates a family-tree technique with an input-output approach that generates the capital and labor information. It tracks 24 major materials, with supply disaggregated among primary and recycled materials, imports, and domestic sources. Net energy consumption is derived, along with capital and labor impacts disaggregated by 90 industries. The model was used to examine a broad range of scenarios, encompassing various automobile design technologies and constraints imposed by safety and emissions regulations. All the scenarios show fleet fuel consumption declining through 1985, as the gains in fleet fuel efficiency outweigh the growth in distances traveled. With a few exceptions, the weight-conscious designs and innovative structures result in a significant reduction in consumption of the major materials used in automobile production. Finally, increased capital expenditures in the automobile industry are offset by capital savings in other sectors of the economy.

As a major consumer of petroleum, the automobile has been the subject of much recent attention. Various techniques have been proposed for improving automobile fuel economy, ranging from simple retrofit devices to advanced engines and innovative structures. Unfortunately, the focus of this attention has been exclusively on petroleum consumption and has tended to ignore the other vital resources consumed by the automobile fleet. Automobile production and operation require energy, materials, capital, and labor resources in delivering a level of service that is usually measured in terms of vehicle distances traveled, or vehicle miles traveled (VMT). Aggregate demand for any of these four resources can be reduced through the substitution of the others. Thus, the selection of fuel-efficient automobile designs should be viewed and evaluated in terms of the trade-offs in aggregate resource requirements that they represent. The increased use of aluminum in automobiles, which would displace materials such as cast iron and sheet steel, is an example of these concepts.

Due to its light weight, aluminum substitution would lower the overall weight of the vehicle and improve fuel economy. However, aluminum production is very energy intensive. Whether or not there is a net energy savings would depend on whether the reduction in propulsion fuel consumption exceeds the changes in automobile fabrication and materials processing energy. Going further, it can be shown that similar trade-offs exist among the other resource categories; additional capital requirements are needed for motor vehicle and aluminum production facilities, but these are offset by investment savings in such areas as refineries, petroleum distribution, and steel manufacturing.

The aluminum example suggests the broad range of options available in the selection of future automobile design concepts and the large number of consequences. There are substitution possibilities within resource categories (e.g., between materials or between energy forms) and trade-offs between resource sectors (e.g., capital displacing energy). These trade-offs raise several critical issues:

1. In the process of lowering petroleum imports, are we creating a vulnerability in another area to a potential cartel?

2. Is the implementation of the design concepts feasible or constrained by supply bottlenecks?
3. To what extent do the direct energy savings exceed any increase in the indirect energy requirements?

In order to address these questions, a computer-based model was developed for generating the resource impacts of alternative automobile technologies and constraints imposed by safety and emissions regulations. The model derives the aggregate energy, materials, capital and labor requirements for automobile production and usage from 1975 through 2000. Functionally, the simulation is usually operated as an accounting model and not as a predictive model. In this mode, consumer behavior is exogenously specified, in terms of fleet size, new car sales, sales mix, and fleet VMT. Data on the attributes of alternative automobile design concepts are another input to the model.

The object of this paper is to present and discuss representative results showing the resource impacts of alternative automobile design technologies. To facilitate this goal, the paper first presents an overview of the methodology, including a description of the component submodels and the manner in which they are tied together. Next, a series of scenarios is described, encompassing a broad spectrum of automobile design options and constraints associated with meeting safety and environmental goals. The resource impacts of these cases are summarized and their energy, materials, capital, and labor implications discussed. Those readers interested in a more detailed description of the methodology and results are directed to Rubinger and Prensky (1).

MODEL OVERVIEW

An overview of the analysis process is presented in Figure 1. The Resource Accounting Model is comprised of three component submodels with an integrated data flow: the Fleet Attributes Model, the Aggregate Materials and Energy Consumption Model (ARAM), and the Capital and Labor Impacts Model (INFORUM). Figure 1 also identifies the exogenous scenario-specific information required by the model. These data fall into three general categories: automobile design data, marketing and mobility projections, and scenario descriptors.

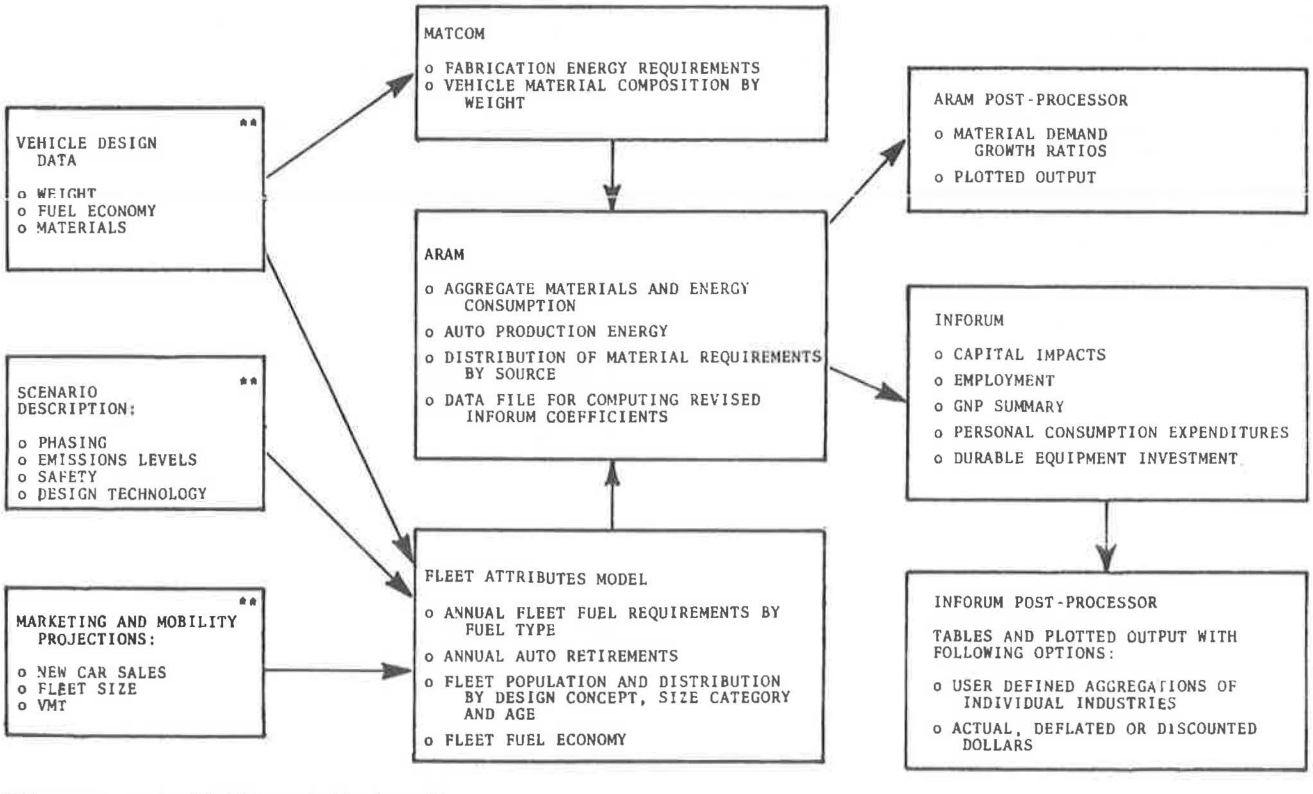
The impact analysis process is initiated by the specification of a scenario. Each scenario involves the selection of a series of automobile design technologies that are to be phased into production, along with schedules for implementing safety and environmental goals. The scenarios examine various combinations of automobile structure, engine, and drive train (each designated an automobile design concept); these rely on vehicle design data developed by the Auto Design Panel of the Federal Task Force on Motor Vehicle Goals Beyond 1980 (2). The specific automobile design concepts considered appear in Table 1. For each of these concepts, the value

Table 1. Automobile design concepts examined.

Fleet No.	Automobile Design Concept			Fleet Fuel Economy (km/L)
	Structure	Engine	Drive Train	
1	Current	Current	Current	6.9
3	Weight conscious	Top 1975	Current	9.7
4	Weight conscious	Top 1975	Improved transmission	10.5
5	Innovative	Top 1975	Improved transmission	11.7
7	Weight conscious	Diesel	Improved transmission	12.4
8	Innovative	Diesel	Improved transmission	13.5
10	Innovative	Advanced	Improved transmission	13.5

Note: 1 km/L = 2.47 mpg.

Figure 1. Overview of the Resource Accounting Model (RAM).



**Exogenous scenario-related data required by the model.

of such key vehicle attributes as weight, fuel economy, and material composition was required. Three size classes were used—small (four-passenger), midsize (five-passenger), and large (six-passenger).

The Fleet Attributes Model integrates marketing and mobility projections with automobile design characteristics to produce the scenario-dependent data required (a) to generate fuel consumption projections, (b) to run ARAM, or (c) to conduct a refinery impact study. In addition, it generates information on composite fleet emissions and the distribution of fleet VMT by age, automobile concept, safety level, and emissions standard. Projected fuel requirements are disaggregated into leaded and unleaded gasoline, diesel, and broadcut fuel. Since the Btu content of fuels differs, total fuel consumption and average miles per gallon statistics are calculated in gasoline equivalent measures (where 1 gal of diesel fuel is assumed to have the same energy content as 1.1 gal of gasoline or broadcut fuels). [The models were constructed using customary units; therefore SI equivalents are not given.]

The materials and energy consumed by the production and operation of automobiles are tracked by ARAM. A total of 24 major materials used in the production of automobiles are followed, and the total demand disaggregated among primary production, secondary production, and imports; this allocation is based on projections for future shipments and reflects a changing import ratio plus increased use of recycled materials.

ARAM also tracks the energy requirements, disaggregated by energy form (i.e., coal, natural gas, and so on) for materials production and processing, automobile fabrication, and automobile fleet operation.

The sequence of operations followed by ARAM is illustrated in Figure 1. Scenario-dependent data are supplied by the Fleet Attributes Model and Materials Composition (MATCOM). ARAM also includes an extensive internal data file containing all the nonscenario specific parameters. The values of the internal data coefficients and additional information on ARAM may be found in DeWolf and others (3).

Aggregate capital and labor requirements for the scenarios are generated by INFORUM, a dynamic model of the interindustry flows within the U.S. economy developed by the Interindustry Economic Research Project of the University of Maryland (4). The INFORUM input-output model was modified so that each scenario is translated into a new set of demands on the motor vehicle, producers durables, construction, and fuel supply sectors. For example, increased automobile industry investment requirements are converted into purchases from the producers durables and construction industries (3, 5). In addition, corresponding to the automobile design requirements, technical coefficients are modified to reflect the new pattern of purchases by the motor vehicles sector from supplier industries such as steel, aluminum, and plastics. Under these scenario-imposed constraints, INFORUM determines the gross national product (GNP) summary, personal consumption expenditures for the products of 200 industries, employment (disaggregated by 90 industries), durable equipment investment by each of 90 industries, and structures investment.

RESOURCE IMPACTS: REPRESENTATIVE RESULTS

The Resource Accounting Model provides the framework for examining a broad range of scenarios. For each case, the results will, of course, reflect the input assumptions regarding such factors as the rate of technology inplementation, the weight and fuel efficiency of the design configurations, new car sales, and fleet VMT projections. It is important to recognize that the validity of the methodology is independent of the choice of exogenous data. If other input assumptions were preferred, the simulation would be rerun with the alternate data. A useful application of the model is the examination of the sensitivity of the results to the input assumptions; this knowledge puts the significance of changes in the input data and the value of additional information into perspective.

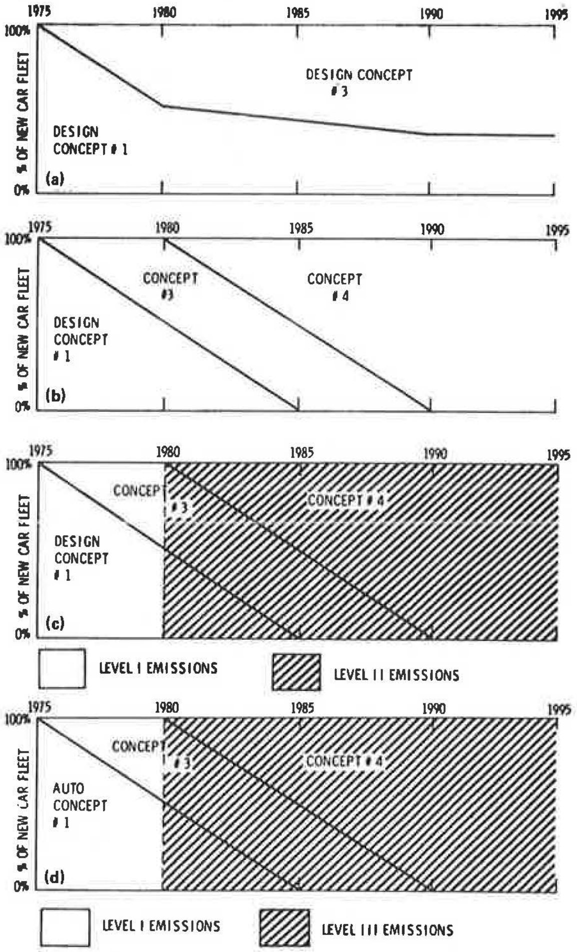
In the remainder of this paper representative results are presented and their implications for energy, materials, capital, and labor resource utilization are discussed. The cases selected focus on the resource impacts of alternative automobile design technologies and constraints related to national safety and emissions standards. To isolate these effects, the marketing and mobility projections (i.e., sales, market shares, VMT) have been held invariant between scenarios. For this purpose it was assumed that the future sales mix remains comparable to that in 1975. Furthermore, the growth in new car sales, fleet size, and VMT were based on the central projection of the Federal Task Force on Motor Vehicle Goals Beyond 1980 (6). These estimates are only dependent on the expected demographic and economic growth of the nation and not on a scenario's fleet fuel efficiency or other vehicle characteristics. Actually, some variations in sales and mobility between cases would be expected. However, a recent study showed that these perturbations are quite small (7) and can be ignored in deriving a first order approximation of the impacts. It should be emphasized that the resource accounting simulation has the flexibility of handling situations where sales, market mix, and VMT vary between scenarios; however, these results will not be presented here.

The central marketing and mobility projections assume new car sales grow from about 10 million units in 1976 to 16 million in the year 2000, an annual growth rate of about 2 percent. Simultaneously, total fleet size is expected to increase from 95.2 million vehicles (in 1976) to 161 million vehicles by the year 2000. Over this time period the corresponding growth in VMT is from 1648 to 2816 billion km (1030 billion miles to 1760 billion miles).

Four scenarios are illustrated in Figure 2. In scenario A (see Figure 2a), designated the Reference Case, 1975 begins with 100 percent production of automobile design concept 1 (see Table 1), the "average 1975" vehicle. Production of concept 1 is gradually reduced by the phase-in of automobile concept 3, which is characterized by a weight-conscious structure and top 1975 engine technology. Concept 3, which has a composite (i.e., averaged over sales mix) fuel economy of 10 km/L (24.2 miles/gal), is phased into production at the rate of 10 percent per year through 1980 and 2.2 percent per year between 1980 and 1990. This phasing assures that composite new car fuel economy in 1980 will be 8 km/L (20 miles/gal), the goal of both the voluntary fuel efficiency improvement program and the Energy Policy and Conservation Act of 1975 (8). Between 1980 and 1990, new car fuel economy improves an additional 10 percent and levels off thereafter at 8.8 km/L (22 miles/gal).

In scenario B (see Figure 2b), designated 1975 Technology Upgraded, design concept 3 is introduced into production at the rate of 10 percent per year, but production of concept 4 is initiated in 1980. This latter design concept is a weight-conscious vehicle as in concept 3, but in addition includes an upgraded transmission; its composite fuel economy is 10.5 km/L (26.3 miles/gal).

Figure 2. Scenario descriptions.



Design concept 4 is introduced into production at the rate of 10 percent per year and by 1990 represents 100 percent of new car production.

Scenario C (see Figure 2c), designated Upgraded 1975 Technology with Level II Emissions, is the first in a series designed to examine the impact of constraints associated with alternative emissions and safety standards. The emissions standards considered, identified as level I and level II, require that emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen not exceed 0.93/9.3/1.9 and 0.25/2.11/1.2 g/km, respectively. The figure for level III emissions is 0.25/2.11/0.25 g/km. Safety and damageability level II is characterized by a 64 km/h (40 mph) crashworthiness, plus antiskid brakes. Scenario C is identical to case B (see also Figures 3-5) in terms of the automobile design concepts produced. However, beginning in 1980, it requires that new cars meet level II exhaust emissions.

Case D, Upgraded 1975 Technology with Level III Emissions, is similar to the previous case except that all vehicles produced after 1979 must now meet more stringent (i.e., level III) emissions requirements (see Figure 2d). Meeting these standards requires that cars be equipped with dual or three-way catalysts. Estimates of the fuel economy penalties associated with future standards vary and range from zero to 20 percent; a penalty of about 10 percent was assumed for this scenario.

Case E, Upgraded 1975 Technology With Improved Safety, is similar to case B, except that there is an additional emphasis on safety. Automobile design concept 4, initiated into production in 1980, is assumed to meet level II safety and damageability requirements. The safety-enhanced vehicles are phased in gradually, achieving 100 percent of production in 1990.

Case F, Fuel Economy Emphasized with Level II Emissions, resembles case B in terms of phasing. However, the automobile design concept initiated in 1980 has a lightweight diesel engine, weight-conscious structure, and upgraded drive train. Automobile concept 7 is phased into production at the rate of 10 percent per year and represents 100 percent of the new car fleet by 1990. The superior fuel economy of the diesel allows the attainment by 1990 of a new car fleet fuel economy of 12.4 km/L (31.3 miles/gal, i.e., expressed in terms of gasoline equivalent gallons).

Representative results for the scenarios described here are given in Figures 3, 4, and 5. Figure 3 shows the average fleet fuel economy over the interval 1976 through 2000. It should be noted that improvements in fleet fuel economy lag behind new car fuel economy by about 10 years. This delay reflects the time it takes to scrap the older design concepts.

Total fuel consumption for scenarios and cases is compared in Figure 4. All the scenarios show fleet fuel consumption declining through 1985 as the gains in fleet fuel economy outweigh the growth in VMT. However, beyond 1985 the curves diverge, and by the year 2000 the reference case requires about 800 000 barrels/d more petroleum than the top 1975 technology case. It is also noteworthy that the adoption of the weight-conscious Otto designs allows fleet fuel consumption to be held below current levels through the year 2000, while maintaining the functional attributes of the vehicles. Viewed in terms of net energy requirements, production plus propulsion energy, the weight-conscious designs result in a savings of about 2 quads annually by the year 2000. Examination of the components that

Figure 3. Average fleet fuel efficiency.

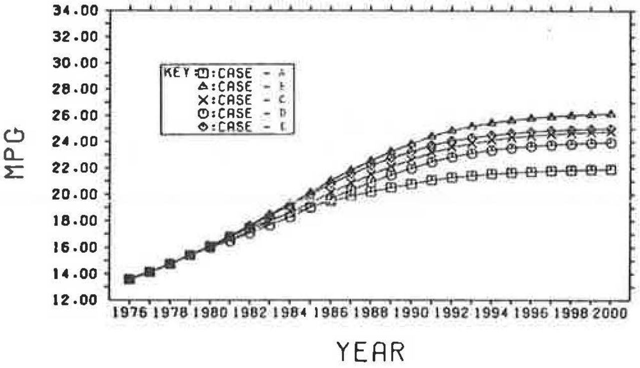


Figure 4. Comparison of annual fleet fuel consumption trends for selected scenarios.

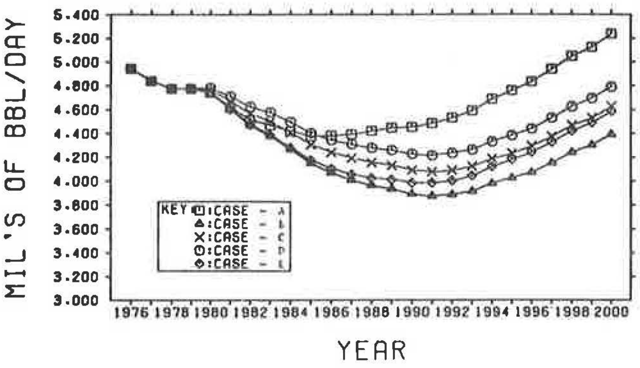
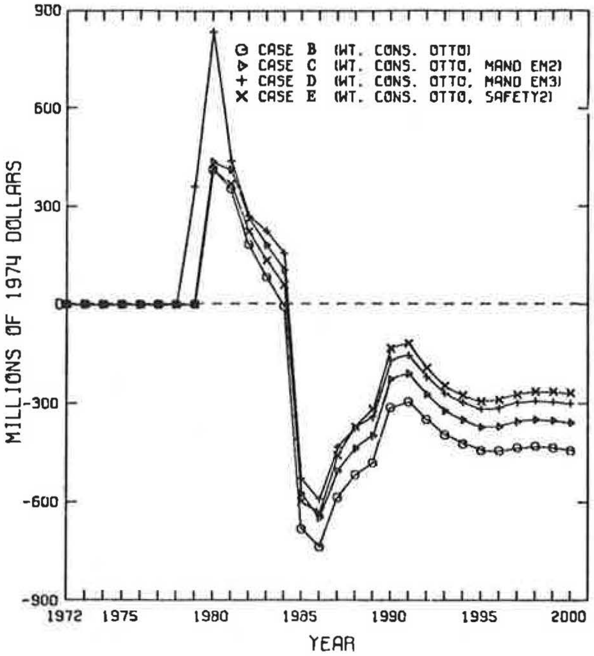


Figure 5. Total investment by case, as delta from the base case.



constitute net energy reveals that automobile production accounts for only about 9 percent of the total energy consumed by the fleet. Thus, the savings in propulsion energy achieved by material substitution (e.g., additional aluminum or plastics) overshadows the impact of any increase in vehicle production-fabrication energy.

The weight-conscious designs and innovative structures generally result in a significant reduction in consumption of the major materials used in automobile production. For example, the annual savings in steel consumption reaches about 1 million tons annually by the year 2000, while the comparable figure for cast iron is 150 000 tons. However, there are some exceptions to this trend. Increases are projected for specialty materials such as platinum, palladium, and stainless steel as a consequence of tighter emissions goals, while adoption of innovative structures leads to greater requirements for aluminum and plastics. Analysis of the material demand growth rates suggests that supply bottlenecks can be avoided with adequate planning.

The alternative design scenarios have greater investment requirements during the implementation phase, relative to the reference case, but show capital savings during the later years (see Figure 5). Whether or not there is a net capital savings depends on the discount rate used. Examination of the investment composition reveals that the capital impacts are determined by four primary effects:

1. An increase in investment requirements for the motor vehicle sector associated with the introduction of new design concepts;
2. A decrease in investment in the distribution sector due to lower levels of fleet fuel consumption;
3. Additional investments for service station conversion accompanying any shift to diesel fuel; and
4. A general decrease in capital investment requirements in the rest of the economy as a result of producing lighter vehicles (e.g., reduced demands upon the materials supply sector). A few industries run counter to these trends, most notably aluminum and the capital equipment manufacturers.

Finally, the employment impacts of the scenarios were relatively small. These impacts may be considered insignificant when compared with recent changes in the unemployment rate.

ACKNOWLEDGMENT

This work was carried out as part of the Automotive Energy Efficiency Project at the Transportation Systems Center and was sponsored by the Office of the Secretary, U.S. Department of Transportation. The Resource Accounting Model was developed by a multidisciplinary team that drew upon the advice of numerous experts in government. In particular, I wish to acknowledge the assistance of Bart DeWolf, Chris Davis, Peter Heinemann, Ron Mauri, and Alex Robb.

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Consumer Costs of Unnecessary Automobile Repairs

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Automotive repair is the subject of much consumer, as well as congressional, debate. This paper summarizes the results of a three-year automotive diagnostic inspection program aimed at collecting and analyzing automotive repair costs, especially unnecessary repair costs.

The excessive costs of owning, maintaining, and repairing automobiles have become increasingly burdensome. These costs have generated widespread consumer discontent and concern about the automobile, its costs and repairability. Except for the initial purchase of a car, the cost of almost every maintenance and repair item, as well as the cost of operation associated with the automobile, has risen significantly faster than the overall cost of living.

These excessive costs have resulted in much criticism of the repair industry. Beginning in 1968, the U.S. Senate Subcommittee on Antitrust and Monopoly began a 4-year investigation of the automobile repair industry. These hearings disclosed major areas where multibillion-dollar economic losses occur to the motorists. Foremost was the cost of unnecessary and unsatisfactory repairs. Other areas included the enormous damage suffered by vehicles in very low speed crashes, used cars that had the odometers turned back to enhance their value, and the economic losses resulting from stolen vehicles.

These factors served as the justification for the passage of the Motor Vehicle Information and Cost Savings Act of 1972 (PL 92-513). Title III of this act authorized the U.S. Secretary of Transportation to establish a number of motor vehicle diagnostic inspection and test centers throughout the country. The objective of the program was to provide for the accumulation of data to determine if diagnostic inspections are cost effective, i.e., do public benefits exceed program costs. Specific types of data collected by the inspection centers included vehicle outages, exhaust emission rates, repair costs, facility operation and staffing requirements, vehicle-in-use standards and feasible reject levels, equipment reliability and interchangeability, and the capability of the repair industry to correct diagnosed deficiencies.

This paper discusses one of the five motor diagnostic inspection demonstration programs. Specifically, this paper addressed the results of the analysis of the vehicle repair cost data from the Alabama motor vehicle diagnostic inspection demonstration project. Emphasis is placed on the unnecessary repairs by major vehicle system, by type of repair facility, and by selected vehicle components (1, 2).

DESCRIPTION OF AUTO CHECK

The Alabama motor vehicle diagnostic inspection demonstration project (3), known locally as Auto Check, was established by the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) in the fall of 1974. Auto Check is conducted by the University of Alabama in Huntsville, Office of Highway and Traffic Safety.

Auto Check has been designed as a model automotive diagnostic inspection facility. The exterior of the facility is shown in Figure 1, and a corresponding layout of the facility is shown in Figure 2. The facility covers over 1288 m^2 (14 000 ft^2) including administrative offices, a reception area, and a 30-seat theater. The facility can inspect 228 vehicles in an 8-h shift.

The inspection area consists of three parallel lanes 34 m (110 ft) long. Each lane contains five inspection stations. A description of the equipment in each lane is given in the following table:

Station	Equipment	Manufacturer	Model
1	Exhaust gas analyzer	Chrysler	Model 1
	Chassis dynamometer	Clayton	1492 watts (200 hp)
2	Dynamic wheel alignment system	Hunter	F-60
3	Headlight tester	Hunter	HD
4	Dynamic brake analyzer	Clayton	DB-8-CP
5	Twin post lifts	Dover	WABU-28-H
	Twin post lifts	Hunter	DA 76 cm (30 in)

In addition to the five stations, there are also two engine diagnostic bays each containing a Clayton CSS/7100 Engine Analyzer.

An inspection consists of checking 106 items on a vehicle. These items include tires, glass and body, interior, under hood, engine emissions, wheel alignment, headlight alignment, all lights and turn signals, brakes, wheels, fuel system, exhaust system, steering, and suspension.

Auto Check began inspecting cars early in 1975. The initial NHTSA guideline limited inspection to only the more popular vehicles in the 1968-1973 model years. The only foreign cars inspected were Volkswagens, Toyotas, and Datsuns. Since June 1976, Auto Check has been inspecting all model years, including pickup trucks and vans.

Auto Check has conducted over 30 000 inspections on 19 000 vehicles. Over 22 percent of the vehicles have returned for a follow-up or repair inspection after the defective items had been repaired. Many cars have returned for second, third, fourth, and even fifth periodic inspections at 6-month intervals.

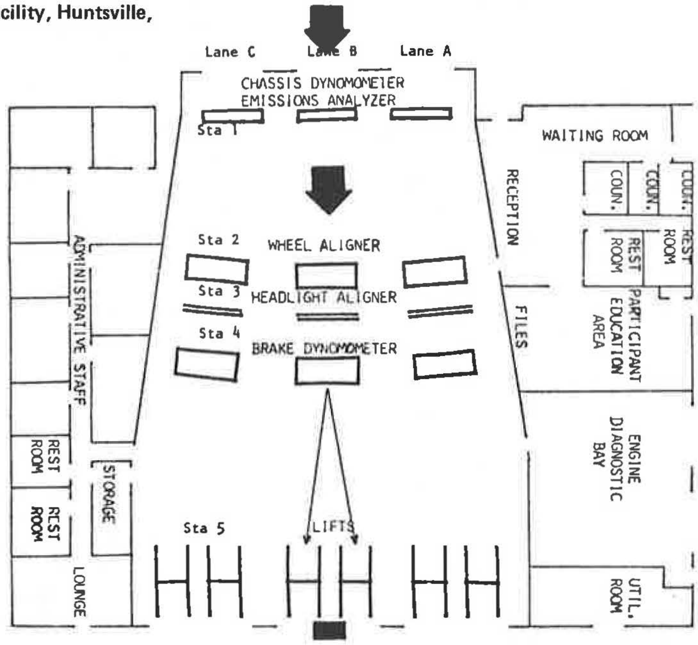
During the first two years of the program, the motorists were divided into two groups. One group, the experimental group, received detailed diagnostic inspection results. The other group, the control group, received only generalized inspection results typical of a state vehicle inspection. After the vehicles were repaired, they were again inspected to determine if the repairs were satisfactory. At that time, repair cost data and fuel and maintenance data were obtained from the motorists.

SELECTION OF SAMPLE

The sample for this study consisted of only those 1968-1973 model-year vehicles that had a brake, engine, alignment, steering, or suspension repair. The peri-

Figure 1. Exterior view of Auto Check facility, Huntsville, Alabama.

Figure 2. Interior layout of Auto Check facility, Huntsville, Alabama.



odic inspection results along with the repair costs for these vehicles were then entered into the university's computer.

The repair costs were analyzed relative to the 106 items on the Auto Check Inspection Form by a team of two individuals: an experienced garage shop supervisor and an experienced automotive parts specialist. Both of these individuals reviewed each form. In those instances where the two could not agree, an automotive engineer was consulted.

The following data elements were entered into the computer for each repair item or repair action:

1. Repair item—value of 1-106 corresponding to the inspection items;
2. Repair classification—required, recommended, optional, or unnecessary repair;
3. Repair facility classification—car dealer, tire dealer, merchandising chain (i.e., Sears), independent garage, service (gas) station, or owner repair—determined by the facility's major source of income;
4. Repair facility name;
5. Labor costs;
6. Parts costs; and
7. Participant's sex, age, marital status, and zip code.

The repair of each item was classified as being required, recommended, optional, or unnecessary. The criteria for determining the repair classification were

1. A repair was considered required if the repaired item was found to be substandard during the Auto Check inspection (judged as failed or marginal by data on the inspection form);
2. A repair was considered recommended if the repaired item is normally repaired as part of the repair of another substandard item, even though nothing was found to be substandard with the subject item during the Auto Check inspection, i.e., a wheel alignment when a worn steering system component is replaced;
3. A repair was considered optional if the repaired item could or could not be normally repaired as part of another substandard item repair, even though nothing was found to be substandard with the subject item during the Auto Check inspection, i.e., brake cylinder rebuilding when brake linings are replaced; and
4. A repair was considered unnecessary if the repaired item was found to be satisfactory during the previous periodic inspection and no other repair of any other marginal or substandard component would normally affect the decision to repair the subject item, i.e., a tuneup when only the carburetor idle mixture

ratio screw needed adjustment, or brake drum turning when only the linings were worn but the drum was not scored.

It should be noted that an unnecessary repair does not necessarily indicate that the motorist was "ripped off." Instead, it indicates that a repair action was made to an item that passed the Auto Check inspection. For example, an unnecessary repair may have been requested by the motorist for preventive maintenance. Or, in fairness to the repair facility, unnecessary repairs may have been performed to ensure compliance with the Auto Check reinspection. To ensure compliance, the industry may tend to take a conservative posture, much as a medical doctor with the fear of malpractice may over-test patients. Consequently, the repair facility may tend to over-repair not only to ensure compliance but also to ensure that the motorist does not have to return in the near future for additional repairs.

Specific criteria were developed for classifying the repairs (4). The criteria for classifying brake repairs are given in Table 1. In reading this table, it is recommended that the brake linings be repaired (replaced) when the brake drum is repaired (presumably because the drums are scored). A repair was only considered unnecessary if a prudent, knowledgeable individual, knowing the condition of that component and all the related components within the system, would not have the item repaired.

The distribution of the sample by make and model within vehicle year is given in Table 2. Of the 3140 vehicles, 10 percent were 1968 models; 14 percent, 1969; 17 percent, 1970; 19 percent, 1971; 21 percent, 1972; and 20 percent, 1973. Likewise, 46 percent were manufactured by General Motors (GM), 21 percent by Ford, 20 percent by Chrysler, 5 percent by American Motors Corporation (AMC), 4 percent by Volkswagen (VW), 3 percent by Toyota, and 2 percent by Datsun.

REPAIR COST ANALYSIS

A summary of the 6075 repair actions by each of the five major vehicle systems is given in Table 3. Of these repair actions, 65 percent were classified as required, 3 percent recommended, 7 percent optional, and 25 percent unnecessary.

A summary of the repair costs by each of the five systems is given in Table 4. A total of $129 217 in repair costs were analyzed. The unnecessary repair costs accounted for 29 percent of the repair dollar; the recommended, 3 percent; and the optional, 8 percent.

Systems Repairs

Table 5 summarizes the unnecessary repair actions and associated repair costs by vehicle system and repair facility. Overall, 30 percent of service station, 28 percent of tire dealer, 28 percent of chain, 26 percent of independent garage, 25 percent of car dealer, and 20 percent of owner repairs were unnecessary. There is no significant difference among the repair facilities, except for owner repairs, which were significantly lower ($p \cong 0.03$).

The unnecessary repair rate was significantly higher for female participants (27 percent) than for male participants (24 percent). Females also spent statistically more (38 cents) for unnecessary repairs than males (30 cents).

The unnecessary repair rate was the same (24 percent) for both the control and diagnostic groups. Also, 33 cents of every dollar the control group spent for repairs and 31 cents of every dollar the diagnostic group spent for repairs were unnecessary (not statistically significant).

The detailed statistical analyses of engine repairs indicated that chain stores had the highest rate of unnecessary repairs (40 percent); however, there is no significant difference among the repair facilities, except for owner repairs, which were significantly lower ($p \cong 0.001$).

Males performing their own engine repairs had a significantly lower unnecessary repair rate (21 percent) than those males who had their repairs made commercially (34 percent). Uninformed females in the control group spent more on unnecessary engine repairs than on legitimate repairs. However, informed females in the diagnostic group had unnecessary repair costs comparable to those for informed males.

Engine system repair costs were grouped into three categories: under $10, $10-$40, and over $40. The first category is a typical cost of an engine idle mixture ratio adjustment, the replacement of spark plugs, or a

Table 1. Classification of repairs performed on brake system components.

Failed Item	Repaired Item: Drum	Lining	Structural Parts	Brake Cylinders
Drum	Required	Recommended	Unnecessary	Unnecessary
Lining	Unnecessary	Required	Unnecessary	Optional
Structural parts	Unnecessary	Unnecessary	Required	Unnecessary
Brake cylinders	Unnecessary[a]	Unnecessary	Unnecessary	Required

[a] This repair is unnecessary unless the repaired item was contaminated by brake or axle fluid.

Table 3. Repair actions by vehicle system.

Vehicle System	Repair Action: Required No.	%	Recommended No.	%	Optional No.	%	Unnecessary No.	%	Repairs Total	%
Emission	894	60	10	1	130	9	445	30	1479	24
Steering	26	58	0	0	9	20	10	22	45	1
Alignment	1060	84	20	2	84	7	101	8	1265	21
Brakes	1675	60	143	5	191	7	789	28	2798	46
Suspension	277	57	5	1	35	7	171	35	488	8
Total	3932	65	178	3	449	7	1516	25	6075	100

Table 2. Sample distribution by manufacturer, 1968-1973 models.

Manufacturer	Model Year: 1968	1969	1970	1971	1972	1973	Total/%
General Motors	169	229	266	243	282	260	1449/46.1
Ford	47	76	117	138	136	132	646/20.6
Chrysler	52	84	80	107	160	137	620/19.8
American Motors	9	23	27	17	43	45	164/5.2
Volkswagen	24	23	18	20	16	11	112/3.6
Toyota	4	7	14	25	14	22	86/2.7
Datsun	1	4	11	21	19	7	63/2.0
Total/%	306/9.7	446/14.2	533/17.0	571/18.2	670/21.3	614/19.6	3140/100

Table 4. Total repair cost by vehicle system.

Vehicle System	Repair Classification									
	Required		Recommended		Optional		Unnecessary			
	Amount ($)	%	Amount ($)	%	Amount ($)	%	Amount ($)	%	Total ($)	%
Emission	20 518	54	175	0	3 903	10	13 155	35	37 750	29
Steering	477	60	0	0	138	17	184	23	799	1
Alignment	11 233	83	227	2	923	7	1 099	8	13 482	10
Brakes	35 398	59	3521	6	4 139	7	16 693	28	59 750	46
Suspension	9 624	55	120	1	1 186	7	6 507	37	17 436	14
Total	77 250	60	4043	3	10 289	8	37 638	29	129 217	100

Table 5. Unnecessary repair actions and costs by repair facility.

System/Repair Facility	Unnecessary Repair Actions		Unnecessary Repair Costs	
	Number	%	Amount ($)	Cents/$
Engine				
Service station	52	35	1671	45
Tire dealer	6	26	264	39
Car dealer	146	33	4317	44
Independent	98	32	3086	33
Chain	40	40	1081	49
Owner	27	20	441	15
Brakes				
Service station	86	32	2312	36
Tire dealer	120	38	2138	31
Car dealer	142	25	4340	32
Independent	153	28	3336	31
Chain	84	34	2254	32
Owner	44	20	455	14
Alignment				
Service station	7	12	109	17
Tire dealer	16	8	172	8
Car dealer	13	6	131	5
Independent	15	8	131	7
Chain	18	8	185	7
Owner	0	0	0	0
Suspension				
Service station	5	22	179	20
Tire dealer	23	43	962	41
Car dealer	18	29	913	38
Independent	23	32	975	33
Chain	56	40	1669	42
Owner	6	26	180	30
All				
Service station	150	30	4272	36
Tire dealer	165	28	3537	30
Car dealer	319	25	8765	34
Independent	289	26	7530	31
Chain	198	28	5186	33
Owner	77	20	1077	16

Table 6. Unnecessary repairs for selected brake components.

System/Repair Facility	Number Unnecessary Repairs	Unnecessary Repair Rate (%)	Unnecessary Repair Costs ($)	Unnecessary Repair Costs (%)
Front disc or drum				
Service station	16	62	188	56
Car dealer	29	59	414	48
Independent	37	54	402	43
Tire dealer	32	70	310	70
Chain	10	77	158	50
Individual	1	9	47	15
Front lining				
Service station	31	44	1056	49
Car dealer	48	50	1487	50
Independent	32	35	883	34
Tire dealer	19	28	631	34
Chain	25	37	667	32
Individual	5	11	68	9
Rear disc or drum				
Service station	7	37	90	21
Car dealer	19	63	178	54
Independent	28	57	240	54
Tire dealer	38	79	251	67
Chain	4	67	22	21
Individual	2	20	49	16
Rear lining				
Service station	19	28	437	24
Car dealer	19	18	515	18
Independent	25	24	612	25
Tire dealer	17	25	350	23
Chain	20	36	533	36
Individual	16	27	136	21
Rear wheel seal				
Service station	14	39	123	26
Car dealer	17	35	547	43
Independent	28	44	279	27
Tire dealer	13	46	194	46
Chain	32	67	354	57
Individual	8	62	26	38

basic timing adjustment. The second category is a typical cost of a tuneup. The third category is a typical cost of a more expensive repair such as a carburetor replacement or the grinding of exhaust valves. The results were 18 percent of the unnecessary repairs were below $10; over 51 percent of the required repairs were in this price range. On the other hand, over 20 percent of the unnecessary repairs exceeded $40; only 13 percent of the required repairs exceeded this amount. The data suggest that an unnecessary repair is more likely to be an expensive repair ($p < 0.001$).

The females in the uninformed group (control group) had a significantly higher percentage of unnecessary repairs in excess of $40 compared with the male and informed female groups. This suggests that an uninformed female who has a vehicle's engine repaired is likely to have an excessive repair bill, because she is less able to interface with the repair facility from a knowledge level. On the other hand, if the female has information, suggesting that she could verify the repair shop's conclusion, she is not as likely to have an excessive repair bill.

With legislation shifting to the concept of long term, low emissions from automobiles and some states now requiring motorists to drive nonpolluting cars, the data suggest that the female, if she is required to maintain her automobile according to a set of standards, may be unable to interface with the repair facility from a knowledge level.

The detailed statistical analyses of brake repairs indicated that tire dealers had a significantly higher ($p \simeq 0.001$) rate (38 percent) of unnecessary repairs than the other repair facilities (25 percent). On the other hand, owners performing their own repairs had a significantly ($p \simeq 0.005$) lower rate (16 percent) of unnecessary repairs than the commercial facilities (25 percent). Also, 74 percent more owners performed their own repairs when they were given diagnostic information.

Brake system repair costs were grouped into three categories: under $9, $9-$30, and over $30. The first category is a typical cost of cleaning and adjusting the brakes. The second category is a typical cost of minor repairs or relining the brakes on a single axle. The third category is a typical cost of a complete brake job, such as relining all four drums. The results were 27 percent of the unnecessary repairs were below $9; 38 percent of the required repairs were in this price range. On the other hand, over 32 percent of the unnecessary repairs exceeded $30; only 22 percent of the required repairs exceeded this amount. As with engine repairs, it appears that an unnecessary brake repair is an expensive repair ($p < 0.001$).

Selected Component Repairs

The analysis at the component level consisted of evaluating only brake disc or drum, brake lining, rear wheel seal, control pivot arm, idler arm, lower ball joint, and shock absorber repairs. Repairs to these nine components represented 34 percent of the repair actions, 40 percent of the repair dollars, and 53 percent of the unnecessary repair costs for all critical system repairs.

Brake Components

Table 6 gives the unnecessary repair rates and costs for the selected brake components by type of repair facility. The most notable results are that 70 percent of the front disc or drum and 79 percent of the rear drum repairs performed by tire dealers were unnecessary. Also, 70 cents of the repair dollar spent for front disc or drum repairs and 67 cents of the repair dollar spent for rear drum repairs at tire dealers were unnecessary.

The new car dealers had a significantly ($p < 0.005$) higher unnecessary repair rate (50 percent) for front wheel lining repairs. On the other hand, the new car dealers had a low unnecessary repair rate (18 percent) for rear lining repairs. This anomaly cannot be explained at this time.

Chain stores had a significantly ($p < 0.05$) higher unnecessary repair rate (36 percent) for rear brake lining repairs. Also, 36 cents of every dollar spent at chain stores for rear brake lining repairs was unnecessary. Chain stores had a significantly ($p < 0.005$) higher unnecessary repair rate (67 percent) for rear wheel seals. Also, 57 cents of every repair dollar spent for rear seal repairs at chain stores was unnecessary.

Steering Components

Table 7 gives the unnecessary repair rates and costs for the selected steering components by type of repair facility. The tire dealers and the chain stores had a 53 percent unnecessary repair rate for idler arm repairs. Although this was the highest unnecessary repair rate, it was not significantly higher. Of the steering system unnecessary repair costs, 55 percent were due to control arm pivot repairs. All the repair facilities had a high unnecessary repair rate for control arm repairs.

Table 7. Unnecessary repairs for selected steering components.

Component	Number Unnecessary Repairs	Unnecessary Repair Rate (%)	Unnecessary Repair Costs ($)	Unnecessary Repair Costs (%)
Idler arm				
Service station	1	17	30	23
Car dealer	9	32	251	37
Independent	4	19	102	22
Tire dealer	10	53	244	47
Chain	10	53	305	52
Individual	3	27	41	27
Control pivot arm				
Service station	4	80	150	78
Car dealer	10	83	357	92
Independent	15	83	543	86
Tire dealer	5	71	192	77
Chain	19	83	771	84
Individual	1	100	4	100

Suspension Components

Lower ball joint and shock absorber repairs accounted for 96 percent of the suspension system unnecessary repair costs. Table 8 gives the unnecessary repair rates and costs for these components by type of repair facility.

There was no significant difference among the various types of repair facilities in the unnecessary repair rates of lower ball joints. However, 25 cents of every repair dollar spent for ball joints at independent facilities was unnecessary, while 45 cents of every repair dollar spent at the tire dealers was unnecessary. The tire dealers had a significantly higher unnecessary repair rate (55 percent) for shock absorber repairs. Also, 56 cents of every repair dollar spent for shock absorbers at tire dealers was unnecessary.

Repair Variations Within Type of Repair Facility

Figure 3 gives the unnecessary repair rates by specific car dealer. A chi-square test indicated that the variation in the unnecessary repair rates is significant ($p = 0.01$).

Dealers B and K had a significantly lower ($p \cong 0.005$) unnecessary repair rate. Dealer G had a significantly higher ($p \cong 0.015$) unnecessary repair rate. The out-of-Huntsville car dealers had a significantly lower ($p \cong 0.001$) unnecessary repair rate. This suggests that the car dealers in the small towns may be more sensitive to the effects of unnecessary repairs on their reputations.

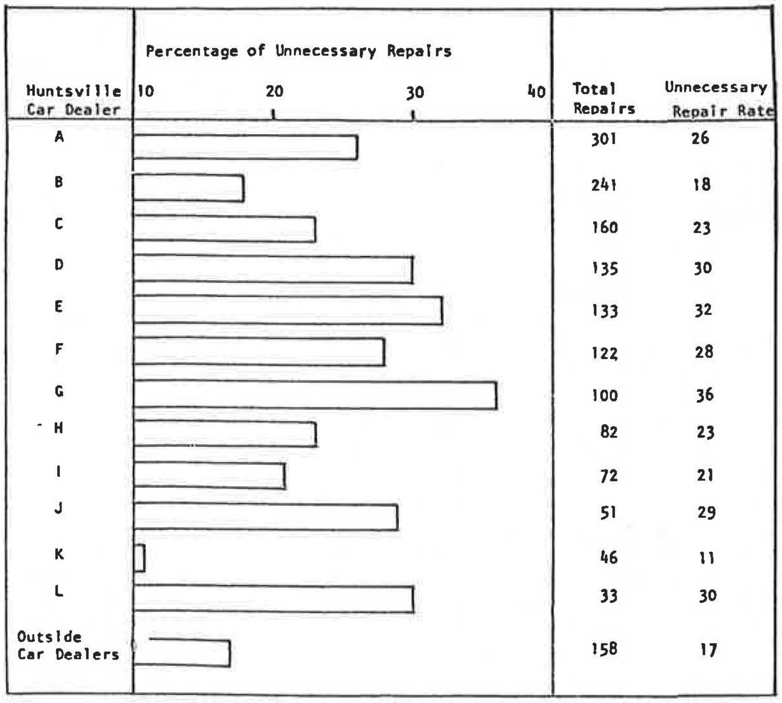
Unnecessary repair rates by specific chain store were also analyzed. A chi-square test indicated that the variation in the unnecessary repair rates between individual stores is significant ($p \cong 0.001$) for the chain stores. For example, chain F contributed 73 percent to the chi-square and was the principal contributor to the nonuniformity in the unnecessary repair rates.

Discretion must be used in assuming that any one repair facility is good or bad based upon the performance of its particular type. For example, for all brake repairs, one merchandising chain only had a 26 percent unnecessary repair rate, while another chain had a 66 percent unnecessary repair rate. This may reflect local conditions such as labor, skill, or local and national management attitudes. In addition, the overall unnecessary brake repair rate for dealers of American-made cars varied from 18 percent to 35 percent. The public appears to be aware of these variations in the quality among the various repair facilities. The best performing chain did 252 percent more brake work than the poorest one. The new car dealer with the best performance did 70 percent more business than would

Table 8. Unnecessary repairs for selected suspension components.

Component	Number Unnecessary Repairs	Unnecessary Repair Rate (%)	Unnecessary Repair Costs ($)	Unnecessary Repair Costs (%)
Lower ball joint				
Service station	2	40	110	40
Car dealer	7	23	573	36
Independent	11	26	572	25
Tire dealer	8	47	428	45
Chain	8	40	392	40
Individual	2	22	63	27
Shock absorber				
Service station	7	37	243	33
Car dealer	6	25	272	31
Independent	9	33	336	40
Tire dealer	21	55	875	56
Chain	51	37	1723	43
Individual	6	32	171	33

Figure 3. Unnecessary repairs by specific car dealers, both in and outside Huntsville, Alabama.



Huntsville Car Dealer	Total Repairs	Unnecessary Repair Rate
A	301	26
B	241	18
C	160	23
D	135	30
E	133	32
F	122	28
G	100	36
H	82	23
I	72	21
J	51	29
K	46	11
L	33	30
Outside Car Dealers	158	17

Figure 4. Effects of prescription form use on unnecessary repair rates, by repair facility.

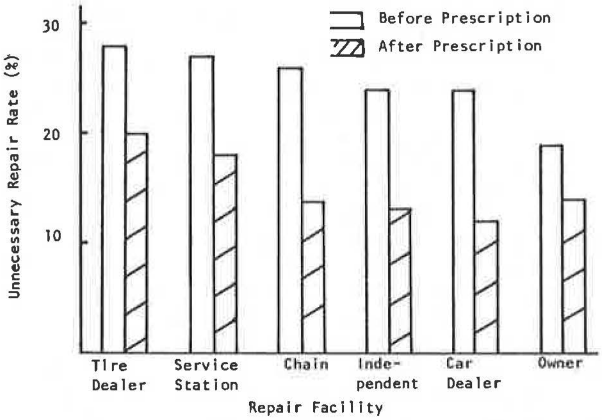
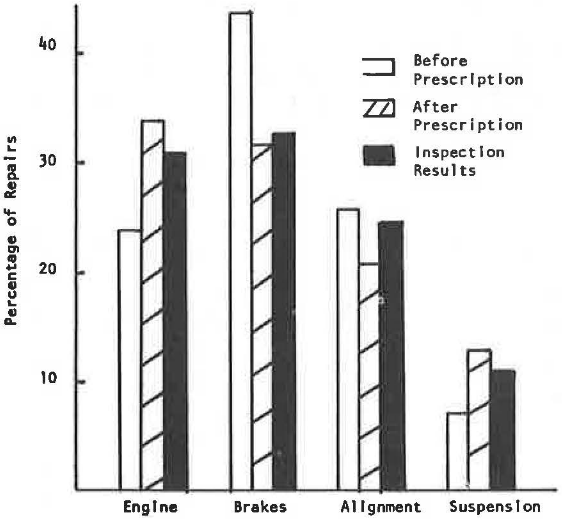


Figure 5. Effect of prescription forms on consumer's repair priorities.



have been expected based on the population of the vehicles that it sells.

SUPPLEMENTARY INFORMATION SUPPLIED TO THE PARTICIPANT

During the 3 years of the Auto Check program, several experiments were conducted in transferring the results of the diagnostic inspection to the participants so that the participants could interface better with the repair industry, and, hopefully, could minimize repair costs. Initially, the participants were given a copy of the inspection results, with the experimental group receiving the detailed results and the control group receiving more general results. In addition to these forms, an Auto Check counselor reviewed the inspection form with each participant.

Beginning in January 1976, the counselor gave the participants in the experimental group repair hint booklets in addition to the inspection form. Only those participants whose vehicles had either engine or brake outages or both were given the booklets. These booklets further explained the results of the engine and brake inspection results. Distribution of these booklets was terminated after July 1976.

Beginning in January 1977, the counselor gave all participants a prescription form which gave the participants the specific repair instructions to convey to the repair facility. Two prescription forms were actually used. One form was for engine-related outages, while the second form was for brake, tire, steering, suspension, and wheel alignment outages. The forms have a priority column where the counselor indicates the relative importance of each repair.

With only the inspection forms, the unnecessary repair rate was 25 percent. The use of the repair hint booklets reduced the unnecessary repair rate to 24 percent. The use of the prescription forms significantly reduced the unnecessary rate to 13 percent ($p < 0.0001$).

The unnecessary engine repairs were reduced from 33 percent to 16 percent after the participants were given the prescription forms. Likewise, the unnecessary brake repairs were reduced from 30 to 18 percent, unnecessary alignment repairs from 8 to 4 percent, and unnecessary suspension repairs from 36 to 19 percent. The unnecessary repairs for both males and females were significantly lower ($p < 0.01$) after they were given the prescription forms.

All repair facilities had a lower unnecessary repair rate after the introduction of the prescription forms (see Figure 4). The unnecessary repair rates were significantly lower for car dealers ($p < 0.0001$), independents ($p < 0.001$), and chains ($p < 0.01$).

The prescription forms had an effect on the consumer's repair priorities (see Figure 5). Prior to the prescription forms, 24 percent of all repairs involved the engine; after the prescription forms, 34 percent involved the engine. Normally, based on the inspection results, 31 percent of all repairs should have involved the engine assuming that the participants saw no risk in having any repairs made. Likewise, before the prescription, 44 percent of all repairs involved brakes, 26 percent alignment, and 7 percent suspension. After the prescription forms, 32 percent involved brakes, 21 percent alignment, and 13 percent suspension. These data compare favorably with the inspection results, indicating that 33 percent should have involved the brakes, 25 percent alignment, and 11 percent suspension.

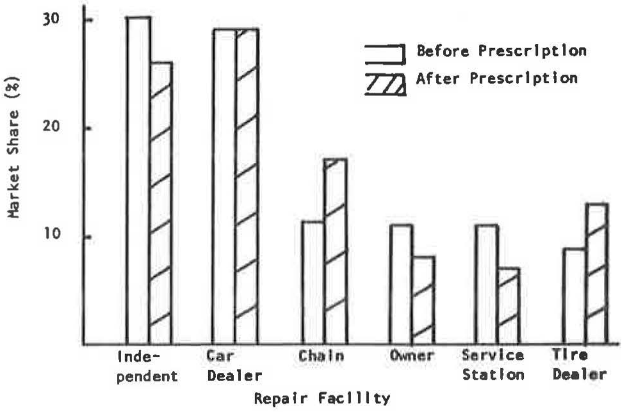
The prescription forms also had an effect on the market shares of the repair facilities (see Figure 6). The chains and tire dealers increased their market shares at the expense of the service stations, independents, and owner repairs. The car dealers maintained their share.

Participants were asked: Who do you think provides the best repairs? This survey noted that 50 percent said independents, 27 percent car dealers, 15 percent chains, 6 percent service stations, and 1 percent tire dealers. Although only 1 percent thought that tire dealers gave the best repairs, 9 percent (of those going to a commercial facility) actually took their cars to tire dealers before the prescription form and this share increased to 13 percent with the prescription form. Tire dealers do a large amount of advertising and offer specials which are probably major factors attributing to this difference. It is possible that the prescription form reduced the participant's anxiety in dealing with a type of repair facility that he or she does not trust entirely in order to obtain the cost advantage.

REPAIR COST-EFFECTIVENESS

By reinspecting each vehicle after it was repaired, it was possible to calculate the cost-effectiveness of the repair facilities. Cost-effectiveness is defined as the total cost of necessary, unnecessary, successful, and unsuccessful repairs per successful repair. Necessary (required, recommended, optional) and unnecessary repairs have already been described. A successful repair is one that eliminates a previously observed outage, whereas an unsuccessful repair is one that does not.

Figure 6. Representation of market share of legitimate repairs experienced before and after prescription forms were introduced.



The cost per successful repair, or cost-effectiveness, by system and by type of repair facility is given in the following table:

Repair Facility	Engine ($)	Alignment ($)	Brakes ($)	Suspension ($)
Service station	40.36	14.38	45.05	38.00
Tire dealer	28.33	14.22	47.18	49.45
Car dealer	31.82	15.65	35.85	38.17
Independent	48.74	12.98	41.23	48.30
Owner	34.64	12.00	24.99	27.69
Chain	41.18	14.22	51.46	35.67
Average	38.52	14.34	40.04	39.82

A considerable variation existed in the cost-effectiveness of the various types of repair facilities. The most cost-effective commercial facility type for engine repairs cost the public 42 percent less per successful repair than the least cost-effective type of facility. For brakes, the most cost-effective commercial facility type cost the public 30 percent less than the least cost-effective facility. However, one must not assume that, while a type of facility is efficient, any member of that type also would be efficient.

Table 9 presents the cost-effectiveness for the local members of the car dealer group. The average cost-effectiveness includes the cost of unnecessary repairs to perfectly satisfactory systems. (This explains why dealer L has an average cost-effectiveness greater than the cost-effectiveness of any individual system.) The cost-effectiveness for individual systems only includes the monies spent on systems that had a previously noted outage. Of the 12 car dealers, the six most cost-effective performed twice as many repairs as the six that were the least cost-effective; this fact suggests that a portion of the public may be aware of the shops doing the best work. Car dealer A is particularly notable in that, among all shops performing ten or more repairs on any one system or 30 or more repairs on all systems, it was the most cost effective for the engine, alignment, and brake systems; had the highest success rate for the engine and alignment systems; and stood at 82.4 percent in overall repair success.

AVERAGE VEHICLE REPAIR COSTS

The average vehicle repair costs were computerized for the major systems. On the average, the motorist spent $28.14 for a brake repair, $25.91 for an engine

Table 9. Cost-effectiveness figures for various new-car dealers.

Dealer	Total Repairs	No. of Successful Repairs	$/Successful Repair				
			Engine	Align-ment	Brakes	Suspen-sion	Aver-age
A	68	56	20.13	10.20	16.06	42.59	29.65
B	16	16	22.86	12.40	31.56	43.97	30.38
C	148	104	28.82	12.65	27.16	48.53	32.23
D	89	68	25.72	15.93	52.82	27.70	39.84
E	181	131	33.80	20.75	41.82	38.26	40.87
F	32	24	17.99	15.68	57.20	96.16	42.35
G	31	18	61.25	25.22	- -	- -	42.62
H	49	43	37.00	10.80	45.26	6.89	43.51
I	53	38	38.76	11.00	32.23	47.75	48.31
J	44	29	51.15	23.20	24.44	48.02	49.78
K	65	47	53.91	12.64	63.39	30.07	53.81
L	21	19	40.15	16.02	45.70	66.42	76.05

repair, $15.65 for a steering repair, $35.64 for a suspension repair, and $10.22 for an alignment repair.

The average vehicle repair costs were analyzed by 2-month intervals for all the critical systems excluding steering. A regression analysis indicated that the overall average repair cost has increased by an estimated 12 percent, which approximates the rate of inflation.

In analyzing the data, there appears to be a learning function operating during the lifetime of Auto Check. Assuming that this learning effect does exist, then it is possible to estimate the amount of unnecessary repair costs motorists are saving by having their vehicles inspected at Auto Check. It can be assumed that the vehicle repair costs for the first time period are representative of a nonparticipant in Auto Check. Likewise, the vehicle repair costs for the last time period should be representative of an Auto Check participant. The difference in the cost would represent the potential savings to the consumer.

The average vehicle repair costs were analyzed by 2-month intervals for the engine and brake systems. A regression analysis indicated that the average unnecessary engine repair costs decreased $4.41, while the average unnecessary brake repair costs decreased $4.27. This suggests that a person participating in the Auto Check program may be saving up to $8.68 in unnecessary engine and brake repairs.

CONCLUSIONS

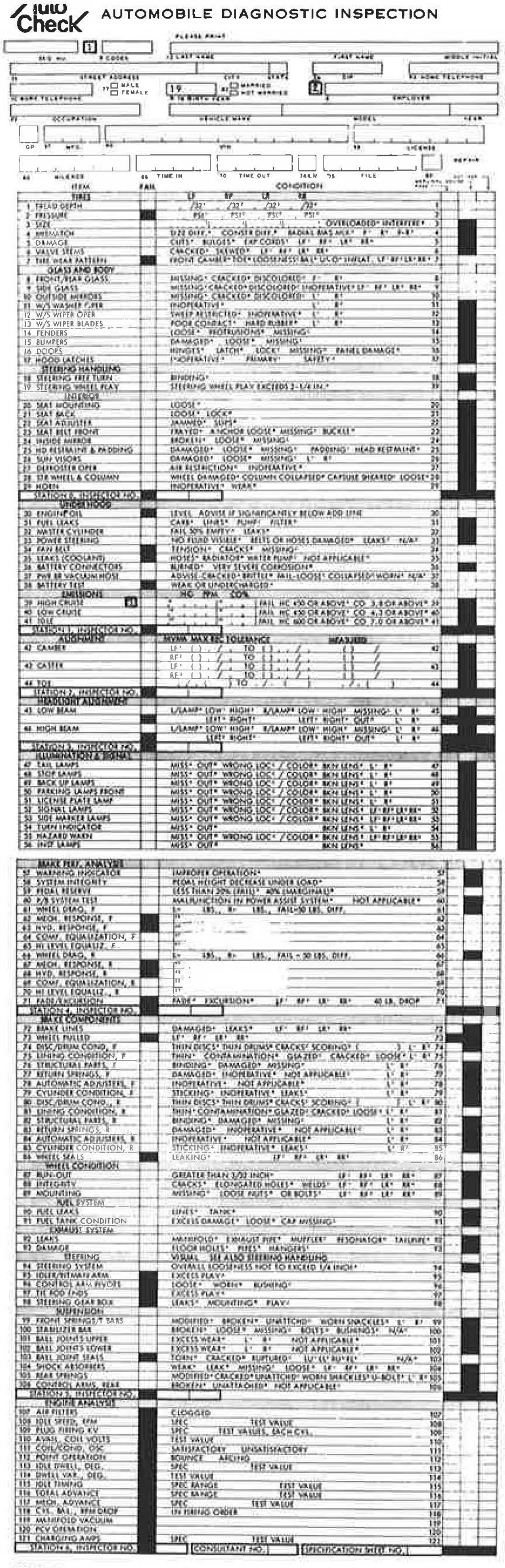
The results of this study, related to the local vehicle repair environment, are summarized as follows:

1. Of all engine, brake, steering, alignment, and suspension repairs, 25 percent were unnecessary. These unnecessary repairs represented 29 percent of the repair costs. After the participants were given the prescription forms as a means of communicating with the repair industry, the unnecessary repair rate was reduced to 13 percent.
2. High unnecessary repair rates were noticed for control arm pivots (82 percent), brake discs or drums (60 percent for rear and 58 percent for front), and rear wheel seals (47 percent).
3. Local car dealers who performed the most cost-effective repairs also had more than their share of the repair business.
4. Chain stores with the lowest unnecessary repair rates had the greatest business.
5. Out-of-Huntsville car dealers had a significantly lower unnecessary repair rate (17 percent) than the Huntsville car dealers (25 percent).
6. The rate of repair to the engine and suspension systems increased after the participants were given the prescription forms and reflect the rate of observed system outage.
7. The market share of the chains and tire dealers increased after the participants were given the prescription forms. Likewise, the market share decreased for service stations, independents, and owner repairs, but remained the same for car dealers.

From the above results, the following conclusions are made regarding the local repair environment:

1. Even with the results of a diagnostic inspection (see form reproduced in Figure 7), the consumer is still subject to, and agrees to, many unnecessary repairs.
2. The consumer has difficulty in communicating with the repair facility, even though detailed results of

Figure 7. Reproduction of Auto Check's automobile diagnostic inspection form.



Auto Check AUTOMOBILE DIAGNOSTIC INSPECTION

PLEASE PRINT

1

☐ MALE
☐ FEMALE

19

☐ MARRIED
☐ NOT MARRIED

2

EMPLOYER
OCCUPATION
VEHICLE MAKE
MODEL
YEAR
GP
MFG.
VIN
LICENSE
MILEAGE
TIME IN
TIME OUT
FILE
REPAIR

ITEM	FAIL	CONDITION	
TIRES		LF RF LR RR	
1 TREAD DEPTH		/32" /32" /32" /32"	1
2 PRESSURE		PSI* PSI* PSI* PSI*	2
3 SIZE		OVERLOADED* INTERFERE*	3
4 MISMATCH		SIZE DIFF.* CONSTR DIFF.* RADIAL BIAS MIX* F* R* F-R*	4
5 DAMAGE		CUTS* BULGES* EXP CORDS* LF* RF* LR* RR*	5
6 VALVE STEMS		CRACKED* SKEWED* LF* RF* LR* RR*	6
7 TIRE WEAR PATTERN		FRONT CAMBER* TOE* LOOSENESS* BAL* UCO* INFLAT. LF* RF* LR* RR*	7
GLASS AND BODY			
8 FRONT/REAR GLASS		MISSING* CRACKED* DISCOLORED* F* R*	8
9 SIDE GLASS		MISSING* CRACKED* DISCOLORED* INOPERATIVE* LF* RF* LR* RR*	9
10 OUTSIDE MIRRORS		MISSING* CRACKED* DISCOLORED* L* R*	10
11 W/S WASHER OPER		INOPERATIVE* L* R*	11
12 W/S WIPER OPER		SWEEP RESTRICTED* INOPERATIVE* L* R*	12
13 W/S WIPER BLADES		POOR CONTACT* HARD RUBBER* L* R*	13
14 FENDERS		LOOSE* PROTRUSIONS* MISSING*	14
15 BUMPERS		DAMAGED* LOOSE* MISSING*	15
16 DOORS		HINGES* LATCH* LOCK* MISSING* PANEL DAMAGE*	16
17 HOOD LATCHES		INOPERATIVE* PRIMARY* SAFETY*	17
STEERING HANDLING			
18 STEERING FREE TURN		BINDING*	18
19 STEERING WHEEL PLAY		STEERING WHEEL PLAY EXCEEDS 2-1/4 IN.*	19
INTERIOR			
20 SEAT MOUNTING		LOOSE*	20
21 SEAT BACK		LOOSE* LOCK*	21
22 SEAT ADJUSTER		JAMMED* SLIPS*	22
23 SEAT BELT FRONT		FRAYED* ANCHOR LOOSE* MISSING* BUCKLE*	23
24 INSIDE MIRROR		BROKEN* LOOSE* MISSING*	24
25 HD RESTRAINT & PADDING		DAMAGED* LOOSE* MISSING* PADDING* HEAD RESTRAINT*	25
26 SUN VISORS		DAMAGED* LOOSE* MISSING* L* R*	26
27 DEFROSTER OPER		AIR RESTRICTION* INOPERATIVE*	27
28 STR WHEEL & COLUMN		WHEEL DAMAGED* COLUMN COLLAPSED* CAPSULE SHEARED* LOOSE*	28
29 HORN		INOPERATIVE* WEAK*	29
STATION 0, INSPECTOR NO.			
UNDERHOOD			
30 ENGINE OIL		LEVEL. ADVISE IF SIGNIFICANTLY BELOW ADD LINE	30
31 FUEL LEAKS		CARB* LINES* PUMP* FILTER*	31
32 MASTER CYLINDER		FAIL 50% EMPTY* LEAKS*	32
33 POWER STEERING		NO FLUID VISIBLE* BELTS OR HOSES DAMAGED* LEAKS* N/A*	33
34 FAN BELT		TENSION* CRACKS* MISSING*	34
35 LEAKS (COOLANT)		HOSES* RADIATOR* WATER PUMP* NOT APPLICABLE*	35
36 BATTERY CONNECTORS		BURNED* VERY SEVERE CORROSION*	36
37 PWR BR VACUUM HOSE		ADVISE CRACKED* BRITTLE* FAIL-LOOSE* COLLAPSED* WORN* N/A*	37
38 BATTERY TEST		WEAK OR UNDERCHARGED*	38
EMISSIONS		HC PPM CO%	
39 HIGH CRUISE		FAIL HC 450 OR ABOVE* CO 3.8 OR ABOVE*	39
40 LOW CRUISE		FAIL HC 450 OR ABOVE* CO 4.3 OR ABOVE*	40
41 IDLE		FAIL HC 600 OR ABOVE* CO 7.0 OR ABOVE*	41
STATION 1, INSPECTOR NO.			
ALIGNMENT		MVMA MAX REC TOLERANCE MEASURED	
42 CAMBER		LF* ( ) TO ( ) RF* ( ) TO ( )	42
43 CASTER		LF* ( ) TO ( ) RF* ( ) TO ( )	43
44 TOE		TO	44
STATION 2, INSPECTOR NO.			
HEADLIGHT ALIGNMENT			
45 LOW BEAM		L/LAMP* LOW* HIGH* R/LAMP* LOW* HIGH* MISSING* L* R* LEFT* RIGHT* LEFT* RIGHT* OUT* L* R*	45
46 HIGH BEAM		L/LAMP* LOW* HIGH* R/LAMP* LOW* HIGH* MISSING* L* R* LEFT* RIGHT* LEFT* RIGHT* OUT* L* R*	46
STATION 3, INSPECTOR NO.			
ILLUMINATION & SIGNAL			
47 TAIL LAMPS		MISS* OUT* WRONG LOC* / COLOR* BKN LENS* L* R*	47
48 STOP LAMPS		MISS* OUT* WRONG LOC* / COLOR* BKN LENS* L* R*	48
49 BACK UP LAMPS		MISS* OUT* WRONG LOC* / COLOR* BKN LENS* L* R*	49
50 PARKING LAMPS FRONT		MISS* OUT* WRONG LOC* / COLOR* BKN LENS* L* R*	50
51 LICENSE PLATE LAMP		MISS* OUT* WRONG LOC* / COLOR* BKN LENS* L* R*	51
52 SIGNAL LAMPS		MISS* OUT* WRONG LOC* / COLOR* BKN LENS* LF* RF* LR* RR*	52
53 SIDE MARKER LAMPS		MISS* OUT* WRONG LOC* / COLOR* BKN LENS* LF* RF* LR* RR*	53
54 TURN INDICATOR		MISS* OUT* BKN LENS* L* R*	54
55 HAZARD WARN		MISS* OUT* WRONG LOC* / COLOR* BKN LENS* LF* RF* LR* RR*	55
56 INST LAMPS		MISS* OUT* BKN LENS*	56
BRAKE PERF. ANALYSIS			
57 WARNING INDICATOR		IMPROPER OPERATION*	57
58 SYSTEM INTEGRITY		PEDAL HEIGHT DECREASE UNDER LOAD*	58
59 PEDAL RESERVE		LESS THAN 20% (FAIL)* 40% (MARGINAL)*	59
60 P/B SYSTEM TEST		MALFUNCTION IN POWER ASSIST SYSTEM* NOT APPLICABLE*	60
61 WHEEL DRAG, F		L= LBS., R= LBS., FAIL=50 LBS. DIFF.	61
62 MECH. RESPONSE, F			62
63 HYD. RESPONSE, F			63
64 COMP. EQUALIZATION, F			64
65 HI LEVEL EQUALIZ., F			65
66 WHEEL DRAG, R		L= LBS., R= LBS., FAIL = 50 LBS. DIFF.	66
67 MECH. RESPONSE, R			67
68 HYD. RESPONSE, R			68
69 COMP. EQUALIZATION, R			69
70 HI LEVEL EQUALIZ., R			70
71 FADE/EXCURSION		FADE* EXCURSION* LF* RF* LR* RR* 40 LB. DROP	71
STATION 4, INSPECTOR NO.			
BRAKE COMPONENTS			
72 BRAKE LINES		DAMAGED* LEAKS* LF* RF* LR* RR*	72
73 WHEELS PULLED		LF* RF* LR* RR*	73
74 DISC/DRUM COND., F		THIN DISCS* THIN DRUMS* CRACKS* SCORING* ( ) L* R*	74
75 LINING CONDITION, F		THIN* CONTAMINATION* GLAZED* CRACKED* LOOSE* L* R*	75
76 STRUCTURAL PARTS, F		BINDING* DAMAGED* MISSING* L* R*	76
77 RETURN SPRINGS, F		DAMAGED* INOPERATIVE* NOT APPLICABLE* L* R*	77
78 AUTOMATIC ADJUSTERS, F		INOPERATIVE* NOT APPLICABLE* L* R*	78
79 CYLINDER CONDITION, F		STICKING* INOPERATIVE* LEAKS* L* R*	79
80 DISC/DRUM COND., R		THIN DISCS* THIN DRUMS* CRACKS* SCORING* ( ) L* R*	80
81 LINING CONDITION, R		THIN* CONTAMINATION* GLAZED* CRACKED* LOOSE* L* R*	81
82 STRUCTURAL PARTS, R		BINDING* DAMAGED* MISSING* L* R*	82
83 RETURN SPRINGS, R		DAMAGED* INOPERATIVE* NOT APPLICABLE* L* R*	83
84 AUTOMATIC ADJUSTERS, R		INOPERATIVE* NOT APPLICABLE* L* R*	84
85 CYLINDER CONDITION, R		STICKING* INOPERATIVE* LEAKS* L* R*	85
86 WHEEL SEALS		LEAKING* LF* RF* LR* RR*	86
WHEEL CONDITION			
87 RUN-OUT		GREATER THAN 3/32 INCH* LF* RF* LR* RR*	87
88 INTEGRITY		CRACKS* ELONGATED HOLES* WELDS* LF* RF* LR* RR*	88
89 MOUNTING		MISSING* LOOSE NUTS* OR BOLTS* LF* RF* LR* RR*	89
FUEL SYSTEM			
90 FUEL LEAKS		LINES* TANK*	90
91 FUEL TANK CONDITION		EXCESS DAMAGE* LOOSE* CAP MISSING*	91
EXHAUST SYSTEM			
92 LEAKS		MANIFOLD* EXHAUST PIPE* MUFFLER* RESONATOR* TAILPIPE*	92
93 DAMAGE		FLOOR HOLES* PIPES* HANGERS*	93
STEERING		VISUAL SEE ALSO STEERING HANDLING	
94 STEERING SYSTEM		OVERALL LOOSENESS NOT TO EXCEED 1/4 INCH*	94
95 IDLER/PITMAN ARM		EXCESS PLAY*	95
96 CONTROL ARM PIVOTS		LOOSE* WORN* BUSHING*	96
97 TIE ROD ENDS		EXCESS PLAY*	97
98 STEERING GEAR BOX		LEAKS* MOUNTING* PLAY*	98
SUSPENSION			
99 FRONT SPRINGS/T BARS		MODIFIED* BROKEN* UNATTCHD* WORN SHACKLES* L* R*	99
100 STABILIZER BAR		BROKEN* LOOSE* MISSING* BOLTS* BUSHINGS* N/A*	100
101 BALL JOINTS UPPER		EXCESS WEAR* L* R* NOT APPLICABLE*	101
102 BALL JOINTS LOWER		EXCESS WEAR* L* R* NOT APPLICABLE*	102
103 BALL JOINT SEALS		TORN* CRACKED* RUPTURED* LU* LL* RU* RL* N/A*	103
104 SHOCK ABSORBERS		WEAK* LEAK* MISSING* LOOSE* LF* RF* LR* RR*	104
105 REAR SPRINGS		MODIFIED* CRACKED* UNATTCHD* WORN SHACKLES* U-BOLT* L* R*	105
106 CONTROL ARMS, REAR		BROKEN* UNATTACHED* NOT APPLICABLE*	106
STATION 5, INSPECTOR NO.			
ENGINE ANALYSIS			
107 AIR FILTERS		CLOGGED	107
108 IDLE SPEED, RPM		SPEC TEST VALUE	108
109 PLUG FIRING KV		SPEC TEST VALUES, EACH CYL.	109
110 AVAIL. COIL VOLTS		TEST VALUE	110
111 COIL/COND. OSC		SATISFACTORY UNSATISFACTORY	111
112 POINT OPERATION		BOUNCE ARCING	112
113 IDLE DWELL, DEG.		SPEC TEST VALUE	113
114 DWELL VAR., DEG.		TEST VALUE	114
115 IDLE TIMING		SPEC RANGE TEST VALUE	115
116 TOTAL ADVANCE		SPEC RANGE TEST VALUE	116
117 MECH. ADVANCE		SPEC TEST VALUE	117
118 CYL. BAL., RPM DROP		IN FIRING ORDER	118
119 MANIFOLD VACUUM			119
120 PCV OPERATION			120
121 CHARGING AMPS		SPEC TEST VALUE	121
STATION 6, INSPECTOR NO.		CONSULTANT NO. SPECIFICATION SHEET NO.	

COMMENTS

a sophisticated diagnostic inspection such as Auto Check are available.

3. The consumer is in a much better position to communicate with the repair facility if he or she has specific repair instructions to give the repair facility (i.e., prescription forms).
4. The consumer will be more likely to have the more costly and more sophisticated systems such as the engine repaired if he or she has the specific repair instructions to give the repair facility.
5. The consumer will change his or her habits and have car repairs done at different repair facilities if specific repair instructions are at hand.
6. The repair facilities that perform the best, most cost-effective repairs get the most business, suggesting that a good reputation (and performance to match) is critical to business success.

In summary, the results of the 3 years of operation of the Alabama motor vehicle diagnostic inspection demonstration program indicate that the cost of unnecessary repairs can be reduced, if effective communication techniques are used to transfer the results of the diagnostic inspection to the repair industry and if the repair industry is made aware of the financial effects of questionable repair practices.

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Notice: The Transportation Research Board does not endorse products or manufacturers. Trade and manufacturers' names appear in this report because they are considered essential to its object.

Portable Interactive Data Acquisition and Analysis System for Driver Behavior Research

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This report describes a portable interactive data acquisition and analysis system designed for roadway experiments studying driver behavior. The system is microcomputer-controlled and features multichannel sampling capability, on-line operator control of experimental parameters, and on-line data reduction capability. Several novel transducers are incorporated.

The Road Safety Unit of Transport Canada has a general requirement to perform measurements of driver behavior under actual driving conditions (1). The Defence and Civil Institute of Environmental Medicine (DCIEM), Ontario, was asked to provide a car-portable system to provide these measurements.

The general requirements for the instrumentation system were

1. True portability (it was to fit most North American cars, mid-size and larger; installation time of less than 24 h was desired);
2. Low power consumption;
3. Modular design;
4. On-line data analysis capability; and
5. On-line control over experimental procedures.

There can be as many types of instrumentation systems as there are road experiments. Performance of portable systems can be limited in many ways including sampling rate, data storage, degree of experimental control, power requirements, bulk, and cost.

Generally, a system's bulk, power requirements, and cost are directly related to its capability in terms of sampling rate, data storage, and experimental control. The more sophisticated experimental vehicles are typically equipped with fixed instrumentation and sensors. These are usually expensive, heavy, cumbersome vehicles, bearing more resemblance to portable laboratories than to the family automobile they are intended to simulate.

At the other extreme, the truly lightweight, low-power, inexpensive portable data recording systems are usually inflexible, often monitor few transducers, have slow sampling rates and limited data storage, and offer little control over the experimental parameters.

The LSI-11 system described herein resulted from trade-offs between the conflicting requirements of portability and capability.

SYSTEM OVERVIEW

The performance of the system is outlined in Table 1. The system also has the capability of transforming basic measures or combining them on-line or both, to form complicated derivative measures.

A functional block diagram appears in Figure 1. The central component is a Digital Equipment Corporation (DEC) LSI-11 microcomputer, a compact machine that consumes relatively little power. When interfaced with appropriate peripheral devices and operated with commercially available software, it behaves like a conventional minicomputer. In the present configuration there are 24 K (24 576) words of metal oxide semiconductor (MOS) memory, with the option to add another 4-K module.

Random access bulk storage is provided by a floppy disk unit (DEC RX01). The storage medium is a preformatted flexible diskette, or floppy disk, which can store 256-K eight-bit bytes of information. These disks are used for storing data collected during the course of an experiment and providing permanent records of programs.

Table 1. Measurement parameters for a portable interactive data acquisition and analysis system.

Parameters	Range	Accuracy[a]	Sampling Rate (Hz)[b]
Time (relative)	Practically unlimited	0.001 s	100
Speed	0-53 m-s^{-1}	3%	10
Distance[c]	Practically unlimited		
Acceleration			
X	0 to ±25 m-s^{-2}	0.5%	20
Y	0 to ±25 m-s^{-2}	0.5%	20
Z	0 to ±25 m-s^{-2}	0.5%	50
Steering wheel position	±0.35 rad (fine)	0.5%	50
	±2Π rad (coarse)	0.5%	50
Accelerator	0 to full	<1%[d]	50
Brake pedal force	0 to 1300 N	1%	50
Lateral position	±2 m	0.5%	50
Discrete driver responses			Interrupt
Analog responses		1%	10

Note: 1 m ≅ 3.28 ft, Π rad = 180°, 1 m-s^{-1} ≅ 2.25 mph, 1 m-s^{-2} ≅ 0.1 G, and 1 N ≅ 0.224 lbf.

[a] Accuracy given in percent of full scale, except time.

[b] Typical.

[c] Distance is integrated from speed.

[d] Nonlinear measurement, accuracy determined by calibration table.

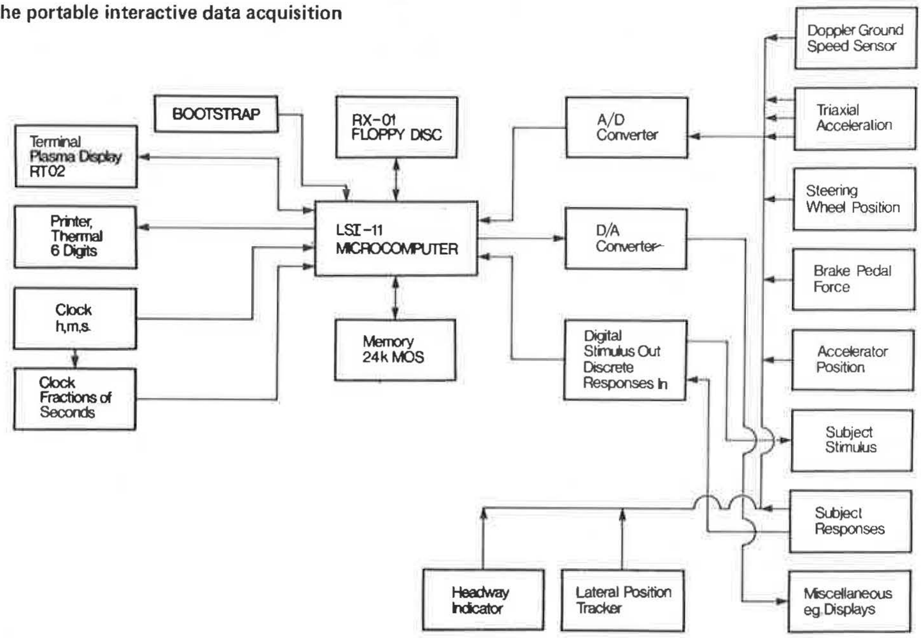
The other peripherals that provide communication between the operator and the computer include a keyboard terminal with a single line gas-discharge display, a thermal printer for providing limited hard copies of numerical data, and two digital clocks. One clock reads the time of day in hours, minutes, and seconds, while the other provides a millisecond readout. The two clocks can be used to time events under program control. A hardware bootstrap facilitates system initialization when the computer is turned on.

The LSI-11 communicates with the measurement transducers by means of a data acquisition module that samples up to 24 differential analog channels and performs a 12-bit analog-to-digital conversion for each. Under program control, the computer can provide two channels of analog output, using two 12-bit, digital-to-analog converters. In addition, there is provision to accept either discrete inputs from digital transducers or to generate discrete signals for controlling external devices (e.g., light signals).

Speed is measured by a microwave radar Doppler speed sensor (2), and a measure of distance is derived by summation. Coarse and fine readouts of steering wheel position are obtained by measuring the rotation of two potentiometers. Accelerator position is obtained by measuring the displacement of the linkage at the carburetor with a linear displacement transducer. Acceleration along three axes is measured by three sensitive, low-frequency, force-balance accelerometers, mounted orthogonally. Brake pedal force is determined using a force transducer available from GSE Incorporated, Livonia, Michigan. A sophisticated optoelectronic lane tracker, specially designed by the Human Factors Research Corporation of Goleta, California, measures the lateral distance of the vehicle from the roadway center line. A device to measure the distance to either a leading or trailing vehicle is currently under development.

The system is powered by a high-current (105 A) alternator that replaces the vehicle's original alternator. A reserve battery is included. A nominal 12 V

Figure 1. Functional block diagram of the portable interactive data acquisition and analysis system.



is supplied to a 12-V/12-V converter, 12-V/5-V converter, and a 115-V/60-Hz inverter to provide well-regulated power. Maximum power consumption in the present configuration is less than 800 W.

The total weight of the system, 140 kg (310 lb), is evenly distributed throughout the vehicle. No single component weighs more than 25 kg (55 lb). The system components are typically located in the vehicle as shown in Figure 2.

MICROCOMPUTER SYSTEM

The use of a microcomputer and associated peripherals for on-road data processing and control represents the most novel aspect of the instrumentation system.

LSI-11 Microcomputer

The microcomputer consists essentially of one 25-cm × 22-cm (10-in × 8.5-in) "quad-width" board that houses the microprocessor chip set, consisting of a control chip, data chip, two microinstruction chips, and an extended arithmetic-floating point arithmetic chip. The latter is an option, which was purchased to facilitate arithmetical computations.

The microprocessor includes a hardware memory stack for handling structured data, subroutines, and interrupts (3). In addition, there are six general-purpose and two special-purpose registers for data storage or for use as pointers or accumulators.

The microprocessor board also contains 4K words of MOS memory. Another 20K of MOS memory is located on five 12.7-cm × 22-cm (5-in × 8.5-in) "double-width" modules, which follow immediately after the microprocessor board on the LSI-11 bus. MOS memory has the advantages of compactness, low power consumption, and fast access times, but requires a periodic refresh operation to maintain the charge in the memory elements.

After power is turned on, the hardware bootstrap first performs a series of tests of the processor and memory, and then loads the machine with a monitor program. The monitor program, which is part of the RT-11 software system, permits programming in Assembler, Fortran, or Basic and contains a large number of utility programs and a library of subroutines. The LSI-11 software is identical to that of the series of PDP-11 minicomputers, so programs written for the LSI-11 can be transferred to other DEC-11 machines.

Peripherals are interfaced to the microcomputer using plug-in parallel line interface units and serial line units. The priority assigned to a peripheral device decreases with electrical distance along the bus. The processor, memory, and interface modules are housed in two backplanes that provide mechanical support, power, and signal connections. These backplanes are located in an instrument case (see Figure 3), along with the data acquisition equipment, clocks, printer, a ±15-V supply, and a fan. This case is 53 cm × 30 cm × 66 cm (21 in × 12 in × 26 in) and is normally located on the back seat of the car behind the driver, on top of a similar case housing the floppy disk unit.

Data and Program Storage

Bulk storage for the system is provided by the RX01 dual floppy disk unit. Its interface is located immediately after the MOS memory on the LSI-11 bus, making it the highest priority peripheral.

The floppy disk unit is a compact magnetic storage device requiring less power than other disk or magnetic tape drives. With an average access time of 500 ms, it is considerably slower than other disks but faster than tape.

Figure 2. Mounting locations for system components.

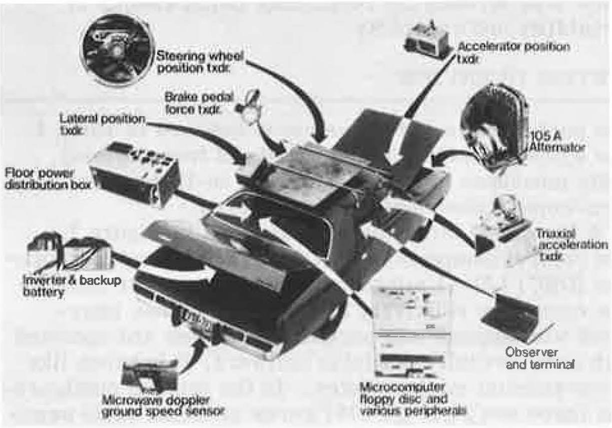
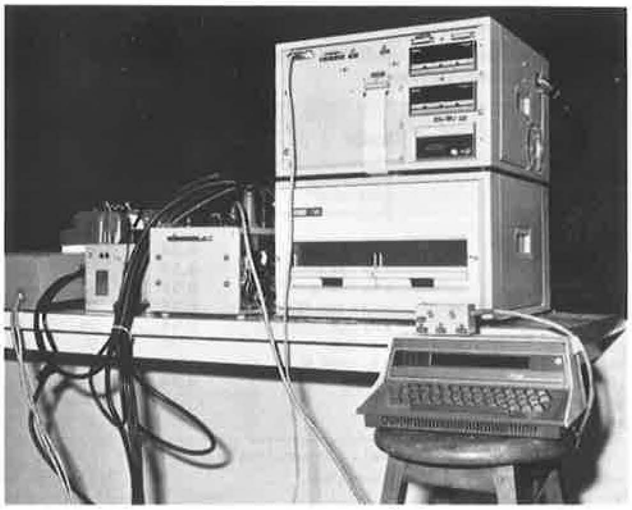


Figure 3. Major system components benched (left to right: terminal power supply, reserve battery, inverter, power distribution module, microcomputer and floppy disk unit, terminal and power control box).



During bench operation, the floppy disk is used to store system programs, user programs, and data files. During on-road operation, the operating program is normally resident in the MOS memory, and both diskettes are available for data storage. Depending on the nature of the experiment, specifically on the frequency of data samples, considerable data processing can be performed before storage.

The mounting of the floppy disk unit is illustrated in Figure 3. It may be necessary to use more than two floppy disks for data storage during the course of an experiment. Therefore, indicators tell which diskette is currently being accessed, permitting the operator to change the other without halting the experiment.

Data Acquisition Panel

Data from either digital or analog transducers can be acquired. Most transducers provide analog outputs and are interfaced to a data acquisition module (analogic MP 6912 with expander). This module requires only one parallel line interface unit on the LSI-11 bus, so all analog transducers appear physically as one device to the computer.

The data acquisition module presents the computer with 12 bits of discrete data for each sample input. Thus the data are quantized both in time and amplitude. Twelve-bit quantization corresponds to a resolution of one part in 4096, or approximately 0.024 percent.

Up to 24 differential input channels can be multiplexed by the data acquisition module. Differential inputs are essential since many transducers produce small full-scale voltages and are connected by long cables in the noisy environment of the car.

Under command of the computer, the data acquisition module selects one of the transducer channels either sequentially or randomly, using a channel address supplied by the computer. The transducer signal is then sampled in an operation that is virtually instantaneous compared to the slow variation of the transducer signals. The sampled datum is held and a 12-bit successive approximation analog-to-digital conversion is performed. The maximum throughput for 12-bit conversions is 30 000/s.

The data acquisition module is located on the rear panel of the microcomputer instrument case. Some transducers require amplification or filtering or both, and the circuits that perform these functions are located in the same area.

Although no digital transducers are employed at the present time, they can be added, requiring the use of one bus interface slot each. Two 12-bit digital-to-analog converters, occupying one bus slot each, provide analog outputs to drive external devices. They are also useful in a feedback arrangement to test the operation of the data acquisition module.

Operator Interface

During experiments on the road, extensive communication between the computer and operator is not normally required. The experimenter needs the ability to command and interrogate the system. A display of certain essential information is also needed.

Two-way communication is provided by a terminal (DEC RT02), which includes a keyboard and a one-line wraparound display. For compactness, the terminal's power supply has been separated from the remainder of the circuits. The power supply is in the trunk, while a small keyboard on a platform is located in front of the operator.

Since the experimenter may wish to retain numerical information after the terminal display has changed, a small thermal printer is included that provides six columns of numerical output. The printer can be turned on or off from the panel in order to conserve power.

The time of day in hours, minutes, and seconds is displayed by a crystal-controlled digital clock located on the computer panel (see Figure 3). The computer can access this information as well as that from a digital stop clock. Although the stop clock has microsecond resolution, only the millisecond outputs are used for our purposes. The clocks are synchronized and together provide a millisecond event timing facility. The clocks are set from the front panel, and their displays can be turned off to conserve power.

For bench operation, the RT02 terminal is usually replaced by a teletype with paper printout. The microprocessor, memory, floppy disk unit, and teletype then constitute a stand-alone computer system, useful as a general laboratory tool.

MEASUREMENT TRANSDUCERS

Lateral Position

For driver behavior studies, one of the most important but most difficult measurements to make is that of lateral position on the roadway. The Human Factors Research Incorporated lane tracker is the most sophisticated and novel transducer to be incorporated in the system to date. The lane tracker can measure lateral displacement from either a solid or dashed lane marking, or—in the absence of painted lines—from the boundary between the surface and shoulder provided there is sufficient contrast between the two surfaces.

The primary signal output is an analog voltage proportional to displacement from the lane marking. Secondary outputs include an analog video sweep signal, proportional to the light imaged at consecutive sampling points in the focal plane, and a sweep synchronization pulse train.

The lane tracker consists essentially of a Reticon LC600 line scan camera, camera AGC and computational circuitry, a power supply, and mounting hardware.

The focal plane of the line scan camera contains a 256-diode linear array. The diodes are sequentially interrogated, resulting in a 256-pulse video signal. The amplitude of each pulse is proportional to the light intensity incident on the diode, corresponding to light from a section of the field of view. Typically, the lateral extent of roadway scanned is 3 m (10 ft). The resolution, defined by the lateral dimension of a diode, is about 1.2 cm (0.5 in).

The lane tracker counts the number of diodes interrogated from the start of a scan until a signal from one of the diodes exceeds a preset data threshold. By adjusting scan rate, the AGC circuitry permits operation at optimum sensitivity over a range of seven F-stops. Signal-conditioning circuits permit continuous tracking of striped delineations and rejection of high frequency noise associated with transient road surface characteristics. The lane tracker draws about 1.25 A at 12 V.

In a typical mounting position (see Figure 2), the lane tracker is aimed at the road surface behind the left rear wheel. A venturi, mounted on the side of the transducer, maintains a reduced pressure inside the case to inhibit fogging of the optics.

Speed

True ground-speed information is obtained using an RCA Doppler ground-speed sensor (2). The range of operation is up to approximately 53 m/s (120 mph). Its published accuracy is 1 percent over the range from 9 to 30 m/s (20 to 70 mph).

The unit transmits a 30-mW, 10.53 GHz signal that is diffusely reflected by the road surface. The backscattered component is received and mixed with the transmitted signal to separate the Doppler difference frequency. The Doppler frequency is proportional to ground speed and is in the low audio region.

Two outputs are provided, a 6-V square wave with frequency equal to the Doppler frequency, and a train of constant width 6-V pulses of the same frequency but with varying duty cycle, which can be integrated to obtain an analog output. The device includes a calibration and checking circuit. For our purposes, the analog output is amplified and low pass filtered to obtain a full-scale output of 5 V.

The dimensions of the unit are 20 cm × 13 cm × 1.6 cm (8 in × 5 in × 0.6 in). In Figure 2 it is shown mounted beneath the rear bumper at a 45° angle to the road.

Acceleration

Measurement of vehicle acceleration is provided by three orthogonally mounted, low frequency, force balance accelerometers (Columbia SA 107). Their range is ±24.5 m/s (2.5 g) with full-scale linearity of 0.2 percent. Their output is ±5.0 V full scale for ±15-V dc excitation. The signal is filtered and applied directly to the data acquisition module. The accelerometer package, including a spirit level, is approximately 13 cm × 13 cm × 8 cm (5 in × 5 in × 3 in), and is mounted on the hump in the floor of the vehicle beside the driver.

Brake Pedal Force

Brake pedal force is measured using a pedal force transducer (GSE Incorporated, Model 300), designed specifically for the job. A maximum force of 1300 N (300 lb) can be measured with an accuracy of 2 percent of full scale. This is a bridge-type transducer that has a full-scale output of 22.5 mV. Consequently, the signal is amplified by a factor of 220 before being applied to the data acquisition module. Mounting this transducer is easy; it simply clamps on the pedal as shown in Figure 2.

Accelerator Position

Measurement of accelerator position is accomplished using a linear displacement transducer (Celesco Model PT101) attached to the carburetor linkage. This attachment is simple and unobtrusive. The computer compensates for nonlinear effects due to the nature of the linkage using a calibration table.

Displacements of up to 15 cm (6 in) can be measured with the transducer, with a resolution of 0.003 cm (0.001 in). The dimensions of the transducer are 13 cm × 7 cm × 6 cm (5 in × 3 in × 2 in).

Steering Wheel Position

The only transducer that has been manufactured in-house is the steering wheel position transducer. To get a high resolution measurement of steering wheel reversals about the center position, a potentiometer is used which completes one revolution for every 0.7 rad (40°) of steering wheel travel. A geared pulley and non-slip drive belt are used with this potentiometer. Coarse measurement of position over the full range of steering wheel movement is provided by a ten-turn potentiometer, with which a standard pulley and O ring are used.

Both potentiometers are miniature precision types and have a linearity better than 0.5 percent and a resolution better than 0.01 percent. They are mounted on the steering wheel housing as shown in Figure 2.

Future Transducers

Eventually, it should be possible, using radar, to monitor the distance between the test vehicle and a leading or trailing vehicle. Other transducers may be added to monitor physiological parameters, including heart and respiratory rates, and head and eye position.

POWER DISTRIBUTION

Power distribution is summarized in Figure 4. The entire system is powered by the car using a high current alternator (105 A) and an extra battery. The reserve battery allows up to 15 min of operation of the computer system without the alternator. Therefore, in the event that the engine stops, the experimenter has ample time to save all data.

A 12-V to 12-V dc converter rated at 8 A and a 12-V to 5-V dc converter at 30 A provide regulated direct current to supply the computer, digital devices, and some transducers. A 500-W inverter provides 115-V/60-Hz power to devices normally operated from the line, such as the floppy disk unit and terminal. Most analog transducers require ±15 V direct current, which is provided by a small modular encapsulated power supply operating from the inverter.

The system features well controlled grounds. All grounds are referenced to a single point that may be chosen anywhere on the car chassis as convenience dictates.

Control circuits allow either the alternator or reserve battery or both to be switched in. In any case, power is initially applied to the converters and the inverter loaded only by the clocks and fans. These devices are considered essential to the basic operation of the system. Another switch applies power to the processor, its peripherals, and the transducers. All power is monitored by a switched meter on the power control unit, and by signal lights on the computer control panel.

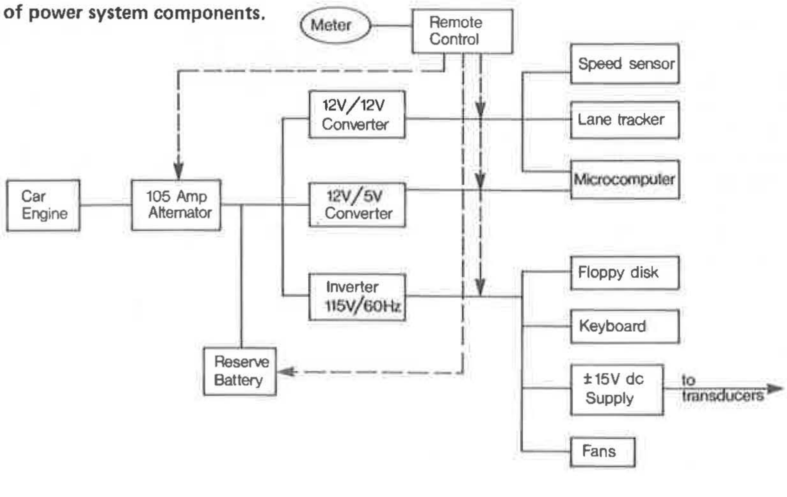
SOFTWARE

Software for the system may be conveniently classified in three categories:

1. General purpose,
2. Diagnostic, and
3. Operational.

General purpose software was purchased as a package (DEC RT-11) with the microcomputer. It includes

Figure 4. Block diagram of power system components.



utility programs for microcomputer operation and permits programming in Assembler, Fortran, or Basic. A library of subroutines is provided. With a good knowledge of RT-11 and either Fortran or Assembler, it is possible to write routines to acquire data from the transducers and store the data on diskettes. Using this approach, a program has been written to sample up to nine transducers every 100 ms and to store their outputs and a possible marker. This program has been used for transducer testing and early experiments.

Diagnostic software for checking the microcomputer was also purchased (DEC RXDP-11) in a convenient floppy-disk-based package, useful for exercising and checking the microcomputer, including memory, instructions, and interfaces. The diagnostic programs can be run in either stand-alone, chained, or interactive mode. Since the package is modular, other diagnostic programs can be added.

To run experiments in which many transducers are sampled and calculations are performed on-line, a dedicated system program is being developed. This system program will give the experimenter control over such parameters as sampling rate, channel to be selected, start-stop, and functions to be evaluated. The program will be modular so that it will be possible to add routines or modify existing routines without disturbing its overall framework. To save memory space it will not be necessary to load routines that are not required for an experiment. With this program, it is estimated that up to 15 channels can be sampled at 10-ms intervals.

CONCLUSION

This system has been operating on the road since the spring of 1977. Its success has been made possible by recent advances in microcomputer and data acquisition technology and continued progress in these fields will probably lead to higher sampling rates and relatively lower costs. In the meantime, it provides a unique opportunity to study behavior in actual driving situations in a quantitative manner.

ACKNOWLEDGMENT

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Michigan's Driver Education Evaluation Project: Classroom Testing and In-Car Development

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During 1977, the Michigan Department of Education evaluated statewide driver education programs. Rather than use the traditional approach of accidents and violations, the department investigated students' cognitive skills by means of objective-referenced tests. Previously, minimal performance objectives for both classroom and in-car portions of driver education had been developed. These objectives are considered basic for every Michigan program. After finalizing the objectives, appropriate test items were developed with the major focus on the classroom objectives. Following the pilot testing of the classroom items, 60 objectives were selected for statewide administration. Objective-referenced tests enabled not only the education department but also individual teachers to know the strengths and weaknesses of students and classroom environments. Each classroom objective was measured by five items; to attain an objective, a student would have to answer at least four items correctly. Statewide, the a priori criterion was that 80 percent of the students would attain each objective. Results based on approximately 100 000 students showed that only 13 objectives met the criterion level. These results indicate that there is a need for improvement in instruction of driver education. As skills became more advanced, attainment decreased. In the summer of 1977, an in-car measure was developed and raters were trained. The in-car test was administered to 30 students to determine its reliability. Forty students were used to validate the measure against the Michigan State University's Driver Performance Measure. Results for both studies were positive. Time, however, did not permit pilot testing this measure on a stratified sample of students.

Since the mid-1930s, Michigan has offered driver education to its youth. By 1954, approximately one-half of the state's school districts offered such instruction.

Then, in 1955, Michigan enacted a law mandating that all local school districts provide driver education. The law further states that all individuals under the age of 18 must have passed an approved driver education program before being eligible for a driver's license.

Although recognized as a leader in driver education, it was not until the last few years that any systematic research on this subject was initiated. In 1975, the Michigan Department of Education (MDE) received a 3-year grant from the Michigan Office of Highway Safety Planning under section 402 of the National Highway Safety Act to evaluate driver education. There were several events that prompted the MDE to write a proposal requesting such funds.

In 1972, the superintendent of public instruction was requested to report to the legislature on the effectiveness of current driver education programs (1). At that time, four questions were posed:

1. Do current driver education programs assure that the student acquires the knowledge and skills necessary to successfully pass the state driver licensing examination?
2. Is one type of driver education program more effective than another in providing students with the knowledge and skills necessary to successfully pass the state driver licensing examination?
3. Does successful completion of a driver education program have a positive impact on road safety?
4. Is there any evidence to suggest that one type of driver education program is more effective than another in terms of positive impact on road safety?

Using questionnaires and interviews, the 1972 study addressed only the fourth question. However, the results of the study were tentative and provided only possible relationships between driver education and road safety. Therefore, additional research was necessary.

In part, the present project is an attempt to answer the general concepts of the first two questions. The third question is difficult to respond to since there is no control, or comparison, group presently available. Although the 1972 report did recommend that a control population be formed through legislation, this has not occurred. Present records indicate that almost all 18-year-olds have received driver education training from an approved program.

A second factor, which prompted this study, was the MDE's consideration in 1974 of asking the legislature to increase the driver education reimbursement. Public schools currently receive $30.00 for each student who completes a minimum of 24 hours of classroom and 4 hours of road instruction—the minimum for issuing a certificate is still the successful completion of at least 30 hours of classroom and 6 hours of road instruction. However, at that time, it was decided that more information was required before any recommendation be made regarding this issue.

Finally, it was the impression of the MDE staff that schools and individual teachers did not have any objective method by which to determine program effectiveness. Intuition and "gut level" feelings were being applied in the decision of what should be taught and how. This impression is emphasized by Chapman (2, p. 95), who states that "for too long, an unnecessary burden has been placed on those responsible for driver preparation, forcing them to conduct programs in terms of performance objectives they have to derive intuitively."

The department decided that the use of accident records, points, injuries, and so forth was not necessarily the most appropriate procedure to follow. Previous research using this method has generally yielded conflicting or inconclusive results. Brody maintains that ". . . if we seek to evaluate driver education in terms of accident reduction, we are confronted with so many variables, known, unknown and highly variable if not unpredictable, that we become enmeshed in an endless chain of proof" (3, p. 85). If indeed younger drivers do have a greater percentage of accidents per kilometer driven, it may be no more than a cultural artifact. It may be related to inexperience and early learning errors rather than to age or emotional maturity.

The ultimate goal of driver education is to produce collision-free drivers; however, the total elimination of crashes and violations by young drivers is an unrealistic goal. The way to assess the achievement of this goal may not be through drivers' records because, as R. Zylman states, "What appears on the driver's records may have nothing to do with driver behavior" (4, p. 7). He continues, "It is clear that driver's records as they appear in the DMV [Department of Motor Vehicles] files are not a valid measure of driver behavior. The problem has its origin in the fact that data are being used for purposes for which they were not intended."

For these reasons, the MDE decided to evaluate its driver education programs with objective-referenced measures of both students and classroom situations. Objective-referenced tests are designed to differentiate between students who have and have not mastered stated objectives. The measures are not aimed at ranking individuals or comparing them with each other as is true in norm-referenced testing. Objective-referenced tests focus on a student's achievement relative to a predetermined criterion or standard of quality, while normed tests focus on a student's standing relative to a given group. Besides using these measures to ascertain which students have mastered the material, it is also possible to use the results in conjunction with an analysis of the classroom delivery system. Theoretically, following instruction, all students should master all objectives taught. If the class as a whole does not perform well, a teacher could look at the way in which the material has been presented and make the necessary changes to improve the achievement level.

PROJECT DESIGN

The basic design for the project involved five stages:

1. Develop, review, and revise performance objectives for both the classroom and in-car experiences;
2. Develop test measures to match each of the performance objectives;
3. Pilot test, review, and revise the classroom items—selecting those appropriate for a final battery—and determine the reliability and validity of an in-car measure;
4. Administer the final classroom measure to all students; and
5. Analyze the data.

Performance Objectives

The initial step in the evaluation project was the development of basic objectives that should be included in all driver education programs regardless of program format or type of school (public, private, parochial, or commercial) offering the course. The first draft of the objectives was written by one of the driver education consultants on the MDE staff.

Because of the potentially wide variability across the state, it was decided that as many driver education specialists (teachers, curriculum specialists, professors) as possible should be included in the review and revision of the objectives. It was assumed that their pooled opinions would represent the general principles included in all Michigan driver education programs.

During the first year of the project, the objectives were reviewed by over 250 individuals. The following four criteria were used in this review:

1. They should be minimal or basic to all programs. Knowledge of the history of driver education would not be considered a basic skill.
2. They must be specific rather than global or general. An objective such as "A student will be able to drive safely at all times" is too general to be of any value. A better objective is "A student will know the meaning of roadway signs by their shapes."
3. The wording of the objectives has to be clear to those using them. Incorporating terminology that is vague will only cause teachers to interpret the meaning in a variety of ways; thus, consistency is lost.
4. The objectives must be measurable. If an objective cannot be tested by some procedure, then it serves no useful purpose.

These persons also rated the objectives according to their importance (priority) in producing safe drivers (e.g., how to plan a trip was not considered very important) and to the similiarity with which they are taught statewide. For example, freeway driving receives greater attention in the metropolitan areas than in the rural areas, but the procedures for making a right turn should be emphasized in all geographical areas.

The final set of objectives included both classroom (cognitive) and in-car (psychomotor) skills. In the first category, the students would be tested by paper and pencil tests; in the second, students would drive a vehicle and would perform certain specified maneuvers. A trained observer would rate the students' performance on each of the selected objectives.

It was decided that there would not be any objectives dealing with the affective domain. The reason for this is that most measures of this nature are very superficial, and students are capable of responding in the manner deemed appropriate for the circumstances. Thus, it is difficult to obtain any accurate measure of a student's true attitudes or beliefs.

Classroom Performance Measures

With the finalization and general acceptance of the performance objectives, the item-writing process began. Four workshops in which 120 individuals participated were conducted across the state. At each workshop, several hours of instruction were provided on how to write proper objective-referenced test items. Some of the important factors that the item writers were taught included:

1. The language should be at the sixth-grade level except for specific driver education terminology. If uncertain about a word, writers should try to use a simpler one.
2. Items should be presented in a straightforward manner. The intent is not to trick students.
3. The items should measure a single concept and should be neither too long nor too involved.
4. When reasonable, four responses (foils) per item should be included. The responses should be appropriate for the question being asked.

The principal criterion for good items is that each item directly measure the objective for which it is being written. As Popham and Husek (5, p. 133) point out, the objective-referenced test writer's "chief rule is to make sure the item is an accurate reflection of the criterion behavior. Difficult or easy, discriminating or indiscriminate, the important thing is to make the item represent the class of behaviors delineated by the [objective]."

The goal was to have between 10 and 15 items per objective; the results were 0 to 115 items. There was one objective which, unfortunately, was written in vague terms and could not be clearly interpreted by the item writers. The objective covering sign shapes was so easy that 115 items were constructed.

Following the workshops, the items were reviewed by the MDE staff and then submitted to a technical support contractor. The goal of the technical support contract was to obtain at least 10 good items for each of the 152 classroom objectives by either revising items written during the workshops or constructing new items using the teacher items as prototypes. In most instances this goal was met; however, there were a few objectives so limited in scope that the development of 10 items was not feasible. The objective for which no items were written was dropped from consideration because of the difficulty in interpreting its intent.

The MDE reviewed each of the items prepared by the contractor and then had a meeting with the contractor to determine the manner in which the items would be pilot tested. Following this review, four additional objectives were dropped because of problems in writing items which would not be biased or too obvious. Therefore, a total of 147 objectives tested by 1366 items were prepared for pilot testing.

The items were packaged in 20 test booklets of approximately the same length. Each test book covered about eight objectives, each of which was measured by approximately 10 items.

Pilot Testing

Schools participating in the pilot testing of the classroom test items numbered 126. The schools were selected randomly from the four most common program formats: two-phase, three-phase range, three-phase simulator, and four-phase. The number of schools selected in each category was based upon the total percentage of schools in the state offering the various formats. Programs ending between July 26 and August 27, 1976, were eligible for selection. Consideration in the selection process was also given to the size of the city (metropolitan, urban, rural) as well as geographical location.

In addition to the summer posttesting tryouts, eight schools participated in pretesting some of the high priority items. These schools administered the tests during the first few days of their fall programs. The information obtained from the pretests enabled the MDE to be aware of students' performance prior to any formal classroom training.

Teachers in both the pretesting and posttesting samples were requested to provide the MDE with comments concerning both the general aspects of the tests as well as comments about specific test items. These comments would be included during future review sessions.

Selection of Items for Statewide Testing

The tests were scored by Michigan State University, and results were sent to each of the participating teachers. The university also performed the necessary test analyses. Since these were objective-referenced tests, the analyses were computed on each of the objectives and corresponding test items. The analyses computed included a foil analysis, a KR_{20}, Livingston internal consistency (6), point biserials, biserials, and item discrimination.

In mid-October 1976, a review meeting was held in which 50 driver education teachers and specialists reviewed the test results, statistics, and teacher comments. Suggestions were made regarding revisions and deletions of items. Also, input was provided on which objectives should be included in the final battery.

Another review session was held with the contractor and MDE staff. During this time, decisions were made concerning the final test and format. Decision rules for dropping or revising items depended on the content of the objectives and teachers' review. Items for objectives which were rated as commonly taught required a higher P-value (percent of students answering correctly) than those less commonly taught. Foils which did not operate well were revised where possible. Items were dropped in cases where the point biserials were too low. A special effort was made to simplify the vocabulary and reading level of all items retained. Several entire objectives were dropped because of measurement difficulties, high pretest results, or the inadequacy of the objectives themselves.

The final tests covered 60 basic objectives generally considered by driver education teachers as essential for effective programs. The five best items for each of these objectives were chosen for inclusion in the test packages.

The choice of five-item tests was based upon several considerations. The first was the minimum number of items judged necessary to provide a reasonably adequate measure of a student's attainment of an objective. A second was the amount of testing time available—the average student should be able to complete the test in one classroom period. However, since the test was untimed, the slower reader would not be penalized.

Of the five items per objective, a student must answer correctly four or five items to be considered as having mastered the objective. Since the classroom portion of the evaluation was in a multiple-choice format, it was necessary to minimize the possibility of misclassification. Therefore, a passing score was selected so that an objective would be attained by guessing no more than 2 percent of the time. According to Millman (7), the passing score associated with no more than a 2 percent chance of its being obtained by random guessing is 80 percent, or four out of five in this situation.

Four test booklets were designed. Each one covered 15 objectives measured by five items for a total of 75 items. The 15 objectives per booklet were randomly selected from the total set of 60 objectives. This was done so that the booklets would be comparable in the areas being tested.

Following the packaging of the booklets, a readability analysis was computed on each of the items as well as on the four test booklets. The goal was to have the average reading level of each book at the sixth grade. The four booklets had an average reading level of 6.3, 6.2, 6.4, and 6.3. Therefore, the reading level was consistent among the four forms and was not likely to have an adverse effect when students' performance was analyzed.

In-Car Performance Measure

During the summer of 1977, the MDE, with assistance from a Michigan State University doctoral student in traffic safety, began designing an in-car road test. The intent of the instrument was to measure certain in-car performance objectives; however, those dealing with parking and emergency situations were to be omitted from the final measure.

The initial activity was the design of an appropriate route. The route would need to include a variety of driving situations—city, expressway, and residential—yet not require too much driving time. Certain other driving elements had to be included, such as turns from and to one-way and two-way streets. A further consideration was that student drivers would not be placed in an intentionally dangerous situation; that is, they would not be requested to make unsafe maneuvers or be forced off the road and try to regain control. The eventual route encompassed all desired objectives. It covered approximately 17.6 km (11 miles) and required about one-half hour of driving time.

The route was divided into areas of specific and general observations. The specific areas were designated as Location(s) of Performance Evaluation (LOPEs). While in these areas, the raters would pay close attention to definite driver behaviors. No recording of observations would occur at these points; instead, the recording plus general observation would occur at other times. Also, there would be a warmup period of several blocks during which both the rater or raters and the driver could become acquainted, thus reducing any apprehension or tension felt by the driver.

Specific directions, as well as points where directions were to be given, were written. Strict adherence to the directions and locations for giving them was necessary for appropriate driver reaction. Directions would be given with sufficient time for the driver to make all requested maneuvers safely.

The actual in-car test was divided into two main sections: vehicle familiarization and driving. The vehicle familiarization section was a checklist for indicating whether or not an individual knew various parts of the vehicle, e.g., information gauges, starting and control devices, and safety devices. Also included were observations of a driver's preignition control tasks: starting the engine, putting the vehicle in motion, stopping the vehicle, and securing it.

The driving section consisted of a series of observations to be made by the evaluators. There are three main concepts involved in all driving—search, speed, and direction. Included in each of these points is the element of timing. Although timing is an important element of driving, it was included in the evaluation only when an objective specifically mentioned it. Finally, there were certain areas in which the drivers were judged on whether they yielded to pedestrians, or vehicles, or both. For each of the Specific Performance Objective Test Sites (SPOTS), an indication of satisfactory and unsatisfactory behavior was listed. These descriptions would assist the evaluators while making their judgments as to the driver's performance. The last page of the driving unit included another type of checklist related to how well the driver obeyed traffic signs, signals, and lane markings.

Five individuals were selected to be raters for the driving measure. Each individual had completed the training necessary for riding with unlicensed drivers. These five persons, along with an MDE member, participated in a 3-day training session. The route, directions, and meaning of terms were explained during this training. One of the most crucial aspects of the training was the familiarization of the route. The key to a successful evaluation was knowing the route and what to observe. Frequent reviews of the route, via actual driving, were included during the training. Also, some practice trials with student drivers were made so that raters' perceptions and scoring could be reviewed and discussed.

Following the training session, the agreement between ratings on practice drives was reviewed to determine if any of the raters were less qualified than others. The various pairings of raters indicated that agreement was quite high; therefore, the actual pairings for the test situation would not influence results.

Reliability of In-Car Measure

During the first two weeks of August 1977, the reliability study was carried out. An attempt was made to avoid Mondays and Fridays because of the atypical driving situation on these two days. Students from seven local school districts were selected randomly for participation. The school districts had recently completed a driver education program. The students selected had passed the course, but were not yet licensed drivers. Letters were sent to the parents or guardians of 80 students requesting permission for them to participate. The study required at least 45 students. The additional students were included because of possible time conflicts, vacations, or failure to return the permission forms.

The chosen design was such that each of 30 students would be evaluated by four raters. The extra 15 students would be used as alternates in case some of the 30 students were unable to complete the test.

Of the six trained raters, four were chosen to test the 30 subjects. Because there were no significant differences in the ratings for the practice trials, the four were selected randomly. The other two raters observed the alternates.

Validation of In-Car Measure

Following the analyses for the reliability study, plans for a concurrent validation were initiated. Most driving tests rely upon content validation rather than including the additional step of concurrent validation. The department was fortunate enough to have a criterion measure that could be utilized for establishing this additional validity.

The Highway Traffic Safety Center (HTSC) at Michigan State University (MSU) had developed a carefully designed and validated road measure (criterion instrument) for use in the concurrent validation of in-car road tests. The HTSC procedure provided a criterion of safe and skillful driving performance necessary to validate the department's road test. The Driver Performance Measure (DPM) is considered as a research tool to "serve as a basis for and as a means of validating practical, simpler testing procedures which could be used by teachers and examiners" (8, p. 26).

The validation study took place during the months of October and November 1977. A total of 40 students, randomly selected from students who had successfully completed the Lansing summer program, were assigned a particular date and time. As in the reliability study, alternates were chosen in case some students were unavailable at the requested time.

Four individuals trained in using the DPM were included in this study; three of the MDE's raters were used. Both the MDE and DPM raters received additional training so that they were familiar with the route, the measures, and the characteristics to observe. Several practice trials were provided.

Each subject drove the department's route once and the DPM route twice. One-half of the students drove the MDE route first; the other half drove the DPM route first. This procedure was utilized to alleviate any possible practice effects. Also, during the DPM, there were two raters per drive. After the first drive, the raters switched positions, from front to back seat and vice versa. This would reduce any effect either position might have on the observations.

Internal consistency measures were computed on both the DPM and MDE tests. Both measures included scores on students' speed, search, and directional control. In addition, the DPM had an overall rating (PATTERN) for each point of observation. This score was determined by whether or not the driver performed safe or unsafe maneuvers in relation to the environment. The PATTERN score was not related directly to the other three scores. Finally, a correlation between driving scores on the MDE and the DPM was computed. Both total score and element scores were correlated. Since there were four DPM ratings per subject, these correlations were made using the average DPM score.

Testing

Beginning January 17, 1977, all students enrolled in a driver education program at a public, private, parochial, or commercial school were required to take one form of the classroom test at the conclusion of their course. About 3 weeks prior to the end of each program, teachers received the required number of tests and answer sheets as well as instructions for administration. By December 15, 1977, approximately 140 000 students had been tested.

In addition to those students who completed the test at the conclusion of their course, some 4000 students took the test prior to any formal instruction. Teachers were requested to administer the pretests (the same tests used in the posttesting) to the students during the first or second day of class. The pretest information would provide the MDE with an idea of students' cognitive knowledge prior to receiving their formal driver education training.

Because the driver education evaluation was not intended to penalize students with reading difficulties, teachers were informed that the test was not to be timed. Therefore, students could have as much time as needed to complete the test. Also, the teachers could answer any questions regarding the meaning of words, if the assistance did not give away the correct answer. In many instances, the tests were read to the students; some schools even provided cassette recordings of the test or audiovisual materials.

Teachers were requested to submit comments to the MDE after they had administered the evaluation tests. The department received over 400 general comments, which were generally favorable toward the test construction and intent of the project.

Less than a month after a class completed the test, the teacher received two reports. The first indicated how well each student did on each objective, and the second showed the percentage of students in the classroom answering 0 to 5 items correctly for each objective. By using the objective-referenced testing procedure, it was hoped that teachers would use the information provided to revise their curriculum where they deemed it necessary.

STATEWIDE ATTAINMENT

Throughout the year, the MDE received periodic reports on the statewide attainment of the 60 basic objectives. The final report was based on approximately 25 000 students per test form. The percentage of students correctly answering four or five items for each objective is shown in Table 1. The criterion level established was that 80 percent of the students would correctly answer at least four items. Table 1 shows that only 13 of the 60 objectives were attained—less than 22 percent of the basic objectives. Even if attainment were lowered to 75 percent, only an additional nine objectives would be met. The number and percent of objectives and cumulative objectives achieved by students are shown in the following table:

Students (%)	Number of Objectives Achieved	Objectives Achieved (%)	Cumulative Percentages
80-100	13	22	22
75-79	9	15	37
50-74	32	53	90
25-49	5	8	98
0-24	1	2	100

For students to have achieved an objective, they must have answered correctly at least four of the five items.

The classroom objectives are divided into six units. The first two represent the very basic tasks of vehicle familiarization and basic control tasks. Of the 43 objectives tested from these two sections, only nine reached the desired level of attainment and eight of these were in vehicle familiarization. This unit covers areas of the driving compartment, starting and stopping the vehicle, driving fundamentals, and traffic control. The objective with the poorest achievement (49 percent) in the first unit dealt with signs and their respective colors. Putting the vehicle in motion had the highest

Table 1. Attainment rates for 60 objectives used in the Michigan driver education project.

Objective Description		Attainment Pretest (%)	 Posttest (%)	 Difference (%)
Vehicle familiarization				
A2.2	Preignition control procedures	58	70	12
A2.3	Starting engine	55	67	12
A2.4	Putting vehicle in motion	80	89[a]	9
A2.5	Stopping vehicle	69	73	4
A2.6	Securing vehicle	75	82[a]	7
A3.2A	Steps for right turn	38	60	22
A3.2A	Steps for left turn	33	41	8
A3.3	Vehicle positioning for turning left or right	50	67	17
A3.4A	Natural forces when rounding a curve	41	61	20
A3.4B	Compensation for effects of natural forces	53	70	17
A3.5	Effects of gravity going up or down hill	55	62	7
A3.6	Maintaining proper speed control	74	81[a]	7
A4.1A	Traffic sign shapes with their purpose	71	88[a]	17
A4.1B	Traffic sign shapes with driver action	55	79[b]	24
A4.1C	Traffic sign shapes with colors	25	49	24
A4.2A	Traffic signals with their purpose	70	80[a]	10
A4.2B	Traffic signals with driver action	68	79[b]	11
A4.3A	Pavement markings with their purposes	76	86[a]	10
A4.3B	Pavement markings with driver action	68	80[a]	12
A4.4	Driver action for traffic control persons	71	83[a]	12
Basic control tasks				
B1.1	Vehicle movement at intersections	54	63	9
B1.2A	Potential conflict at intersections	59	72	13
B1.2B	Reducing risks at intersections	64	77[b]	13
B1.3A	Entering freeway	30	57	13
B1.3B	Exiting freeway	43	61	18
B1.4A	Path of travel on freeway interchanges	72	78[b]	6
B1.4B	Potential conflicts at freeway interchanges	60	67	7
B2.1	Maintaining a space cushion	71	85[a]	14
B2.2	Speed and directional control on space cushion	54	75[b]	21
B2.3	Establishing proper following distances	51	67	16
B2.4	Vehicle blind spots for various situations	47	70	23
B2.6	Kinetic energy on stopping distance	8	22	14
B4.1	Conditions requiring lane changes	50	69	19
B4.2	Procedure for lane changes	44	73	29
B5.1	Body and hand positions for backing	42	70	28
B5.2	Vehicle handling when backing	36	51	15
B6.2	Overtaking and passing another vehicle	44	72	28
B6.3A	Legal overtaking and passing on the left	70	79[b]	9
B6.3,4	Illegal overtaking and passing on right/left	51	60	9
B6.4	Legal overtaking and passing on right	29	51	22
B6.5	Overtaking and passing a school bus	41	55	14
B7.2	Minimizing hazards when being passed	40	48	8
B8.5	Communicating with other vehicles	70	75[b]	5
Driver fitness tasks				
C1.2	Compensation for visual impairments	59	77[b]	18
C3.1,2	Minimizing distractions (inside and outside)	78	84[a]	6
C4.2	Compensation when under emotional situations	61	76[b]	15
C6.1	Physical effects of alcohol	74	82[a]	8
C6.2	Psychological effects of alcohol	42	57	15
Intermediate control tasks				
D1.2B	Increased speed on friction and impact	27	51	24
D1.6B	Hazardous features of freeway engineering	48	61	13
D2.1	Parallel parking on incline	21	40	19
D5.6	Social responsibilities of drivers	70	82[a]	12
Advanced control tasks				
E1.1	Hazardous situations for night driving	35	73	38
E1.2	Weather conditions and hazardous driving	74	84[a]	10
E1.2	Precautions to take for adverse weather	38	70	32
E1.5	Factors reducing availability of friction	35	59	24
E2.1	Driver response for emergency situations	30	61	31
E3.1A	Vehicle warning lights (malfunctions)	59	65	6
E3.3	Steps to take with vehicle malfunctions	56	66	10
Vehicle				
F2.4	Procedures to follow in traffic accidents	35	45	10

[a] 80 percent of the students answered 4 or 5 items correctly.
[b] 75-79 percent of the students answered 4 or 5 items correctly.

attainment (89 percent), both in this unit and in the entire test.

The second unit, basic control tasks, includes the concepts of being passed and passing, backing, lane changes, being followed and following, and intersections. The only objective in this unit that was attained dealt with maintaining a space cushion. The objective on the effects of kinetic energy on stopping distance had an attainment of only 22 percent. The items measuring this objective involved the notion of what happens when the speed of a vehicle is doubled. Most students responded that the stopping distance doubled as the speed doubled.

The best unit with regard to high achievement was on driver fitness tasks. This unit includes the topics of drugs, alcohol, risk taking, attitudes, distractions, and physical attributes. Attainment ranged from 57 percent (psychological effects of alcohol) to 84 percent (minimizing distractions—inside and outside). Students did better with the physical rather than psychological effects of alcohol.

There were four objectives included from the intermediate control tasks unit. One objective, social responsibilities of drivers, had an achievement level of 82 percent. The other objectives were below 65 percent attainment.

The unit on advanced control tasks includes topics of what to do in an emergency or in adverse conditions. Seven objectives were tested, but only one had an attainment of over 80 percent. The other attainment levels ranged from 59 to 73 percent.

The final unit on the vehicle deals with car care, purchasing a vehicle, insurance, and accidents. Only one objective was considered basic enough to test. This one dealt with the procedures to follow when involved in a traffic accident. Only 45 percent of the students were able to answer at least four of the five questions.

From the attainment rates, it appears that most of the course work covered the sections on vehicle familiarization and driver fitness tasks. As the skills became more advanced, attainment decreased. Thus, it appears that more time is required in the classroom or that attention should be focused on the more critical skills.

In November 1977, a meeting of 35 driver education specialists was held to review the items and corresponding objectives. Their task was to determine the probable reason for poor attainment. The main question to be answered was whether lack of attainment was due to poor items or limited instruction.

The reviewers' overall impression of the objectives tested was that they were appropriate, measurable, and teachable. However, because of the shortness of most programs, many objectives were deleted or only mentioned briefly. In some areas, such as natural forces (friction, gravity), the teachers themselves may not have fully understood the concepts.

Since attainment was chosen to be at least four correct answers per objective, even with one poor item, students should have been able to answer the other four correctly if they knew the material. There were a few instances in which two or three items were inappropriate or incorrect; therefore, attainment would be expected to be low. Of the 60 objectives tested, 28 had attainments below 70 percent. Of these 28, 15 were judged to have low attainment because of limited or insufficient teaching. A few of the general areas, which did not appear to be emphasized in the courses, were emergency procedures, accident involvement, natural forces, parallel parking, and freeway driving.

Although the tests were not to be timed, some teachers may have stopped the students after a given amount of time. If this occurred frequently, a decrease in attainment should have been found near the end of each booklet. This did not seem to be the case. An inspection of the results for each booklet revealed that there was no consistent pattern of decreasing attainment levels in the latter sections of the booklets. The most striking example of a nondecreasing trend occurred in booklet three. Some 82 percent of the students attained the last objective, social responsibilities of the driver; while only 22 percent attained the next to the last objective, kinetic effects on stopping.

The pretest attainment levels along with the difference between pretest and posttest results are also shown in Table 1. The results showed an improvement in all the objectives; therefore, some acquisition of knowledge occurred during the driver education programs. The pretest attainments ranged from 8 to 80 percent and the posttest results ranged from 22 to 89 percent with the same objectives being the highest and lowest in both instances. Fifteen objectives had pretest attainment of 70 percent or better. There were 36 objectives (60 percent) in which at least one-half of the students answered four or five items correctly in the pretest.

The difference between pretest and posttest results ranged from 4 to 38 percent with an average increase of slightly more than 15 percent. The objective showing the greatest improvement (from 35 to 73 percent) covered hazardous situations for night driving. The smallest gain (from 69 to 73 percent) was on how to stop a vehicle.

For those objectives that reached the posttest criterion of 80 percent, the increase from pretest to posttest was about 10 percent. This would tend to indicate that on objectives for which desired posttest attainment was achieved, students knew the material fairly well prior to beginning the course.

DRIVING PERFORMANCE MEASURE RESULTS

The other performance measure developed was for the observation of actual driving behavior. During the first few weeks of August 1977, 30 students were tested for the purpose of determining the reliability of an in-car measure and the raters. Four raters evaluated each of the students. Rather than combining the results of the four individuals, a separate reliability factor was obtained for each of the test components for each rater. The following table shows the test reliabilities:

Test Component	Rater 1	Rater 2	Rater 3	Rater 4
Sum	0.92	0.90	0.86	0.87
Drive	0.91	0.88	0.86	0.87
Search	0.77	0.67	0.83	0.84
Speed	0.80	0.75	0.76	0.61
Direction	0.84	0.87	0.78	0.81
Familiarization	0.67	0.71	0.59	0.34
Signs	0.42	0.76	0.37	0.44

The sum represents the entire test and includes 147 observations. The drive component consists of the actual driving skills and includes search, speed, and directional control. Familiarization tasks involve whether students know the location of various parts of the vehicle as well as how to start and stop a vehicle. The final section, signs, includes students' attention to and compliance with the designated signs and pavement markings.

All but five of the reliabilities obtained were greater than 0.60, which is quite acceptable regardless of the type of research and is very good for a driving measure. The values derived in a study by Jones (9) and in the

Table 2. Pearson correlation of the MDE in-car measure.

Test Component	Sum	Drive	Search	Speed	Direction	Familiarization	Signs
Sum	1.00						
Drive	0.98	1.00					
Search	0.86	0.86	1.00				
Speed	0.83	0.84	0.67	1.00			
Direction	0.77	0.81	0.47	0.52	1.00		
Familiarization	0.50	0.34	0.40	0.45	0.04	1.00	
Signs	0.43	0.36	0.26	0.10	0.49	-0.07	1.00

Table 3. Validity of the MDE driving component.

	Driver Performance Measure				
MDE	Sum	Search	Speed	Direction	Pattern
Drive	0.46^{a} (0.50)	0.35^{a}	0.35^{a}	0.32^{b}	0.44^{a} (0.51)
Search	0.51^{a}	0.56^{a} (0.60)	0.23	0.29^{b}	0.42^{a}
Speed	0.32^{b}	0.21	0.32^{b} (0.40)	0.16	0.36^{a}
Direction	0.31^{b}	0.10	0.34^{b}	0.32^{b} (0.36)	0.33^{b}

$^{a}p < 0.01$. $^{b}p < 0.01$.

Michigan Road Test Evaluation (November 1977) by Vanosdall and others—the latter unpublished—were equal to or less than those obtained in the present study. The lower values for familiarization were due to a lack of variance within the items—71 percent of the items had means of 0.9 or better and 44 percent had means of 1.0; the items were scored as either 0 or 1. The small number (9) of items for the signs section also affected the reliability results.

In addition to the reliabilities of the measure, rater agreement was calculated for each of the test components. Since the raters were not always paired with the same person, these correlations were computed for pair one (disregarding individuals) on drive one and pair two on drive two. The results are shown below:

Test Component	Pair 1	Pair 2
Sum	0.86	0.83
Drive	0.80	0.80
Search	0.67	0.79
Speed	0.72	0.51
Direction	0.75	0.50
Familiarization	0.83	0.52
Signs	0.49	0.54

The correlations obtained showed a high degree, in most instances, of agreement between the pairs of raters. In all instances the correlations were significant at $p < 0.01$. In other words, both raters saw the same behavior and rated it in similar fashion. These results verify that the training program was successful.

Because acceptable reliabilities were obtained, it was possible to proceed with a concurrent validation study. This study was conducted in October and November 1977, after students had been driving for at least two months. Most students (85 percent) had already obtained their driver license. Each of the 40 students was rated by one MDE rater and two DPM raters. In addition, the DPM route was driven twice so that there were actually four observations provided on the DPM.

Interitem reliabilities were again computed for the MDE test and found to be consistent with those of the reliability study. The correlations ranged from 0.54 for familiarization to 0.89 for drive. Except for familiarization and signs, all correlations were above 0.70.

The intercorrelations of the total test score and each of the six subscales are presented in Table 2. Scores on the drive component, which comprises approximately 60 percent of the total test, correlated almost perfectly (0.98) with the total test score. Each of the elements that were a part of the drive correlated above 0.80 with drive. However, both the familiarization and signs elements had low correlations with the total test score (0.50, 0.43) and even lower correlations with drive (0.34, 0.36). This would indicate that these two components were not necessarily measuring the ability to drive properly as measured by the MDE drive. For example, students may know where each of the parts of a vehicle are, but may or may not know how to operate a vehicle correctly. Finally, the correlation between sign and familiarization was -0.07, indicating no relationship between the two components.

The correlations between scores obtained on the DPM and the MDE were computed to ascertain the validity of the MDE measure. The mean score of the DPM was used in the correlation since there were four observations made per student. The results are shown in Table 3.

According to the authors of the DPM, the pattern score is the most important in determining whether or not an individual can drive safely. This element correlated 0.44 with the MDE drive component, which was significant at $p < 0.01$. In fact, the MDE drive components were significant at $p < 0.05$ when correlated with the corresponding DPM components. Of the 20 correlations obtained, only four were found to be nonsignificant. The correlations obtained in this research are comparable to those obtained when the DPM was used to validate a new Michigan state road test by Vanosdall and others.

If only one DPM rater had been used, the correlations between the MDE and DPM would have been equal to the values shown in parentheses in Table 3. In all instances, the MDE elements would have been significant at $p < 0.01$ when correlated with the appropriate DPM elements.

DISCUSSION

The goal of the driver education evaluation project was to answer several questions regarding Michigan's driver education programs. The major question was: Are current driver education programs achieving the classroom performance objectives? The answer was obtained by the use of objective-referenced tests. After 1 year of testing, the MDE now has a clearer idea of what is being taught in driver education programs and thus can provide suggestions or assistance in improving the attainment of the classroom performance objectives.

The development of appropriate performance objectives should enable the state to obtain consistency across all programs. The objectives will, at least, provide teachers with more complete knowledge of what should be taught. In turn, the consistency in performance objectives should be of value for future evaluation studies of driver education programs.

The statewide results indicate that the material considered basic for all programs is not being attained as expected. Using the a priori criterion of 80 percent of the students answering correctly at least four items per objective, only 22 percent of the objectives were met. If the criterion were lowered to 75 percent, then 37 percent of the objectives would be met; reduction to 70 percent attainment would mean that 53 percent of the objectives were met. Further reduction in the criterion level would be inappropriate given the way the tests were constructed.

In fact, when one remembers the basic premise of the test construction, the theoretical goal would be that everyone should be able to answer correctly every question. The objectives were selected by a representative sample of driver education teachers and specialists as being basic; the questions were constructed by driver education experts as being elementary and not tricky; and the average reading level of each test booklet was sixth grade. These factors were incorporated to assure that a criterion of 80 percent would not be unrealistic.

One positive aspect of the research was that there was always an improvement from the pretest to the posttest scores. Some learning is obviously occurring in driver education and this would indicate that driver education should not be eliminated. However, on those objectives that reached the posttest criterion level, there was less improvement from the pretest to the posttest scores than for the other objectives. This would indicate that, for these particular areas, students were already familiar with the topic prior to entering the program. It might be advisable for teachers to administer a pretest to their classes and advance students from their entrance level. This might mean more time could be spent on the advanced skills.

Another factor to consider is the time generally available for teaching—less than 30 hours in typical programs when all nonteaching duties are considered. The 30 hours of classwork may be insufficient for the instruction considered necessary. Even in longer programs, teachers may be merely reiterating the same concepts as in short courses rather than working on the advanced skills. More careful attention should be paid to this variable along with an in-depth review of what is being taught in the longer programs.

Comments from the posttest review pointed out that the most frequent reason for low attainment on the tests was probably the limited or absence of teaching about many areas. This could be due to the time constraints imposed by the 30-hour classroom minimum requirement or because teachers were unfamiliar with some of the material. There were only a few instances in which the test items were viewed as the reason for failure.

It is somewhat paradoxical that both the students and teachers considered the test to be fairly simple. Some even suggested that the tests should be made more difficult or that the correct answers be less obvious. However, these comments did not coincide with the results obtained.

The driving measure was shown to be both reliable and valid. However, because of the time constraints imposed upon the project, it was not possible to select a stratified random sample of students for actual test administration of the in-car measure.

The results of the classroom testing should not be construed to mean that driver education programs are a waste of time; but rather that there is a need to take a closer look at what students are being taught and how the 30 hours of classroom time are being used, as well as the preparation that teachers have received. Perhaps it is necessary for the MDE and the local school districts to work together to provide the necessary preservice and inservice training so that teachers will be better able to instruct their students. Also, a closer examination of how best to present the material in the given time frame would be important. Finally, a more extensive examination of the longer or full-semester programs should be implemented.

Since the department and the local school districts now have some concrete data on the achievement of students' cognitive knowledge, some changes may be possible. Although the results obtained provide a clearer picture of Michigan's driver education program, there are still questions that need to be answered. However, at this time, the information contained herein is the best information available regarding classroom performance.

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Evaluation of Educational Treatment for Rehabilitation of Problem Drivers

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A unique rehabilitative treatment for improving the performance of problem drivers was developed and evaluated in Florida. Entitled Responsible Driving, the treatment places emphasis on group discussion of concepts and principles derived from transactional analysis, a theory of personality developed by Eric Berne, M.D. In order to test the effectiveness of the treatment, hearing officers from five Florida cities randomly assigned 432 problem drivers to an experimental treatment group, a defensive driving course group, and a control group. All subjects had lost their driver's licenses and were attempting to obtain a temporary license for some hardship reason. Safety officers from the Florida Highway Patrol taught both the experimental and the defensive driving course. In addition to written pretests and posttests for study subjects, the driving records established by each were followed for 12 months. Results showed that the experimental treatment was significantly more effective ($p = 0.05$) than no treatment in reducing the number of traffic collisions and the number of convictions for moving traffic law violations. The defensive driving course was not significantly different from any group at $p = 0.05$. Although the findings of this study may be questioned due to small sample size and the lack of rigorous supervision in its conduct, there was evidence to support the use of the new treatment for helping problem drivers improve their driving behavior. It is recommended that this treatment be evaluated in a larger, more rigorous study.

The majority of drivers will obey traffic laws most of the time either because they are aware of the value of the laws or they are afraid of getting caught and facing the consequences. However, a small percentage of drivers repeatedly disobey traffic laws, or frequently become involved in collisions, or both.

In attempts to modify errant driver behavior, highway safety authorities have used fear tactics, such as warning letters, fines, license suspension and revocation, and imprisonment. These methods have had an effect on some so-called problem drivers (1, 2). However, the authorities found that fear tactics did not work for other problem drivers and even appeared to have a negative effect on them (3, 4).

Therefore, other, less punitive measures have been implemented. These measures have included attempts to educate problem drivers by improving driving knowledge and skill. Other measures have attempted to improve the attitudes of problem drivers or have dealt directly with the maladaptive behavior. Each of these treatments has demonstrated short-term success when compared with results of punitive measures (5, 6, 7, 8, 9, 10). Evidence of long-term effectiveness does not exist (11). One reason may be that these measures attempted to treat only a part of the problem. Driving behaviors are formed by past experiences, present conditions, and future expectations. These, in turn, are based on existing knowledge, skills, thoughts, attitudes, and emotions.

Research in the field of human factors in traffic safety in particular and in the field of human behavior in general has pointed the way toward a more comprehensive understanding of human actions. Although many studies have attempted to show the relationship between certain character traits and driving (12, 13, 14, 15, 16, 17), the major conclusion with the most validity is that maladaptive driving habits and overinvolvement in traffic collisions are manifestations of drivers' life-styles (12, 18, 19, 20). This conclusion was further substantiated by Shaw and Sichel (21). These researchers found that total personality, rather than any one trait, was the significant predictor of how a person drives.

Another conclusion which is pertinent to helping a person make a more permanent change in driving habits has been uncovered in human behavior research. This conclusion is one of the major assumptions upon which the theory of operant conditioning rests (22) and was expanded to become a major aspect of transactional analysis, or TA (23, 24, 25). In effect, this assumption states that a person does not act without a payoff. According to TA theory, this payoff is a feeling, either real or artificial, positive or negative, conscious or subconscious. Most habitual behavior patterns, which appear to be maladaptive to an observer, have more positive than negative value to the individual performing the behavior. Every behavior is the end result of an internal decision-making process of thoughts and feelings.

Therefore, if an attempt is made to help a person deal more effectively with only one aspect of this process—e.g., thoughts (knowledge or attitudes), feelings, or actions—the person will need to learn how to deal with the remaining aspects. This reduces the probability that long-term change will be effected. Old habits are comfortable; new behavioral patterns are uncomfortable. Long-term changes can result only if the new patterns become internalized. Internalization of new behavior patterns can occur over a short or a long period of time, depending on an individual's willingness to learn and readiness for change (level of motivation).

A new treatment for the rehabilitation of problem drivers was developed based on these ideas (26). The treatment was tested in three Florida cities. Based on the positive results of these tryouts (27), a larger study compared the new treatment with a traditional treatment (28).

PURPOSE OF STUDY

The primary purpose of this study was to compare the short-term and long-term effectiveness of two treatments on the driving behavior of problem drivers. The two treatments were the National Safety Council's Defensive Driving Course (DDC) and the new treatment, referred to as Responsible Driving. DDC is primarily a knowledge-based course using lectures, films, and other media as the major instructional techniques. The experimental treatment focused on helping participants learn to accept responsibility for their actions, especially while driving. Using group discussion, role playing, decision-making techniques, the lecture, films, and other media, participants were invited to express their feelings and ideas while learning to increase their self-awareness, driving knowledge, and, above all, willingness to perform in a responsible manner while driving.

METHODOLOGY

All subjects for this study were selected from Florida's population of problem drivers who requested and received a hearing from a hearing officer regarding their loss of driving privileges due to accumulated points received for traffic law violations, or collisions, or both. All subjects were permanent residents of Florida who had lost or were about to lose their driver's license for a period of 30 days or more and were attempting to obtain a restricted driver privilege for some hardship reason.

The evaluation design called for a total of 144 problem drivers to be randomly assigned to the experimental treatment, designated as group 1. Another 144 problem drivers were to be randomly assigned to a Defensive Driving Course, designated as group 2. A third block of 144 randomly selected problem drivers were to receive no treatment (control group) and were designated as group 3. Pretests and posttests were administered to all participants in each of the three study groups. It should be noted that, for group 1 and group 2, an identifiable, but differing, treatment supplemented a suspension of drivers' licenses. The pretests and posttests were administered to the control group in order to determine time and testing effects.

The experimental design employed was as follows:

Random Assignment	Pretest	Treatment	Posttest
R	0_1	X_1	0_1
R	0_2	X_2	0_2
R	0_3	X_3	0_3

where

X_1 = TA treatment, group 1;
X_2 = DDC treatment, group 2;
X_3 = no special treatment, group 3;
O_1 = scores and driving record data from group 1;
O_2 = scores and driving record data from group 2; and
O_3 = scores and driving record data from group 3.

The design was considered appropriate, since the subjects within each of the three groups were not likely to be acquainted with each other previous to, during, or after completion of the treatment. Therefore, any effect on the posttest scores that might have been caused by acquaintances or cross-contamination was probably eliminated.

In the book Experimental and Quasi-Experimental Designs for Research (29), Campbell and Stanley rated the preceding design high on internal validity, a major concern. External validity was not a major concern since generalization of inference of such a small group cannot be claimed with confidence. Further, since the control group represented randomly assigned problem drivers from the general profile of problem drivers, generalization was somewhat built in.

Analysis of variance was used to test the null hypotheses involving mean scores on pretests and posttests of knowledge and attitudes, mean number of collisions, and mean number of violations 1 year before and 1 year after treatment for the three study groups. The Scheffé test of significance was applied to the analysis of variance results that were significant in order to isolate the groups that were significantly different. To test those null hypotheses, which involved only two variables, a t-test was used to determine significant differences. A confidence level of 0.05 was used for all tests of significance. A level of 0.10 was also used with the Scheffe test in order to avoid acceptance of null hypotheses that may have been rejected if larger numbers of subjects had been involved. Although some question might exist as to the appropriateness of applying the analysis of variance procedure to sets of data for convictions and collisions, it has been argued (30) that empirical studies of the effects of systematic departures from normality of data analyzed using the analysis of variance do not completely invalidate application of this technique. Apparently, the effect of applying the analysis of variance to J-shaped distributions is to cause more of the potential null hypotheses to be retained than would be expected by ordinary reference to Snedecor's F-tables. In other words, application of an F-test should be viewed as a conservative procedure and slightly biased toward acceptance of the hypothesis of no significant difference.

The hypotheses tested included the following:

1. No significant difference will exist among mean scores on pretests of driving knowledge made by three groups of randomly assigned problem drivers.
2. No significant difference will exist among mean scores on posttests of driving knowledge made by three groups of randomly assigned problem drivers.
3. No significant difference will exist among means of the differences between scores on pretests and scores on posttests of driving knowledge made by three groups of randomly assigned problem drivers.
4. No significant difference will exist among mean scores on pretests of attitude-related traffic opinions made by three groups of randomly assigned problem drivers.
5. No significant difference will exist among mean scores on attitude-related traffic opinions made by three groups of randomly assigned problem drivers.
6. No significant difference will exist among the means of the differences between scores on pretests and scores on posttests of attitude-related traffic opinions by three groups of randomly assigned problem drivers.
7. No significant difference will exist among the three groups in regard to the mean number of convictions for traffic law violations received during the 12-month period immediately preceding the scheduled group treatments.
8. No significant difference will exist among the three groups in regard to the mean number of convictions for traffic law violations received during the 12-month period immediately following the scheduled group treatments.
9. No significant difference will exist among the three groups in regard to the means of the differences between the number of convictions for traffic law violations received during the 12-month period immediately preceding the scheduled group treatments and the number of convictions received during the 12-month period immediately following the scheduled group treatments.
10. No significant difference will exist among the three groups in regard to the mean number of convictions for moving traffic law violations received during the 12-month period immediately preceding the scheduled group treatments.
11. No significant difference will exist among the three groups in regard to the mean number of convictions for moving traffic law violations received during the 12-month period immediately following the scheduled group treatments.
12. No significant difference will exist among the three groups in regard to the means of the differences between the number of convictions for moving traffic law violations received during the 12-month period immediately preceding the scheduled group treatments and the number of convictions received during the 12-month period following the scheduled group treatments.
13. No significant difference will exist among the three groups in regard to the number of points received for moving traffic law violations during the 12-month

period immediately preceding the scheduled group treatments.

14. No significant difference will exist among the three groups in regard to the number of points received for moving traffic law violations during the 12-month period immediately following the scheduled group treatments.

15. No significant difference will exist among the three groups in regard to the means of the differences between the number of points received for moving traffic law violations during the 12-month period immediately preceding the scheduled group treatments and the number of points received during the 12-month period immediately following the scheduled group treatments.

16. No significant difference will exist among the three groups in regard to the mean number of collisions that involved a member as a driver during the 12-month period immediately preceding the scheduled group treatments.

17. No significant difference will exist among the three groups in regard to the mean number of collisions that involved a member as a driver during the 12-month period immediately following the scheduled group treatments.

18. No significant difference will exist among the three groups in regard to the means of the differences between the number of collisions that involved a member as a driver during the 12-month period immediately preceding the scheduled group treatments and the number of collisions during the 12-month period immediately following the scheduled group treatment.

Five instruments were used in the study as well as data obtained from Florida's driver records system to evaluate the relative effectiveness of the treatments. Three tests of knowledge were used: (a) one on general knowledge of driving, Achievement Scale on Motor Vehicle Transportation; (b) one to assess attainment of the knowledge content of the experimental treatment, Knowledge Test for Experimental DI Course; and (c) one to assess attainment of knowledge content of the DDC, Defensive Driving Course Final Examination. The Driver Reaction Scale was used to assess attitude change. There were two measures—one subjective and one objective—used to ascertain possible behavioral changes resulting from the treatment. The subjective measure was the participants' verbal responses to the follow-up evaluation. The objective measure of behavior change was the data obtained from the driver records system of the state of Florida.

A group of safety officers from the Florida Highway Patrol were identified as the most logical choice to serve as group leaders for both the DDC and the experimental treatment. Every officer was active in teaching DDC and participated in a 4-day training workshop in TA. Nine officers were selected from 17 who were trained as group leaders. These officers were selected because they worked in the four cities from which the subjects were chosen for the study. Three officers were from Orlando and two each were from Tampa, Fort Lauderdale, and Jacksonville.

Problem drivers were randomly assigned to three groups as they appeared for hearings in the four cities. Members of group 1 were assigned to the experimental treatment. Members of group 2 were assigned to the DDC. Members of group 3 were assigned to the control group and were given no treatment other than license suspension, which all subjects received.

At the hearing, the hearing officers told each member of group 1 and group 2 that participation in the course was considered part of the process for regaining their driving privilege. In addition, the hearing officers stated:

1. The courses were designed to assist participants in improving driving performance;
2. The courses consisted of four sessions lasting from two to two-and-a-half hours per session; and
3. The locations and schedules of the courses were given.

All pretests and posttests were administered in the following manner. The hearing officers administered the pretests to all study subjects at the time of their initial interviews. Posttests for groups 1 and 2 were administered by the safety officers at the end of the treatments. For the control group (group 3), the hearing officers assigned each member an appointment date in his office for administration of the posttests. The safety officers administered the follow-up evaluation by telephone to subjects in groups 1 and 2.

The safety officers were each responsible for teaching DDC to 18 study subjects and the experimental treatment to 18 other subjects, except in one location where three officers were each responsible for teaching DDC to 12 subjects and the experimental treatment to 12 other subjects. However, administrative problems arose that led to a reduction in the sample population.

The study was conducted during a 6-month period from December 1, 1975, through June 1, 1976. One year from the end of the last treatment, the test data and the driving records of all study subjects were analyzed.

RESULTS

The first three hypotheses tested in this study related to driving knowledge. The means and standard deviations of the three groups on both the pretest and posttest for the Achievement Scale on Motor Vehicle Transportation, testing overall driving knowledge, as well as the mean differences and standard deviations, are presented in Table 1. Analysis of variance conducted on these data revealed a significant difference for both the pretest ($p = 0.03$) and posttest ($p = 0.01$) but not for the differences ($p = 0.32$). Scheffé tests revealed that, for both tests, the control group had significantly higher scores than the DDC group, while no other groups were significantly different at the 0.05 level of significance. At the 0.10 level, both the control and the experimental groups had significantly higher posttest scores than the DDC group. Therefore, the first two null hypotheses were rejected; the third hypothesis failed to be rejected.

Analysis of the results of the two tests of special knowledge revealed a significant increase from pretests to posttests (for both tests, $p = 0.01$). However, since the control group was not given these tests due to time and administrative constraints, it is impossible to say how much of the increase in learning was due to time and pretest effects.

The next three hypotheses, which were tested in this study, relate to attitude-related behavioral tendencies. Since the instrument used to assess this factor was not submitted to a test of reliability, the results should be viewed with caution. However, there was no other test of this factor available that had proved reliable. Analysis of variance of these data revealed no significant differences: for the pretest, $p = 0.13$; for the posttest, $p = 0.77$; and for the differences, $p = 0.22$. Hypotheses 4, 5, and 6, therefore, failed to be rejected.

The remaining hypotheses tested in this study related to the driving records of the subjects compiled 1 year prior to and 1 year following treatment. Hypotheses 7, 8, and 9 related to the total number of convictions for traffic law violations received by members of each group. Table 2 presents the means and standard deviations for these results. Analysis of variance performed on these data revealed no significant difference among the groups 1 year before treatment ($p = 0.65$). However, a significant difference between the groups was found for the violations compiled 1 year after treatment ($p = 0.01$) and for the differences ($p = 0.03$). At the 0.10 level, group 1 was significantly different from group 2 (DDC) 1 year after treatment. Therefore, hypothesis 7 failed to be rejected, while hypotheses 8 and 9 were rejected. The members of the experimental group reduced the total number of violations they received to a greater extent than did the members of either the DDC or the control group.

Table 3 presents the means and standard deviations of the number of moving traffic law violations received by the three groups as well as the means and standard deviations of the differences. Analysis of variance conducted on these data showed that, although there was no significant difference among the groups 1 year before treatment ($p = 0.52$), there was a significant difference 1 year after treatment ($p = 0.01$) as well as in the differences from before to after treatment ($p = 0.04$). Scheffé tests revealed that the experimental group was significantly different from the control group at the 0.05 level for the after treatment and for the differences. Therefore, hypothesis 10 failed to be rejected, while hypotheses 11 and 12 were both rejected. The experimental group had a significantly greater reduction in moving violations than the control group.

The next three hypotheses related to the number of points received by subjects for traffic law violations during the two periods. The means and standard deviations for these data are presented in Table 4. Analysis of variance run on these data revealed that there were significant differences among the groups for all three comparisons—for the 1 year before treatment comparison, $p = 0.03$, while for both the 1 year after treatment period and for differences between the two periods, $p = 0.01$. Using a 0.05 level of significance, Scheffé tests showed that the experimental group was significantly different from the control group for all three comparisons.

Table 1. Pretest and posttest group means and standard deviations obtained from Achievement Scale on Motor Vehicle Transportation (N = 287).

	Pretest		Posttest		Differences	
Group	Mean	SD	Mean	SD	Mean	SD
1 (experimental)	22.29	4.56	23.67	4.56	1.38	4.53
2 (DDC)	21.57	5.22	22.09	5.19	0.52	5.51
3 (control)	23.42	4.16	23.95	4.03	0.53	3.41

Note: Highest possible score equals 32.

Table 2. Means and standard deviations of convictions for traffic law violations before and after completion of treatment and of the differences (N = 358).

	Number of Violations 1 Year Before Treatment		Number of Violations 1 Year After Treatment		Differences	
Group	Mean	SD	Mean	SD	Mean	SD
1 (N = 137)	3.01	1.88	0.59	0.85	(2.42)	1.97
2 (N = 109)	2.86	1.93	0.93	1.22	(1.93)	1.96
3 (N = 112)	2.80	1.80	1.01	1.37	(1.79)	1.91

Therefore, the experimental group reduced the number of points they received significantly more than the control group. It was also found that, when a 0.10 level of significance was used with the Scheffé test, the experimental group had a significantly greater reduction in point differences than the DDC group. Hypotheses 13, 14, and 15 were all rejected.

The last three hypotheses tested related to the number of collisions in which members of each group were involved during the two periods. The means and standard deviations for these results are presented in Table 5. The distributions of the number of collisions in which each group were involved are presented in Figure 1 for comparative purposes. Analysis of variance conducted on these data showed no significant differences for either the before treatment ($p = 0.23$) or the after treatment ($p = 0.07$) comparisons. However, there was a significant difference among the differences ($p = 0.03$). A Scheffé test revealed that the experimental group was significantly different from the control group at the 0.05 level.

Therefore, although hypotheses 16 and 17 failed to be rejected, hypothesis 18 was rejected. The experimental group had a significantly greater reduction in collisions after treatment than the control group.

The last data to be reviewed were the input received from the follow-up evaluation. These data were obtained from a total of 153 subjects—74 from the experimental group and 79 from the DDC group. Members of both groups responded that they felt they had benefited from the treatments.

CONCLUSIONS

Although the results of this study should be considered tentative due to the small sample size, dropouts, possible contaminations occurring during the conduct of the study, and lack of a more suitable statistical procedure for analysis of the driving records, some important findings were revealed. There was strong evidence to support the future use of the experimental treatment for helping problem drivers improve their driving behavior. The study was useful in showing that the experimental treatment was significantly more effective than no educational treatment (control group) and somewhat more effective than the DDC for this sample of problem drivers.

The experimental treatment was found to be most effective in helping problem drivers reduce total convictions for traffic law violations and violations points. The DDC group had a greater reduction than the control group for all driver record criterion variables analyzed. However, none of these were significantly different at either the 0.05 or 0.10 level of significance.

One interesting finding of this study was that all groups had a high pretest score on a test of overall knowledge and no groups made a significant improvement in their scores on the posttest. No group had a mean pretest score of less than 67 percent on this test. It would appear from this evidence that driving knowledge is not one of the critical variables applicable to most problem drivers.

Based on the results of this study and the results of the earlier tryouts of the experimental treatment, it is recommended that a larger study ascertain the effectiveness of the new treatment by comparing it with other approaches that aim to help problem drivers improve their driving behavior. It would also be of value to include in this study an analysis of which age groups, socioeconomic groups, sex, and other subgroups of the populations of problem drivers are helped most by this new treatment.

Table 3. Means and standard deviations of moving traffic law violations before and after completion of treatment and of the differences (N = 358).

	Number of Violations 1 Year Before Treatment		Number of Violations 1 Year After Treatment		Differences	
Group	Mean	SD	Mean	SD	Mean	SD
1 (N = 137)	2.60	1.58	0.41	0.64	(2.19)	1.67
2 (N = 109)	2.49	1.59	0.61	0.85	(1.88)	1.76
3 (N = 112)	2.38	1.45	0.72	0.89	(1.66)	1.56

Table 4. Means and standard deviations of violation points received before and after completion of treatment and of the differences (N = 358).

	Points Received 1 Year Before Treatment		Points Received 1 Year After Treatment		Differences	
Group	Mean	SD	Mean	SD	Mean	SD
1 (N = 137)	10.39	7.89	1.44	2.37	(8.95)	7.99
2 (N = 109)	9.17	5.90	2.15	3.26	(7.02)	6.62
3 (N = 112)	8.22	4.98	2.75	3.84	(5.47)	5.66

Table 5. Means and standard deviations of collisions before and after completion of treatment and of the differences (N = 358).

	Collisions 1 Year Before Treatment		Collisions 1 Year After Treatment		Differences	
Group	Mean	SD	Mean	SD	Mean	SD
1 (N = 137)	0.49	0.75	0.14	0.35	(0.35)	0.81
2 (N = 109)	0.40	0.61	0.23	0.44	(0.17)	0.73
3 (N = 112)	0.35	0.57	0.26	0.50	(0.09)	0.77

It is recommended that the new treatment be implemented under the direct supervision of a person well trained in its application. The treatment could be used alone or in conjunction with other treatments, such as DDC. Results of these applications should be analyzed for at least 2 years to identify the most effective treatment or combination of treatments.

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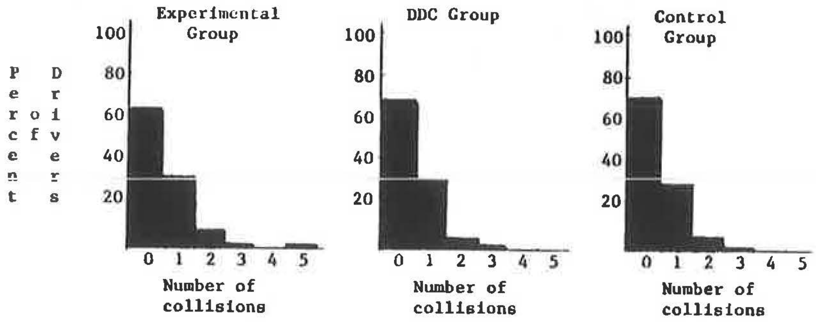
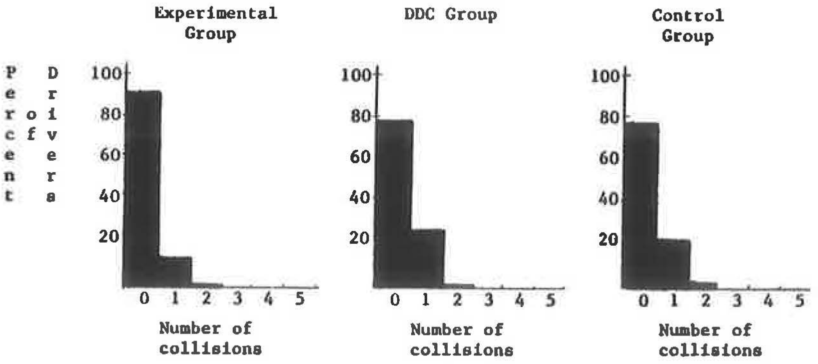
Figure 1. Distributions of the number of collisions per driver before and after treatment.

One Year Before Treatment



One Year After Treatment



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Driver Education for Stress Conditions

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A set of driver performance training activities has been developed to prepare drivers to handle a vehicle under such stress conditions as tire failure, skid situations, off-road recovery when one or more wheels drop off pavement, and to properly steer vehicle, to evade sudden impending dangers, and to brake the vehicle without losing control. As this paper points out, when these activities are learned and practiced, improvements occur in a driver's ability to operate a vehicle and to respond to stress conditions with a high degree of success. In addition, reductions in accidents and property damage have also taken place.

The program described in this paper was developed from information obtained through a search of the literature and through experiences gained by participating in training programs previously developed by such organizations as Liberty Mutual Insurance Company, General Motors Proving Ground, and the National Safety Council.

For many years, the Liberty Mutual Insurance Company has provided information via films and workshops concerning the ability to control a vehicle in various skid situations (1). General Motors Proving Ground first developed a series of activities that were aimed at improving skills of drivers in handling emergencies (2). The National Safety Council has for many years conducted Winter Driving Techniques Workshops at Stevens Point, Wisconsin (3).

Others have conducted training programs that have incorporated these and similar activities. The Bob Bondurant School of High Performance Driving provides a program and helped with the production of a film by the Chevrolet Division of the General Motors Corporation (4). The National Park Service and several state highway patrols have produced programs to develop driver skills in responding to emergency situations.

The program discussed here was developed by the Safety Department at Central Missouri State University and is a composite of many ideas. The course centers around three important elements in the driving task—the driver, the vehicle, and the environment.

CLASSROOM ACTIVITIES

Classroom activities involved the following:

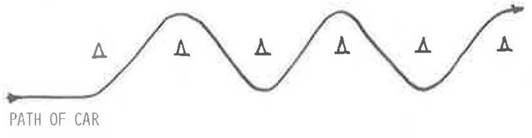
1. Course orientation;
2. A simplified approach to tire interaction with the surface and traction (braking traction and cornering traction);
3. Differences in the coefficient of friction among dry, wet, and ice-covered surfaces;
4. Comparative stopping distances of new tires versus worn tires on various surfaces;
5. Relation of friction to cornering, stopping, and driving;
6. Centrifugal force related to vehicle control;
7. Understanding of the fact that all four wheels help steer and control the vehicle path;
8. Visual perception pretest, improvement exercise, and posttest; and
9. An introductory description and discussion of each in-car exercise including serpentine steering, evasive maneuvering, controlled braking, off-road recovery, skid control, and blow-out simulation.

Following discussion, a fixed-base simulator presentation is used to prepare drivers for the type of actions they will be required to perform in the car.

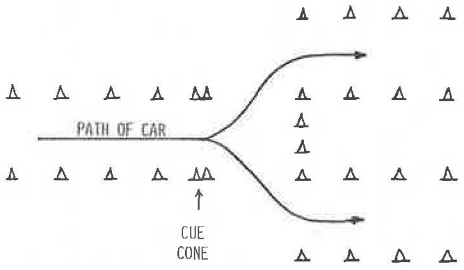
LABORATORY IN-CAR EXERCISES

The in-car phase of the course includes hands-on experience to develop skill in performing the exercises accurately and skillfully. Each exercise is demonstrated, and the student is allowed to practice the exercises under direct supervision of the instructor.

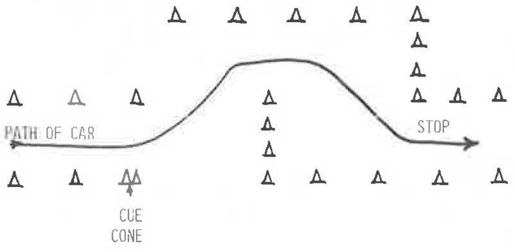
Serpentine Steering. The purpose or objective of this exercise is to develop proper timing of steering input, judging the relationship of fixed objects to the vehicle.



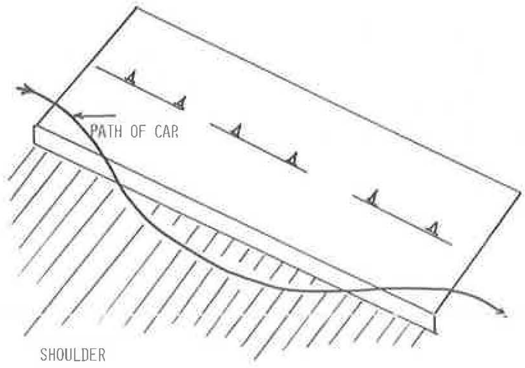
Evasive Maneuver. This exercise allows students to discover that the evasive capabilities far exceed the stopping capabilities. A car can evade an object in a shorter distance than the driver can stop the vehicle.



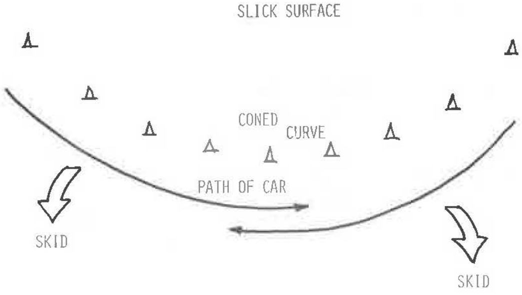
Controlled Braking. This exercise allows students to master the skill of being able to use maximum braking force to stop a vehicle in the shortest distance possible, while retaining steering control of the vehicle.



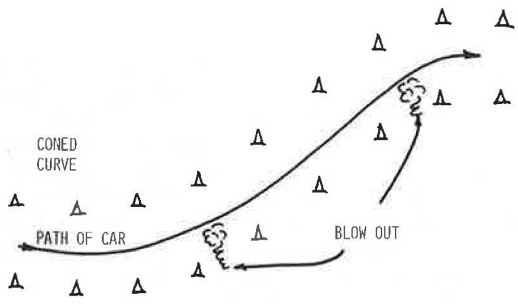
Off-Road Recovery. This exercise develops skill in getting a vehicle back onto the pavement at highway speed when either two or four wheels drop off the pavement onto the shoulder. This is used only in unusual situations, where there is neither time nor space in which to slow down.



Skid Control. This exercise allows students to sense the feel of a vehicle in a skid and to develop proper driving techniques to control the vehicle.



Blowouts. This exercise allows students to develop skills of vehicle control in the event of front or rear blowout and to control the car either in a straight line or curve.



Blowout is induced somewhere within the coned course. A mechanical device (blowout simulator) is used to suddenly remove air from tire in approximately one-quarter of a second.

PROGRAM EVALUATION

The Advanced Driving Techniques Programs have received a high degree of acceptance by professionals in the traffic safety field. These programs have also been deemed of great value by those who have been trained in these activities. However, little has been done to evaluate the programs as to their long-range effectiveness in reducing accidents and violations.

A small study, conducted by the General Motors Proving Ground in 1969, to validate its training program did provide indications of very satisfying results (5). The study involved 60 police officers. Matched groups were selected, and one group was given the training program. After 18 months, these data showed that the trained group had only half as many accidents; a record of one-tenth the total costs in terms of injuries, days lost, lost wages and vehicle damage; and an average cost per accident of 20 percent of that of the untrained group (5). Although General Motors did not feel that this small study was an adequate validation of the course, it did provide promising results (5).

The Safety Department at Central Missouri State University has conducted several programs of this nature and, while data regarding long-range results are not yet available, primary indications from change in ability to operate a vehicle under emergency conditions following the instructional program lead us to believe that results similar to those in the General Motors study may be in the offing. Groups trained included adult drivers, student drivers, U.S. Air Force personnel, AT&T instructor personnel, and fleet operators.

The Missouri Safety Center, in cooperation with the Missouri Division of Highway Safety, has conducted a pilot program for the training of emergency vehicle operators in advanced driver education. The Greater St. Louis Training Academy agreed to serve as the study group for this project.

Material reported in this paper concerning this study has been taken from The Evaluation of a Curriculum on Advanced Driver Education for Emergency Vehicle Operators in Missouri, an unpublished doctoral dissertation by Fredrick W. Reuter (1977). The purpose of the project was to evaluate the long-range benefits that may be derived from a curriculum in advanced driver education specially designed for operators of emergency vehicles throughout the state of Missouri.

The hypotheses to be tested in this study were

1. H_01: There is no difference in performance on pretests of knowledge, low speed skill, and increased speed skill between the advanced driver education group and the control group, which does not receive advanced driver education.
2. H_02: There is no difference in performance on posttests of knowledge, low speed skill, and increased speed skill between the advanced driver education group and the control group, which does not receive advanced driver education.
3. H_03: There is no difference in learning between the group receiving advanced driver education and the control group, which did not receive advanced driver education, as measured by differences in pretest and posttest knowledge, low speed skill, and increased speed skill scores achieved by persons in either of the groups.

A literature review indicated that a wide variety of training programs of this type are being conducted across the nation. Few programs are the product of a strong statistical analysis to ensure continued program evaluation and development. Information available at the local, state, and national levels readily attests to the need for a comprehensive and concise education program for emergency vehicle operators. As an example, information from the National Safety Council's Fleet Safety Contest shows accident rates (per 1.6 million vehicle-kilometers) for municipal patrol cars are 31.33, compared to 8.32 for passenger cars and 11.4 average for all vehicles in fleet use (6).

CURRICULUM DEVELOPMENT

Contributions to the curriculum, which was developed over a 4-month period, came from a review of the literature and a study of the Driving Task Analysis conducted by the Human Resources Research Organization on driver and traffic safety education (7). Major elements in the curriculum were the National Safety Council's defensive driving course, the Maryland State Department of Education's system of perceptual driving, and the General Motors Proving Ground's evasive maneuvers course.

The curriculum stressed a systems approach to understanding the driving task, a visual perception improvement program to upgrade the driver's visual habits, and a series of advanced driver education off-street range exercises designed to improve driver skills. Materials developed included the following:

1. Instructor manual—a two-phase supplement to the student manual—with pretests and posttests for both knowledge and skill; and
2. Student manuals for each phase: phase 1 (classroom), 6 hours of modular classroom study with visuals; phase 2 (range exercises), performance objectives for skill evaluations.

Ten hours of advanced range activities were also included in the program.

The curriculum was reviewed by 16 practicing professionals in the field of driver and traffic safety education. Each was given a complete set of curriculum materials and asked to make comments, corrections, and suggestions regarding the curriculum. In addition, a reading specialist was asked to correct the curriculum materials for sentence structure and readability. The operator's manual (phase 1) had a 12th grade reading level.

Instructor Training

Central Missouri State University personnel trained six St. Louis Police Academy officers at their Highway Safety Instructional Park. A 24-h classroom and range study program was given to these instructors who, in turn, would be instructing trainees. The instructors had an opportunity to familiarize themselves with the curriculum materials, and worked with some Air Force recruits to master teaching techniques for the program.

Figure 1. Driver evaluation form number 1.

EXERCISE 1 - Serpentine - Low Speed			Operator ID.______________	
Attempts: 1 2 3 4 5 6 7 8 9 10			Speed: 20 28	
SKILLS	Value	FIRST TRIAL	MIDDLE TRIAL	FINAL TRIAL
9-3 Hand Position	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Close Cone Approach	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Maintains Speed	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Good Steering Inputs	10	0 2 4 6 8 10	0 2 4 6 8 10	0 2 4 6 8 10
Clear Right Side Vehicle	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Clear Left Side Vehicle	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Clears All Cones	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Good Visual Procedure	10	0 2 4 6 8 10	0 2 4 6 8 10	0 2 4 6 8 10
Good Range Safety Procedures	R*	. . . . . .	. . . . . .	. . . . . .
Completes Pre-Driving Check	R*	a b c d e f g	a b c d e f g	a b c d e f g
Instructor's Comments:				
TOTAL POINTS	50			

* Required

Figure 2. Driver evaluation form number 2.

EXERCISE 2 - Skid Control - Low Speed			Operator ID.______________	
Attemps: 1 2 3 4 5 6 7 8 9 10			Speed: 25 30	
SKILLS	Value	FIRST TRIAL	MIDDLE TRIAL	FINAL TRIAL
Controls Vehicle	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Maintains Course	5	0. 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Good Response to Skid	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Good Steering Inputs	10	0 2 4 6 8 10	0 2 4 6 8 10	0 2 4 6 8 10
Good Countersteer	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Good Hand Technique	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Clears All Cones	5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
Good Visual Procedure	10	0 2 4 6 8 10	0 2 4 6 8 10	0 2 4 6 8 10
Good Range Safety Procedure	R*	. . . . . .	. . . . . .	. . . . . .
Completes Pre-Driving Check	R*	a b c d e f g	a b c d e f g	a b c d e f g
Instructor's Comments:				
TOTAL POINTS	50			

* Required

Study Group

The study group consisted of 24 persons chosen from a group of 38 recruits in training during March and April 1976 at the Greater St. Louis Police Academy. A choice of groups was available according to the academy-scheduled time of training. This group of 24 was chosen because they appeared to represent a more heterogeneous cross section from the greater metropolitan area of St. Louis. The recruits were divided into two groups of 12 by the academy driver training coordinator. One group was to remain untrained. Both groups were given the same pretests and posttests on knowledge and skill performance.

Not all of the skill exercises in the original curriculum could be tested due to the physical character of the driving facility available. Off-road recovery and tire failure exercises were deleted in this study.

Evaluation Team

An evaluation team, consisting of three professional driver educators on the Missouri Safety Center staff, conducted evaluations of program operation and administered both pretests and posttests to cadets in the Academy Advanced Driving Project.

The evaluation team received training in the use of the skill rating form developed for the curriculum prior to reaching St. Louis. The evaluation team had an opportunity to familiarize themselves with the St. Louis range and to practice the rating procedure.

Evaluation team members assumed the "primary rater" position in the right front seat. Academy instructors assisted and rated from the "secondary rater" position in the right rear seat. No conversation was permitted between raters during testing times. This process allowed a check of objectivity and reliability of the test instruments. Samples of the evaluation instruments (Figures 1 and 2) are included here.

ANALYSIS OF DATA

Data from the study received statistical treatment via a t-test to determine if a significant difference existed at the 0.05 level of significance. Analysis of data gathering from pretests and posttests showed the following:

1. $H_0$1 stated, "There is no difference in performance on pretests of knowledge, low speed skill, and increased speed skill between the advanced driver education group and the control group, which does not receive advanced driver education." This hypothesis was rejected because in each pretest (knowledge, low speed, and increased speed) the data showed a significant difference between the groups. The data showed that a difference did exist between the trained group and the untrained group before the study began.
2. $H_0$2 stated, "There is no difference in performance on posttests of knowledge, low speed skill, and increased speed skill between the advanced driver education group and the control group, which does not receive advanced driver education." This hypothesis was rejected because the data showed that a significant difference existed in performance between the trained group and the untrained group on posttest scores of knowledge, low speed skill, and increased speed skill. The trained group had received the curriculum materials before the posttest, while the untrained group had not.
3. $H_0$3 stated, "There is no difference in learning between the group receiving advanced driver education and the control group, which did not receive advanced

driver education, as measured by differences in pretest and posttest knowledge, low speed skill, and increased speed skill scores achieved by persons in either of the groups." This hypothesis was rejected because there was a significant difference in learning between the trained group and the untrained group as measured by the differences in pretest and posttest scores on knowledge and increased speed skill tests. The trained group significantly improved their pretest and posttest scores on low speed skill. The hypothesized difference between the groups was shown by the difference in the scores on low speed skill tests. The trained group significantly improved their scores on pretests and posttests on increased speed skill. The untrained group showed no significant improvement in these scores.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are warranted by the data gathered in this study:

1. The subjects were not homogeneous before the study began. Selection of recruits for this study was not done randomly. Therefore, the results can be applied only to study groups.
2. The untrained group was apparently able to significantly increase their test scores on low speed skill by skills learned in the performance of the pretest.
3. The untrained group was not able in most cases to significantly improve their test scores in knowledge and skill. This was most apparent in posttest increased speed skill, where the greatest difference in mean scores appeared.
4. The trained group was able to improve their scores as measured by the differences between pretest and posttests of knowledge and skill. This is most apparent on the posttest of increased speed skill. The degree of difficulty was highest for this skill, and the trained group showed significant improvement for this skill.
5. The curriculum was considered successful because the trained group significantly increased their posttest mean scores, while the untrained group did not (with the exception of the low speed skill testing).
6. The development and evaluation of this curriculum are considered successfully accomplished.

Because of the experience gained by the development and evaluation of this curriculum for advanced driver education for emergency vehicle operators, the following recommendations are made:

1. Urban police, fire, and rescue vehicle operators throughout the state of Missouri should be given the opportunity to be trained in this curriculum.
2. Rural police, fire, and rescue vehicle operators throughout the state of Missouri should be given the opportunity to be trained in this curriculum.
3. The Missouri State Highway Patrol should give each of its patrol officers the opportunity to be trained in this curriculum as part of their basic training program.
4. A task analysis for police officers on patrol should be developed in order to identify the interrelationships of driving and patrol duties (e.g., surveillance and radio operation).
5. More emphasis should be placed on the perceptual skills part of the classroom information as it relates to driving in the skill exercises.
6. As this curriculum is used, it should be continuously evaluated and judiciously abridged when needed.

The following recommendations for future research are made:

1. In order to ensure homogeneity of the subjects in each group, there should be random selection of subjects for both the study and control groups.
2. Further research is needed to establish validity and reliability for the study's evaluation instruments. Special attention should be given to the low speed skill test so that an instrument capable of discrimination can be developed despite the elementary level of skills involved.
3. A follow-up study comparing accident records of the two groups should be conducted to determine if the curriculum had any long-range effect on accident rates of the study group members.
4. Further statistical analysis of the study group through accident records should be conducted and compared against the results of this present study.
5. The need for an adequate driving range facility should be recognized so that a complete program can be conducted (including all exercises provided for in the curriculum).
6. All future instructors of this curriculum should be trained in the same manner as in this study, in order to ensure a consistently high program level.
7. The need for adequate funding for classroom and range facilities should be recognized in advance of implementation of the curriculum program so that a complete and comprehensive application of the curriculum may be made.

DISCUSSION

Although the accepted method of randomization was not used for the selection of the study group, it was my observation that the study groups were not visibly different. Also, the evaluation procedure in skill exercises was considered to be a necessarily fatiguing experience for the raters. Consideration should be given to providing a longer time period in which to complete these skill exercise evaluations. Some raters, including secondary raters, became ill due to the rough maneuvers required.

One of the strong features of this curriculum which was not measured by the evaluation was the enthusiasm of the subjects in the trained group for both the classroom and the range programs. The prospect of the challenge in actual behind-the-wheel experience at skill exercises seemed to gain the interest of the most skeptical participant.

Unsolicited responses from the subjects who had completed the curriculum indicated numerous opportunities for practical application of the curriculum information. In these cases, the subjects expressed the opinion that their training had resulted in improved ability in accident avoidance.

The reason for the untrained group's significant improvement on low speed skill posttest scores is difficult to identify. One should consider that the basic level of skill required and the speed used is low enough that the testing procedure alone could cause enough increase in learning to allow a significant improvement in posttest scores. It should be noted that when a higher order of skill and speed was needed, as in the increased speed skill exercises, the trained group showed a large and significant improvement, while the untrained group showed only slight improvement.

Two other projects have been conducted by the Missouri Safety Center and the Safety Department. One project was to conduct workshops for emergency vehicle operators throughout the state of Missouri. A second project was conducted by the Safety Department at Central Missouri State University and involved the use of the same curriculum materials as described in this paper, but was designed for operators of U.S. Air Force military vehicles at Whiteman Air Force Base, Missouri. This project sought to teach young military driver's license holders 24 years of age and under.

The purpose of these projects was to evaluate the long-range benefits that may be derived from a curriculum in advanced driver education specially designed for operators of emergency vehicles throughout the state of Missouri.

Instructor Training

Central Missouri State University trained instructors conducted the workshops throughout the state of Missouri. Also, the university trained six Air Force persons at its Highway Safety Instructional Park. Instructors who would, in turn, be instructing trainees participated in a 24-h classroom and range study program.

Missouri Statewide Project

To date, the statewide project has conducted 23 instructional workshops in Rolla, Poplar Bluff, Kirksville, Clinton, St. Louis (for fire personnel only), Kirkwood, Neosho, Liberty, and Cape Girardeau. A total of 443 drivers of police, fire, and ambulance type vehicles participated.

At the beginning of each workshop, a film is used to help demonstrate the need for the program. An attempt is made to match the film to the majority of participants. Films used included "Ambulance Run" (for emergency medical groups), "Police Pursuit" (for police personnel), "Defensive Driving III" (for police personnel), "Fire Truck" (for fire personnel), and "GM Emergency Driving" (for general purposes).

USAF - Whiteman AFB Project

This project has been in operation approximately 6 months. To date, 325 drivers (24 years of age and under) have been trained. The project is designed to provide training for all drivers of military vehicles on an annual basis.

Driver and accident records are kept and will be reviewed every 6 months throughout the project. Since the program is just beginning, no follow-up data are available. However, to date no person trained has had any kind of accident. Several trained persons have sought out instructors to relate experiences where their training has prevented an accident in their privately owned vehicles. Further, one trained driver stated that his training had prevented an accident while he was operating an Air Force vehicle.

Conclusions

Although no formal statistical follow-up data are available yet from either of these studies, the experience of those trained and their enthusiasm for the program have been significant enough to have funding continued for another year. Also, the Air Force wing and base commanders have given the project approval to continue as planned.

Follow-up data may be obtained, when available, from the Missouri Safety Center, Central Missouri State University, Warrensburg, MO 64093; or Dr. Robert A. Ulrich, head, Safety Department, Central Missouri State University, Warrensburg, MO 64093.

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