

# Highway Safety: Roadway Improvements, Accident Rates, and Bicycle Programs

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# Highway Safety: An Agenda for Action

HARRY E. STRATE

Among transportation modes, approaches to safety improvement are significantly different because vehicle and facility design and the driver or operator control functions are unique to each mode. The highway-automobile mode represents the lowest level of operational and design control of any mode, and results in lower levels of driver or operator performance. This factor and the growing degree of legal liability make an organized systematic approach to enhancing highway safety imperative. These dual requirements underline the need for an empirically based highway safety program that has the capability of gauging system operation through monitoring of actual accident experience and analysis of physical evidence. A comprehensive highway transportation safety program must achieve maximum use from available funds and respond to certain minimum standards of safe design and operation. An effective safety-improvement program at the state or metropolitan level involves processes of data collection, data analysis, engineering studies, formulation of project priorities, implementation, and postimplementation evaluation. Street surveillance and control-device management involve organized review, monitoring, and follow-up of corrective measures. The emphasis in both programs is to create (a) a single point of responsibility, (b) a permanent documented record, and (c) special recognition of conditions of citizen complaints or review findings. Each jurisdiction that maintains authority over highway operations must take aggressive positive action to coordinate and implement safety-improvement programs. Although no program can be implemented instantaneously, a definitive agenda must be established that will result in establishment of procedures as quickly as possible.

The comprehensive, systematic solution of safety problems is long overdue in each of the nation's transportation modes. However, the safety crisis must compete with many other national and international priorities, such as energy and air pollution. Although transportation safety possesses significantly more drama and political volatility following a catastrophic accident, persistent pressure on citizens' personal health and pocketbook is lacking. In other words, the perception is that safety problems go away. This manifestation of the problem hampers the ability of federal, state, and local governments to mount a continuing offensive designed to improve transportation safety.

## SAFETY PERFORMANCE

Transportation modes show markedly different safety-performance records. As summarized in Figure 1 [from Safety in Urban Mass Transportation (1)], scheduled air service tends to have the highest fatality rate per number of occupants but is placed in the top rank when vehicle miles (air miles) are considered. Significantly, motorcycle safety is second only to general air by these measures of safety performance.

Among transportation modes, safety-improvement approaches are significantly different because vehicle and facility design and the driver or operator control functions are unique. The highway-automobile mode represents the lowest level of operational and design control of any mode. Three areas of wide variability are evident:

1. Vehicle: size, weight, and operating characteristics;
2. Facility: design and operational standards; and
3. Driver: training, capability, and temperament.

In short, the less conformity and uniformity in an operating system, the greater the chance for operational failure in the form of accidents and injuries. This unique characteristic underlines the need for an empirically based highway safety program that has the capability to gauge system operation

through monitoring of actual experience and analysis of physical evidence.

## DEVELOPMENTS IN HIGHWAY SAFETY

In the early 1950s, the concept of developing a systematic approach to highway safety began to appear in technical papers and government regulations. In the late 1960s and early 1970s, the comprehensiveness of highway safety was emphasized through legislation and research. During the same time, the need to organize and systematize a program approach was emphasized through the private and public sectors.

Even with this acceptance, the systematic-process approach to highway safety has been the most difficult to implement and lags in many areas. Contributing to this difficulty has been the phenomenon of highway safety in its entirety. The emotion and volatility connected with motor vehicle accidents and fatalities can divert attention from many pragmatic program concerns. However, a greater problem has been the relative scarcity of funds for highway safety systems development. The process approach is founded on data collection and much study. The analysis, development, and implementation related to effective action to improve highway safety can be costly and labor-intensive.

Many forces are at work that continually shape and direct the form and substance of the highway safety program. Two of the most powerful are federal regulations and legal precedent. The following sections explore the comprehensive, systematic approach to highway safety as dictated by the new Federal Highway Administration (FHWA) regulation in the Federal-Aid Highway Program Manual (2) and program direction dictated by court opinion. A comprehensive highway safety program in today's environment must address both regulations and court-based demands.

## Federal Regulations

The overall program framework is embodied in the FHWA Federal-Aid Highway Program Manual (2). The processes of safety-improvement planning, implementation, and evaluation are the basic concepts of the directive. The policy statement contained in the directive asserts (2):

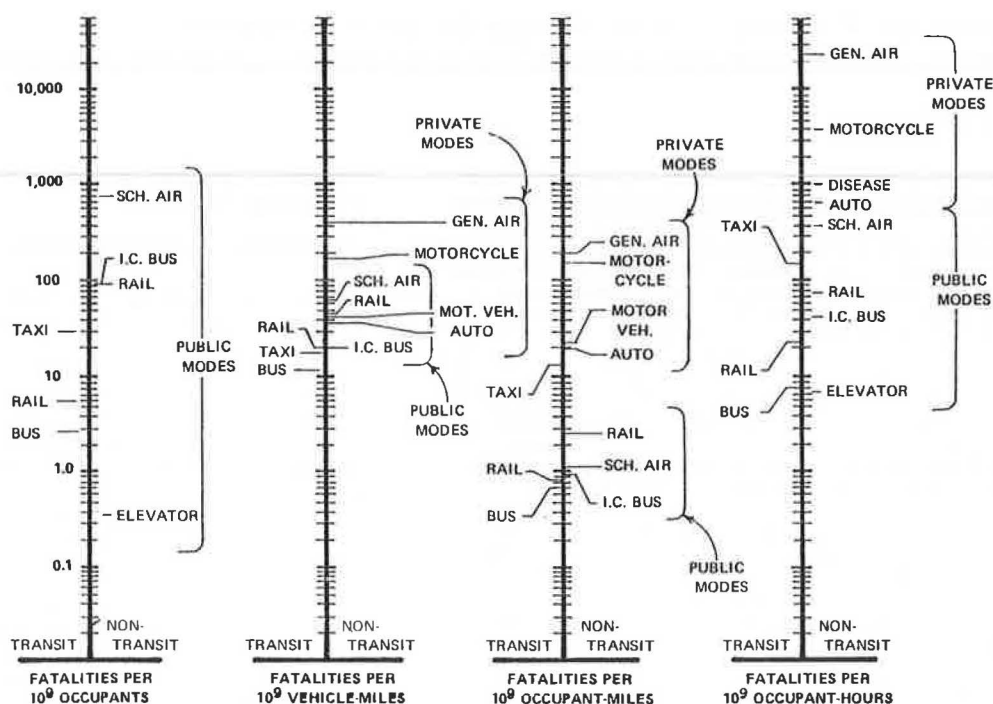
Each State shall develop and implement, on a continuing basis, a highway safety improvement program which has the overall objective of reducing the number and severity of accidents and decreasing the potential for accidents on all highways.

## Legal Precedent

If we place highway safety concerns in the context of current legal developments, as summarized by David C. Oliver, FHWA legal counsel (3),

Litigation over highway accidents has become a way of life.... It is clear to me that either highway officials provide a safe thoroughfare or highway construction will come to a halt--bankrupt by the increasing awards given to the victims of a system which is unsafe.

Figure 1. Comparative safety performance of transit and nontransit modes.



Together the forces of regulation and legal precedent dictate that a comprehensive, systematic highway safety program must

1. Obtain maximum use from available funds and
2. Respond to certain minimum standards of safe design and operation regardless of cost (and perhaps funding availability).

#### HIGHWAY SAFETY EXPENDITURES

Safety improvements total more than 20 percent of all federal-aid highway construction funds spent annually. In fiscal year 1979, there was approximately \$8.5 billion obligated for all federal-aid programs administered by FHWA. Of this, rough indications are that \$2.0 billion, or nearly 24 percent, was spent for safety improvements.

In order to relate to these figures, two important points must be made. First, total state and local expenditures are about four times federal expenditures for highways. In other words, an \$8.5 billion federal expenditure relates to a \$34 billion state and local expenditure. The latter figure includes maintenance, police, construction, and other highway-related activities. The impact of this ratio is that nationwide expenditures for highway safety are realistically in the \$8-billion to \$9-billion range when all safety expenditures are considered.

The second point is that the actual safety benefits realized from expenditures of these dollars vary dramatically. In fact, an imperceptible safety improvement is achieved in far too many cases. The purpose of an effective process for safety improvement is to elevate the cost-effectiveness of the \$8 billion expended annually through better program and project planning, development, and evaluation.

#### EVALUATION RESULTS

The payoff from implementing a comprehensive safety-improvement program is achieved through initiation of effective and economical highway

improvements. More-reliable definition of safety problems and more cost-effectiveness analyses during formulation of project priorities will lead to enhanced overall program performance.

#### Program Cost-Effectiveness

Safety programs that stress the need for systematic analysis generally reap a higher rate of return than those that do not. Table 1 [from Strate (4)] summarizes the accident evaluations achieved through federally funded safety programs. All programs achieved significant reductions.

Considering overall cost per unit of effect, recent evaluation results demonstrate that permanent improvements such as elimination of obstacles or upgrading of Interstates reduce fatal accidents with the most cost-effectiveness. As shown in Figure 2 [from Strate (5)], the high-hazard location program based on accident-data analysis ranks best for total accident reduction. These two results underline the need for a two-stage safety approach of cost-effectiveness analysis and minimum design standards. Quantifying the dollar benefits of accident reductions, Table 2 [from Strate (4)] shows the benefit/cost ranking of these programs (benefits are calculated by using annual U.S. Department of Transportation societal costs). Although all programs were effective, the categorical safety construction program made possible by the 1973 Highway Safety Act, as amended, resulted in the highest composite

Table 1. Accident reduction by safety construction programs.

Program	Reduction by Accident Severity (%)			
	Fatal	Injury	PDO <sup>a</sup>	Total
Categorical	25	8	11	10
Interstate safety	29	7	2	4
Other federal-aid	20	12	10	11
All federal-aid	26	8	8	8

<sup>a</sup>PDO = property damage only.



Figure 2. Cost-effectiveness of highway safety programs.

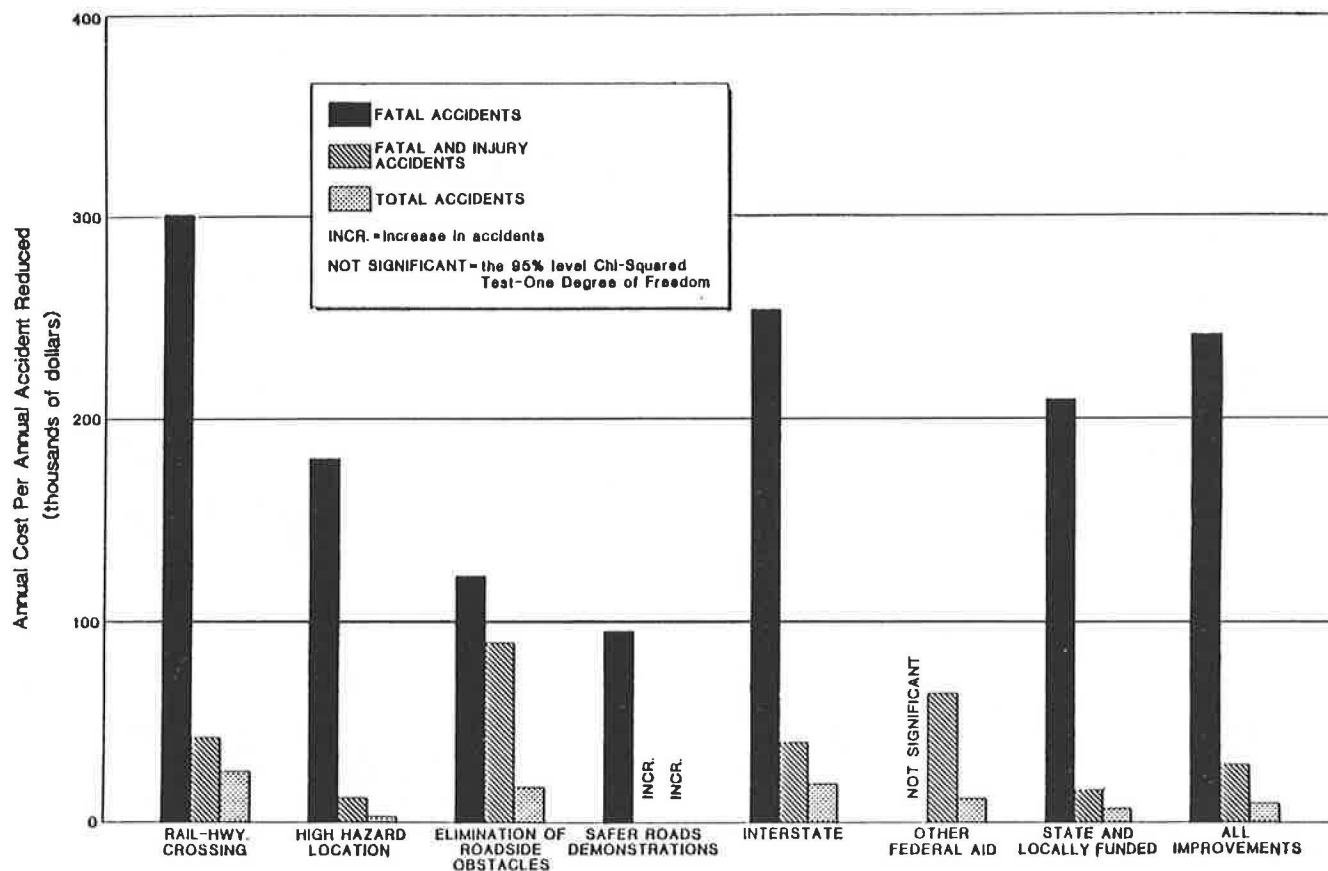


Table 2. Benefit/cost ranking of federally funded safety improvements.

Safety Program or Funding Source	Rank	B/C <sup>a</sup>
Safer-roads demonstration	1	4.5
High-hazard location	2	3.0
Total categorical safety <sup>b</sup>	—	2.6
Interstate safety	3	1.9
Roadside obstacle	4	1.6
All federally funded	—	1.6
Other federal-aid <sup>c</sup>	5	0.4
Rail-highway crossing	NS	NS

Note: NS = not statistically significant.

<sup>a</sup>Ratio of annual safety benefits to annual construction costs.

<sup>b</sup>Includes safer-roads demonstration, high-hazard location, roadside obstacle, and rail-highway crossing.

<sup>c</sup>Includes primary, secondary, urban, etc., federal-aid funds.

benefit/cost ratio. The low payoff of other federal-aid improvements is partly explained by the failure to follow strict data-analysis requirements. The categorical safety programs carry the strictest requirements for systematic safety analysis prior to implementation.

#### Cost-Effectiveness of Improvements

Individual safety improvements have demonstrated economical effectiveness in solving safety problems. Table 3 [from Strate (4)] ranks the improvements by benefit/cost ratios calculated as in Table 2. The overall effectiveness is only tempered by the relatively high cost of some improvements. Traffic signs and roadside, minor-structural, and sight-distance improvements constitute the calculated benefit/cost ratio. Careful analysis and

formulation of priorities are needed to deliver effective, low-cost improvements to areas of highest safety need.

#### STATE PROGRAM IMPLEMENTATION

Since the early 1960s, most states have been striving to implement a comprehensive safety-improvement program. Several have developed remarkable systems capable of fulfilling most day-to-day operating needs. Progress nationwide has been less than desirable, however.

#### Deficiencies

Within the general theme of overall slow progress in implementation are five common deficiencies in state implementation efforts:

1. Data-system incompatibility: Data-system incompatibility can result from a number of causes. Generally, the two most common are failure to develop adequate roadway data files and accident data files and failure to effectively interface the two.

2. Inadequate data analysis: Data analysis is often restricted to identification of high-accident locations with no consideration of accident potential. This deficiency limits consideration of a full range of investment opportunities.

3. Failure to prioritize by safety payoff: Formulation of project priorities based on anticipated safety payoff is necessary to optimize budget investments. Relying solely on geographic distribution and a first-come, first-served basis, as is often the case, will probably not accomplish the best expenditure of scarce funds.

Table 3. Ranking of highway safety improvements by benefit/cost ratio.

Rank	Description	Code	Ratio <sup>a</sup>
1	Traffic signs	60	9.30
2	Other roadside improvements	69	5.92
3	Minor structural improvements	33	5.71
4	Intersection sight distance	13	5.33
5	Other intersection improvements	19	4.38
6	Road edge guardrail	62	3.80
7	Pavement grooving	25	3.78
8	Highway divided—new median	22	3.52
9	Safety provisions for roadside feature and appurtenance	90	3.21
10	Markings and delineators	64	2.90
11	Pavement widening and shoulder improvement	24	2.33
12	Intersection channelization	10	2.31
13	Pavement widening—no lanes added	20	2.28
14	Signs and guardrail	6C	2.13
15	Intersection traffic signals	11	2.12
—	All improvements	—	1.76
16	Railroad flashing lights replacing signs	—	1.74
17	Median barrier	63	1.72
18	Intersection channelization and traffic signals	12	1.66
19	Combination cross-section improvements	29	1.26
20	Lanes added—no median	21	1.15
21	Railroad automatic gates replacing signs	55	1.15
22	Pavement overlay (skid treatment)	26	1.12
23	Horizontal alignment	40	1.00
24	Other structural improvements	39	0.79
25	Replace bridge	31	0.27
26	Railroad grade separation	51	0.13
27	Shoulder, breakaway signs, guardrail, marking, lighting, and drainage structure	91	0.08
28	New bridge	32	Incr <sup>b</sup>
29	Shoulder widening or improvement	23	Incr
30	Vertical and horizontal alignment	42	Incr
31	Pavement widening and overlay	2A	Incr
32	Side slopes, widen bridge, guardrail, misc.	9C	Incr
33	Lighting	65	Incr
34	Guardrail, drainage structures, misc.	6F	Incr

<sup>a</sup>Ratio of annual safety benefits to annual construction cost.

<sup>b</sup>Incr = increase in accident costs.

4. Deficient project evaluations: Once implemented, projects should be evaluated to assure that their results match expectations. Project evaluations may be put off or delayed because of competing work tasks. A state's failure to pursue evaluation programs actively may cause safety programs to stagnate.

5. Exclusion of local highway needs: Local highway systems are not generally included in the various safety processes. Data collection and analysis processes do not address unique local road circumstances. Project priorities and postimplementation evaluations often do not include local safety-improvement projects. Significantly, this deficiency not only includes low-volume roads in low-density areas but may also include high-volume roads in heavily populated areas.

#### Tort Liability

Also since the 1960s, the number of tort claims and lawsuits has increased markedly. According to a recent report from the American Association of State Highway and Transportation Officials (AASHTO), claims pending against state governments total more than \$4 billion for design, maintenance, or operational flaws. The defense of sovereign immunity is now limited to less than one-third of the states. Because of the increasing cost of liability insurance, states are turning to self-insurance and comprehensive programs of risk management to demonstrate care for and attention to issues of motorist safety.

#### Management Concerns

The commitment to formalize and implement a compre-

hensive safety-program approach carries with it certain management concerns:

1. Who will assume the lead responsibility and what will be the roles and responsibilities of supporting departments, agencies, and personnel?
2. Will the program reduce or increase liability?
3. What assurance is there that the team can formulate and implement a cohesive, effective safety program?
4. Will the cost of implementation be in line with benefits to be received and will the new system be any better than the system currently in use?
5. How much continuing burden will this approach place on operating and overhead costs?

No glib answers can be offered for these concerns because answers will vary by state. Of course, the most overriding concern is whether the ability or expertise possessed by state or local agency personnel is sufficient to guide and administer the programs to fruition. The presence or absence of expertise will affect the capability to implement an effective program. Expanding the staff, training, or obtaining consultant services are all viable options to be considered by the program manager.

#### SAFETY-IMPROVEMENT PROCESSES

##### Description of Processes

In order to implement this program approach, process concepts must be translated into concrete procedures, accepted engineering techniques, or other understandable terms. In all likelihood, questions that pertain to several areas will be left to state and local agencies:

1. What should the emphasis be on local road systems?
2. What data elements should be routinely collected and updated?
3. What analysis techniques give the desired results?
4. What level of personnel and funding should be devoted to the program?

Before these issues can be addressed, the processes must be understood, since they address the activities of safety-improvement development.

The highway safety program should be composed of two equal parts: (a) safety improvements based on accident analysis and (b) street surveillance and control-device management.

The overall safety-improvement process is defined as a series of empirically based activities undertaken to effectively and economically improve the safety afforded the traveling public who use the nation's highways. These improvements are implemented through activities that systematically identify and analyze problems, develop alternative solutions, apply the solution, and then judge the success in solving the problem. The processes that make up the highway safety program are data collection, data analysis, engineering studies, priority formulation, implementation, and evaluation.

Street surveillance and control-device management are keyed to making quick remedial treatments for unsafe conditions. The routine risk-management program is a means to limit liability through conduct of routine comprehensive activities such as inventorying traffic-control devices and developing design reviews. Although most of these activities are currently being conducted, they are rarely organized or coordinated to gain maximum legal or safety benefits.



### Data Collection

The data collection process is defined as those activities involved with the collection, storage, and retrieval of data to be used to support safety-improvement implementation. Data requirements and system organization and operation are determined by the analyses, studies, etc. that will be performed in subsequent processes.

#### Data Elements

Data to be collected and stored are dictated by needs from analysis, engineering studies, priority formulation, and evaluation processes. The data collection process should not strive to collect all data, only those that are routinely or frequently used and economically justified. Data elements should include the following:

1. Accident data (by location of occurrence): location, time and date, severity, weather and light conditions, pavement conditions, intended path and type of accident, and types of vehicles involved; and
2. Roadway data by location: traffic volumes and mix, geometric layout (horizontal, vertical, angle of intersection, etc.), functional classification, number of lanes and width, pavement type, control devices, curb and shoulder type and width, special operational practices, railroad grade crossings (including description), bridges (including description), land use, and speed limit.

Because the lists are practically limitless, especially regarding roadway data elements, the task is to define a set of data that are actually used as well as desirable. Starting small, designing an expandable system, and establishing procedures for collection of additional data probably constitutes the most realistic and economical approach.

#### Basic Systems

Three basic systems, shown in Figure 3 [from Strate (6)], constitute the core of the data collection process--the location reference system, the accident data system, and the roadway data system. These systems may be organized within an overall statewide traffic records system and coordinated with driver or vehicle records systems, but the key relationship for highway-improvement purposes is among the three systems.

The location reference system is necessary to report and record traffic accidents, to collect highway and traffic data, and to interface the two records. Although locations are needed on state and local highways alike, the types of referencing systems and their accuracy can vary dramatically without adverse impact on overall system operations.

The accident data system extends from the reporting of accidents through the storage and retrieval of data. Key considerations in the accident reporting and recording system are state and local agency participation in the statewide system, use of a uniform accident report form, checks for report and coding accuracy, and processing, storing, and retrieval of information and reports.

The roadway data system involves collection and storage of highway and traffic data through inventories, photologging, traffic counting, maintenance reports, sufficiency ratings, etc. Considerations in storing and retrieving the data may include method and location of storage and filing, interface with other systems, and accessibility and availability to users.

### Data Analysis

The data analysis process involves the examination of collected data to identify highway locations, features, or practices that have the highest accident potential. The analysis is performed to discover problems susceptible to treatment and correction by safety improvements.

#### Analysis Techniques

Data available through the data systems as well as other inputs shown in Figure 4 [from Strate (6)] are used in the data analysis. Any of the analyses shown in the process, individually or in combination, could be acceptable for any given highway segment. Considerations in selecting the analysis technique would include traffic volumes, expected accident experience, and availability of funds for implementation of improvements. Additional considerations in implementing the process include the following:

1. Timing, form, and reliability of data or comparisons routinely supplied to the analysis staff;
2. Timing, quality, and expected use of routine analysis made by staff;
3. Quantity, type, and turnaround time afforded special requests; and
4. Number and expertise of the analysis staff.

#### Nonaccident Indicators

Of special significance are attempts to develop indicators of accident potential other than acci-

Figure 3. Systems that are core of data collection process.

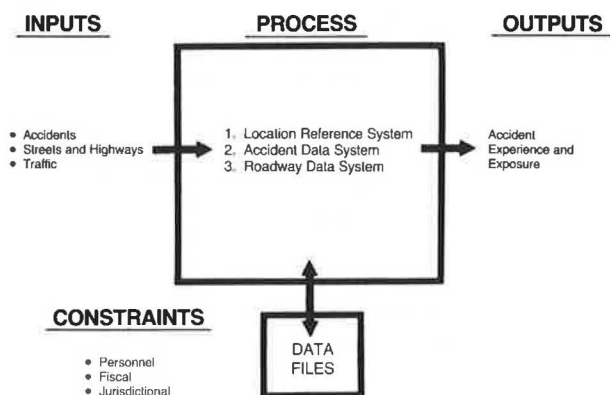
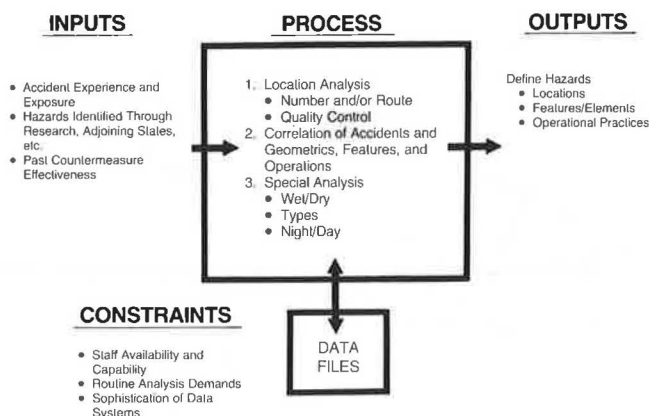


Figure 4. Data analysis process.



dents. The hope is to identify and correct hazards before pain, suffering, and economic loss are inflicted through accident experience. Some familiar techniques, such as skid testing and hazard indices, and some developing techniques, such as conflicts analysis and erratic maneuvers, are most reliably and economically applied during the engineering study phases. At present, the most accurate non-accident hazard indicators are correlation of geometrics and accidents, consideration of locations that have similar characteristics, and some types of sufficiency ratings.

### Outputs

Three general types of listings or outputs could be expected from the process, as shown in Figure 4. These may be organized by road system, responsible agency, or some other classification to facilitate study of the most serious problems first. Process outputs include the following hazards:

1. Locations expressed in terms of intersections, spots, or segments;
2. Roadway features, design elements, or roadside hardware; and
3. Traffic operational practices that include traffic control through construction zones, reversible lanes, contraflow lanes, diagonal parking, etc.

### Engineering Studies

The engineering study process develops safety improvements to solve the problems identified during the data analysis process. This is accomplished through additional detailed data analysis, supple-

mentary studies, and on-site visits.

Until this point, the purpose of the safety process has been to learn more about what is taking place within the transportation system. The engineering study process in Figure 5 [from Strate (6)] begins the activities necessary to alter current highway performance through safety-improvement actions. Based on the hazards identified, this process strives to prescribe what action or actions can effectively remedy the problems.

### Highway Improvements

Engineering studies are intended to develop three distinctly different types of highway improvements, as shown in Figure 6 [from Strate (6)]. The three outputs of the analysis function and measures of past improvement effectiveness are the bases for those studies. The first type, hazardous locations, is the basis for improving roadway safety at singular locations (spots or intersections). For each location, accident data reports, current traffic data, and highway data are necessary. The accident and roadway environment data systems should be designed to provide this information. An engineering study to develop alternative corrective measures is performed that involves field visits and special analysis. The study results in quantification of the hazard or hazards, recommended improvements, costs for improvements, measures of potential benefits, and a plan for evaluation after improvement implementation.

The second type, hazardous roadway features, design elements, etc., is the basis for improving systemwide roadway safety. The thrust is to address accident potential more squarely by looking at a number of locations or extended highway segments. Design reviews and performance reviews must be keyed to the on-going analysis of design and roadway hazards. For each potential hazard, accident data and reports, traffic data, and necessary highway data are obtained from the accident and roadway data systems. In some cases, special inventories may be necessary to further quantify problem areas.

The third type, hazardous traffic operational practices, is similar in intent to the study types just discussed. The purpose is to tie operational reviews to accident data functions, especially in the case of unique, experimental, or complex traffic operation practices. This engineering study will strive to correlate accidents and operational practices and to seek locations that have similar accident-causing characteristics. Data requirements and study outputs are similar to those identified above.

For the second and third types, two points are important. First, studies and reviews may be performed by jurisdiction, state highway district, geographic area, or major route. Second, these improvements may be warranted by some overall accident experience, by hazard identification, or by being the type of improvement that lends itself to systemwide project implementation.

### Study Techniques

The performance of engineering studies may involve a number of study techniques and methods. Techniques that can be used during this part of the process include the following: collision/condition diagrams, sufficiency ratings, operational reviews, conflicts analysis, erratic maneuvers, lane-replacement studies, speed studies, turning movements, skid testing, and hazard indicators.

### Project Priority Formulation

Formulation of priorities is achieved through sys-

Figure 5. Engineering study process.

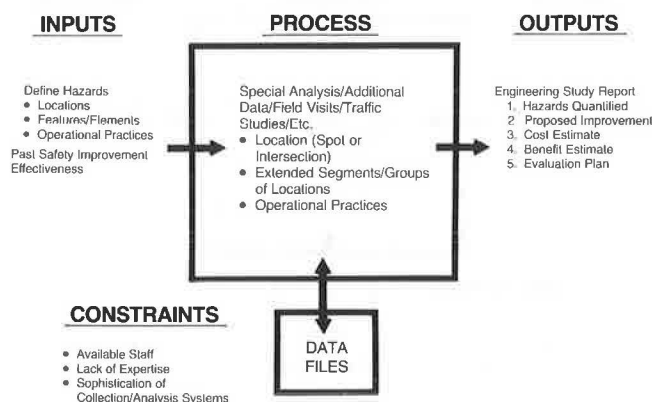
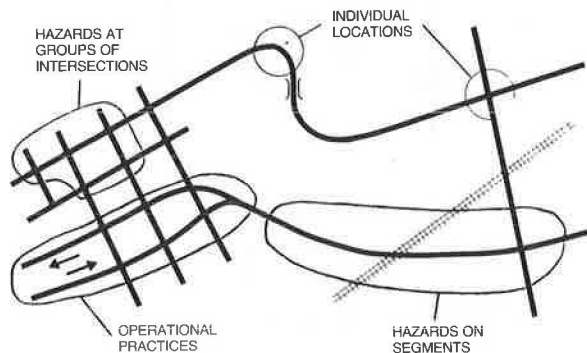


Figure 6. Types of engineering studies.



tematic comparison of alternative safety improvements. Constraints of funding and available personnel require that improvements be implemented that best contribute to the accomplishment of overall program objectives.

Projects are scheduled for implementation based on results of the engineering studies. Priority safety improvements are identified and then matched against other highway needs through a statewide programming of projects. The formulation of priorities and development of implementation schedules shown in Figure 7 [from Strate (6)] must consider a wide range of technical and management factors.

The overall objectives of the safety program require consideration of the magnitude of the safety problem and potential improvement effectiveness. The five considerations are shown in Figure 5. Although relationships of costs and benefits are important, relationships affect improvements. These are shown under Constraints in Figure 5 and tend to restrict the outputs of the process.

Collected data and engineering studies are used to develop aids to decision making. Economic analyses offer the most assistance in establishing improvement priorities. Some of these include benefit/cost ratio, incremental benefit/cost ratio, rate of return, cost-effectiveness, net benefit, and dynamic and integer programming.

### Implementation

The implementation process is defined as those activities that lead directly to removal, installation, and construction of approved improvements.

The process that leads to implementation of improvements may be the most complex in many ways. In addition, the many technical details, contracting procedures, and administrative regulations can be rigorous and time-consuming. Based on an approved program and schedule of projects, the activities involved in implementation of safety improvements are shown in Figure 8 [from Strate (6)].

Less complex and costly projects can often be implemented with less-sophisticated designs or by in-house personnel at a savings over contract efforts. Further, some improvements fall under the auspices of maintenance and operations personnel. Time and overhead can be saved by a careful management study of the implementation process.

### Evaluation

The evaluation process involves the examination of past improvement and program decisions, the judgment of the degree of success in accomplishing objec-

tives, and the recommendation of methods or information to improve the quality of future decisions. The results of the first five processes are evaluated in order to implement an adaptable and continually improving state safety program.

### Evaluation Types

The parameters that define safety evaluations are shown in Figure 9 [from Strate (6)]. Evaluations may be classified as three types--effectiveness, economic, and administrative. Effectiveness (or impact) evaluation measures the achievement of ultimate objectives such as the reduction in the rate of accident occurrence. Economic evaluations generally quantify effectiveness in terms of dollar expenditure to achieve given results. Administrative evaluations measure the attainment of intermediate or management objectives such as unit cost, timeliness, staff productivity, etc.

### Methodologies

In addition to types of evaluation, evaluation criteria may be categorized as one of three methodologies--scientific, clinical, or personal. A large degree of statistical reliability and data collection and analysis are sought in the scientific approach. Personal evaluations are subjective and rely on the past experience of the evaluator for the evaluation criteria. A broad middle ground exists in which scientific and personal evaluations inter-

Figure 7. Improvement priorities.

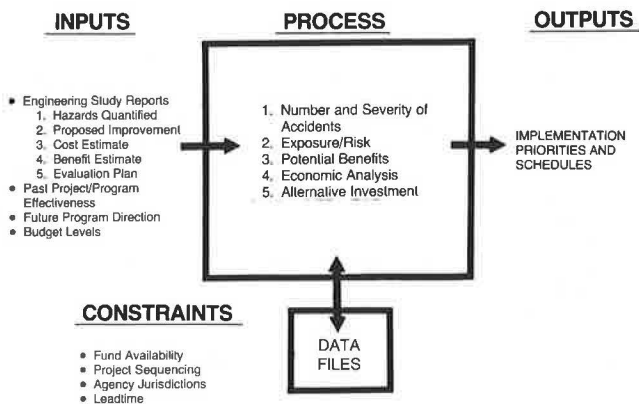


Figure 8. Implementation-related activities.

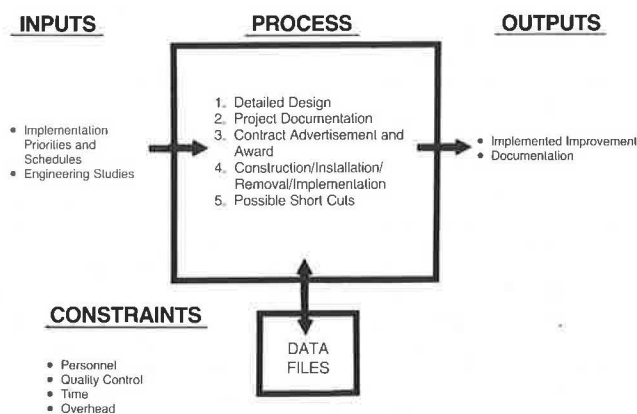
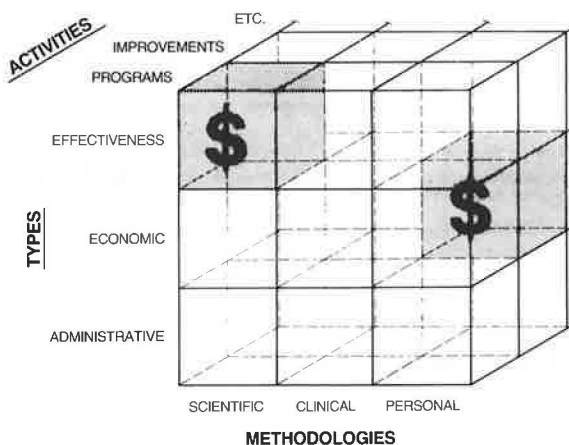


Figure 9. Types of highway safety evaluation.





mingle to produce many degrees of precision; this type is referred to as clinical.

Evaluations may be made of many types of past decisions. Individual improvements may be evaluated, as may entire funding programs. The operation of the data collection system and the methodology used to formulate priorities can each be evaluated as to the degree of accomplishment of defined objectives.

These three factors interrelate to affect the cost, complexity, and staff requirements to perform the evaluations. Broad-based scientific evaluations of program effectiveness would be costly, whereas personnel judgments of an office's operational efficiency would not. To be worthwhile, an evaluation process must be keyed to the entire safety program and the need for information by the decision maker.

Figure 10 [from Strate (6)] summarizes the process inputs, outputs, and constraints. Because safety evaluations are performed after the fact, they are often viewed as optional activities that have low funding and staffing priority. However, evaluations provide valuable input into upgrading the quality and quantity of information concerning the performance of the highway system and the effectiveness of the safety-improvement program.

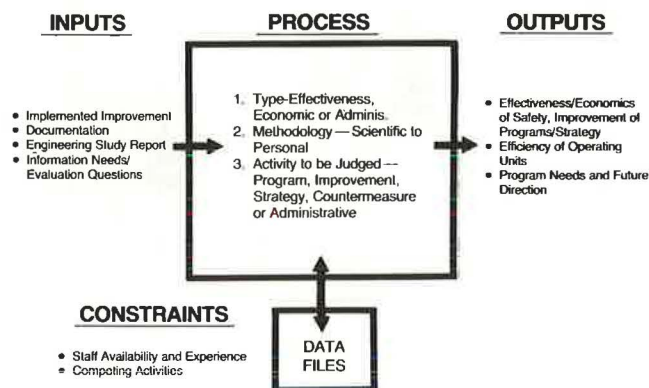
#### STREET SURVEILLANCE AND CONTROL-DEVICE MANAGEMENT

As contrasted with accident data collection and analysis, activities connected with street surveillance and control device management take advantage of visual, routine inspection of the road and street system. Although some coordination might be achieved with the process for safety improvement, the emphasis is to be placed on firsthand knowledge and management of actual physical and operational conditions. These activities are composed of three distinct subactivities: street surveillance, control-device management, and corrective measures.

##### Street Surveillance

Street surveillance takes advantage of organized (e.g., design reviews) and voluntary (e.g., citizen complaints) activities to create a permanent record of physical developments. The following street-surveillance activities are annual: drive or walk inspection, photographic record, photographic update, skid testing, and design and operations reviews. The following are routine: employee monitoring (including traffic-control devices), citizen complaints (including those about traffic-control devices), commission meetings, maintenance records, and hot spots.

Figure 10. Evaluation summary.



For each of the activities given above, these factors should be considered, especially in response to tort-liability issues:

1. Creation of a permanent documented record of all surveillance activities, including time and date, names and positions of those participating, location and scope of activity, description and purpose of activity, findings and recommendations, and follow-up activities;
2. Creation of a single point of responsibility of each surveillance function; and
3. Special attention to conditions of citizen complaints.

##### Control-Device Management

Control-device management strives to organize and monitor the performance of replacement signs, pavement markings, delineators, and signals. These activities go beyond simple reference to the FHWA Manual on Uniform Traffic Control Devices and involve specific activities for materials and inventory control. The growing sophistication in techniques and materials requires a special emphasis in recording and maintaining accurate records. The following control-device-management activities are performed annually: traffic-control-device inventory and inventory update; the following are routine: enforcement of standards; inspection of construction, maintenance, and utility zones (including during the night, in wet weather, and under other adverse conditions); and hot spots.

Of special importance is the review of the performance of signs, signals, etc. under adverse conditions. Although special design and operations review is an important tool, all agency employees should receive instructions in monitoring and reporting defective devices.

##### Corrective Measures

Remedial activities in the form of maintenance, replacement, or improvement are an essential complement to surveillance and management activities. The following corrective measures are annual: sign replacement, minor road repairs (e.g., potholes), pavement overlays, and safety improvements. Routine corrective measures, which are essential, include the following: maintenance of signs and markings, minor road repairs, improvement of sight distance (impaired by trees, brush, etc.), and hot spots.

As in the first two groups of activities, maintenance of a permanent record to document type and time of remedial treatment is essential. The system should be designed to report back to the originator of the report or complaint as a positive aid to follow-up.

#### SUMMARY AND CONCLUSIONS

The need for an organized process approach to highway safety has grown in acceptance. As stated in the U.S. Department of Transportation's Evaluation of the Highway Safety Program (7):

Over the past two decades much has been learned about the effectiveness of safety planning and evaluation techniques... [and] the need for comprehensive, "do everything" action has given way to a widespread adoption of an organized system to define, implement, and evaluate cost-effective improvements.

Yet care must be taken not to carry this direction to its illogical extreme either by requiring cost-

effectiveness analysis for all maintenance-type improvements or by foolishly reducing expenditures or operational standards to create a false economy of current savings.

Federal regulations and case laws have been developed based on reviews, facts, and court cases that have evolved over the last four years. The comprehensive approach made up of the processes included in the planning, implementation, and evaluation functions can lead to implementation of the most effective and economical highway safety improvements. At the same time, surveillance and control-device management will assure that a high daily level of safety is afforded the traveling public.

Based on recent regulatory and legal developments, the course of action is clear. Each state and affected municipality must establish an agenda to accomplish organization of a comprehensive, systematic approach to highway transportation safety improvement. Although safety problems may appear to go away, they are in fact lingering transportation system weaknesses that appear at times of catastrophic accidents. To oversee implementation, each state and metropolitan area should develop a single point of responsibility and, with authority to require adherence to standards, insist on implementation of safety actions.

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# Interstate Safety Improvement Program

J.G. PIGMAN, K.R. AGENT, AND C.V. ZEGER

The purpose of this paper is to prepare prioritized rankings of recommended improvements that could be implemented for the Interstate Safety Improvement Program in Kentucky. Considerable detail is presented that documents analysis procedures used to determine sites, sections, and elements of the roadway in need of improvement. The average number of accidents per interchange, bridge, 1.6-km (1.0-mile) section, and 0.48-km (0.3-mile) spot was summarized for large urban, medium urban, and rural sections of the Interstate system. At specified levels of statistical significance, critical numbers of accidents and critical accident rates were calculated to assist in identifying high-accident locations. A limited field inventory of the Interstate system was conducted, and the results are incorporated into the program. Dynamic programming was used to develop prioritized rankings for safety improvements that totaled approximately \$27 500 000. A user's guide for preparation of a safety improvement program was developed.

To provide the highest degree of safety on the Interstate system, there is a need to continually upgrade and make improvements. The program described here is intended to identify specific locations, elements, or sections of highways that are hazardous or potentially hazardous and to implement correction of the identified hazards. Accident analyses are the basis for recommending improvements. Interstate funds are not available for safety improvements unless they are justified and selected under the provisions of the Federal Highway Administration (FHWA) Federal-Aid Program Manual (1).

A previous report dealt with development of procedures for preparation of an Interstate Safety Improvement Program (2). The purpose of this report is to prepare prioritized rankings of recommended improvements that could be implemented as part of the Interstate Safety Improvement Program in Kentucky.

## PROCEDURE

### Accident Analyses

All police-reported accidents in Kentucky are coded and placed in a computer accident file. An extensive amount of data is coded for each accident. However, for the analysis necessary in this study, copies of the accident reports were necessary. To obtain these, a manual search of all police-reported accidents in 1976 was conducted.

From the reports, each accident was classified into one of three broad categories: (a) interchange-related, (b) bridge-related, or (c) related to other highway sections. Each accident was assigned a code based on an analysis of the accident description. The accident types for the three broad categories are given in Table 1. These data, along with information to identify the location of the accident, were punched on computer cards. The Interstate system was divided into three groups based on population of the general area.

Lists of high-accident interchanges, bridges, and other highway sections were obtained. A list of the location of interchanges and bridges was obtained. Accidents classified as either bridge-related or interchange-related were assigned to a specific bridge or interchange. By using this procedure, the number of accidents that occurred on each interchange and bridge was obtained. The number of accidents could then be compared with a critical number of accidents. The critical number of an interchange, bridge, or specific length of road was calculated by using the following equation (3):



$$N_c = N_a + K\sqrt{N_a} + 0.5$$

(1)

K = constant related to level of statistical significance selected (for  $P = 0.95$ ,  $K = 1.645$ ; for  $P = 0.995$ ,  $K = 2.576$ ).

where

$N_c$  = critical number of accidents,  
 $N_a$  = average number of accidents, and

The average number of accidents per interchange, bridge, 1.6-km (1.0-mile) section, and 0.48-km (0.3-

Table 1. Types of accidents on interchanges, bridges, and other highway sections.

	First Event		All Events		
Type of Accident	No. of Accidents	Percent of Total	No. of Accidents	Percent of Total	Severity Index
Interchange					
Entrance Ramp					
Rear-end accident on ramp	194	16.9	199	15.1	1.53
Angle accident between ramp vehicle and main-line vehicle	92	8.0	95	7.2	1.73
Ramp vehicle hit fixed object	34	3.0	41	3.1	3.57
Accident at intersection with cross street	35	3.1	36	2.7	1.00
Rear-end accident on main line at ramp	24	2.1	26	2.0	2.30
Sideswipe accident on ramp	26	2.3	26	2.0	1.00
Other accident related to entrance ramp	22	1.9	23	1.7	2.84
Sideswipe accident between main-line vehicles	14	1.2	14	1.1	1.85
Extreme weather conditions (dense fog, driving rain, ice or snow)	8	0.7	13	1.0	1.42
Vehicle overturned	3	0.3	12	0.9	2.67
Drastic human error (driver fell asleep)	2	0.2	7	0.5	1.00
Ran off road	6	0.5	7	0.5	2.50
Trailer problem	3	0.3	6	0.4	2.25
Main-line vehicle hit fixed object near ramp	4	0.3	6	0.4	2.25
Vehicle malfunction	4	0.3	5	0.4	7.38
Hit median near ramp	1	0.1	2	0.1	1.00
Animal-related accident	0	0.0	0	0.0	0
Construction-related accident	3	0.3	6	0.4	1.00
Subtotal	475	41.5	524	39.5	
Exit Ramp					
Rear-end accident on ramp	275	24.0	283	21.5	1.25
Accident at intersection with cross street	77	6.7	81	6.1	1.19
Rear-end accident before ramp	66	5.8	67	5.1	1.04
Vehicle hit fixed object not in gore	38	3.3	58	4.4	3.45
Vehicle hit fixed object in gore	38	3.3	55	4.2	2.78
Extreme weather conditions (dense fog, driving rain, ice or snow)	30	2.6	47	3.6	2.69
Other accident related to exit ramp	39	3.4	46	3.5	2.02
Sideswipe accident on ramp	45	3.3	45	3.4	1.00
Drastic human error (driver fell asleep)	8	0.7	18	1.4	4.86
Vehicle overturned	3	0.3	17	1.3	4.67
Ran off road	11	1.0	17	1.3	3.72
Sideswipe due to vehicle turning onto ramp from wrong lane	15	1.3	15	1.1	1.18
Vehicle malfunction	7	0.6	10	0.8	4.67
Crash-cushion accident	8	0.7	10	0.8	2.57
Construction-related accident	1	0.1	9	0.7	1.00
Vehicle hit median near ramp	3	0.3	6	0.4	1.00
Sideswipe due to lane drop	3	0.3	4	0.3	1.00
Trailer problem	3	0.3	3	0.2	2.25
Animal-related accident	0	0.0	0	0.0	0
Subtotal	670	58.0	791	60.1	
Total	1145	100.0	1315	100.0	
Bridge					
Accident on bridge after skid on icy or wet deck	113	27.6	125	22.0	2.79
Hit bridge rail	35	8.5	86	15.1	2.89
Rear-end accident on bridge	75	18.3	78	13.7	2.03
Hit another car on bridge (dry conditions)	53	12.9	61	10.7	1.72
Construction accident	50	12.2	50	8.8	1.78
Hit bridge abutment	18	4.4	37	6.5	3.16
Hit bridge curb	7	1.7	28	4.9	3.25
Hit guardrail just past bridge	7	1.7	21	3.7	4.38
Vehicle overturned	1	0.2	15	2.6	0
Drastic human error	10	2.4	14	2.5	2.25
Hit approach guardrail	9	2.2	12	2.1	3.40
Vehicle malfunction	8	1.9	11	1.9	3.79
Hit overpass bridge pier on left side of road	6	1.5	9	1.6	3.67
Other bridge-related accident	7	1.7	8	1.4	2.57
Hit overpass bridge pier on right side of road	5	1.2	6	1.1	4.90
Trailer or wide-load problem	3	0.7	4	0.7	4.67
Ran off road	2	0.5	3	0.5	1.00
Animal-related accident	1	0.2	1	0.2	0
Total	410	100.0	569	100.0	

Table 1. Continued.

	First Event		All Events		
Type of Accident	No. of Accidents	Percent of Total	No. of Accidents	Percent of Total	Severity Index
Other Highway Sections					
Rear-end accident in traffic lane	1544	35.1	1715	29.6	1.82
Sideswipe accident due to lane change	783	17.8	877	15.1	1.33
Hit fixed object on right side of road	285	6.5	644	11.1	2.80
Extreme weather conditions (heavy fog, driving rain, ice or snow)	390	8.9	505	8.7	1.90
Other noninterchange accident or not stated	326	7.4	389	6.7	1.78
Vehicle overturned	26	0.6	226	3.9	4.04
Vehicle malfunction	198	4.5	216	3.7	2.43
Drastic human error	178	4.0	215	3.7	3.04
Hit fixed object on left side of road	73	1.7	167	2.9	2.61
Trailer problem or wide load	125	2.8	157	2.7	1.92
Ran off road	71	1.6	146	2.5	3.71
Hit median barrier	60	1.4	121	2.1	2.00
Rear-end accident on shoulder	50	1.1	72	1.2	3.52
Construction-area accident	46	1.0	63	1.1	1.00
Head-on collision	32	0.7	53	0.9	4.53
Forced off road	46	1.0	52	0.9	1.80
Animal-related accident	46	1.0	47	0.8	1.12
Accident at rest area	36	0.8	37	0.6	1.00
Accident at entrance or exit ramp to rest area	21	0.5	22	0.4	2.36
Median cut (angle or other accident due to U-turn)	21	0.5	21	0.4	3.58
Sideswipe or rear-end accident due to car pulling from shoulder	17	0.4	17	0.3	3.94
Median cut (rear-end due to U-turn)	11	0.2	12	0.2	2.50
Weigh-station accident	4	0.1	4	0.1	2.25
Wrong-way vehicle (other than collision)	5	0.1	19	0.3	2.50
Total	4394	100.0	5797	100.0	

mile) spot was calculated for the large urban, medium urban, and rural sections of Interstate roads as well as for the entire Interstate system. By using certain levels of statistical significance, critical numbers of accidents were calculated. Also, by using volume data, average and critical accident rates were calculated. For bridges, the length of bridge along with the volume provided vehicle kilometers. The vehicle kilometers traveled on a particular section of road were calculated directly from the volume and section length. For interchanges, the total interchange volume was estimated by using the volume and the number of ramps. Interchange volume counts were used to obtain the percentage of the total interchange volume that occurred on the ramp. Volume counts were available only for a few interchanges, and other volumes had to be estimated. The critical rate for highway sections is given by the following equation (4):

$$A_c = A_a + K\sqrt{A_a/m + 1/(2m)} \quad (2)$$

where

$A_c$  = critical accident rate [accidents per 1.6 million vehicle-km (1.0 million vehicle miles)],

$A_a$  = average accident rate (accidents per 1.6 million vehicle-km), and

$m$  = annual million vehicle kilometers.

For spots and interchanges, the total annual volume was used rather than the number of vehicle kilometers. Thus, the values of  $A_c$  and  $A_a$  were expressed in terms of accidents per million vehicles.

Dividing the calculated accident rate for a particular interchange, bridge, or roadway section by the critical accident rate for the location results in a critical rate factor. A critical rate factor above 1.0 means that the location has a critically

high accident rate. A computer listing by critical rate factor (in descending order) was then obtained for each category. These lists served as one of the primary means of selecting high-accident locations.

Summaries were also made of the number of occurrences of each accident type. These lists gave general information relating to the types of accidents that occurred most frequently. The severity of each type of accident was also calculated by using a severity index.

As previously stated, a large amount of data is routinely coded for each police-reported accident. To obtain summaries of this information, a series of computer programs was written.

Another procedure was used to determine locations that had a critical number of a particular type of accident. The average number of accidents per kilometer of a specific type was calculated for each of the three Interstate categories. By using the formula given for determining the critical number of accidents, the critical number of accidents per kilometer was calculated. Some of the specific types investigated included injury and fatal accidents, accidents that occurred during darkness, accidents that involved a guardrail, and accidents that involved a rock cut or earth embankment.

A special investigation of fatal accidents that occurred on the Interstate system was performed. Copies of the accident reports of all accidents that involved a fatality were obtained for a four-year period (1974-1977). Information from these reports was coded and summarized. Each accident was placed into one of several accident-description categories. Sections of Interstate on which several fatal accidents had occurred were summarized. Also, locations at which several accidents of a specific type had occurred were summarized.

Some other types of accident summaries were prepared. A comparison of accident data on bridges with and without full-width shoulders was made. A

comparison of accident rates on bridges that had various sufficiency (adequacy) ratings was performed. Also, interchanges were divided into several types, and accident rates were calculated for each type.

#### Field Inventory

It was necessary to travel the entire Interstate system [approximately 1046 km (650 miles)] for the purpose of visually inspecting the high-accident locations and conducting an inventory of selected items. The accident analysis yielded lists of high-accident bridges, interchanges, sections, and 0.48-km spots. The accident reports for these high-accident locations were studied, and visual inspections were also conducted. These were done along with a field inventory. The analysis of specific accident types indicated that certain roadway features should be upgraded. For example, the present standard for guardrail ends is the breakaway-cable terminal. However, only a few sections of Interstate have this type of terminal. Most sections have buried guardrail ends, and a few blunt ends still exist. It was necessary to conduct an inventory of the number of each type of guardrail end to estimate the costs of updating all guardrail ends to current standards.

The general roadway features included in the field inventory are as follows: type of guardrail end, bridge pier protection, bridge shoulder width, bridge safety features, curb on bridge, protection of gap between bridges, signs, lightpoles, gore-area features, rock cuts, and crossovers. The number of buried, breakaway, and blunt guardrail ends was determined for guardrail used to protect or divert vehicles from fills, bridge piers, bridge rails, and gaps between bridges. The type of safety device used to divert vehicles from median bridge piers was also noted: guardrail, earth mound, crash cushion, etc. For bridges, the shoulder width, the existence of a curb, the type of protection at the median gap, and the safety features were inventoried. The safety features consisted of the bridge-rail and guardrail transition and end treatment. Safety features had previously been rated as good or poor and these ratings were checked. Rigid signs and lightpoles were counted. All gore areas were classified as clear, or the features in the gore were noted. The features included an exit sign (if not breakaway), lightpole, guardrail, or combination of several features. The lengths of all rock cuts closer than 9.1 m (30 ft) to the pavement were tabulated. The rock cuts were divided into those that occurred on curves or those on tangents. Median crossovers were also counted. Crossovers were divided into those that were designed and those that had been created by frequent use. All the features inventoried, with the exception of bridges, were summarized by kilometer and milepost.

#### Determination of Benefits and Costs

To obtain a priority ranking of the recommended safety improvements, benefits and costs had to be assigned. The annual benefits were calculated based on the number of fatal, injury, and property-damage-only accidents that would be affected by the improvement and the estimated percentage of reduction in each of these types of accidents. Monetary benefits from the reduction in accidents were based on National Safety Council costs (5). The percentage of reductions used was based on previous research findings for the types of improvements considered as well as subjective opinions based on results of past safety improvement programs. The costs used were

the installation or construction costs of the improvement plus the annual maintenance cost. The improvement cost was based on past unit-price bids for the type of improvement, other research reports, and information from manufacturers of various safety devices.

The present worth of the benefits was calculated from a given interest rate, an exponential growth-rate factor for traffic volume, and a service life for each improvement. Benefit/cost ratios were then determined for each improvement.

#### Dynamic Programming

Multistage dynamic programming was used as the means of priority ranking the improvements. By using the present worth of the benefits and costs of the improvements along with a specific program budget, the combination of improvements that would yield the greatest benefits was determined. Several hypothetical budgets were input into the program, and the improvement types that would yield optimum results were output for each budget. Procedures used for ranking were similar to those applied to Kentucky's high-accident spot-improvement program (6).

### RESULTS

#### Accident Analyses

The manual search of reports for 1976 yielded a total of 5948 accidents that occurred on the Interstate system. The largest percentage of accidents (64 percent) occurred in large urban areas. Also, the largest percentage of accidents (74 percent) was not related to either a bridge or an interchange. The percentage of bridge-related accidents was about the same for the three population groups. However, the percentage of interchange-related accidents was much higher for the large urban group, and the percentage of nonbridge or interchange accidents was highest for the rural group.

All the accidents were classified into the three categories shown in Table 1 (interchange, bridge-related, and noninterchange). In some cases, an accident could not be classified as a single event. A single-event accident involved one of the accident types shown in Table 1. Summaries of the number of accidents in each of the three categories divided into the number of first events and all events are given as well as the percentage of all accidents in each category. The combined severity index of each category is also given.

Interchange accidents were found to occur more frequently on the exit ramp than on the entrance ramp. On both the exit and entrance ramps, the largest number of accidents was the rear-end type. On entrance ramps, rear-end accidents were the second most frequent, followed by angle accidents between a vehicle that was leaving the ramp and a vehicle on the main line, which indicates that merging created the largest number of accidents. On exit ramps, rear-end accidents were much more numerous than any other type. It was presumed that these accidents were caused in most cases by drivers who were not properly slowing when exiting. Some of the most severe accidents involved hitting a fixed object.

Bridge-related accidents commonly involved ice or water on the deck. Bridge-related accidents included several severe accident types; the most severe types occurred primarily when a bridge pier or abutment or the bridge curb was hit.

Accidents on other highway sections were predominantly the rear-end type. Sideswipe accidents were the second most frequent. Many of these were low in



severity. The most severe involved collisions with fixed objects, single-vehicle accidents, and head-on collisions.

Data on the number of accidents for each population group and the mileage and annual average daily traffic (AADT) of each group permitted calculation of average and critical numbers of accidents and rates. These values were found for accidents on the entire system (Table 2) and for bridge-related accidents, interchange-related accidents, and accidents

on other highway sections (Table 3).

Whereas 77 percent of the Interstate mileage was in rural areas, only 28 percent of all accidents occurred in those areas. The volume was much lower in rural areas, and the accident rate for large urban areas was found to be more than five times that in rural areas (Table 2). The number of accidents per 1.6 km in a large urban area was approximately 14 times that in the rural area. The critical number of accidents, for a level of significance of 99.5 percent, varied from a value of 65 accidents per 1.6 km for urban areas to 8 accidents per 1.6 km for rural areas.

The average rate, expressed as accidents per 160 million vehicle-km, was higher on bridges than on the entire Interstate system (Table 3). The average and critical numbers of accidents per bridge were lower in rural areas. However, when volumes were considered, the average accident rate was slightly higher in rural areas.

For interchange-related accidents, the accident rate was expressed in accidents per million vehicles. The number of accidents per interchange in large urban areas was more than nine times that for rural areas. Also, the number of interchanges per 1.6 km in large urban areas was more than five times that for rural areas.

The average accident rate was lower for the other highway sections compared with that for the entire Interstate system (Table 2). The critical number of accidents per 0.48-km spot and per 1.6-km section

Table 2. Accident and volume data on Interstates (all accidents).

Item	Type of Area			Total
	Large Urban	Medium Urban	Rural	
No. of accidents	3 809	487	1 652	5 948
Total distance (km)	135.3	101.7	813.5	1 050.5
Accidents per 1.6 km	46.5	7.7	3.3	9.1
Critical accidents per 1.6 km				
P = 95.0	60	14	7	16
P = 99.5	65	15	8	17
Avg AADT	40 623	27 305	15 669	20 528
Million vehicle kilometers	2 006	1 014	4 635	7 871
Average accident rate <sup>a</sup>	305	77	57	122

Note: 1 km = 0.6 mile; 160 million vehicle-km = 100 million vehicle miles.  
<sup>a</sup>Accidents per 160 million vehicle-km.

Table 3. Summary of accidents and volumes on bridges, interchanges, and other highway sections.

	Type of Area			
Item	Large Urban	Medium Urban	Rural	Total
Bridges				
No. of accidents	276	23	111	410
No. of bridges	130	18	139	287
Accidents per bridge	2.1	1.3	0.8	1.4
Critical accidents per bridge				
P = 95.0	5	4	3	4
P = 99.5	6	5	4	5
Avg AADT	51 144	29 683	14 137	31 864
Avg accident rate <sup>a</sup>	11.2	11.8	15.5	12.3
Avg length per bridge (m)	79.9	85.0	86.6	83.2
Total bridge length (km)	10.4	1.53	1.20	23.94
Million vehicle kilometers	193.7	16.6	62.1	272.4
Avg accident rate <sup>b</sup>	229	223	288	242
Interchanges				
No. of accidents	948	82	114	1 144
No. of interchanges	72	20	79	171
Accidents per interchange	13.2	4.1	1.4	6.7
Critical accidents per interchange				
P = 95.0	21	9	4	12
P = 99.5	23	10	5	14
Avg AADT	68 046	31 678	17 638	40 502
Avg accident rate <sup>c</sup>	0.53	0.36	0.22	0.45
Interchanges per 1.6 km	0.86	0.32	0.16	0.26
Other Highway Sections				
No. of accidents	2 585	382	1 427	4 394
Total distance (km)	135.3	101.7	818.5	1 050.5
Accidents per 1.6-km section	30.7	6.0	2.8	6.7
Accidents per 0.48-spot	9.2	1.8	0.8	2.0
Critical accidents per spot				
P = 95.0	16	5	3	5
P = 99.5	18	6	4	6
Critical accidents per 1.6-km				
P = 95.0	42	11	7	12
P = 99.5	45	13	8	14
Avg AADT	40 623	27 305	15 669	20 528
Million vehicle kilometers	2 006	1 014	4 653	7 871
Avg accident rate <sup>a</sup>	207	61	49	90

Note: 160 million vehicle-km = 100 million vehicle miles; 1 m = 3.2 ft; 1 km = 0.6 mile.

<sup>a</sup>Accidents per 100 million vehicles.

<sup>b</sup>Accidents per 160 million vehicle-km.

<sup>c</sup>Accidents per million vehicles.

Table 4. Detailed description of fatal accidents.

Description	Number	Percent of Total
Wrong-way head-on collision	20	9.3
Vehicle run off road (no collision)	14	6.5
Accident involved pedestrian		
Workman	1	0.5
Not driver or passenger of another vehicle	8	3.7
Driver or passenger of another vehicle	3	1.4
Passenger or driver of disabled vehicle	8	3.8
Driver or passenger of previous accident	2	0.9
Total	22	10.2
Median crossover	4	1.9
Driver lost control of motorcycle	5	2.3
Accident involved guardrail		
General	4	1.9
Vehicle punctured by blunt guardrail end	7	3.2
Vehicle hit buried guardrail end and overturned	3	1.4
Vehicle jumped guardrail	6	2.8
Vehicle went through guardrail	1	0.5
Vehicle hit guardrail and overturned	9	4.2
Vehicle jumped over buried guardrail end	1	0.5
Total	31	14.4
Cross median head-on collision	16	7.4
Rear-end accidents		
General	15	6.9
Vehicle hit slow-moving truck	11	5.1
Vehicle hit during lane change	2	0.9
Traffic backed up (congestion)	1	0.5
Disabled vehicle	2	0.9
Previous accident	2	0.9
Vehicle on emergency strip	9	4.2
Total	42	19.4
Bridge-related accidents		
Vehicle hit bridge pier	7	3.2
Vehicle hit bridge abutment	3	1.4
Vehicle went through bridge railing	6	2.8
Icy bridge	1	0.5
Gap between parallel bridges	2	0.9
Vehicle rebounded off bridge railing	5	2.3
Total	24	11.1
Accident involved other fixed object		
General	1	0.5
Culvert	2	0.9
Sign	3	1.4
Rock cut	13	6.0
Lightpole	3	1.4
Earth embankment	5	2.3
Total	27	12.5
Accident involved sideswipe		
General	1	0.5
Passing	6	2.8
Merging from entrance ramp	1	0.5
Total	8	3.7
U-turn (no crossover)	3	1.4

was calculated for each population group. The number of accidents per 1.6-km section and the accident rate were much higher in large urban areas.

The accident rate, critical rate, and critical rate factor were calculated for each bridge. Computer listings in order by critical rate factor were prepared for all bridges in each population group. All the computer listings of the critical rate factors of high-accident bridges, interchanges, 1.6-km sections, and 0.48-km spots were made in descending order. This was done because the critical rate factor was the means used to rank high-accident locations. The listing gave location (county, route, and milepost); volume; bridge length; sufficiency rating; number of accidents; accident rate; critical accident rate; and critical rate factor.

Similar printouts were made for each interchange in each population group. These printouts were also in order by critical rate factor and gave the loca-

tion and accident information. In addition, the number of ramps and number of accidents per ramp, entrance ramp, and exit ramp were given. Also, the total interchange volume was given.

The critical number of accidents in a 1.6-km section or 0.48-km spot (excluding bridge and interchange accidents) for each population group had been determined previously. A listing of all locations that had a critical number of accidents was obtained. Volumes were found, and the accident rate, critical accident rate, and critical rate factor were determined. Computer listings were made for the 1.6-km and 0.48-km locations in order by route and milepost.

In addition to the search for high-accident locations, the accident analysis included a list of roadway elements that contributed to cause or severity. One method of obtaining this list was from general summaries of accident information. A particularly useful summary was a printout by type of accident (first event). This table enabled calculation of the average number of accidents per 1.6 km for specific types of accidents. The critical number of accidents per 1.6 km could then be calculated, and a printout of locations that exceeded the critical number was obtained. Critical numbers of accidents per 1.6 km were determined by population group for all accidents, injury and fatal accidents, accidents during darkness, and accidents on wet pavement. Also, a critical number of accidents per 1.6 km that involved guardrail was determined. Lists of locations at which more than one accident had to do with a bridge, light support or pole, or a signpost were obtained. The most common types of fixed-object accidents involved a guardrail (most common type), a rock cut, or an earth embankment.

A separate analysis was made of fatal accidents that occurred in a four-year period (1974-1977). All the fatal accidents were put into one general category. The largest number were collisions with another motor vehicle; second most numerous were collisions with fixed objects. In the order of frequency, the fixed objects were guardrails, bridges, and rock cuts. Each fatal accident was also placed into a detailed category (Table 4). Data from Table 4 indicated general types of improvements that could be made to reduce the number of fatal accidents. For example, there were 20 fatal accidents that involved wrong-way head-on collisions. This indicated a need to prevent wrong-way entrance onto the roadway. Other areas that needed safety improvements were revealed by the number of fatal accidents in which rock cuts (a total of 13) and blunt guardrail ends (a total of 7) were involved. An investigation of seatbelt use disclosed that only 4.2 percent of the persons fatally injured were wearing a seatbelt. Thirty-six percent of the fatalities involved ejection from the vehicle.

Other summaries of available information with respect to population were made. The percentage of collisions with other vehicles was much higher in the high-volume large urban areas, whereas the percentage of fixed-object and single-vehicle accidents was much higher in the low-volume rural areas. Accident rates were calculated for Interstate segments in each county. A comparison of accident data on bridges with and without full-width shoulders showed that bridges that had full-width shoulders had an 18 percent lower accident rate and 51 percent fewer accidents per bridge compared with bridges that did not have full-width shoulders. All interchanges were classified into one of 13 categories. The rates tended to be higher for the higher-volume interchange types. The lowest rates were for interchanges that consisted of entrance or exit ramps only and for a T-type or trumpet-type interchange.

A comparison of bridges based on adequacy ratings was done. It was shown that bridges that had higher adequacy ratings had lower accident rates.

### Field Inventory

A summary of the number of each type of guardrail end treatment was made. The majority of existing guardrail ends was buried (85 percent). Some guardrails have been upgraded to breakaway-cable terminal types (11 percent); a few blunt-end treatments remain (4 percent).

A listing of the types of safety devices at median and shoulder piers was given. For the median pier, the most common type was a guardrail (69 percent). The other common type was the earth mound (23 percent). A few piers were equipped with crash cushions (2 percent), and some provided no protection for the vehicle (6 percent). For the shoulder pier, the guardrail was the only safety device to divert the vehicle. In some cases (9 percent), the pier had been placed more than 9 m from the roadway. Also, a few of the shoulder piers (5 percent) were not shielded from traffic. The Watterson Expressway (I-264) had the largest percentage of unshielded piers.

A summary of the bridge inventory data was done. Altogether, 290 bridges were inventoried. It was found that 75 percent of the bridges had a curb. This feature has been eliminated in current standards. Slightly less than one-half of the bridges had full-width shoulders (43 percent). The predominant method of protecting or diverting vehicles at the median gap between the bridges was a guardrail (78 percent). There were various arrangements of guardrails. Some of the older installations provided very little protection. In addition to a guardrail, a few installations had shrubs that provided increased protection. Some bridges were at locations that had a median barrier. In a very few instances on I-264, no protection was provided. For more than one-half of the bridges (60 percent), all the safety features were rated as good. The safety features consisted of the bridge-rail and guardrail transition and end treatment.

The other roadway features inventoried were summarized. Rigid signs and lightpoles totaled 544, and 78 percent were on I-264. Only 20 percent of the gore areas were found to be free of obstructions. The most common obstruction in the gore area was an exit sign. Many of these signs were supported by channel posts placed back to back, which have been classified as the nonbreakaway type. Approximately 113 km (70 miles) of rock cuts closer to the pavement than 9 m were found. The largest number of rock cuts was on I-75 and I-64. Crossovers were identified as those that were designed and those that had been created by frequent traversing. A total of 290 crossovers was located; 29 percent had not been designed.

### RECOMMENDED IMPROVEMENTS

After an in-depth inventory and accident analysis, a number of improvements were recommended. These were classified as related to 0.48-km spots, 1.6-km sections, bridges, or interchanges. The types of improvements were based partly on guidelines for Interstate safety upgrading distributed in 1978 by FHWA as the types of highway safety improvement work to be included in the 1979 Interstate cost estimate. This listing included 29 general improvement types.

Priority listings were made of all hazardous spots, sections, bridges, and interchanges. These were based on critical rate factors, as explained

earlier. Locations that had abnormally high accident experiences were investigated in the field to determine geometric deficiencies. For 0.48-km spots, recommendations were offered for 20 locations. Most of the improvements were variable-message signs to provide advanced warning to drivers. There were 12 interchanges on which preliminary recommendations included ramp metering, gore improvements, transverse striping, and addition of acceleration lanes. Of the 51 bridges in the listing, 15 needed no improvement. Delineation, variable-message signs, widening, and ice warning signs were recommended.

In addition to improvements at specific high-accident sites, improvements were needed to upgrade substandard highway features. Based on the inventory of substandard features, a listing of safety improvements was made for each route. The unit costs for each improvement were also given.

A combined list of proposed safety improvements was developed for high-accident spots, sections, bridges, and interchanges; for substandard geometric features; for low adequacy rating (bridges only); and for unusually slippery pavements. The listing included 58 projects. Some projects consisted of several hundred individual sites.

The information given for each improvement type included improvement description, number of installations, accident history (annual), percentage of accident reduction, improvement costs, maintenance costs, average annual benefits, literature references relating to the improvement, benefit/cost ratio, and service life. The expected percentage of reductions in accidents was determined based on one or more of the 42 references. Benefit/cost ratios range from near 0 to 44.

The percentage of accident reductions was given separately for fatal, injury, and property-damage accidents. Some improvements will reduce severity but not affect the number of accidents. In such cases, total accidents will remain unchanged, but injury and fatal accidents will be reduced. Thus, the number of property-damage accidents shows a negative percentage of reduction because some injury and fatal accidents are expected to be reduced in severity to property-damage accidents after improvements have been made.

Improvement costs were taken primarily from average unit bid prices for all projects awarded by the Kentucky Department of Transportation in 1977 (7). Service lives and annual maintenance costs were also selected for each project based on information contained in other sources (6).

The total cost for all proposed projects was more than \$27 million. Of that total, nearly \$20 million would result in a benefit/cost ratio of more than 1.0. All the general improvements would pay for themselves (benefit/cost ratios of 1.0 or higher). Almost all the ramp improvements would have benefit/cost ratios of 1.0 or higher, whereas less than half of the deslicking, bridge widening, and spot-improvement projects would be cost-effective.

### PRIORITY RANKING

To put projects in order of priority, construction costs and expected accident savings must be known. Also, interest rates, growth rates, and maintenance costs are needed. Projects were then subjected to dynamic programming analyses. Some changes in the computer programs were made to adapt the procedure to the Interstate Safety Improvement Program.

Input into the program included numbers of injuries, fatalities, and property-damage-only accidents for each project location during the previous year. Percentage of reductions for these accidents

was also used as well as improvement costs, annual maintenance costs, and service lives of each project. An interest rate of 8 percent was used along with a volume growth rate of 5 percent per year.

Output from the program included information for each improvement project and a listing of all projects in order of benefit/cost ratio that could be used to determine priority rankings based on benefit/cost ratios alone. The largest benefit/cost ratio was 44.01, which was for the addition of exit signs on the left side of I-65 south of Louisville. Projects that had the largest benefit/cost ratios were generally those that had the smallest improvement costs. Projects ranged in cost from \$2000 for the left-exit signs to more than \$5 million for removal of rock cuts. Several other projects had improvement costs of more than \$1 million. The next project (benefit/cost ratio of 33.16) was the installation of diagrammatic signs at the I-65 bridge in Louisville. A total of 41 of the 58 projects had a benefit/cost ratio of 1.0 or higher. This listing also provides a column of cumulative benefit/cost ratios that allows for the selection of projects by the benefit/cost method for a given budget.

The dynamic programming output was also obtained for assumed budgets of \$5 million, \$10 million, \$15 million, \$20 million, \$25 million, and \$30 million. For the \$5 million budget, only 15 of the projects were selected; they had a combined benefit/cost ratio of 4.04. The combined benefit/cost ratios for other budgets were 2.88 for the \$10 million budget, 2.32 for the \$15 million budget, 2.00 for the \$20 million budget, 1.80 for the \$25 million budget, and 1.55 for the \$30 million budget.

#### SUMMARY

The proposed Interstate Safety Improvement Program for Kentucky has been presented. A compilation of procedures, results, and priority rankings of the recommended improvements has been included. Considerable detail is presented in this report; however, reference should be made to Appendix G of the Kentucky Interstate Safety Improvement Program (8) for a user's guide to assist in the preparation of this program and its expansion into other highway systems. The original intent was to prepare a separate report as a user's guide; however, a more practical approach was taken, and a generalized guide was prepared and references were made to details in a companion report (2).

Evaluation of the Interstate Safety Improvement

Program was not covered in this report or in the earlier report (2). Guidelines for the evaluation are presented in the FHWA Federal-Aid Highway Program Manual (1). The basic requirements for an evaluation should include the following:

1. An assessment of the costs and benefits of various means and methods used to eliminate identified hazards,
2. A comparison of accident data before and after the improvements,
3. Basic cost data used for each type of corrective measure and the number of each type of improvement undertaken during the year, and
4. Methods employed in establishing project priorities.

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## Review of FHWA's Evaluation of Highway Safety Projects

G.A. FLEISCHER

The Federal Highway Administration has recently funded the development of a guide, Evaluation of Highway Safety Projects, and related training materials, which have been used in almost 30 workshops throughout the United States over the past two years. Evaluation methodology described in these materials is based on six related functions: (a) develop the evaluation plan, (b) collect and reduce data, (c) compare measures of effectiveness, (d) perform tests of significance, (e) perform economic analysis by using either the benefit/cost or the cost-effectiveness technique, and (f) prepare evaluation documentation. The document is described, with particular emphasis on the proposed economic analysis methodology. Among the specific elements discussed are the following: the significance to decision makers of the benefit/cost and the cost-effectiveness ratios; appropriate notation for the discount factors; restricted use of

the end-of-period assumption in the discounting models; appropriate techniques for dealing with project elements that have unequal service lives; discounting cash-flow sequences other than uniform series; discount rate; treatment of risk and uncertainty associated with forecasts of parameter values; and bibliography and list of selected readings.

Attempts to document procedures for the evaluation of publicly financed plans, programs, and projects are not new or novel. The application of these procedures within the context of highway safety has a



These earlier efforts (and others) notwithstanding, the Federal Highway Administration (FHWA) concluded that an appropriate methodology should be developed with the FHWA that would (a) be suitable to the determination of the extent to which individual highway safety projects contribute to the reduction in the frequency, rate, and/or severity of traffic accidents and (b) link these beneficial consequences, if significant, to associated costs. The goal would be to assist "State and local agency personnel improve their ability to select and implement those improvements which provide the highest safety pay-off based on evaluation results of past experiences" (5, p. S-2).

An important feature of this recent effort was a series of concurrent contracts with 24 states to actually put into effect the procedures outlined in the manual. Almost all the 24 states did so, but with mixed results. (A review of the users' experience is beyond the scope of this paper.) In my judgment, the absence of a users' follow-up explains in great part the failure of the earlier NHSB/NHTSA and AASHTO efforts to have any substantial impact.

**Figure 1. Project purpose listing (sample).**

Page \_\_\_\_\_ of \_\_\_\_\_

**PROJECT PURPOSE LISTING**

Evaluation No. A-1

Date/Evaluator 2/23/77/DDP Checked by 2/28/77/HES

Project No. P-1

Project Description and Location(s) Replace four-way stop sign with two-phased fixed time controller at Broadway and 7th Streets

Countermeasure(s)/Codes Traffic Signal Installation (FHWA Code 11)

[illegible]

The principal document is a set of explanatory and reference materials incorporated into a loose-leaf notebook. The main body of the notebook is a six-part discussion of the underlying philosophy, methodology, and techniques. (An overview is presented below.) Appendices include a glossary of terms, sample worksheets and data forms, statistical tables, compound-interest tables for the single-payment and uniform-series present-worth (PW) factors ( $i = 5, 6, 7, 8, 9, 10, 12, 14, \text{ and } 16$  percent), and a 17-item bibliography. Also included in the notebook are five fully worked out case studies.

## OVERVIEW OF METHODOLOGY

In this section we will summarize briefly the principal functions, or elements, of the proposed methodology. The reader is referred to the source document (6) for a more-detailed presentation.

Function A: Develop Evaluation Plan

Step A1: Select the project to be evaluated. Among the selection criteria recommended are current and future highway safety project efforts, project implementation dates, data availability, sufficiency of accident data, and project purpose. A sample worksheet for project purpose is given in Figure 1.

Step A2: Stratify projects, i.e., aggregate similar projects into groups (where warranted), on the basis of countermeasure types and geometric and environmental characteristics.

Step A3: Select evaluation objectives and measures of effectiveness (MOEs). The fundamental objectives to be specified in all evaluations are total accidents, fatalities, injuries, and property damage. A sample worksheet that relates evaluation objectives to MOEs is given in Figure 2.

Step A4: Select the experimental plan most suitable for the evaluation study. Four alternatives are specified: (a) use plan before evaluation and also use after with control, (b) use plan before and after only, (c) use parallel study in which accident experience at the project site is compared with that at a similar control site(s), and (d) use plan be-







Figure 6. B/C analysis worksheet (sample).

Evaluation No: <b>C5-3</b>			
Project No: <b>P-3</b>			
Date/Evaluator: <b>8-9-77/GCD</b>			
1. Initial Implementation Cost, I:	\$ <b>450,000</b>		
2. Annual Operating and Maintenance Costs Before Project Implementation:	\$ <b>0</b>		
3. Annual Operating and Maintenance Cost After Project Implementation:	\$ <b>2,500</b>		
4. Net Annual Operating and Maintenance Costs, K (3-2):	\$ <b>2,500</b>		
5. Annual Safety Benefits in Number of Accidents Prevented:			
<u>Severity</u>	<u>Expected</u>	<u>Actual</u>	<u>Annual Benefit</u>
a) Fatal Accidents (Fatalities)	8.8	1.3	7.5
b) Injury Accidents (Injuries)	22.9	8.7	14.2
c) PDO Accidents	26.1	15.0	11.1
6. Accident Cost Values (Source <b>NSC</b> ):			
<u>Severity</u>	<u>Cost</u>		
a) Fatal Accident (Fatality)	\$ <b>125,000</b>		
b) Injury Accident (Injury)	\$ <b>4,700</b>		
c) PDO Accident	\$ <b>670</b>		
7. Annual Safety Benefits in Dollars Saved, $\bar{B}$ :			
5a) x 6a) = 7.5 x \$125,000 =	\$ <b>937,500</b>		
5b) x 6b) = 14.2 x \$4,700 =	\$ <b>66,740</b>		
5c) x 6c) = 11.1 x \$670 =	\$ <b>7,437</b>		
Total =	\$ <b>1,011,677</b>		
8. Services life, n:	<b>20</b> yrs		
9. Salvage Value, T:	\$ <b>0</b>		
10. Interest Rate, i:	<b>10 % = 0.10</b>		
11. EUAC Calculation:			
$CR_n^i =$	<b>0.1175</b>		
$SP_n^i =$	<b>0.0175</b>		
$EUAC = I (CR_n^i) + K - T (SP_n^i)$	<b>= \$450,000(0.1175) + \$2,500 - 0 = \$55,375</b>		
12. EUAB Calculation:			
$EUAB = \bar{B}$	<b>= \$1,011,677</b>		
13. B/C = EUAB/EUAC =	<b>\$1,011,677 / \$55,375 = 18.3</b>		
14. PWOC Calculation:			
$PW_n^i =$			
$SPW_n^i =$			
$PWOC = I + K (SPW_n^i) - T (PW_n^i)$	<b>N/A</b>		
15. PWOB Calculation:			
$PWOB = \bar{B} (SPW_n^i)$			
16. B/C = PWOB/PWOC =			

where  $\bar{B}_y$  is benefits in project year y and m is number of years since project implementation; and

10. Calculate the ratio of annualized project costs to average annual benefits. A sample C/E analysis worksheet is shown in Figure 7.

#### Function F: Prepare Evaluation Documentation

Step F1: Organize evaluation study materials.

Step F2: Assess the project in terms of its degree of success.

Step F3: Determine reasons for project failure, if indicated.

Step F4: Identify evaluation results for inclusion in the aggregate data base.

Step F5: Discuss and document the evaluation study results.

#### CRITIQUE

##### Significance of B/C Ratio

As noted above, the proposed procedure calls for the determination of a B/C ratio in those instances in which the traffic safety consequences, especially the costs of deaths and injuries, are expressed in monetary terms. There are two alternative equations:

$$B/C = EUAB/EUAC \quad (\text{annualized approach}) \quad (2)$$

$$B/C = PWOB/PWOC \quad (\text{present-worth approach}) \quad (3)$$

See Figure 6 (steps 13 and 16) for illustration.

The authors do recognize that there are a number of analysis techniques other than the B/C ratio

method--for example, (internal) rate of return and net present worth. They also indicate, quite correctly, that "any project that has a benefit/cost ratio greater than 1.0 is considered economically successful" (6, p. E-3). Unfortunately, they do not emphasize that the B/C ratios do not reflect the relative desirability of alternative projects. Indeed, the point is not made at all in either the Summary or the Procedural Guide. In the absence of such a caveat, it is not only possible but likely that unsophisticated users will attempt to rank-order projects on the basis of their respective B/C ratios.

##### Significance of C/E Ratio

"An alternative to the benefit/cost technique is to determine the cost to the agency of preventing a single accident and then deciding whether the project cost was justified. This is the cost/effectiveness technique" (6, p. E-3).

There are two problems, at least, when one uses this technique. The first arises from the fact that a unique C/E value can only be derived when there is a unique MOE for the project. As illustrated in Figure 7, for example, the reduction of 10.6 accidents per year is effected by an EUAC of \$13 216 (step 9) or a C/E value of \$1250 per accident prevented (step 11). But suppose an EUAC of, say, \$13 200 resulted in a reduction of two injury accidents and eight PDO accidents per year. A unique expression for the C/E value is not possible unless the equivalency between injury and PDO accidents is specified. It should be noted that the authors do recognize this problem: "This [C/E] can only be



Figure 7. C/E analysis worksheet (sample).

Evaluation No: <b>C3 - 1</b>	
Project No: <b>P - 1</b>	
Date/Evaluator: <b>12-3-77/ABE</b>	Checked by: <b>12/10/77/HES</b>
1. Initial Implementation Cost, I:	<b>\$ 80,000</b>
2. Annual Operating and Maintenance Costs Before Project Implementation:	<b>\$ 0</b>
3. Annual Operating and Maintenance Costs After Project Implementation:	<b>\$ 200</b>
4. Net Annual Operating and Maintenance Costs, K (3-2):	<b>\$ 200</b>
5. Annual Safety Benefits in Number of Accidents Prevented, B:	
Accident Type	Expected - Actual = Annual Benefit
TOTAL ACCIDENTS (3 YEARS)	<b>133.0 - 101</b>
TOTAL ACCIDENTS/YR.	<b>44.3 - 33.7</b>
Total	<b>44.3 - 33.7 = 10.6</b>
<b>Accidents Prevented per yr. = 10.6</b>	
6. Service Life, n:	<b>10 yrs.</b>
7. Salvage Value, T:	<b>\$ 0</b>
8. Interest Rate:	<b>10 % = 0.10</b>
9. EUAC Calculation:	
$CR_n^i =$	<b>0.1627</b>
$SF_n^i =$	<b>0.0627</b>
$EUAC = I (CR_n^i) + K - T (SF_n^i)$	
<b>= 80,000 (0.1627) + 200 - 0 = \$ 13,216</b>	
10. Annual Benefit:	
$B$ (from 5) =	<b>10.6</b>
11. C/E = $EUAC/B = 13,216/10.6 = 1,247 \approx 1,250$	
12. PWOC Calculation:	
$PW_n^i =$	
$SPW_n^i =$	<b>N/A</b>
$PWOC = I + K (SPW_n^i) - T (PW_n^i)$	
13. Annual Benefit	
n (from 6) =	<b>10 yrs.</b>
$B$ (from 5) =	<b>accidents prevented per year</b>
14. C/E = $PWOC(SF_n^i)/B$	

performed for one type of accident at a time" (6, p. E-3).

The second problem--perhaps more important than the first--is that C/E values are useful in selecting from among alternatives in only three very special situations: dominance in both costs and effectiveness, projects that have equal effectiveness, or projects that have equal costs (9). Otherwise, given two or more projects with unequal costs and effectiveness, the relative attractiveness of these

alternatives is not reflected by their respective C/E ratios.

It is not entirely clear what the authors would have the users do with the resulting C/E values. The discussion in the text appears incomplete. Their intent may be inferred, however, by reference to the sample problems in the Procedural Guide. At the end of one of these problems, there is the statement: "The results of this analysis may be interpreted by comparing this C/E value with those from other competing highway safety projects" (6, p. E-19). Exactly how this comparison is to be done and its validity are unclear. Certainly it is not correct to rank-order alternative projects solely on the basis of their C/E values.

#### Notation

Four compound-interest factors are included in the Procedural Guide: (a) capital recovery, (b) sinking fund, (c) series PW, and (d) single-payment PW. The four factors and their algebraic formats are given in the first two columns of Table 1 (i is the interest rate; N is the number of interest periods for compounding and discounting). Unfortunately, the superscript-subscript notational scheme adopted by the authors (third column of Table 1) is old-fashioned. The American National Standards Institute (ANSI) Committee Z94 recommended two standardized notational schemes in 1970--mnemonic and functional (10). These are shown in the last two columns of Table 1. Virtually all engineering economy textbooks published during the past decade have adopted one of these two schemes. (The new ANSI committee report, to be published shortly, will recommend universal adoption of the functional notation.)

#### End-of-Period Convention

The evaluation models described in the Procedural Guide imply the end-of-period convention for cash flows and compounding and discounting. For example, the series PW factor is used to determine the equivalent present value of annual safety benefits as well as the equivalent present value of net annual operating and maintenance costs. Specifically,

$$PWOC = I + K(P/A, i, N) - T(P/F, i, N) \quad (4)$$

$$PWOB = B(P/A, i, N) \quad (5)$$

where

I = initial implementation cost,

K = net annual operating and maintenance costs,

T = salvage value,

B = annual safety benefits in dollars saved,

N = service life,

(P/A, i, N) = uniform-series PW factor, and

(P/F, i, N) = single-payment PW factor.

These formulations imply that annual effects--operating and maintenance costs and safety benefits--occur at the end of each period. These implications, or assumptions, are unwarranted. Annual operating and maintenance costs, for example, are likely to occur at a number of times within the year, say, quarterly, monthly, or daily. And safety benefits, in a statistical sense, are distributed uniformly over the year. Thus a more-reasonable discounting model should provide for continuous cash flows within the year with continuous discounting at effective interest rate i. (As a rule of thumb, the

Table 1. Comparison of notational schemes.

Factor	Algebraic Format	Notational Scheme		
		FHWA	Mnemonic	Functional
Capital recovery	$i(1+i)^N / [(1+i)^N - 1]$	$CR_n i$	$(CR, i, N)$	$(A/P, i, N)$
Sinking fund	$i / [(1+i)^N - 1]$	$SF_n i$	$(SF, i, N)$	$(A/F, i, N)$
Series PW	$[(1+i)^N - 1] / i(1+i)^N$	$SPW_n i$	$(SPW, i, N)$	$(P/A, i, N)$
Single-payment PW	$1 / (1+i)^N$	$PW_n i$	$(PW, i, N)$	$(P/F, i, N)$

continuous model is more accurate than the end-of-period model when there are at least four cash flows within the period.)

The discount models proposed in the Procedural Guide are easily modified to reflect the continuous-cash-flow assumption. One simply uses the correction factor  $i/\ln(1+i)$  in those instances in which there are at least four occurrences within the year. Thus,

$$PWOC = I + K[i/\ln(1+i)](P/A, i, N) - T(P/F, i, N) \quad (6)$$

$$PWOB = \bar{B}[i/\ln(1+i)](P/A, i, N) \quad (7)$$

The magnitude of the correction factor is a non-linear function of the interest rate. When  $i = 10$  percent, for example,  $i/\ln(1+i) = 1.049$ . That is, the end-of-period assumption understates the annual consequences by about 5 percent. This error, I believe, is not insignificant.

#### Treatment of Unequal Service Lives

The authors properly draw the attention of users to potential problems created when projects contain multiple countermeasures that have unequal service lives. They are quite correct in stating: "While the economic evaluation of a completed project does not involve comparison of alternatives, the determination of present worth of costs for improvements with unequal service lives becomes a problem similar to the issue of comparison of alternative projects" (6, p. E-8). The governing principle here is that all alternatives must be measured over a common planning horizon in order for differences between alternatives to be fully and fairly assessed. Thus, if a component of a project has a service life  $n$  that is shorter than the life of the project itself  $N$ , the analyst must assess the consequences between periods  $n$  and  $N$  to complete the evaluation.

After making this point, the authors assert that only the annualized B/C formulation can be used for projects that have multiple countermeasures with unequal service lives; the PW formulation cannot be used. Put somewhat differently, the authors' position is that the B/C ratio must be based on the annualized approach:  $B/C = EUAB/EUAC$ . This instruction is misleading, if not incorrect. It stems from a failure to appreciate fully the assumption inherent in the annualized formulation.

Either the annualized or the PW formulation, properly applied, can lead to valid analysis in the presence of alternatives (or components) that have unequal lives. This can be illustrated by a very simple numerical example. Consider two alternatives,  $X$  and  $Y$ , with cash flows as follows:

Alternative	End of Period				
	0	1	2	3	4
X	-100	40	40	40	40
Y	-80	60	60		

(For ease of calculation, we will assume that  $i = 0$ . This simplification has no bearing on the underlying principles, but it does simplify the

arithmetic.) It may be readily seen that

$$PWOB(X) - PWOC(X) = 60 \quad (8)$$

$$PWOB(Y) - PWOC(Y) = 40 \quad (9)$$

$$EUAB(X) - EUAC(X) = 60/4 = 15 \quad (10)$$

$$EUAB(Y) - EUAC(Y) = 40/2 = 20 \quad (11)$$

Which of the above is correct? Is  $X$  preferred to  $Y$  or is  $Y$  preferred to  $X$ ? The answer is that no conclusion can be drawn because the analysis is incomplete at this point. If we adopt the assumption that a replacement for  $Y$  will be implemented at the end of two periods and if this replacement ( $Y'$ ) is identical in every respect to the original  $Y$ , then the net PW of this four-period sequence of cash flows for  $Y$  and its successor ( $Y'$ ) is  $40 + 40 = 80$  and its net benefit per period is  $80/4 = 20$ . Now the alternatives may be compared by either the annualized or the PW formulation because the planning horizon is constant for both:

$$PWOB(X) - PWOC(X) = 60 \quad (12)$$

$$PWOB(Y + Y') - PWOC(Y + Y') = 80 \quad (13)$$

$$EUAB(X) - EUAC(X) = 60/4 = 15 \quad (14)$$

$$EUAB(Y + Y') - EUAC(Y + Y') = 80/4 = 20 \quad (15)$$

It will be noted, of course, that the proper conclusion would have been determined initially by simply using the annualized formulation. But this is so only because of this critical assumption: Replacement(s) for the shorter-lived investment is (are) identical in every respect to the original investment. This assumption is commonly employed in engineering economy textbooks, homework, exams, etc., and students form the unfortunate impression that the annualized approach always yields valid results when one is dealing with unequal lives of components of the analysis.

Parenthetically, it may be noted that the criteria used in the preceding paragraph to illustrate this issue are

1. Maximize (net PW) =  $\max(PWOB - PWOC)$ , and
2. Minimize (net EUAB) =  $\min(EUAB - EUAC)$ .

These were selected because of the intention here to focus on the issue of unequal lives, and these two criteria avoid the ranking problem that arises when the B/C ratio method is used. To demonstrate that the principle outlined above is also valid when the B/C criterion is used, observe the formulations in Table 2. (Note that the B/C ratios for  $Y$  and  $Y+Y'$  are equal because of our earlier assumption of identical replication. This will only be true under this particular condition.) The two alternatives of interest here are  $X$  and  $Y+Y'$ . Since each results in a B/C ratio greater than unity, each is preferred to the do-nothing alternative. To determine whether  $Y$  is preferred to  $X$  (or, more precisely, to determine

Table 2. Analysis by using B/C criterion.

Alternative	Life	Formulation	
		PW	Annualized
X	4	PWOB/PWOC = 160/100 = 1.6	EUAB/EUAC = 40/25 = 1.6
Y	2	PWOB/PWOC = 120/80 = 1.5	PWOB/PWOC = 60/40 = 1.5
Y + Y'	2 + 2	PWOB/PWOC = 240/160 = 1.5	PWOB/PWOC = 60/40 = 1.5

whether Y+Y' is preferred to X), the incremental B/C ratio must be computed:

Incremental Computation	Formulation	
	PW	Annualized
Benefits	240 - 160 = 80	60 - 40 = 20
Costs	160 - 100 = 60	40 - 25 = 15
B/C ratio	80/60 = 1.33	20/15 = 1.33

In either formulation, the B/C ratio exceeds unity, and thus, on the basis of this criterion, alternative(s) Y+Y' is (are) preferred to alternative X.

The criticality of the identical-replication assumption may be illustrated by a simple extension of the above example. Suppose that the replacement (Y') to the original Y costs 110 units at the start of the third period. Other cash flows are the same:

Alternative	End of Period				
	0	1	2	3	4
Y	-80	60	60		
Y'			-110	60	60

Now the comparison with X is as follows:

$$PW(X) = ⑥ \quad (16)$$

$$PW(Y + Y') = 50 \quad (17)$$

$$EUAB(X) = 60/4 = ⑤ \quad (18)$$

$$EUAB(Y + Y') = 50/4 = 12.5 \quad (19)$$

Without careful attention to the cash flows associated with the replacement(s), simplistic use of the annualized approach may lead to improper results.

Because the identical-replication assumption is seldom justified outside the artificial world of textbooks, it is recommended that analysts consider carefully the cash-flow consequences between the end of the service life of the shorter-lived investment and the end of the planning horizon. Otherwise, serious errors could result.

#### Time Distribution of Costs and Benefits

The proposed procedure does not give guidance to users as to the proper treatment of costs and benefits when they vary over the planning horizon (life of the project). Both the annualized (uniform-series) and PW formulations as proposed by the authors infer that annual operating and maintenance costs, as well as annual safety benefits, occur uniformly at the end of each year throughout the planning horizon. Specifically,

$$B/C = \bar{B}/[I(A/P, i, N) + K - T(A/F, i, N)] \quad (20)$$

or

$$B/C = [\bar{B}(P/A, i, N)]/[I + K(P/A, i, N) - T(P/F, i, N)] \quad (21)$$

where (A/P, i, N) is the capital recovery factor and (A/F, i, N) is the sinking fund factor.

There are, however, several other patterns of consequences that the analyst may well encounter in

real-world problems. Let  $C_j$  be the magnitude of the consequence in the  $j$ th period. Compound-interest factors exist in the engineering economy literature for the following sequences:

1. Uniform:  $C_1 = C_2 = \dots = C_N$ ;
2. Arithmetic gradient:  $C_{j+1} = C_j + G$ , where  $G$  is the amount of periodic increase or decrease; and
3. Geometric gradient:  $C_{j+1} = (1+a)C_j$ , where  $a$  is the rate of period increase or decrease.

In the event that the consequences from period to period are not described by one of these well-behaved series (i.e., the consequences are irregular), the following models may be used:

$$PW = \sum_{j=1}^N C_j(1+i)^j \quad (22)$$

$$\text{Equivalent uniform annual amount} = (A/P, i, N) \sum_{j=1}^N C_j(1+i)^j \quad (23)$$

Our point here is that the computational models provided in the Procedural Guide, based on the uniform-series assumption, are overly simplified. Actual experience or projections are likely to be best described by arithmetic or geometric gradient series or, more likely, by the generalized formulation, which also accommodates an irregular pattern of consequences. Thus it is recommended that the economic models be modified as follows:

$$B/C = PWOB/PWOC = \sum_{j=1}^N B_j(1+i)^j / [I - T(1+i)^{-N} + \sum_{j=1}^N K_j(1+i)^j] \quad (24)$$

where all notation is as defined earlier except that  $B_j$  is the annual safety benefits in dollars in the  $j$ th period and  $k_j$  is the cost of operations and maintenance in the  $j$ th period.

Note that the above formulation assumes that all elements of costs and benefits occur at the end of their respective periods. (The initial cost, it is assumed, occurs in a lump sum at the beginning of the first period.) In the event that the continuous-cash-flow convention appears more appropriate, the factor for converting from end of period to during period is simply  $i/\ln(1+i)$ .

#### Discount Rate

As noted previously, the authors suggest that "an annual interest rate of 10% may be used when standard policies do not dictate otherwise" (6, p. E-10). The justification for this value is not provided, however. [The figure of 10 percent is probably based on the 1971 recommendation of the U.S. Office of Management and Budget (11).] Some additional substantiation would be welcome. In any event, my view, admittedly without proof, is that the 10 percent rate understates the true marginal cost of capital in the United States at the present time.

#### Risk and Uncertainty

The principal focus of the manual is the historical

performance of highway safety projects and improvements. Nevertheless, it is clear that evaluations of past efforts are relevant insofar as they affect future decisions. To determine that some previously implemented project or improvement has been cost-beneficial or cost-effective is a sterile exercise unless this information can be used with respect to future decisions about similar or identical investments. To put this somewhat differently, a successful past decision should be replicated in the future, assuming, of course, that the future will yield the same consequences as those previously experienced.

It is this last assumption that is most troubling. There is no assurance that future consequences will in fact be repeated. The reduction of an average of five injury accidents per year over the past six years, for example, may not be repeated over the next six years (or even 20 years) because of a variety of factors: changes in traffic density, vehicle speeds, weather conditions, vehicle design characteristics, and so on. Forecasts of specific costs of operation and maintenance over a 20-year planning horizon may or may not be reasonably accurate. The elements of the analysis--operational results and unit costs--are random variables. The user should be advised to recognize this inherent variability and deal with the issue formally in the analysis. Surprisingly, with the singular exception of the use of sensitivity analysis for the discount rate, this issue of risk and uncertainty is not addressed in the manual. (Note that this issue is separable from the question of statistical significance of observed phenomena.)

#### References

Short lists of suggested readings are included in each section of the Procedural Guide. In the Economic Analysis section, Function E, there is a list of eight references. There is also a 17-entry bibliography included among the appendices.

Unfortunately, neither the suggested readings nor the bibliography contain annotated references, and thus the user has no guidance as to how they are to be used. The references are uneven in quality. They are addressed to quite different issues, even within the same list of suggested readings, and not all of the text of certain individual references is relevant. The user needs some help, and the manual provides none.

It should also be noted that many of the references in the suggested readings are incomplete.

Only the author, title, and date are given. In the absence of publisher information, including mailing address, the interested reader has no way of knowing how to obtain the reference.

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## Optimal Allocation of Funds for Highway Safety Improvement Projects

KUMARES C. SINHA, TARO KAJI, AND C.C. LIU

In the allocation of funds and the scheduling of projects, alternative improvements for all possible locations must be evaluated in a multiyear framework in order to optimize the effectiveness of the entire highway safety improvement program within the constraint of a given budget. A procedure is developed that can be used for optimal allocation of funding available for highway safety improvement projects on a statewide basis. In the model, the reduction in the total number of accidents is the measure of effectiveness. The constraints in-

clude total funding available each year. The model formulation can consider carry-over of unspent funds. A stochastic version of the model is also discussed. A variety of other conditions required by or associated with the policies and objectives of the transportation agency can also be formulated as binding constraints. The application of the model is illustrated. Through a series of sensitivity analyses the impact of the funding level on the effectiveness of a hypothetical highway safety program is evaluated.



Since the enactment of the Highway Safety Act of 1966, a considerable amount of funding has been made available for highway safety improvement programs. However, in many cases the selection of safety improvement projects has not followed any systematic framework, as indicated by a recent report by the General Accounting Office (1). Some states do not make any type of cost-effectiveness analysis of safety improvements, although it has been required by law for several years (2).

In general, the safety projects put into effect through the Highway Safety Act reduced accident rates significantly during the first few years after 1967, even though the safety projects might not have always been selected on a cost-effectiveness basis. The condition of highway safety in those years was so acute that even an indiscriminate selection and implementation of safety projects could cause a safety improvement. But in recent years the accident rates have remained generally stable, and indiscriminate implementation of traffic safety projects can no longer be considered effective. After the initial improvement in safety has taken place, any further improvement will require a careful and systematic approach to achieve cost-effectiveness. This is particularly critical in view of the growing limitation in the funding levels available for such projects.

#### BACKGROUND

Various methods of evaluating highway safety improvement programs have been documented (3). These methods are based on costs and/or benefits. Brown developed a procedure based on cost/benefit optimization (4). However, the problem of establishing the level of benefits in terms of savings in traffic-accident costs is difficult, and any procedure based on dollar values of accident costs can often be misleading. In this context a cost-effectiveness approach is more desirable. Leininger used a cost-effectiveness approach to provide a method for optimal allocation of highway safety budgets for driver education, public safety, and highway expenditures (5). But his study dealt with the evaluation of safety improvement projects; it did not attempt to deal with where, when, and what kind of safety improvements should be installed.

In the allocation of funds and the scheduling of projects, alternative improvements for all possible locations must be evaluated in a multiyear framework in order to optimize the effectiveness of the entire highway safety improvement program within the constraint of a given budget. A procedure is developed that can be used for optimal allocation of funding available for highway safety improvement projects on a statewide basis.

#### BASIC MODEL

In the model, the reduction in the total number of accidents is the measure of effectiveness. The frequency of accidents is directly related to fatalities and injuries on a given highway system. Therefore, the reduction of the total number of accidents can be taken as the decision criterion. However, if it is desired, the reduction of fatal or injury accidents can also be considered as an appropriate decision criterion. The constraint of the model is the total funding available for safety improvement projects in a given year. Then the optimal allocation of funding can be obtained by solving the following integer programming problem:

Maximize:

$$\sum_{i \in A_i} \sum_j N_i r_j g_i X_{ij} \quad (1)$$

Subject to:

$$\sum_{i \in A_i} \sum_j c_j X_{ij} \leq B \quad (2)$$

$$\sum_{j \in A_j} X_{ij} \leq 1 \text{ for each } i \quad (3)$$

where

$N_i$  = total number of accidents for location  $i$ ;

$r_j$  = reduction rate of safety improvement project  $j$ ;

$c_j$  = cost of the safety improvement project  $j$ ;

$g_i$  = growth rate of traffic volume for location  $i$ ,  $g_i = Q_{ai}/Q_{bi}$ ;

$Q_{ai}, Q_{bi}$  = annual traffic volume for location  $i$  after inspection of safety improvement and annual traffic volume before installation of safety improvement;

$B$  = total funding available for entire safety program;

$X_{ij}$  = 1 if safety improvement project  $j$  is installed at location  $i$ , 0 otherwise; and

$j \in A_i$  = safety improvement project  $j$  that is one of the set of alternatives for location  $i$  ( $A_i$ ).

In Equation 1, the objective function--the total number of accidents reduced by the safety program--is maximized. Equation 2 gives the constraint that the total cost of safety improvement projects to be implemented must not exceed the budget ceiling for the safety program. Equation 3 indicates that no more than one safety improvement project can be selected among alternative projects for each location.

#### MULTIYEAR MODEL

A safety improvement program often uses long-term funding and scheduling. Optimal budget allocation for long-term programs should take multiyear programming aspects into consideration. In this section, two types of multiyear models are discussed; one considers no carry-over of unspent budget and the other assumes a carry-over of unspent budget to the following year.

##### No Carry-Over of Unspent Budget

The type of multiyear model in which there is no carry-over of unspent budget can be formulated as follows:

Maximize:

$$\sum_{i \in A_i} \sum_t \sum_j X_{ijt} r_j g_{it} N_i \quad (4)$$

Subject to:

$$\sum_{i \in A_i} [(X_{ijt} - X_{ijt-1})c_j' + X_{ijt}K_j] \leq B_t \text{ for all } t \quad (5)$$

$$\sum_{j \in A_j} X_{ijt} \leq 1 \text{ for all } i \text{ and } t \quad (6)$$

$$X_{ijt} \geq X_{ijt-1} \text{ for all } i, t, \text{ and } j \in A_i \quad (7)$$

where

$c_j'$  = initial cost of safety improvement project;

$K_j$  = annual maintenance cost of safety improvement project  $j$ ;  
 $B_t$  = budget ceiling for  $t$ th year;  
 $g_{it}$  = growth rate of traffic volume for location  $i$  for  $t$ th year,  $g_{it} = Q_{it}/Q_{i0}$ ;  
 $Q_{it}, Q_{i0}$  = traffic volume for location  $i$  in  $t$ th year and in year preceding the safety improvement program period; and  
 $X_{ijt}$  = 1 if project  $j$  is installed at location  $i$  in  $t$ th year, 0 otherwise.

In Equation 4, the objective function--the reduction of the total number of accidents--is maximized. In Equation 5, which deals with the budget ceiling for each year,  $(X_{ijt} - X_{ijt-1})$  equals 1 if safety improvement  $j$  is installed for location  $i$  in the  $t$ th year and 0 otherwise. Equation 6 indicates that no more than one alternative project can be implemented at any location in a given year, and Equation 7 states that if an improvement project has already been installed in a previous year, the maintenance task of that particular project will be performed in the current year. Equations 6 and 7 also imply that, at most, only one alternative project is selected for each location during the whole analysis period.

#### Carry-Over of Unspent Budget

In the type of multiyear model in which there is carry-over of unspent budget, it has been assumed that unspent budget can be used in the following year. Therefore, the budget constraint is different from the model that has no carry-over flexibility. By adding the unspent amount from the  $(t-1)$ th year to the right-hand side of Equation 5, the following equation is obtained:

$$\sum_{i \in A_j} [(X_{ijt} - X_{ijt-1})c_j' + X_{ijt}K_j] \leq B_t + \sum_{t'=1}^{t-1} \left\{ B_{t'} - \sum_{i \in A_j} [(X_{ijt'} - X_{ijt'-1})c_j' + X_{ijt'}K_j] \right\} \quad (8)$$

In Equation 8, the summation from the first year through the  $(t-1)$ th year is shown as follows:

$$\sum_{t'=1}^{t-1}$$

If we rearrange Equation 8, the following equation can be obtained:

$$\sum_{i \in A_j} \sum_{t'=1}^t (X_{ijt'} - X_{ijt'-1})c_j' + X_{ijt}K_j \leq \sum_{t'=1}^t B_{t'} \quad \text{for all } t \quad (9)$$

Equation 9 is then the new constraint concerning budget ceiling in solving the carry-over type of problem.

#### STOCHASTIC VERSION OF MODEL

In the model formulation discussed so far, average values have been considered for the initial cost  $c_j'$ , the annual maintenance cost  $K_j$ , and the reduction rate  $r_j$  of safety projects. However, these values may have a large variance in some cases. Consequently, models should incorporate the stochastic characteristics of these factors.

The observed values of the costs and reduction rate will have intervals as follows:

$$c_j'(1 - \alpha_{cj}) \leq c_{j0} \leq c_j'(1 + \alpha_{cj}) \quad (10)$$

$$K_j(1 - \alpha_{kj}) \leq K_{j0} \leq K_j(1 + \alpha_{kj}) \quad (11)$$

$$r_j(1 - \alpha_{rj}) \leq r_{j0} \leq r_j(1 + \alpha_{rj}) \quad (12)$$

where  $c_{j0}$ ,  $K_{j0}$ ,  $r_{j0}$  are the observed values of the initial cost, the annual maintenance cost, and the reduction rate of safety improvement project  $j$  and  $\alpha_{cj}$ ,  $\alpha_{kj}$ ,  $\alpha_{rj}$  are the percentage of estimation error of the initial cost, the annual maintenance cost, and the accident reduction rate of safety improvement project  $j$ . The values of  $\alpha_{cj}$ ,  $\alpha_{kj}$ , and  $\alpha_{rj}$  can be estimated from the sample variance values of initial cost, annual maintenance cost, and reduction rate, respectively.

Another variance inherent in policymaking--the level of cost overrun allowable--is also brought into consideration in the stochastic model. This not only changes the right-hand sides of Equations 5 and 9 but also imposes a new constraint on the objective function of the model in which there is no carry-over, which restricts the total cost of the safety program to be less than the available budget plus allowable cost overrun.

By adding all these stochastic characteristics, the multiyear model for the case in which there is no carry-over would be as follows:

Maximize:

$$\sum_{i \in A_j} \sum_t X_{ijt} r_j (1 - \alpha_{rj}) g_{it} N_i \quad (13)$$

Subject to:

$$\sum_{i \in A_j} (X_{ijt} - X_{ijt-1})c_j(1 + \alpha_{cj}) + X_{ijt}K_j(1 + \alpha_{kj}) \leq B_t \quad \text{for all } t \quad (14)$$

$$\sum_{i \in A_j} \sum_t (X_{ijt} - X_{ijt-1})c_j(1 + \alpha_{cj}) + X_{ijt}K_j(1 + \alpha_{kj}) \leq \theta \sum_i B_t \quad (15)$$

and Equations 6 and 7.

In Equations 14 and 15,  $\theta$  is the percentage of the level of cost overrun allowable and all other terms are as defined before.

For the carry-over case, the model would be composed of Equations 13, 6, 7, and the following:

$$\sum_{i \in A_j} \sum_{t'=1}^t (X_{ijt'} - X_{ijt'-1})c_j(1 + \alpha_{cj}) + X_{ijt}K_j(1 + \alpha_{kj}) \leq \theta \sum_{t'=1}^t B_{t'} \quad \text{for all } t \quad (16)$$

In Equation 16, the summation from the first through the  $t$ th year is shown as follows:

$$\sum_{t'=1}^t$$

It should be noted here that in the above formulation, only the worse side of each  $c_j$ ,  $K_j$ , and  $r_j$  variation is incorporated into the model. This approximation is appropriate, since it is only the increasing cost or decreasing accident reduction rate that is of concern to the transportation agency. The results so obtained should be conservative and reasonable.

A variety of other conditions required by or associated with the policies and objectives of the transportation agency can also be easily formulated as binding constraints and incorporated into the model. For example, suppose that it is required by policy that a predetermined percentage of accident reduction be achieved at each hazardous location at the end of the safety program. Then the following constraints could be used:

$$\sum_{i \in A_j} \sum_t X_{ijt} r_j (1 - \alpha_{rj}) g_{it} N_i \geq \beta \sum_i N_i g_{it} \quad \text{for all } i \quad (17)$$

where  $\beta$  is the required percentage of accident reduction.

## SAMPLE THREE-YEAR SAFETY PROGRAM

To illustrate the application of the multiyear model formulations, the following problem is considered. It is assumed that the study area has seven hazardous locations and that alternative improvement

**Table 1. Accident experience of hazardous locations in sample study area and alternative improvement projects.**

Location	No. of Accidents per Year	Alternative Improvement Project
1	23	A, B, C
2	15	B, C, E
3	10	D, E
4	8	D, F
5	10	B, C
6	13	B, D, F
7	9	A, C
Total	88	

Note: A = rumble strips; B = flashing beacon; C = signal installed; D = illumination; E = sign and flashing beacon; and F = signal modernization and channelization.

projects for these locations have been selected (Table 1). The reduction rates, initial costs, annual maintenance costs, and their stochastic characteristics (percentage of error) as used in this study are shown in Table 2. It is further assumed that the highway safety division of the area has a three-year safety program the total budget ceiling B of which is \$135 000 ( $B_1 = \$35\ 000$ ,  $B_2 = \$45\ 000$ ,  $B_3 = \$55\ 000$ ). It can be assumed that the traffic growth rate is 5 percent per year throughout the area. The problem is to determine the optimal budget allocation for safety improvement projects.

A computer code, MIPZ1, developed by the Department of Agricultural Economics of Purdue University, was used to solve this sample problem (6). MIPZ1 is a zero-one mixed-integer programming package capable of solving problems that have up to 150 rows and 450 columns. The algorithm employed by MIPZ1 is basically a modified additive algorithm of Balas that has major modifications, including a recorded enumeration tree and mixed-integer capabilities.

By assuming that  $\theta = 110$  percent, the sample problem was formulated as a pure-integer programming

**Table 2. Reduction rates, initial costs, annual maintenance costs, and stochastic characteristics for alternative projects.**

Project	Reduction Rate (%)	Error $\alpha_r$ (%)	Initial Cost (\$000s)	Error $\alpha_c$ (%)	Annual Maintenance Cost (\$000s)	Error $\alpha_k$ (%)
A	10	$\pm 10$	7	$\pm 10$	0.2	$\pm 5$
B	20	$\pm 15$	9	$\pm 10$	0.3	$\pm 10$
C	35	$\pm 10$	17	$\pm 10$	0.6	$\pm 5$
D	40	$\pm 10$	15	$\pm 10$	0.5	$\pm 10$
E	45	$\pm 15$	12	$\pm 15$	0.4	$\pm 5$
F	50	$\pm 15$	20	$\pm 15$	0.7	$\pm 10$

**Table 3. Optimal solutions of multiyear model with and without carry-over.**

Case Without Carry-Over			Case With Carry-Over		
Location	Project	Year	Location	Project	Year
Stochastic Model					
1	C	First, second, third	1	C	First, second, third
2	E	First, second, third	2	E	First, second, third
3	E	Second, third	3	E	Second, third
4	D	Second, third	4	F	Third
5	B	Third	5	C	Second, third
6	D	Second, third	6	D	Second, third
7	C	Third	7	C	Third
Nonstochastic Model					
1	C	First, second, third	1	C	First, second, third
2	E	First, second, third	2	E	First, second, third
3	E	Second, third	3	E	Second, third
4	F	Third	4	D	Second, third
5	B	Second, third	5	C	Third
6	F	Second, third	6	F	Second, third
7	C	Third	7	C	Third

Note:  $B_1 = \$35\ 000$ ;  $B_2 = \$45\ 000$ ;  $B_3 = \$55\ 000$ ;  $\theta = 1.10$ .

**Table 4. Results of optimal solutions of multi-year model.**

Item	Without Carry-Over		With Carry-Over	
	Stochastic	Nonstochastic	Stochastic	Nonstochastic
No. of accidents expected to be reduced	75.3	86.3	76.2	88.4
Cost of safety improvement projects (\$)				
First year	33 550	30 000	33 550	30 000
Second year	49 370	43 400	51 650	49 600
Third year	41 230	40 700	45 750	37 800
Total	124 150	114 100	130 950	117 400
Cost-effectiveness ratio (\$/accident)	1 650	1 320	1 720	1 330

Table 5. Optimal solutions of stochastic model under five budget scenarios for three cost-overrun ( $\theta$ ) levels.

Budget Scenario (\$000s)	No. of Accidents Expected to Be Reduced		Total Cost of Safety Program (\$000s)		Cost-Effectiveness Ratio (\$/accident)	
	Without Carry-Over	With Carry-Over	Without Carry-Over	With Carry-Over	Without Carry-Over	With Carry-Over
$\theta = 1.05$						
75	44.8	46.6	69.12	77.24	1540	1660
105	58.7	59.4	103.65	104.33	1770	1760
135	73.1	75.3	133.58	124.15	1830	1650
165	78.8	78.8	125.12	124.78	1590	1580
195	85.2	86.8	135.53	125.96	1590	1450
$\theta = 1.10$						
75	45.0	47.8	66.29	81.13	1470	1700
105	60.6	62.2	109.41	111.55	1810	1790
135	75.3	76.2	124.15	130.95	1650	1720
165	82.6	84.7	129.68	132.14	1570	1560
195	86.8	89.6	142.39	133.12	1640	1490
$\theta = 1.15$						
75	46.8	49.8	74.41	84.76	1590	1700
105	64.6	66.9	113.14	118.69	1750	1770
135	76.2	77.5	130.95	131.17	1720	1690
165	84.7	84.7	132.14	132.22	1560	1560
195	89.6	90.8	133.37	140.06	1490	1540

Figure 1. Number of accidents reduced and total funds available ( $\theta = 1.05$ ).

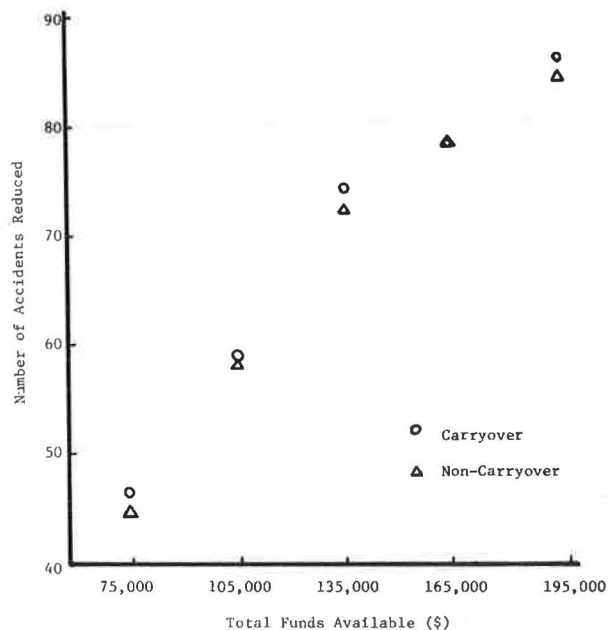
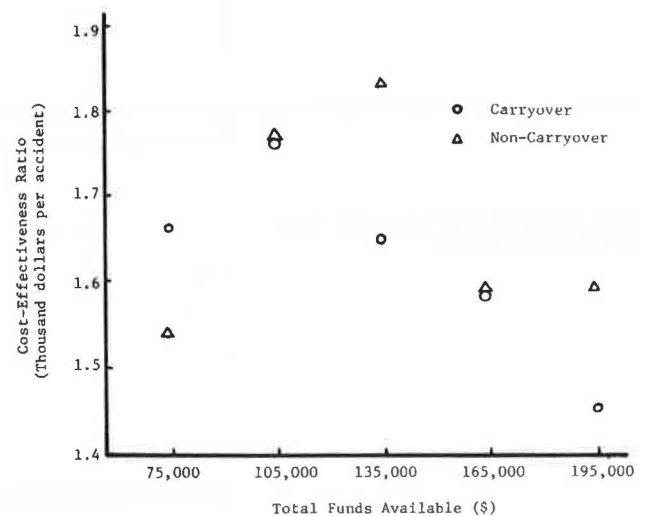


Figure 2. System cost-effectiveness ratio and total funds available ( $\theta = 1.05$ ).



problem that had 51 variables and 59 constraints (58 constraints for the carry-over model). The optimal solutions obtained by MIP2L indicate the year in which a particular alternative project is to be installed at each location to achieve maximum reduction of total accidents during the three-year analysis period subject to the total budget constraint. These solutions are shown in Table 3. The results of these solutions are shown next in Table 4.

In order to further investigate the effects of different amounts of budget availability on total number of accidents reduced, more runs were made by using the stochastic model. The following five budget scenarios were considered:

$B_1$ (\$000s)	$B_2$ (\$000s)	$B_3$ (\$000s)	Total (\$000s)
15	25	35	75

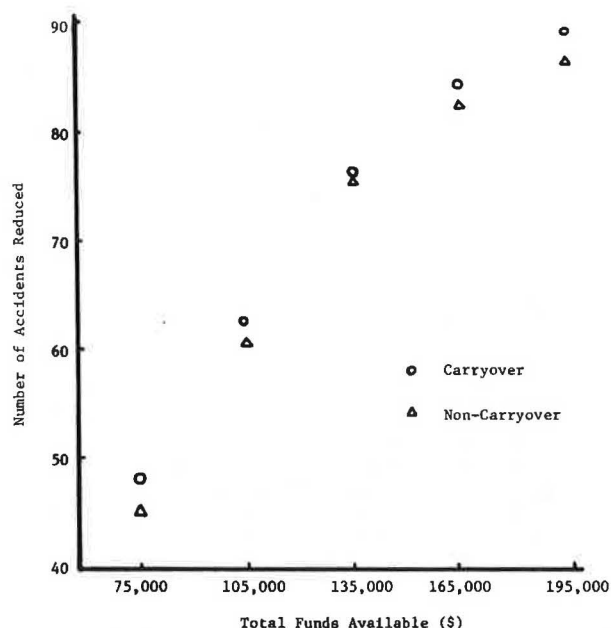
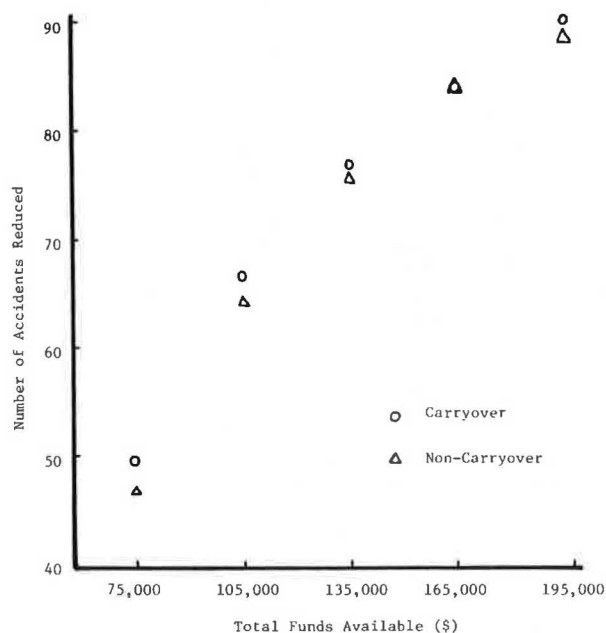
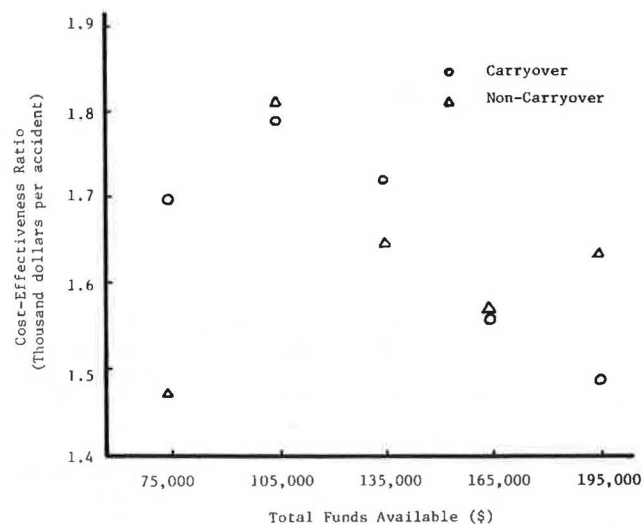
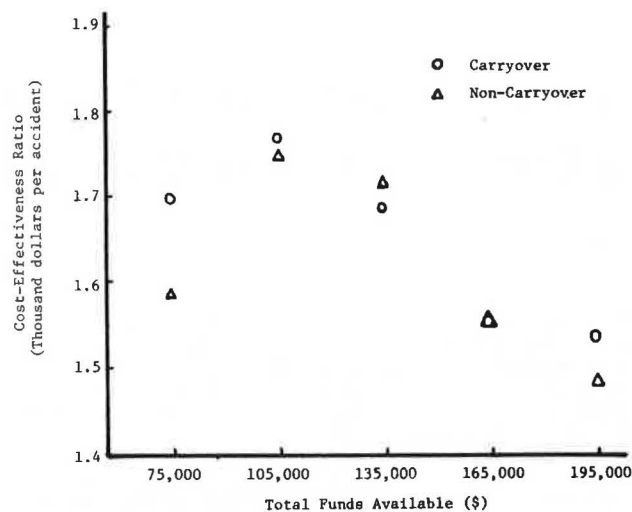
$B_1$ (\$000s)	$B_2$ (\$000s)	$B_3$ (\$000s)	Total (\$000s)
25	35	45	105
35	45	55	135
45	55	65	165
55	65	75	195

Both the carry-over model and the model without carry-over were tested against these five budget ceilings under a set of cost-overrun ( $\theta$ ) levels, namely, 1.05, 1.10, and 1.15. The results are presented in Table 5. For each combination of budget and model type (with carry-over or without carry-over), the total number of accidents expected to be reduced, the total cost of the safety program, and the corresponding cost-effectiveness ratio are tabulated. The results are also plotted for direct comparison in Figures 1 through 6.

Based on the results above, the following observations can be made:

1. Budget carry-over flexibility invariably



Figure 3. Number of accidents reduced and total funds available ( $\theta = 1.10$ ).Figure 5. Number of accidents reduced and total funds available ( $\theta = 1.15$ ).Figure 4. System cost-effectiveness ratio and total funds available ( $\theta = 1.10$ ).Figure 6. System cost-effectiveness ratio and total funds available ( $\theta = 1.15$ ).

increases the total number of accidents that can be reduced under a given budget ceiling (except in two cases in which the number of accidents reduced was equal for both models). However, this flexibility does not necessarily result in a lower cost-effectiveness ratio.

2. Although cost overrun was allowable in all runs ( $\theta = 1.05$ – $1.15$ ), there was no cost overrun for the three higher budget scenarios and the total cost of the safety program was less than the total budget available.

3. For a given budget ceiling, a higher  $\theta$ -value increases the total number of accidents reduced but does not necessarily lead to a lower cost-effectiveness ratio.

4. As the budget ceiling increases (in \$30 000 increments), the total cost of the safety program increases at a decreasing rate. The total cost

appears to be stable between budget scenarios for \$135 000 and \$165 000.

5. For each cost-overrun level studied, the highest cost-effectiveness ratio was associated with budget scenario B = \$105 000 (except ratio without carry-over at  $\theta = 1.05$ ). From that point, the cost-effectiveness ratio actually drops as the budget ceiling increases. This suggests that the budget scenarios studied in this sample problem are probably within the economy of scale.

#### CONCLUSIONS

Since the accident rates have not shown any significant reduction in recent years and the available funding for highway safety improvement projects is becoming limited, it is essential that a systematic approach be taken to determine what projects should be selected. In this paper, an optimization ap-

proach was suggested to deal with the problem of selecting and programming different safety improvement projects. The model formulation included a bauld model and a multiyear model with and without the flexibility of incorporating carry-over of funds. Finally, a stochastic version of the models was formulated to include the uncertainty in estimating cost and accident-reduction parameters. The objective function of the models considered the reduction in the total number of accidents, and the major constraint considered was the funding level.

A hypothetical example was provided to illustrate the use of the models. Through a series of sensitivity analyses, the effect of funding level on the effectiveness of a highway safety program can be determined. The model can also be extended to evaluate the effect of constraints associated with categorical funding of various safety programs.

The stochastic version of the multiyear model can be successfully used to determine what, when, and where safety improvement alternatives should be implemented in order to maximize the reduction of total accidents on an areawide basis, subject to the total funding constraint.

#### ACKNOWLEDGMENT

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## Driver Compliance with Stop-Sign Control at Low-Volume Intersections

JOHN M. MOUNCE

The objective of the research was to determine whether stop-sign control under designated conditions was fulfilling the requirements for application as specified by the Manual of Uniform Traffic Control Devices. This was to be demonstrated by the percentage of observed motorist violations and compliance, assuming that these measures reflect confirmation of need and respect afforded by the public. The dependent variables of violation and compliance rate, conflicts, and accidents were compared in a factorial experimental design with the independent variables of major-roadway volume, minor-roadway sight distance, rural or urban traffic condition, and type of intersection geometry. Minor-roadway volume, signing control, roadway cross section, geography, and weather were all controlled variables. The results from 2830 observations at 66 intersections indicated that the violation rate decreases with increasing major-roadway volume and is significantly high ( $p < 0.001$ ) up to the average-daily-traffic (ADT) level of 2000 and significantly low ( $p < 0.001$ ) above the ADT level of 5000-6000. An interaction effect between major-roadway volume and minor-roadway sight distance results in a violation rate that is significantly higher ( $p < 0.05$ ) when sight is unrestricted than it is when sight is restricted. No conclusive relationships could be established between violations at low-volume intersections either in the rural-urban traffic environment or in the intersection geometry type that had three to four legs. No correlation was established between violation rate and accidents across all study variables; however, conflict rate was reduced at the upper and lower major-roadway volume levels. It was concluded that the operational effectiveness of low-volume intersections could be enhanced with no observed safety detriment by the application of no sign control below major-roadway volume of 2000 ADT, yield-sign control at major-roadway volume between 2000 and 5000 ADT, and, depending on minor-roadway volume, stop-sign control or signalization above 5000 ADT. These recommendations should be modified based on adequate sight distance; yet the determination procedure used in this study seemed insufficient and requires further revision.

The options available for at-grade intersection control range from the right-of-way rule for extremely

low volumes of traffic to computerized signals for extremely high volumes of traffic. The majority of intersections that fall between these extremes uses stop-sign control on the minor roadway. Low-volume intersections at which there is up to 500 average daily traffic (ADT) on at least one intersecting roadway account for literally millions of stop-controlled locations (1). Most of these stop signs at low-volume intersections may be unnecessary and unwarranted, however.

In its general provisions, the Manual of Uniform Traffic Control Devices (MUTCD) states that to be effective a traffic control device should meet five basic requirements (2):

1. Fulfill a need,
2. Command attention,
3. Convey a clear simple meaning,
4. Command respect of road users, and
5. Give adequate time for proper response.

The excessive use of stop control suggests a failure to fulfill a real need, and consequently the control's ability to command the respect of the road user is severely impaired. Such impairment is particularly noticeable where the stop sign has, in effect, become meaningless. Full voluntary compliance at stop signs has steadily declined and is practiced now by less than 20 percent of road users (3). This low compliance rate indicates a misapplication of traffic engineering principles.

Yet the stop sign is still perceived by traffic engineers and the public as desirable. Although both groups believe that everyone is safer if a stop is required on one of the roadways, few studies support this position, especially at low-volume intersections (4,5). In addition, the engineer favors the use of stop signs because they are perceived to be the ultimate safety measure, and this relieves engineer and employer from liability arising from accidents in which other types of controls are used (yield signs, crossroad warning signs, etc.).

In reality, however, the engineer need not take such unnecessary precautions. According to the Uniform Vehicle Code, all drivers on minor roads have similar responsibilities regardless of the sign type--to not enter the intersection when a major-road vehicle is close enough so that such entry would constitute an immediate hazard. To suggest that a stop sign better defines the driver's responsibility is incorrect. The difference is more logically a function of the available sight distance commensurate with a safe approach speed. But the stop sign seems easier to use, although it is not necessarily more efficient nor is it always demonstrably more effective. Since it is a familiar device, it can be employed without much engineering and offers a sense of legal security to the engineer. Many agencies avoid the engineering-judgment issue by applying stop signs indiscriminately.

As a consequence, the driver has been led to think of stop control as the rule rather than the exception. The driver often finds stop signs where the potential conflict is known to be minimal or where it can easily be seen that there is no impending conflict due to exposure to major-roadway traffic. As a result, the driver develops a negative expectancy and begins to treat stop signs at low-volume intersections as yield signs, a reaction aptly shown by stop-control violation rates. The driver does not know immediately where a full stop is important; even worse, if there is not some type of control on the approach, the minor-roadway driver may assume that the other driver is controlled and no longer apply the right-of-way rule.

The overuse or unwarranted application of stop-sign control may be conducive to a complacent attitude toward traffic control in general. This complacency may manifest itself in increased accident frequencies that could be alleviated by more judicious installation of stop control and/or increased use of yield signs at intersections. The criteria for such installations would involve the identification of specific volume levels and sight-distance conditions under which drivers both need and would respect stop-sign control. In this way, only qualified intersections would receive stop controls, which would more closely conform to the intent of the MUTCD guidelines.

#### STUDY OBJECTIVES

The objectives of this study were to assess the effects of major-roadway volume and minor-roadway sight distance on driver compliance with stop signs at low-volume intersections. Driver compliance, which demonstrates obedience and respect, was assumed to be an indicative operational criterion measure of driver confirmation of the need for stop control at the intersection. This need would be dependent on exposure to major-roadway traffic or denial of sufficient sight distance. The hypotheses to be evaluated were that violations to stop-sign control on the minor approach increase as major-approach volume decreases and that violations across major-volume levels decrease with restricted sight distance on the minor approach. If there is a sig-

nificant change in compliance below a designated volume level under conditions of unrestricted sight distance, then it may be demonstrated to be more practical to use some other form of intersection control on the minor approach to reduce needless stops that increase travel time, waste energy, and increase exhaust emissions. The substitution can be employed where there is no significant change in accident experience across the designated volume levels and where there are no sight-distance restrictions.

#### EXPERIMENTAL DESIGN

In accordance with the previously stated objectives, a quasi-experimental design was formulated to address the study variables shown in Table 1. The design is a  $6 \times 2 \times 2 \times 2$  factorial that has the dependent variables of compliance rate and accident rate measured across the independent variables of six major-roadway volumes, two types of minor-roadway sight distance, two traffic conditions, and two types of intersection geometry. Specified variables such as minor-roadway volume, traffic-control regulation, and cross section were also controlled in the design. A minimum of five intersections was evaluated per level; however, the levels were not strictly balanced due to limited available data. Each variable is discussed in detail in the following paragraphs.

#### Independent Variables

Major-approach volume served as an independent variable; a range between 0 and 6000 combined two-way ADT (total of both approaches) was used. The upper volume limit constraint reflected the recommended minimum vehicular volume for consideration of signal installation due to intersecting traffic (2).

The 0-6000 range was broken down into 1000-ADT segments in order to provide an ordinal variable against which changes in the dependent variable could be measured. A minimum of 10 intersections was selected in each of the six groups of major-approach volume and then balanced as reasonably as possible between the rural and urban traffic conditions.

Traffic condition served as an independent variable to assess the nature of the differences in operating characteristics of drivers in urban and rural environments. For the urban condition, the contiguous cities of Bryan and College Station, Texas, were selected; they represent a combined population of 100 000. Those intersections within the metropolitan city limits were designated as urban intersections. Rural intersections were selected from a 10-county region of south central Texas under the jurisdictions of Districts 9, 12, and 17 of the Texas State Department of Highways and Public Transportation. These intersections were specifically restricted to locations outside city limits. Current published volume-count maps were used to locate candidate intersections that met both the volume and traffic-condition constraints.

The third independent variable was minor-approach sight distance along the major approach such that the sight triangle formed would allow the minor-approach vehicle to make a speed adjustment or come to a safe stop prior to the limits of the intersection and prevent an encroachment and/or conflict. This triangle is based on the operational speed of each approach and assumes a 3.0-s perception-reaction time by the driver. Ratios were calculated as previously outlined and based on the standards for intersection sight distance set forth by the American Association of State Highway and Transportation

Table 1. Experimental design.

Variable	Level
<b>Independent</b>	
Major-roadway volume (ADT)	0-1000 1001-2000 2001-3000
Traffic condition	Urban Rural
Minor-roadway sight distance	Restricted Unrestricted
Intersection geometry	Four approaches (cross) Three approaches (T)
<b>Dependent</b>	
Compliance rate	Full compliance [captive (forced) or noncaptive (voluntary)] Partial violation [pause or <8 km/h (roll)] Full violation [>8 km/h (run) or unsafe speed (flagrant)]
Accident rate	Property damage Injury Fatal
Minor-roadway volume <sup>a</sup>	0-500 ADT
Traffic-control regulation <sup>a</sup>	Stop-sign control on minor roadway (MUTCD standard)
Roadway cross section <sup>a</sup>	Two-lane undivided minor approach Two- or four-lane undivided major approach (no channelization)
Geography, climate <sup>a</sup>	South central Texas September-November Fair weather

Note: 1 km/h = 0.6 mph.

<sup>a</sup>Controlled variable (held constant throughout study).

Officials (AASHTO) (6,7). Available sight distance was compared with required sight distance to determine whether it was restricted or unrestricted.

Speeds were sampled by using radar and were measured at the maximum range of detection [due to equipment limitations, approximately 0.40 km (0.25 mile)]. These speeds were taken from inconspicuous positions adjacent to the intersections. Generally speaking, the radar-equipped vehicle was totally hidden from view when the approaching vehicle was at the maximum sight distance.

The sight distance along each minor approach to the stop sign was also measured as well as the stopping distance to the intersection surface. The measurements were recorded as a check to ensure that the visibility both to the traffic control device and to the intersection were adequate, so that violations were not due to detection or recognition problems. To some extent, this measurement acted as a control to the approach alignment, the placement of the traffic control device, and the maintenance of both the stop sign and the area adjacent to the stop sign.

The fourth independent variable was the geometry of the intersection. Both four-leg and three-leg intersections were studied, and turning movements were recorded on each. Obviously, movement and violation patterns are more limited at the three-leg intersection than at the four-leg intersection. The geometry was therefore evaluated in terms of its effect on compliance, conflicts, and/or accidents. No skew or nonstandard configurations were selected.

#### Dependent Variables

The dependent study variables included compliance rate and accident rate at each individual intersection. The compliance rate was assessed under three major categories: full compliance, partial violation, and full violation. Full compliance was defined for this study as the full observance of the legal requirement. Technically, this constitutes a visible state of deceleration to zero and acceleration by the vehicle. Full compliance was further categorized as being captive (forced) due to the presence of vehicles on the major approach of the

intersection or noncaptive (voluntary) due to the absence of vehicles on the major approach and any safety or operational reason for the vehicle to stop. Physically forced compliance occurred within 2 s of the apex of the intersection along either approach at normal operating speed.

A partial violation was measured as either a near stop (pause) at some speed greater than 0 km/h (0 mph) or a moving stop (roll) at a speed between 0 and 8 km/h (5 mph). A full violation was defined as operational behavior that would warrant citation under the majority of municipal and state laws in the United States (8). Full violations were further divided into two categories: (a) vehicles that exhibited a speed greater than 8 km/h past the stop sign and (b) vehicles that exhibited speeds higher than previously specified and judged unsafe and in disregard of both the traffic control device and the right-of-way.

Conflicts were also measured within each compliance and violation category. A conflict occurs when a minor-approach vehicle causes a major-approach vehicle to noticeably decelerate or perform an avoidance maneuver. Nonconflicts represent no impediment to major-approach traffic.

Compliance differences were measured in the field after an appropriate period of observer training to ensure both consistency and reliability in categorization. Compliance and violation rates were determined for both of the minor approaches at four-leg intersections and for the single minor approach at three-leg intersections.

The accident rate was determined based on a three-year history (1976-1978). A mean annual rate was calculated from these data for property-damage, injury, and fatal accidents. Accident-report records were obtained from municipal police and county sheriffs' departments. The major approaches were restricted to two- or four-lane undivided roadways that had variable types of surface, cross-slope, shoulder, and ditch design. Geographical and climatic conditions were controlled as closely as possible. Data were collected at each study intersection for a minimum of 2 h during off-peak time periods of 9:30-11:30 a.m. or 1:30-3:30 p.m. on mid-week days (Tuesday-Thursday).



All data were taken in south central Texas where the terrain was either level or gently rolling pasture and woodland. Data collection occurred during September, October, and November 1979 in fair weather. No measurements were recorded in rain, fog, or ice since these conditions might affect pavement friction or visibility.

#### DATA ANALYSIS

Parametric statistical methods were employed in analyzing the research data. These methods required that the scale of measurement be continuous and either a ratio or an interval. Violation rate, calculated as violations per observed volume, was taken as the comparative measure between variable configurations, and the data were assumed to be continuous by scale. The assumption that the data were normally distributed and homogeneous in variance was tested by using the Kolmogorov Smirnov test ( $p > 0.05$ ) for normality and the F-ratio test ( $p > 0.05$ ) for homogeneity.

Several types of statistical procedures were used in the analysis of the research data. These are listed as follows and are discussed relative to the results of the study:

1. Analysis of variance (ANOVA) for significance of both independent variables in isolation and interactive effects,
2. Duncan multiple-range test for significance between treatment levels of designated independent variables,
3. Linear regression, and
4. Correlation coefficients.

#### RESULTS

Examination of the ANOVA results indicates that both minor-approach sight distance ( $p < 0.05$ ) and major-approach volume ( $p < 0.001$ ) have a highly significant influence on total violation rate, which is the sum of partial and full violations. It can also be seen that the interactive effect of volume and sight distance are significant ( $p < 0.05$ ). The multiple correlation coefficient of determination  $R^2$  for the model that used total violation rate as the dependent variable is very high (0.8023), which means that at least some of these variables account for a large portion of the variation in the dependent variable. Table 2 presents a

summary of the ANOVA results and levels of significance associated with the individual variables.

Only major-approach volume was found to be significant in the ANOVA model that used full violation rate as the dependent variable. This effect is exhibited by the F-ratio and corresponding significance levels ( $p < 0.05$ ). Although the  $R^2$ -value for the model that used full violation rate is acceptable (0.6218), it indicates a weaker multiple correlation than that for the model that used total violation rate; indeed, too weak for use as a predictive model. An interactive effect between geometry and volume was also exhibited for the model that used the dependent variable full violation rate ( $p < 0.05$ ). The model ANOVA that used forced compliance rate as the dependent variable shows the effect of major-approach volume to be highly significant ( $p < 0.001$ ); sight distance also approached significance. Intersection geometry is also seen to be significant ( $p < 0.05$ ), and the  $R^2$ -value is very high for that model (0.8238).

Intersection geometry and sight distance were also highly significant ( $p < 0.01$ ) when measured by voluntary compliance rate; however, major-roadway volume was not found to be significant in the ANOVA model. Partial violation rate was not significantly related to any independent variable. This violation category is the most subjective of any, and the indicated effects may be confounded by other extraneous factors.

The ANOVA for the conflict-rate model indicates that geometry was significant ( $p < 0.05$ ). Sight distance did not display a significant relationship in that model. The multiple correlation coefficient is acceptable (0.6731) but weak. No significant relationships were established by the full-model ANOVA that used total annual accident rate as the dependent variable across all independent variables because the multiple correlation coefficient was unacceptably low (0.3735).

The variable relationships were further analyzed by using the Duncan multiple-range test to determine the treatment ranges between which a designated significant ( $p < 0.05$ ) difference in means existed. For the dependent variable total violation rate and the independent variable major-approach volume, these significant differences occurred between the volume ranges 0-2000, 2000-5000, and 5000-6000 ADT (Figure 1).

By using full violation and forced compliance rates as dependent variables, significant differ-

Table 2. ANOVA summary of variable relationships.

Independent Variable	Dependent Variable						
	Compliance Rate						Total Annual Accident Rate ( $R^2 = 0.3735$ )
	Forced ( $R^2 = 0.8238$ )	Voluntary ( $R^2 = 0.6720$ )	Partial Violation ( $R^2 = 0.4927$ )	Full Violation ( $R^2 = 0.6218$ )	Total Violation ( $R^2 = 0.8023$ )	Conflict Rate ( $R^2 = 0.6731$ )	
Condition	0.2444	0.2041	0.1546	0.1781	0.8085	0.4926	0.8421
Geometry	0.0126 <sup>a</sup>	0.0082 <sup>a</sup>	0.5986	0.8476	0.3656	0.0049 <sup>b</sup>	0.8587
Sight distance	0.5509	0.0050 <sup>b</sup>	0.1087	0.9587	0.0199 <sup>b</sup>	0.8242	0.6757
Volume	0.0001 <sup>c</sup>	0.2260	0.3560	0.0183 <sup>a</sup>	0.0001 <sup>c</sup>	0.0636	0.8170
Condition/geometry	0.3880	0.4381	0.7489	0.9720	0.6198	0.0872	0.2381
Condition/sight distance	0.5108	0.3436	0.5156	0.4545	0.9605	0.3082	0.9965
Condition/volume	0.6162	0.4426	0.8801	0.8659	0.6339	0.7270	0.6770
Geometry/sight distance	0.3362	0.9498	0.8858	0.3990	0.2501	0.8181	0.7505
Geometry/volume	0.1984	0.2839	0.5066	0.0448 <sup>a</sup>	0.1728	0.2235	0.5071
Sight distance/volume	0.2501	0.2121	0.8108	0.5615	0.0126 <sup>a</sup>	0.5232	0.5071
Condition/geometry/sight distance	0.6338	0.4459	0.5298	0.5941	0.9053	0.8658	0.8836
Condition/geometry/volume	0.8071	0.5928	0.9878	0.7348	0.8387	0.0915	0.9912
Condition/sight distance/volume	0.6755	0.6600	0.5291	0.9568	0.5506	0.9743	0.7893
Geometry/sight distance/volume	0.5104	0.5757	0.3655	0.4266	0.6999	0.1834	0.8550
Condition/geometry/sight distance/volume	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

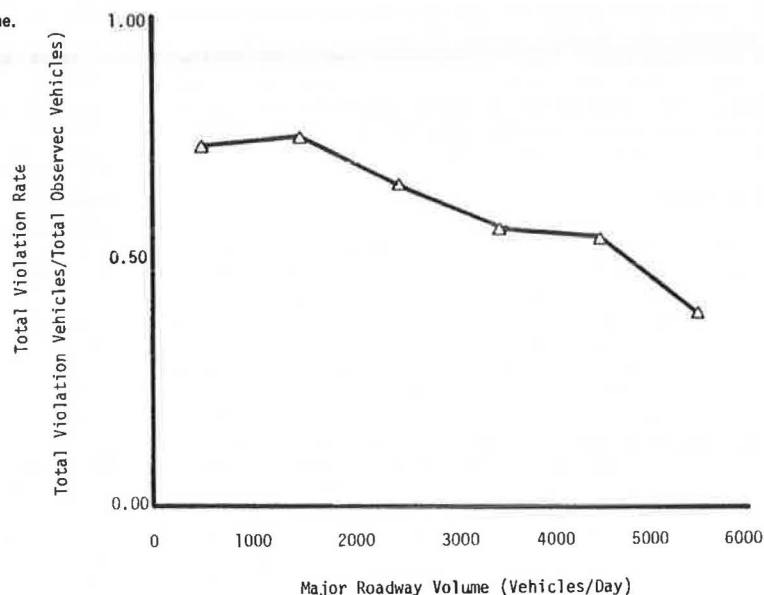
<sup>a</sup> $p > 0.05$ .

<sup>b</sup> $p > 0.01$ .

<sup>c</sup> $p > 0.001$ .



Figure 1. Mean total violation rate versus major-roadway volume.



ences in treatment means occur between 0-2000 ADT and 5000-6000 ADT. There are no significant differences between the volume-level means from 2000 to 5000 ADT. These designated volume breakpoints show no significance when partial violation and voluntary compliance rates are taken as dependent variables. The pattern of significant differences in treatment means by volume level is vastly altered in the conflict-rate model. No significance was established between total accident rate and major-roadway volume. Sight distance and major-roadway volume were found to interact significantly as measured against the dependent variable of total violation rate (Figure 2). Conflict rate and forced compliance rate both displayed a significant interactive relationship with type of intersection geometry and major-roadway volume.

A linear regression was performed based on total violation, full violation, forced compliance, and partial violation, all of which hold significant relationships as specified by the ANOVA. These were taken as the dependent variables with regression about the independent variable of major-approach volume. A linear regression with respect to conflict rate was not undertaken since cursory review indicated no linear relationship. The following equation clearly indicates that major-roadway volume is the best predictor of total violation: total violation rate =  $0.794\ 889 - 0.000\ 063$  (major-roadway volume). The correlation coefficient for this regression is approximately 0.70 and significant to the 0.01 level. A graphical comparison of the observed data and predicted regression line is shown in Figure 3.

#### SUMMARY

In summary, it may be stated that major-roadway volume and minor-roadway sight distance affect the violation rate of stop-sign control. Major-roadway volume and total violation rate hold a strong negative relationship: As volume increases, the total violations decrease. Full violations were also found to be significantly related to major-roadway volume and follow the same trend as total violations. However, there is a mean difference in driver behavioral response of approximately 40-50 percent between full and total violation rates.

The significant breakpoints along major-approach

volume seem to occur around 2000 and 5000 ADT, and total violation rate stabilizes in the lower volume range at approximately 75 percent and drops below 50 percent in the higher volume range. One explanation for this is that approximately 25 percent of drivers that traverse low-volume intersections that have major-roadway volume less than 2000 ADT perceive the need for stop-sign control. Stated differently, only 25 percent of drivers accept stop signs at face value. Conversely, at low-volume intersections that have major-roadway volume that exceeds 5000 ADT, confirmation of this need for intersection control seems readily apparent due to major-roadway traffic exposure as exhibited by the decrease in total violations.

The influence of major-roadway volume on conflict rate shows that less than 2 percent of the vehicles on minor roads create conflicts with a major-road vehicle at both the low-volume (0-2000 ADT) and high-volume (5000-6000 ADT) ranges. Yet conflicts increase in the mid-ranges and peak at almost 7 percent with the 3000- to 4000-ADT level. An explanation for this may be that at the lower major-roadway volumes, the probability of conflict is extremely low, even with 100 percent violation. This explanation is consistent with a previous theoretical study reported by Stockton (9). As major-roadway volume and the probability of conflict increase, however, drivers are still unable to perceive the potential for conflict and continue to make violations, behavior that is reinforced at no risk under lower-volume intersection conditions. Thus, conflicts increase until a higher major-roadway volume level (3000-4000 ADT) forces the driver to perceive the greater risk of conflict, thus producing a decline in total violations and a subsequent reversal in the pattern of conflict rate.

There is also the possibility that driver expectancy may be an influencing factor in this pattern of data. Drivers on the minor road are generally familiar with the major road and judge its potential conflict on the basis of previous experience. Between 2000 and 5000 ADT on the major roadway, there seems to exist a situation of indecision and risk behavior by the driver on the minor roadway. The driver's expectancy of the probability of conflict that was learned at low-volume intersections at which there was 0-2000 ADT on the major roadway is not necessarily confirmed. At some point within the

Figure 2. Mean total violation rate measured against sight distance and major-roadway volume.

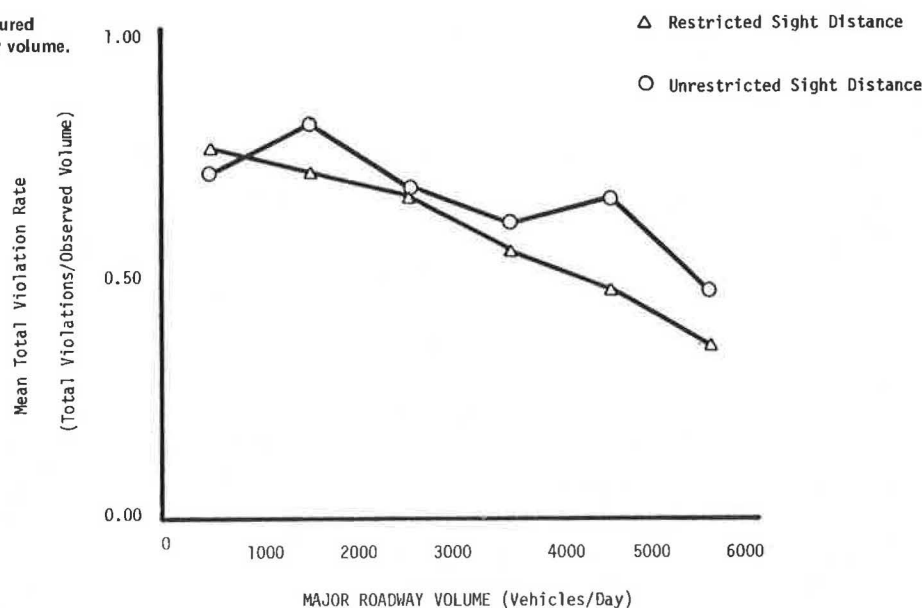
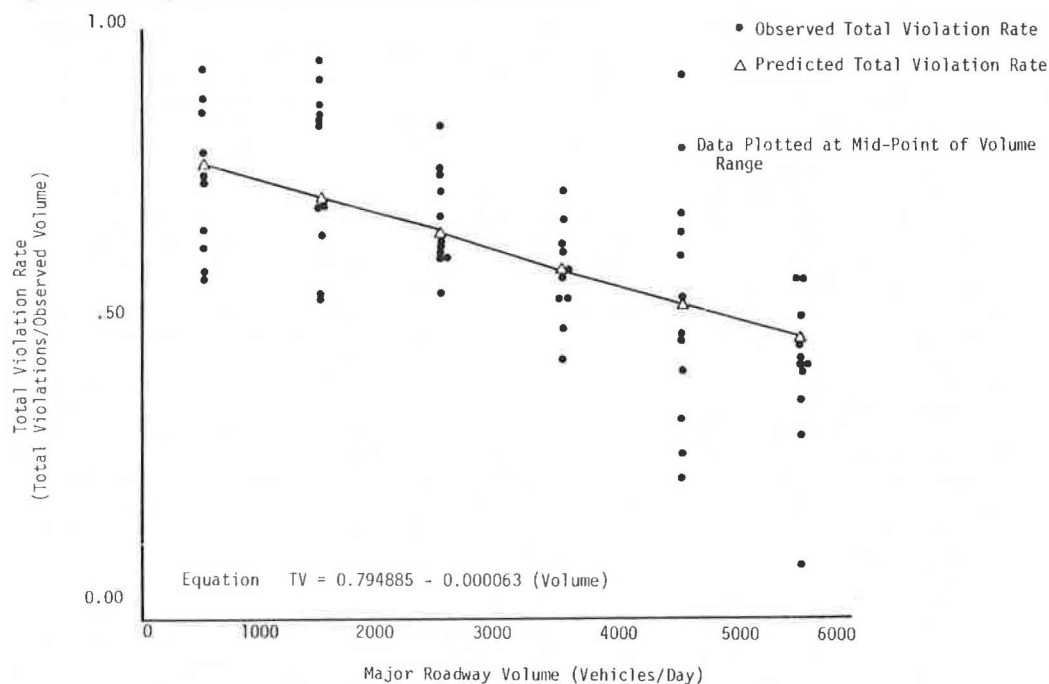


Figure 3. Linear regression: total violation rate versus major-roadway volume.



range 3000-4000 ADT, the driver apparently begins to form a new expectancy due to increasing exposure to major-roadway traffic, and a new behavior pattern results, which causes a reduction in conflicts. As this expectancy of encountering traffic on the major roadway is fulfilled, compliance increases, violations decrease, and the preservation of inappropriate action for intersection conditions is reduced.

Minor-roadway sight distance was found to affect the total violation rate significantly and, conversely, the total compliance rate. Total violations were higher at low-volume intersections at which there was unrestricted sight distance and lower at locations at which there was restricted sight distance. It must be kept in mind that the classification of sight restriction was based on the

calculation of a composite ratio between available and required intersection sight distance for all sight-triangle quadrants. This technique is questionable and possibly creates bias because an intersection is rated by sight distance as a whole entity rather than by individual sight-triangle quadrants.

There was also an interaction effect between sight distance and volume for total violation rate. For both restricted and unrestricted conditions, the total violation rate decreases as major-roadway volume increases. The most visible decline in violations again occurs at approximately 2000 and 5000 ADT. These breakpoints also display the greatest effects of sight-distance restriction as a modifier of violations.

Total violation rate is reduced by up to 20 per-



cent by restricted intersection sight distance within these volume ranges, whereas mid-range major-roadway volumes show maximum declines of only 10 percent. No other category of dependent variable was significantly affected by minor-approach sight distance. Apparently, minor-approach sight distance affects the violation and compliance classifications in general, whereas its effect on any one classification remains insignificant.

It may also be reasonable to assume that at the low-volume range on the minor roadway and at the high-volume range on the major roadway at which driver expectancy is predominantly confirmed by the presence or lack of traffic, unrestricted sight distance acts as a further confirmation that leads to higher violations or compliance. Within the mid-range, unrestricted sight distance may only confirm to the driver that his or her preconception of acceptable risk behavior based on experience at low-volume intersections is now inaccurate.

Intersection geometry was found to be significantly related only to compliance measures. A greater mean percentage of observed vehicles was in forced compliance at three-leg intersections than at four-leg intersections. The only possible explanation for this would involve a disproportionate number of turning movements between three- and four-leg intersections.

Conflict rate was also discovered to be significantly affected by intersection geometry. The mean percentage of conflicts on three-leg intersections was lower than that on four-leg intersections. This confirms published information on differences in potential conflict points. Thus, a higher level of conflicts is consistent with four-leg intersections since these intersections have more conflict points.

No significant relationship could be established between any dependent variables and the independent variable of traffic condition. No significant differences in response between rural and urban intersections were displayed by the data. Although not directly evaluated by a single previous study, other studies implied that violation rates would differ between rural and urban areas (11).

The other primary dependent measure, accident rate, was not significantly affected by independent variables. No correlation could be established between accidents and any other violation measures or with conflict rate at any volume level on major and minor roadways. This finding may be caused by the fact that at these low-volume levels for both major and minor roadways, a three-year accident history is not sufficient to establish trends.

It should be noted that it could not be determined that increased violation rate caused an increase in accidents for the intersection volume parameters studied. Therefore, if violation and compliance are assumed to depict driver operational behavior at an intersection, then low-volume intersections (0-2000 ADT on major roadway) are being used as if there were no traffic control present, yet with no detriment to safety. Within the middle of the volume range, the motorist needs to be informed of the increased probability of conflict, but again, as shown by the violation rate, there is no operational requirement that all minor-roadway vehicles must be stop-controlled. The conflict rate does increase; however, accident experience at these volumes does not warrant stop-sign control; yield signing could be a more meaningful and warranted control. Even at the highest major-roadway volume studied, only 10 percent of minor-roadway traffic voluntarily recognized and obeyed the stop sign in the noncaptive situation. Based on the findings of this study relative to violation and compliance rates, conflict rates, and accidents as the opera-

tional and safety criteria for the effective application of low-volume intersection signing control, the following warrants are recommended for consideration by traffic and transportation officials:

1. No signing control is justified or should be employed at those intersections at which the major-roadway volume is 2000 ADT or less, the minor-roadway volume is 500 ADT or less, and there have been no accidents within a three-year period. This warrant is also contingent on whether the available sight distance along all quadrants of the intersection exceeds the requirement of AASHTO case 1 guidelines. If any of these conditions cannot be met, a more positive form of intersection signing control should be used.

2. For those intersections at which the major-roadway volume is between 2000 and 5000 ADT, minor-roadway volume is 500 ADT or less, and there have been less than two accidents within a three-year period, yield-sign control should be employed. This warrant is also contingent on whether the required available sight distance along all quadrants of the intersection exceed the requirement of AASHTO case 2 guidelines. If any of these conditions cannot be met, a more positive form of intersection signing control should be used.

3. Stop-sign control should be employed at those intersections at which the major-roadway volume is 5000 ADT or more, minor-roadway volume is 500 ADT or less, and there have been two or more accidents within a three-year period. This warrant stands regardless of sight distance availability or requirements. Signalization may be employed as an alternative if justified by other warrants.

Table 3 summarizes the conditions listed above under which each control type should be applied at low-volume intersections. The accident frequencies shown represent a reasonable level of safety. Because of the essentially random nature of accidents observed for all low-volume intersections, a single accident at an intersection is not by itself indicative of a need for greater control. Even two accidents at an intersection represent a marginal condition regarding safety and therefore only a mere hint of a need for more-restrictive control. It is also recognized that as exposure increases, the potential for accidents increases. Therefore, the recommended criteria provide for some margin of error in the direction of more-restrictive control as exposure increases.

#### RECOMMENDATIONS

It is recommended that implementation of the proposed low-volume intersection control warrants be considered in a priority order for two categories: new intersections and existing intersections. New intersections are those created by the opening of new streets, either singly or in subdivisions. For new intersections of low-volume streets that enter major streets at intersections that have less than 5000 ADT (primarily collector streets in urban areas), yield control should be installed soon after the opening of the street. The only analyses required will be an estimate of major-roadway volume and the adequacy of sight distance for proper yield operation. Intersections at which new local streets cross other local streets in a subdivision should be left uncontrolled, provided there is adequate sight distance and no other circumstances that require control.

At existing intersections, control changes at locations at which conditions are known to be within the recommended criteria should be implemented immediately. At all other locations, estimates of



Table 3. Recommended control warrants for low-volume intersections.

Control Warrant	Sight Distance	Accident History	Major-Roadway Volume (ADT)
None	Adequate	None in three years	0-2000
Yield	Adequate	Less than two in three years	2000-5000
Stop	Adequate or inadequate	Two or more in three years	5000+
Stop	Inadequate	-	All

traffic volumes, sight distance, and a determination of accident history must be made prior to putting control changes into effect. For situations in which a citywide or countywide assessment of all intersections is impractical due to funding or personnel constraints, stop-controlled intersections should be considered first because the changeover from stop to yield control produces the maximum benefit. The remaining intersections should be considered as time and funding permit.

It is also recommended that further research be undertaken to address still-questionable issues relative to the proposed warrant for low-volume intersection signing control. These topics are as follows:

1. The legal consequences of several points should be evaluated: the responsibilities of the driver, the misapplication of intersection signing control through a policy that uses the safest device at all locations, and the potential inability to put the proposed warrants into effect because of statutory restrictions.

2. A larger sample of low-volume intersections should be taken and reviewed to further substantiate the findings of this study and the significant relationships identified among the variables.

3. An extension of the study to major-roadway volume levels beyond 6000 ADT would indicate whether the reversal trend in the conflict rate is truly significant or an anomaly shown by further increases in observed conflicts as both potential conflicts and volume increase.

4. Even though minor-roadway sight distance was shown to affect selected operational measures significantly at low-volume intersections, the assessment technique used in this study needs to be evaluated and refined to reflect existing conditions more accurately. The relationship among sight distance, volume, and violation and compliance rates could then be more accurately established.

5. An extension and stratification of minor-roadway volume levels would provide further insight into the effects of this variable on conflicts and accidents.

#### CONCLUSION

These warrants require that a jurisdiction make an assessment of both the combined volumes and sight distances in order to make decisions concerning signing control at low-volume intersections. Such assessment would require more effort from the deci-

sion maker, but the savings to the public would be obvious and substantial. It is hoped that more-judicious and more-definitive application of both stop- and yield-sign control will alleviate the confusion now displayed by drivers, diminish the unsafe behavior, and minimize current violation rates.

The expected result of more-thoughtful sign applications is the heightened attention and respect given sign control by the motoring public. Thus, when the purpose and need for both stop and yield control are more readily perceived by the public, greater public compliance will occur. In order to achieve this end, it is first necessary to realize that universally applied stop control is not the safest or the most-efficient solution to low-volume intersection control.

#### ACKNOWLEDGMENT

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## Abridgment

# Driver Response to a Highway Advisory Radio System in New Braunfels, Texas

JANET C. DABNEY AND CONRAD L. DUDEK

Field studies were conducted in New Braunfels, Texas, to test the effectiveness of a highway advisory radio (HAR) system in diverting freeway traffic destined to a special event (the annual Wurstfest celebration) from the primary arterial routes to an alternate arterial route. Three types of HAR messages were tested. Origin-destination data were collected and a questionnaire was administered to determine driver reactions and attitudes to the HAR route diversion and to identify factors that influenced the drivers' decisions to divert. The findings of the questionnaire study are summarized. The results indicated no differences in response to the three message types. Drivers less familiar with the area were more apt to divert when they heard a message. A high percentage (42 percent) of the drivers interviewed stated that they did not see the advance sign for HAR. Only 56 percent of those who saw the sign tuned to the station. A comparison of HAR tuning and diversion revealed that 67 percent of the drivers interviewed who tuned to HAR diverted to the alternate route.

The Texas Transportation Institute (TTI), in cooperation with the Texas State Department of Highways and Public Transportation (TSDHPT), San Antonio District, and the city of New Braunfels, Texas, conducted field studies in New Braunfels to test the use of a highway advisory radio (HAR) system for diverting traffic during special events. These studies were conducted in conjunction with the annual Wurstfest celebration in New Braunfels. The use of HAR messages to divert freeway traffic from primary arterial routes to a less-congested one was investigated.

A questionnaire was administered by the TSDHPT; then we evaluated it to determine driver attitudes and reactions to the HAR route diversion and to identify factors that influenced the drivers' decisions to divert. Some of the findings of the questionnaire and study are summarized in this paper. Details are included in a report by Dudek and Huchingson (1).

New Braunfels is approximately 35 miles northeast of San Antonio on I-35. Wurstfest, an annual 10-day folk festival, is held at Landa Park, which is located near the downtown area. The event attracts people from several cities in Texas, and most arterial routes in New Braunfels that lead from the freeway to Landa Park become highly congested on weekends during the event. City officials speculated that large percentages of traffic came from cities northeast of New Braunfels that use southbound I-35. Therefore, the HAR study was designed to divert southbound I-35 traffic bound for the Wurstfest.

Figure 1 shows the location of Landa Park relative to I-35 and the New Braunfels exits. Southbound I-35 drivers can take any one of five freeway exits (numbered 1 through 5 in Figure 1) to New Braunfels: US-81, Loop 337, Frontage Road, Seguin Avenue, and Walnut Avenue.

Landa Street, west of Landa Park, intersects Walnut Avenue, which runs directly to I-35. The Walnut Avenue route was selected as the recommended alternate route for this study because it is usually the least congested and leads to convenient parking areas. However, its location after four exits created a somewhat different diversion approach than would normally be expected. The more-common approach is to divert drivers to an alternate route upstream from their intended exit ramps.

In contrast to other reported studies of spe-

cial-event diversion (2,3), Landa Park does not have a central parking facility. Motorists must use private lots, shopping centers, or on-street parking facilities scattered near the park.

## METHOD

The HAR system was operated from a site near radio station FM 306 (see Figure 1). The antenna was mounted on an existing sign support located near the freeway lanes on a fill section. The transmitting equipment (transmitter, tape playback unit, etc.) was placed in the trunk of a vehicle parked at the bottom of the fill section. The system was developed so that it could operate by using power from the car battery. However, power problems developed during the study, and it was necessary to use a portable generator. The generator power resulted in a higher-quality radio signal. The signal was stronger and extended considerably farther than when the car battery was used.

White-on-blue 48x48-in (1.2x1.2-m) radio zone signs were posted on the freeway about 0.75 mile (1.2 km) on either side of the antenna at the limits of the primary radio reception area. Southbound motorists were advised to tune to the 530 AM station by a trailer-mounted advance sign located approximately 1.25 miles (2.1 km) upstream from the antenna. The sign message, WURSTFEST/RADIO TRAFFIC ADVISORY/TUNE 530/1/2 MILE, was composed of individualized letter/number white-on-blue reflectorized panels that had 10-in (25.4-cm) D-series letters. The sign was covered by using four 4x8-ft (1.2x2.4-m) sheets of plywood hooked to the top of the sign trailer when no radio message was being broadcast.

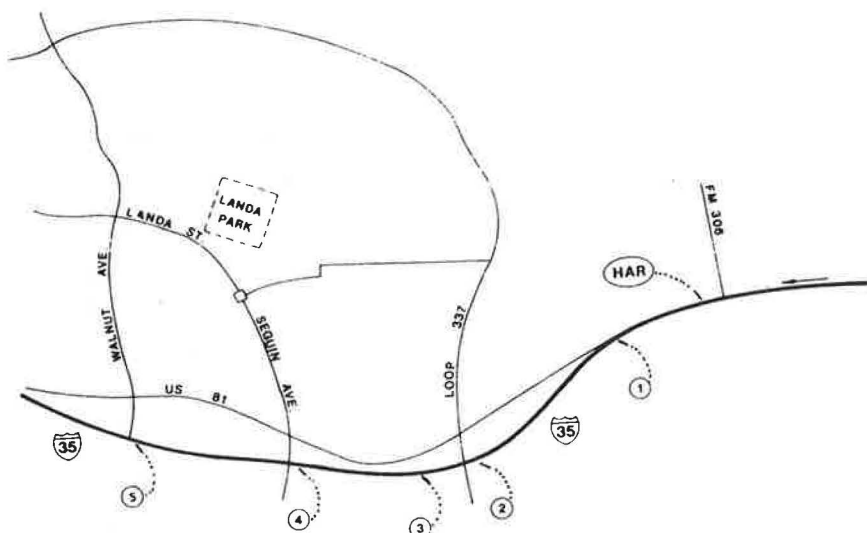
Questionnaires were developed for drivers who took the recommended route and for those on other routes. Questions were included to determine the driver's destination, planned route, familiarity with New Braunfels, type of radio equipment, and experience with the advisory sign and message broadcast signal. In addition, drivers who did not divert were asked open-ended questions about their disregard of the route information presented by HAR and about additional information that would have influenced their choice of route. Drivers on the diversion route were asked to list problems they encountered and the reasons they took the route.

## RESULTS

A total of 1973 vehicles was observed during the two nights during which this study was conducted. Questionnaires were mailed to owners of 1461 of the vehicles. Responses were received from 424 motorists. The effective return rate (number of questionnaires returned as a percentage of the observed number of drivers) averaged 22 percent over the study and was relatively stable. On the average, 85 percent of the drivers who returned the questionnaire went to the Wurstfest. This percentage was fairly constant throughout the study. All subsequent data discussed in this paper are based on the number of responding drivers who were destined for Wurstfest.



Figure 1. Wurstfest study area.



### Advance Sign

Successful operation of an HAR system is in part affected by the advance sign. Failure of motorists to read the sign will affect the size of the system's audience. As shown below, only 58 percent of the Wurstfest-bound respondents who drove through the radio zone while a message was being broadcast saw the sign. Thus, a large percentage (42 percent) of the potential audience was not aware of the HAR system.

Driver	Response (%)		
	Saw Advance Sign	Tuned to HAR	Diverted
Total bound for Wurstfest	58	33	22
Bound for Wurstfest that saw advance sign	-	56	38
Bound for Wurstfest that tuned to HAR	-	-	67

The reasons for this disappointing result are not known. The project staff felt that the sign placement on the first night of the study within a right horizontal curve did not provide sufficient sight distance. The sign was moved to a tangent section on the second night. However, a larger percentage of respondents saw the sign before it was moved than saw it afterwards.

### Tuning to HAR

During the two study days, only 56 percent of the drivers interviewed who saw the advance sign and only 33 percent of the total Wurstfest-bound audience tuned to the HAR station.

The data revealed that a large percentage of the drivers who did not tune to the station after having read the advance sign were simply apathetic toward the system. Of the 72 percent who indicated a degree of apathy, 31 percent preferred to listen to the music that was on their radios, 24 percent stated that they did not need the information, and 17 percent did not want to tune to the HAR station. Only 11 percent of those interviewed stated that they did not understand the message on the advance sign.

### Diversion

The data show that 67 percent of those drivers interviewed who had tuned to the HAR station diverted. As shown above, this is 22 percent of the total bound for the Wurstfest.

The relationship between the driver's familiarity with New Braunfels and willingness to tune to the HAR station is shown below. The results indicate that the degree of driver familiarity did not have any effect on the driver's decision to tune to the HAR station.

Driver's Familiarity	Response (%)	
	Tuned to HAR	Diverted to Walnut Avenue
Within last month	31	15
Within last 18 months	34	21
Within last 5 years	35	28
None	34	31

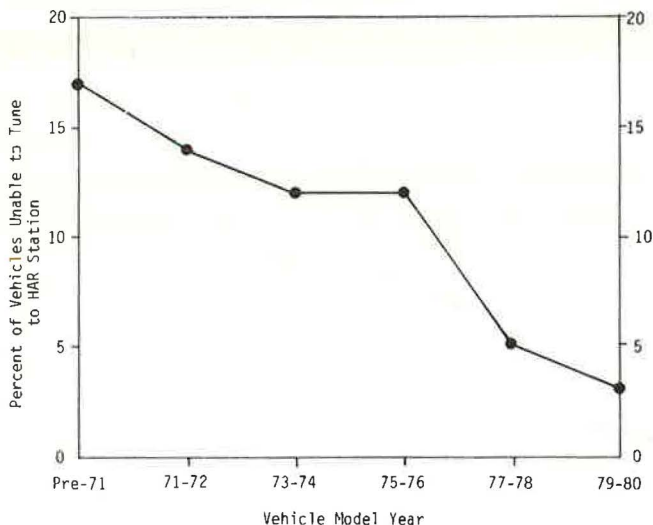
The above tabulation also demonstrates the relationship between driver familiarity and diversion rate.

In general, the diversion rate increased as the driver familiarity with the area decreased. A similar trend was documented in diversion studies conducted by TTI in Dallas (3). In particular, it should be noted that drivers who were very familiar (i.e., those who had been in New Braunfels within the last month) had a low diversion rate (15 percent), especially when their willingness to tune to the HAR station is considered (31 percent). As driver familiarity decreased, this difference diminished so that nearly all the very unfamiliar drivers that tuned to the station also diverted (31 percent diverted of 34 percent that tuned to the station).

### Radio Reception

During this study, some respondents were unable to receive an acceptable HAR signal on their AM car radios. This difficulty was analyzed in relation to the type of antenna (aerial or wire in windshield), the model year of the vehicle, and the installation of the radio (i.e., whether factory-installed). Data analysis indicated that the use of a wire antenna in the windshield seemed to have no effect on the reception characteristics. A similar study in Minneapolis (4) also concluded that windshield antennas had no effect on tuning and reception.

Figure 2. HAR reception related to age of vehicle.



characteristics of AM car radios. The comparison of the model year and the percentage of vehicles unable to tune to the station is shown in Figure 2. There was a general trend toward improved reception at the 530-kHz frequency in the newer vehicles.

Drivers that did receive the HAR message were

asked to rate the signal reception in comparison with that of their regular radio station. The results show that 35 percent of the drivers interviewed rated the HAR signal to be weaker than commercial AM broadcasts but only 6 percent rated the HAR signal to be inferior.

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## Motorists' Needs for Information on Services

GERHART F. KING

A comprehensive review and analysis of the state of the art on motorists' needs for information on travel-related goods and services and on means to satisfy these information needs have been made. Information needs and potential information-transmission means are identified. Problems associated with the design and implementation of service information systems are delineated. A number of existing services information systems are analyzed and a conceptual prototype system that uses existing technology is developed. This system is designed to overcome the information-presentation problems associated with the elimination and control of billboards.

Information concerning goods and services that may be needed during travel represents an important part of the total of motorists' information needs. The satisfaction of these needs is required by the driver for the safe, convenient, and comfortable completion of his or her trip. In the historical development of the total highway information system, this class of needs has traditionally been satisfied by private signing erected on or adjacent to the highway right-of-way.

For instance, a standard text on motel management (1) published just prior to the enactment of the Highway Beautification Act of 1965 (P.L. 89-285, October 22, 1965) stated, "This medium [outdoor display advertising] is probably the most important single promotion method for motels."

Only with the large-scale construction of limited-access highways did traffic engineers begin to consider the need for public signing for services. The 1948 edition of the Manual on Uniform Traffic Control Devices (MUTCD) (2) does not mention signing

for services. The concept was introduced for the Interstate system when the separate Interstate signing manual (3) was published and extended to non-Interstate expressways and freeways when the 1961 edition of MUTCD was adopted (4). These provisions were continued and extended to the conventional system in the 1978 edition of MUTCD (5).

Service signing as covered by MUTCD is restricted to the following six classes: gasoline (and associated services), food, lodging, telephone, hospital, and camping. Miscellaneous goods and services that may be required by the traveler are not included in the MUTCD list.

Traditionally, information transmission concerning brand identification of services has been the role of private signing adjacent to the highway right-of-way. However, the 1958 Bonus Law (23 C.F.R., Part 750, Subpart B, Sections 750.151-705.155, May 12, 1975) and the Highway Beautification Act of 1965 have placed actual or potential limitations on the role that private signing can play.

Since the availability of commercial advertising was reduced by these legal restrictions, Congress recognized a corresponding obligation to provide information about necessary motorist services. Exceptions to the prohibition against commercial advertising were made for certain categories of signs (e.g., on-premise signs) and for certain types of roadside areas (commercial and industrial). In addition, public agencies were authorized to assume



a greater role in providing specific information for the traveling public through official signing for services and incorporation of brand-name identification in official signing.

Considerable concern has been expressed whether this system of amplified public signing and restricted private signing fully satisfies motorists' information needs concerning the availability of and directions to travel-related goods and services along Interstate and federal-aid primary highways. The research summarized in this paper was designed to address this concern.

#### MOTORISTS' INFORMATION NEEDS

The driving task, defined as the total of all activities that take place from the inception of a trip to its termination (6), can be viewed as a series of consecutive driver decisions. A decision is a choice among alternatives. In order to make rational decisions, the driver must reduce his or her uncertainty. The need to reduce uncertainty establishes an information need, which must be satisfied.

Motorists' needs for information on travel-related goods and services form a subset of the total set of driver information needs.

#### General Information Needs

The need for information at three levels of performance of the driving task has been identified (7):

1. Microperformance, which refers to the driver's interaction with his or her vehicle;
2. Situational performance, which refers to the driver's ability to maintain a safe path on the highway; and
3. Macroperformance, which refers to the driver's ability to plan and execute a trip from point of origin to destination.

Later descriptions (8) of this driving-task model and applications of the model to a highway and information system design procedure (9) used the terms "control," "guidance," and "navigation" for these three levels of performance. Drivers' decisions concerning goods and services are considered to be at the macroperformance or navigation level.

An objective ordinal scale can be established to define the relative importance or primacy of the information associated with each of these levels of performance. On this scale, information at both the control and the guidance levels has a higher rank than does information at the navigation level (6).

#### Service Information and Other Travel-Related Needs

It has been stated (10) that the average motorist needs the following:

1. Service information (fuel, food, lodging or camping areas, attractions and other facilities, and other miscellaneous services);
2. Credit-card information (particularly for gasoline);
3. Reliable route-guidance system (which would facilitate getting the driver to his or her destination); and
4. Driver-aid system (which would provide help when the driver is in distress anywhere on the nation's highways).

Of the five categories of service information listed above, the first four are self-explanatory. The fifth, miscellaneous services, is a catch-all of types of goods and services that may be needed by

the traveler. Some typical examples are shown below. (It should be noted that two classes of services--telephone and emergency medical care--are not included; these are considered to be of such importance that special information provisions are usually made.)

Goods	Services
Clothing	Post office
Cosmetics	Western Union
Medicine	Bank
Sports equipment and supplies	Equipment repair (nonautomotive)
Camping equipment and supplies	Laundry and dry cleaning
Packaged food and beverages	Medical care (nonemergency)
Souvenirs and local handicraft	Religious
Gifts	

A study of motorists' needs on rural freeways (11) defined two types of services. Services of necessity are emergency-type services that include police, fire protection, medical aid, and service for disabled vehicles. Need for this type of service is unpredictable and therefore this information cannot be incorporated into travel plans and routes. Services of convenience would include those services that are normally used by the motorist at a specific location--gasoline, food, lodging, communications, and information. An assumption by the motorist of the availability of services can result in problems. If the motorist fails to obtain fuel where it is available, the convenience (fuel) becomes a necessity (disabled-vehicle service) if the driver runs out of fuel. Similarly, in cases of extremely adverse climatological conditions, which make driving impossible or hazardous, lodging may become a necessity.

In another study of motorists' service needs on rural freeways, Voorhees and Associates (12) classified these needs into three broad categories:

1. Emergency (ambulance, towing, etc.);
2. Routine (food, gasoline, and lodging); and
3. Supplementary (souvenirs, ice, etc.).

The study developed a data base of more than 1500 motorist interviews. From this data base, a number of general conclusions concerning motorists' service needs were derived.

The distances that motorists are willing to travel off the freeway for services depend on the type of service. Those needed frequently (routine services) are expected within 1, 2, and 5 miles from the freeway for gasoline, food, and lodging, respectively. About 85 percent of the motorists would prefer not to travel further than this from the freeway to obtain most routine services. Motorists are generally willing to travel further for the less frequently needed services.

Many of the motorists surveyed indicated that their single biggest problem was a lack of information about the availability and quality of services. Such information would include location of emergency services; location and description of routine services such as gasoline, food, and lodging; and availability of supplemental services such as souvenirs, ice, and medicines.

The frequency of need for services ranges from a high of two, three, or four times per day (for example, for gasoline) to a low of once per lifetime or less (for example, the need for a fire engine). Other needs fill the range between these two extremes.



Analysis of the needs of the motorist shows that these can be considered at two levels. The first level concerns availability and location. Table 1 shows the first-level needs for fuel, food, lodging, attractions, and other goods and services.

Table 1. Motorists' information needs.

Information	Fuel	Food	Lodging	Attractions	Other Goods and Services
<b>First-Level Needs</b>					
Location	X	X	X	X	X
Distance	X	X	X	X	X
Directions	X	X	X	X	X
Return	X	X		X	X
Travel time	X	X		X	X
<b>Second-Level Needs</b>					
Brand	X	X	X		X
Type		X	X		X
Quality		X	X	X	X
Hours	X	X	X	X	X
Price		X	X	X	X
Credit card	X	X	X		X
Next or other availability	X	X	X	X	X
Handicapped adaptation		X	X	X	

Table 2. Relative importance of restaurant-choice variables.

Mean Rating	Factor	Importance (%)			
		Very (4)	Moderate (3)	Little (2)	None (1)
4.00	Quality of food	100	-	-	-
3.97	Cleanliness	97	3	-	-
3.91	Service	91	9	-	-
3.68	Cost	74	19	7	-
3.63	Type of meals	67	30	2	1
3.40	Location	53	36	9	2
3.38	Comfort	46	48	5	1
3.24	Type of service	44	41	11	4
3.07	Hours	37	40	17	6
3.03	Atmosphere	28	50	17	5
2.37	Seating	12	36	27	25
2.36	Decor/theme	6	40	37	17
2.03	Chain affiliation	8	25	28	39
1.84	Credit cards honored	12	15	17	56
1.62	Cocktail service	6	13	19	62
1.39	Entertainment	2	6	20	72

Table 3. Relative importance of motel-choice variables.

Mean Rating	Factor	Importance (%)			
		Very (4)	Moderate (3)	Little (2)	None (1)
3.49	Moderately priced	58	35	5	2
3.29	Close to main route	48	38	9	5
3.26	Convenient for parking	49	35	9	7
3.02	Quiet setting	34	43	14	9
2.96	Room size and decor	25	53	15	7
2.85	Close to tourist attraction	35	33	14	18
2.82	Attractive setting	24	46	18	12
2.68	Swimming pool	36	23	14	27
2.67	Restaurant facility	29	31	18	22
2.21	Close to gasoline stations	13	27	28	32
2.18	No charge for children	26	15	10	49
2.16	Close to fast-food restaurant	13	25	27	35
2.14	Color television	11	26	29	34
2.05	Credit cards honored	20	17	11	52
2.03	Late checkout time	10	23	27	40
1.77	Direct-dial telephones	8	16	21	55
1.49	Cocktail facility	5	9	16	70
1.16	Babysitting service	2	3	7	88
1.03	Animal kennel	2	2	3	93

attractions, and other goods and services.

Once the first-level needs are fulfilled--that is, when the motorist is aware that certain goods and services are available--the second-level needs must be met. Second-level needs are for specific information on the goods and services offered (Table 1).

In addition to the general second-level needs of the motorist, there are specific needs that are applicable only to certain categories of services. In the fuel category, besides the other second-level needs, the availability of minor and major repair service and of parts is an important item to all travelers. For some travelers, the availability of alternative fuels (e.g., diesel or propane) represents an important information need.

Specific needs in the food category include waiting and service times, dress code, and the availability of children's meals. The National Restaurant Association conducted an attitude survey of the restaurant habits of travelers (13). As part of the survey, travelers were asked the factors that influenced their choice of restaurant. These factors, shown in Table 2, represent information needs.

Specific needs of the traveler for lodging information include vacancies available, relative location, children's rates, on-premise restaurant, and supplemental hotel or motel services such as pool, television, and telephones. Information on vacancies is not available to the motorist until the motel or hotel has been reached. One way to avoid the question of available rooms is to make advance reservations. A number of studies (14,15) have found that only about one-third of vacationers make advance reservations and that in cases in which reservations are made, they are made at least two (possibly more) days in advance.

A survey (15) found that 83 percent of respondents considered proximity of motels in which they stayed to be an important consideration. These data indicated that the cumulative proportion (P) of motels used is related to the distance (D), a generally exponential relationship the mean of which is about 20 miles and the 90th percentile of which is about 9.5 miles. The survey also questioned travelers on the relative importance of motel-choice variables (Table 3).

For miscellaneous goods and services, the traveler needs to know which are available, the brands, the quality and price, and where they are located.

#### SATISFACTION OF INFORMATION NEEDS

Travelers' information needs are currently satisfied, at least in part, by a number of different information-transmission techniques.

#### Information-Transmission Technology

A communications system, according to theory (16), consists of five separate parts: information source, transmitter, channel, receiver, and destination.

In the system being analyzed here, the information source is the governmental or private agency that decides what information is to be transmitted. The destination of the information is the driver or navigator. The specific transmitter-channel-receiver combination used represents the information-transmission technique.

For the design of a formal information system, only two means of information reception are possible--visual or audio reception. These form one dimension of a taxonomy of information-transmission techniques. The time and place of information

transmission represent the other two dimensions. The entire taxonomy is shown below:

#### Medium

Visual	Audio
Pretrip planning	
Map	Radio and television
Brochure and leaflet	Spoken message
Guide	Telephone
Touring service	
Newspaper and magazine ad	
Service directory	
In-trip--on highway	
Outdoor advertising	Broadcast radio
Signs	Low-power radio
General service	Citizen's-band radio
Logo service	Mobile telephone
Official business	Tape cassette
Standard guide	
In-trip--off highway	
Information centers	Telephone
Manned	Low-power radio
Unmanned	Closed-circuit television
	Talking sign

This taxonomy is somewhat arbitrary, and some categories overlap. For example, hard-copy (i.e., visual) pretrip information sources can and are consulted during a trip either on the highway (by the navigator) or off the highway. Also, information centers always have telephones and may incorporate other audio techniques.

Table 4. Maximum distance from Interstate highways for service signing.

Government	Distance (miles)				
	Fuel	Food	Lodging	Camping	Hospital
Federal	3 <sup>a</sup>	3 <sup>a</sup>	3 <sup>a</sup>	3 <sup>a</sup>	
California	0.5 <sup>b</sup>	1 <sup>c</sup>	1 <sup>c</sup>	10	1 or 3 <sup>d</sup>
Virginia	1	3	3	10	
Massachusetts	0.5	1	1		
Florida	1	1	1	5	10
North Dakota	3.5	3.5	3.5	10	3.5
Idaho	1 or 5 <sup>e</sup>	1 or 5 <sup>e</sup>	1 or 5 <sup>e</sup>	1 or 5 <sup>e</sup>	1 or 5 <sup>e</sup>
Michigan	3	3	3	5	
Illinois	1	1	1	10	5
New York	3	6	9	12	

<sup>a</sup> If one or more services are not available, continue in 3-mile increments up to a maximum of 15 miles, if necessary, to find available service of the type needed.

<sup>b</sup> Except in case of by-passed communities in which service is not available at same or lesser distances.

<sup>c</sup> Point system.

<sup>d</sup> Urban areas, 1 mile; rural areas, 3 miles. Exceptions in areas where hospitals are many miles apart.

<sup>e</sup> If by-passed community, 5 miles.

A comprehensive survey of these techniques that covers characteristics and use patterns may be found in a report by King and Wilkinson (17).

#### Satisfaction of First-Level Information Needs

The signing prescribed by Section 2F-32 of MUTCD (5) is adequate to satisfy the first-level needs of the motorist. The location of the service is pinpointed at an intersection or interchange.

Under current Federal Highway Administration (FHWA) regulations, a service must generally be located within 3 miles to be eligible for signing by using either standard service signs (5) or logo signs (18). This mileage constraint, however, is not apparent to the motorist who sees the sign. In addition, these regulations allow for distances up to 15 miles if services are not available closer to the interchange. Individual states also have criteria for service signing. Table 4 compares maximum-distance criteria for service signing as established by federal and state standards. All states examined used distance as a criterion for all services except California, which used a point system for food and lodging. The point system combines five categories:

1. Minimum distance from exit to first service facility,
2. Number of traffic-control devices (signals or stop signs) between exit and facility,
3. Number of seats or rooms in facilities reachable from interchange,
4. Distance to next highway exit that has facility, and
5. Judgment factor by inspection official.

(Candidate facilities must score at least one point in the last category to be considered at all.)

#### Satisfaction of Second-Level Information Needs

Although MUTCD signing does a fair job in meeting the first-level needs of the motorist, it generally fails to satisfy the second-level needs. Only one category of information--brand--is directly met by logo signing. A number of others, such as type, quality, and credit card, may be inferred in the case of national chains. Formerly, almost all second-level needs were met through the use of outdoor advertising, specifically by billboards. Since the removal of billboards from parts of the highway system, these second-level needs have been satisfied from a different source. Table 5 shows information sources for the second-level needs if

Table 5. Sources of information for second-level needs.

Goods or Service	Second-Level Information Need							Handi-capped Adaptation
	Brand	Type	Quality	Hours	Price	Credit Card	Next or Other Availability	
Fuel	Logo signs, on-premise signs, hard copy	-	-	Federal or state guidelines	-	Brand name, hard copy	Official signing	-
Food	Logo signs, on-premise signs, hard copy	On-premise signs, hard copy	Ratings, hard copy, brand name	Federal or state guidelines	Hard copy	Hard copy	-	Hard copy
Lodging	Logo signs, on-premise signs, hard copy	On-premise signs, hard copy	Ratings, hard copy, brand name	-	Hard copy	Hard copy, national affiliation	-	Hard copy
Camping	Hard copy	Hard copy	-	Seasonal hard copy	Hard copy	Hard copy	Hard copy	Hard copy
Attractions	-	-	Hard copy	Hard copy	Hard copy	-	Hard copy	Hard copy
Other goods and services	On-premise signs, hard copy	Hard copy	-	Seasonal hard copy	Hard copy	Hard copy	Hard copy	-



Table 6. Factors that influence choice of eating establishment.

Meal	Factor <sup>a</sup> (%)					
	On-Premise Advertising	Highway Advertising	Previous Experience	Recommendation	Travel-Directory Advertising	City Visitor's Magazine
Breakfast	46.3	33.6	19.0	28.8	12.3	3.8
Morning snack	42.7	39.8	21.4	29.1	9.7	5.8
Lunch	42.5	43.3	20.1	31.8	10.3	4.6
Afternoon snack	47.6	43.7	16.7	19.0	6.3	7.1
Supper	38.3	32.7	23.4	42.0	17.9	6.6
Evening snack	45.8	30.5	18.3	32.0	9.9	6.9

<sup>a</sup>Does not add to 100 percent due to multiple responses.

Table 7. Patronage of motels based on advertising and location.

Factor	Patronage (%)			
	Use of Outdoor Advertising		Location of Motel	
	Heavy	Light	Interstate	Primary Highway
Roadside advertising (before motel in sight)	29	8	16	17
Signs on motel property	15	34	29	22
Other advertising	2	2	2	3
Recommendation of friend	17	8	17	8
Recommendation of business firm	10	5	8	6
Listing in travel directory or as member of group	26	31	17	39
Appearance of motel	12	32	21	24

billboards, except for on-premise signs, are not used.

#### Food

Quality of food, cleanliness, and good service are the leading restaurant-choice variables (Table 2). Information on these items can currently be obtained through independent ratings (e.g., those of the American Automobile Association) or inferred from brand names. Information on ratings can be included in billboard or hard-copy advertising.

Information concerning waiting and service times or the need for reservations in a restaurant is not normally available except for inference from the type of restaurant being considered. This type of information and information concerning dress code and children's meals can be found in some of the commercial travel guides. These travel guides do not provide complete coverage, however, since they list only selected establishments.

A study (13) for the National Restaurant Association investigated the en-route information sources used and the factors that influenced choice of eating establishments. Highway advertising (on and off the premises) was found to be the primary source:

Information Source	Automobile Vacationers Who Used Source (%)
Highway advertising	50.8
Friend or relative	40.6
Directory or guidebook	25.2
Brochure	23.2
Other vacationer	14.3
Road map	10.9
State welcome center	7.9
Newspaper	7.1
Private business	5.3
Chamber of commerce	4.7

Factors that influenced choice of restaurant were found to vary with specific meal (Table 6).

#### Lodging

The results of a survey (14) on how motels were usually selected are summarized below:

Selection Factor	Distribution of Respondents (%)
Appearance	
Unqualified	17.8
Qualified (room inspection, cleanliness)	11.4
Facilities	10.4
Rates	9.2
Travel-guide recommendation	33.7
Chain affiliation	22.1
Location	6.2
Advertising, billboards	7.3
Early stop or fatigue	3.6
Experience	3.4
Recommendation	6.0
Chance	3.6

Another survey (19) on factors that influence travelers to select a motel took both the motel location and the amount of off-premise outdoor advertising into account. The results are shown in Table 7.

#### Miscellaneous Goods and Services

At the present time, information on miscellaneous goods and services is limited to brochures, on-premise signing, and some legal off-premise signs.

#### PROBLEMS IN IMPLEMENTING SERVICE INFORMATION SYSTEMS

##### Technical Problems

Technical problems with putting service information systems into effect include all problems that arise from or may be remedied by technical aspects. These technical aspects transcend the traditional definition of technology and engineering and may include contributions from the fields of information theory, psychology, and education. Some examples of technical problems are discussed below.

##### Informing Motorists About System

Any information system or information-transmission technique that does not rely on on-highway visual information requires that the motorist be informed about the system and how to operate within it. The problem is particularly acute in those states such as Vermont (20) and Oregon, which rely on off-road unmanned information centers. A study in Oregon (21) showed that almost half of all users of the information center had not been aware of it until



they saw the displays when they entered the rest area. The problem of identifying and locating pretrip information sources also falls into this category. This type of problem may also occur in relation to on-highway visual information sources if these employ coding systems that are not completely self-explanatory.

#### Skills Required to Operate Within System

Any system or technique imposes a requirement that the system user command certain skills. These skills may be as basic as reading or as sophisticated as the ability to make complex inferences or to read detailed maps. Physiological attributes such as vision, hearing, and reading time would fall into this category. Also included are any problems associated with language (i.e., those of system users who do not speak English) or with metric measurements.

#### Criteria for Service and Logo Signing

Logo signs, official business signs, and variations of these are all capacity-limited: The number of establishments listed cannot exceed a maximum, which depends on the type of signing and FHWA and local policies. This limitation necessitates inclusion criteria. Distance inclusion criteria are usually also imposed even if the basic sign capacity is not exceeded. An associated problem occurs when a state line intervenes between the service facility and the logical location of the service sign. Some state policies do not permit signing in these cases.

#### Uniformity and Continuity

At the present time, a number of information systems coexist in the United States and even sometimes on various highway systems within the same state. This creates a difficulty when the motorist proceeds from one system to another, since the tendency is to expect similar systems.

#### Dispensing Hard Copy

Dispensing hard copy is a problem associated with unattended information centers. The information-transmission capacity of unmanned centers is reduced by vandalism and litter problems and difficulty with making hard-copy information, especially maps, available to the driver.

#### Keeping Information Current

With the exception of some audio techniques (e.g., radio and telephone), all information-transmission techniques are subject to the problem of being out of date to a greater or lesser degree. Major travel and service guides have a one- to two-year revision cycle. Sign revision requires a finite lead time the length of which often depends on personnel levels and allocation. Inordinate information change time, which leads to a high proportion of out-of-date information, may seriously affect the credibility and therefore the utility of any information system.

#### Information Center Capacity

Information centers have finite capacities. The Vermont information plazas can accommodate 66 advertisers; the ones in California, more than 30. The Oregon information center has room for 900 column inches of information. These capacities could easily be exceeded in areas that are heavily tour-

ist-oriented, especially if information centers are spaced far apart.

#### Economic Problems

Economic problems include those that are discussed below.

#### State Maps

Now that oil companies no longer distribute free maps, state maps are assuming a more important role in information systems. Funding limitations have led to the lack of state maps in some states, to extensions of the map-revision interval, and to limitations on the number printed and distributed in each state.

#### Information Center Operation

Funding limitations have caused information centers to shorten hours of operation and to reduce staff in busy centers; some centers have been closed and others have seasonal limitations.

#### Billboard-Removal Rate

Based on recent experience, the states have demonstrated a willingness and ability to remove signs faster than funds are being authorized and appropriated by Congress. This conclusion is based on expenditure data and state requests for federal matching funds for fiscal years 1977 and 1978 (according to R.W. Moller, Office of Right-of-Way, FHWA). The level of funding for this activity in 1980 was such that, in some states, it would take decades to accomplish the task rather than the five to eight years originally contemplated. This slow pace of billboard removal is removing the urgency of developing and implementing alternative information systems, particularly information system elements that require the investment of private capital and/or financial commitments from service suppliers.

#### Marketing of Cooperative Systems

The success of cooperative systems (privately operated information centers that sell space to individual services) depends on their ability to market this technique. This marketing effort has been a problem in some cases, especially in Vermont. To a lesser extent, the same principle applies to government-operated programs such as logo signing or to official business signs that require participation and payment by the affected businesses. Rates for these systems are usually nominal. However, an experimental program of official business signs in Massachusetts (22) was able to obtain participation of only half the eligible businesses.

#### Opposition to Information Centers

Prior to the initiation of state-operated or state-contracted information centers, this type of operation was the responsibility of local organizations such as the chambers of commerce. In many cases the information booth was the most prominent example of the chamber's activities and the reason for much of its funding from local businesses. Fear of loss of this funding has generated opposition to some information center programs.

#### Availability of Legal Billboard Sites

The restrictions made on outdoor advertising by the Highway Beautification Act have made legal billboard



sites scarce. Some of the legal sites are tied up by long leases to non-travel-related users. An increase in the number of available sites as a result of changes in land use and/or zoning cannot be expected to have a major effect since those changes would probably not occur in the purely rural area in which the problem is most acute and since the land-use changes themselves might generate new advertisers competing for space.

#### Service Signing on Tollways

Toll facilities form an appreciable portion of the Interstate and primary highway systems, especially in the eastern portion of the United States. Toll-road authorities derive part of their revenue from the service plaza concessionaires. There is therefore opposition on the part of some toll authorities to any service signing that would divert business from their facilities.

#### Competitive Balance

Some information-transmission techniques may have an adverse effect on the competitive balance among various suppliers of services. This problem applies especially to the logo signing program. The use of logos gives a great advantage to national chains over the local independent service. The same advantage may apply to high-rise on-premise signing or other high-cost techniques.

#### Administrative or Legislative Problems

Problems that arise due to administrative or legislative action and that could be remedied by similar means are discussed below.

#### Security of Unmanned Off-Highway Sites

Especially in hilly or heavily forested areas, off-highway information sites may not be visible from the main road. Since motorists must leave their vehicles to use this information source, a potential security problem is created, especially at night. Several states have indicated that the highway patrol does not normally enter rest areas as part of its routine.

#### Vending on Interstate Right-of-Way

As of 1979, vending on Interstate rights-of-way was prohibited by legislation. This prohibition has made it impossible to initiate a number of possible techniques to provide information, such as coin-operated map dispensers.

#### Harassment of Travelers at Information Centers by Religious Groups

Several states have reported the problem of having travelers harassed by members of religious groups who are trying to sell items or dispense information.

#### Free Samples

The practice of handing out free samples (e.g., orange juice in Florida) has led to overcrowding of information centers and overburdening of the center staff, which compromises the basic information-transmission activity.

#### Commercialism in Tourist Advisory Radio

The interpretation by the Federal Communications Commission of the commercialism clause in the regu-

lations applicable to tourist information radio [Federal Register 42 (120):31601, Federal Communications Commission Docket 20509, June 22, 1977] has severely limited the ability of this technique to function as a service information source.

#### PROTOTYPE INFORMATION SYSTEM

This paper contains the highlights of a major survey of information needs and transmission techniques for travel-related goods and services (17). As part of this survey, three current information systems were reviewed critically and evaluated:

1. U.S. standard system (defined in MUTCD and current FHWA regulations): This system, with some local variations, is the one most widely used today.

2. Vermont system: This system attempts to satisfy travel-related information needs without any outdoor advertising. The system has two major components: (a) official business signs that use color coding and symbols and (b) unmanned information plazas.

3. Oregon system: This system uses privately operated, unmanned information centers as a key system element.

Based on the evaluation of these three systems and others reported in detail in the project report, a conceptualized prototype service information system was developed. This system, which is described below, is designed to (a) satisfy travelers' information needs and (b) use existing information-transmission techniques.

The basic system is designed to be put into effect throughout the United States. Since a number of states have enacted billboard controls considerably more severe than those contained in the Highway Beautification Act, the information system does not incorporate outdoor advertising, either on or off site, as a primary information-transmission medium. In those states in which the sign-control provisions of 23 U.S. Code, Section 131, govern, especially those in which there is a relatively great amount of legal sign space, outdoor advertising can continue as a redundant information source if so desired by the advertiser.

The information system described below has three distinguishing characteristics:

1. It is a multimedia system. No single information-transmission technique can meet all the information needs in a timely, convenient, and economical manner.

2. It is an incremental system. The different levels of information are handled by different transmission techniques. The system user can choose which level of information is required. The satisfaction of additional levels of information will require incremental efforts on the part of the user.

3. It is a cooperative system. Responsibility for providing the required information is shared between the public and private sectors.

#### System Used for Interstate and Limited-Access Highways

The system applied to Interstate and other limited-access highways would include the following elements:

1. General service signing: At the first, or simplest, system level, first-level information is transmitted by general service signing. The use of symbols instead of words would permit the transmission of all five types of first-level information needs listed in Table 1. In most cases, signing for



next-available services should be used.

2. Logo signing: The next system level introduces logo signing, which will supplement or replace the general service signing. This system level thus satisfies second-level needs associated with brand information and a certain amount of implied quality information. Cut-off criteria should be based on a plan similar to California's point system.

3. Information centers: The Oregon or California type of private leased operation appears to be preferable to the state-owned operation in Vermont due to the relatively large initial investment required and the profit potential of this type of operation. A combination of the two types is possible. The private operation could be used for major routes and for high-density areas in which private operators would have a reasonable chance of recouping their investment. However, it would be equitable to ask that display rates at these sites be increased in order to subsidize inherently unprofitable information centers in remote or low-density areas. In low-density areas, simple information centers (of the Vermont type) could be erected and maintained by the cognizant highway agency. Although manned information centers have proved effective in a number of states, these do not appear to be an economically feasible alternative, given the number of information centers that would be required.

The three-level system described above would satisfy a considerable number of information needs; it would not satisfy them all. The differences would have to be made up by the use of hard-copy information sources, which could be used for both pretrip planning and in-trip use. A responsible government agency must take a leading role in managing and supervising this information system and must assume the responsibility for seeing that such hard-copy information sources are available and accurate. The Illinois-type service directory is an example of what can be done.

#### System Used for Primary Highways

For the primary highway system, first-level needs can be handled by a combination of visual observation and small logo signs of the trail-blazing type. These information sources would also be used for the lead-out signing from ramp termini. For service facilities located on the secondary highway system and not directly visible from the primary system, Vermont-type official business signs are recommended.

Second-level and specific service information needs for the primary system would be satisfied by information centers. A mixture of privately and publicly operated facilities should be used. In high-density tourist areas, these information centers could be of the manned type operated by a local chamber of commerce or similar agency. Provisions would have to be made for times when the information center is closed.

As can be seen, all these recommended techniques operate on the visual channel. The only audio medium included is the telephone, which is an integral part of information centers. Audio media were excluded as a primary source because the visual channel has traditionally been the main portion of all highway information systems, the audio channel requires receiving equipment in every vehicle in the traffic stream, and information missed on the audio channel cannot be recaptured nor can the receiving rate be slowed down.

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## Comparison of Truck and Passenger-Car Accident Rates on Limited-Access Facilities

WARREN S. MEYERS

A lack of verifiable exposure data (vehicle miles of travel) for passenger cars and trucks has made comparisons of their accident rates suspect. Such comparisons are particularly important at this time because of the current trend toward longer and heavier trucks that travel alongside smaller and lighter automobiles. In response to the weaknesses in the existing accident-rate data, a nationwide survey of accident rates was made of the 1976 through 1978 accident experience for 34 limited-access facilities. These included 21 toll expressways and turnpikes and 13 bridges and tunnels for which accurate exposure figures could be obtained. The results show that fatal accident rates for light and heavy trucks on expressways were significantly greater than that for passenger cars: the rate for light trucks was 135 percent greater than that for passenger cars and that for heavy trucks was 110 percent greater. The injury accident rate for light trucks was 55 percent greater than that for passenger cars, whereas the injury accident rate for heavy trucks was 37 percent higher compared with that for passenger cars. The overall expressway accident rates for light and heavy trucks exceeded that for passenger cars by 72 percent and 58 percent, respectively. For the bridges and tunnels, overall accident rates for light and heavy trucks were seven and four times greater than that for the average passenger car.

The American Automobile Association (AAA) Foundation for Traffic Safety and the Automobile Club of New York undertook a study of the accident potential of the big truck and its impact on the safety of motorists. The study was conducted in part because of motorists' long-standing concern about the safety of the big truck. Motorists report that they are intimidated by the size of many trucks and alarmed by the wind forces created when the large rigs pass their cars on the highway. They also complain that many trucks tailgate on the highway.

Based on the record, the motorists' concern would appear to be justified. Consider, for example, the fact that for every truck driver who dies in a collision with a passenger vehicle, 32 automobile occupants are killed (1).

In addition, prevailing statistics indicate that trucks are increasingly involved in fatal accidents. In 1975, for example, trucks that had gross vehicle weights of more than 10 000 lb accounted for 1 in 16 vehicles involved in a fatal accident. By 1978, these trucks were involved in 1 of 12 fatal accidents (2).

It became rather evident from a review of the truck safety literature that the information available on the accident-involvement rates of large trucks was relatively limited, highly suspect, and unsuitable to factually establish the magnitude of the truck safety problem.

The major weakness found was the difficulty in obtaining accurate and verifiable measures of ex-

posure by federal and state agencies. Because the practice in determining the relative safe operating experience of different types of vehicles in the traffic stream is to present the accident experience in terms of an exposure rate [the number of vehicle miles of travel (VMT)], the data available were inconclusive since they are based on estimates of vehicle exposure, not factual recordings.

For example, a review of the accident rates published by the National Highway Traffic Safety Administration (NHTSA), derived from the Fatal Accident Reporting System (FARS) data, demonstrated these concerns. Although the number of persons killed in car or truck accidents is accurately tallied and probably represents the most reliable figures available on fatal truck accidents, the exposure information used to calculate the fatal accident rates for cars and trucks was based on gross estimates of mileage. These were derived from such types of data as regional gasoline sales, vehicle registrations, and national studies of driving habits. This type of situation is recurring and accordingly renders much of the currently available highway accident-rate information unsuitable to formulate the basis for any discussion of the impact of trucks on highway safety.

A review of the truck accident data collected by the Bureau of Motor Carrier Safety also revealed problems. Their accident records are limited to the self-reporting by regulated carriers involved in interstate commerce, whereas the experience of unregulated intrastate trucks is overlooked and not represented in the bureau's accident statistics.

As a result, the consensus of the literature search was that the problem with the data available from the federal government and other agencies is that the information provided on exposure--the potential for an accident--was largely an estimate made without adequate data. The problem of big-truck safety could not then be effectively approached until it could be factually established that the big truck is actually disproportionately involved in traffic accidents. In other words, in order to gain support for improving the safety of the big truck, it must first be documented that the big truck is in fact unsafe.

In an effort to provide national statistics, the AAA foundation called on local AAA clubs to assist in the collection of exposure and accident data for controlled-access facilities for which the on and



Table 1. Expressway and turnpike overall accident rates.

Facility	Accident Rate/100 Million VMT <sup>a</sup>								
	Passenger Cars			Light Trucks			Heavy Trucks		
	1976	1977	1978	1976	1977	1978	1976	1977	1978
California Interstate 15	N/A	50.0 <sup>b</sup>	—	N/A	48.0 <sup>b</sup>	—	N/A	88.0 <sup>b</sup>	—
Florida									
Florida's Turnpike	47.6	64.4	81.2	67.5	33.0	85.3	106.5	66.0	111.7
Airport Expressway	172.3	228.8	292.6	208.6	489.2	359.6	1725.8	2329.6	3249.0
East-West Expressway	187.6	214.7	216.1	201.5	251.2	167.2	1389.9	1900.3	1157.8
Everglades Parkway	537.2	595.3	682.7	350.9	443.1	359.1	236.6	292.7	520.5
West Dade Expressway	45.2	63.1	60.3	30.0	45.1	23.9	41.1	35.4	66.9
Illinois Turnpike	174.4	192.6	N/A	380.2	368.5	N/A	129.7	135.8	N/A
Kansas Turnpike	94.2	116.2	127.8	270.0	316.1	365.7	162.2	180.8	205.1
Kentucky									
Bluegrass Parkway	92.5	114.7	84.5	195.4	215.4	180.4	130.9	123.3	81.3
Cumberland Parkway	52.2	66.0	90.6	59.3	170.3	74.5	65.6	35.8	51.3
Daniel Boone Parkway	195.6	119.3	220.3	242.7	255.0	420.2	136.4	155.8	145.4
Green River Parkway	90.0	117.6	106.1	36.8	186.7	103.5	52.0	106.6	107.4
Purchase Parkway	114.2	121.9	118.9	323.0	196.8	174.7	107.8	146.7	68.1
Mountain Parkway	104.2	122.5	107.9	331.4	447.2	377.9	206.5	182.9	121.2
Pennyrile Parkway	192.6	195.4	216.1	324.5	228.6	304.7	88.3	267.0	208.2
Western Kentucky Parkway	94.6	103.1	106.8	131.2	169.9	220.4	83.3	151.6	111.6
Ohio Turnpike	N/A	112.4	109.5	N/A	225.6	238.1	N/A	207.8	197.1
New Jersey Turnpike	61.6	72.5	69.4	— <sup>c</sup>	— <sup>c</sup>	— <sup>c</sup>	165.0 <sup>c</sup>	201.2 <sup>c</sup>	234.7 <sup>c</sup>
New York State Thruway		107.0 <sup>d</sup>			88.0 <sup>d</sup>			221.8 <sup>d</sup>	
Pennsylvania Turnpike	63.9	76.1	88.3	— <sup>c</sup>	— <sup>c</sup>	— <sup>c</sup>	37.0 <sup>c</sup>	42.5 <sup>c</sup>	47.2 <sup>c</sup>
West Virginia Turnpike	97.1	128.0	105.0	851.6	376.7	530.3	71.4	174.7	241.5

Note: N/A = not available.

<sup>a</sup>Includes property-damage, injury, and fatal accidents.<sup>b</sup>1977 and 1978 data were combined and are listed under 1977.<sup>c</sup>Light and heavy truck data were combined.<sup>d</sup>1976, 1977, and 1978 data were combined.

off movements of vehicles (both passenger cars and trucks) were documented by toll-collection records. By using a controlled environment, both the exposure and accident experience could be accurately determined for all vehicles on the highway; a valid comparison of the safety record of the various types of road users was thereby produced.

The subsequent response by AAA clubs provided data on the VMT and the number of accidents for each vehicle class for highways, bridges, and tunnels across the country; this study encompassed a representative mix of rural and urban facilities from almost every region of the United States.

#### STUDY METHOD

The data used in the foundation's study were obtained from agencies responsible for the day-to-day operations of controlled-access toll highways, bridges, and tunnels. As mentioned previously, controlled-access toll facilities were used because the on and off movements of all vehicles are precisely known and because of the assured availability of accurate accident statistics.

The total VMT on a highway represents what is commonly referred to as exposure, and when these historical mileage data are related to the number of vehicles involved in accidents, the resulting expression is a vehicle accident involvement rate, that is, the number of vehicles in accidents for a specified distance of travel.

For purposes of this study and consistent with accepted practices, accident rates are expressed as the number of vehicle accident involvements per 100 million VMT.

The accident information provided the number of vehicles by type that used the facility, their exposure, the number of vehicles involved in accidents, and the type of accident (whether they involved property damage, resulted in injuries, or produced a fatality). The data covered the years 1976 through 1978.

The three broad categories of vehicles investigated were passenger cars, light trucks (those that

weighed 10 000–26 000 lb), and heavy trucks (vehicles more than 26 000 lb).

The overall accident rates reported in this study include property-damage, injury, and fatal accidents. In the calculation of the injury accident rate, accidents that involved both injuries and fatalities were included.

The accident data provided in Tables 1–4 permitted an analysis of 2.3 billion vehicle trips that covered 49.1 billion vehicle miles and 73 500 truck and passenger-car accident involvements.

The accident rates for controlled-access highways were evaluated separately from those for bridges and tunnels because of suspected differences in traffic operating characteristics between the two types of facilities. As a result, the conclusions of the study are based primarily on information from the controlled-access highways because the exposure information was predominantly for that type of facility (91.2 percent of the exposure was for expressways versus 8.8 percent for bridges).

#### RESULTS

Because the data collected and analyzed in connection with this report were based on reasonably accurate exposure and accident data, the conclusions that have been drawn would likewise have greater accuracy than many of the statistics that have been reported in the past.

The analysis shows that, for whatever reason, light and heavy trucks are disproportionately involved in traffic accidents as compared with passenger cars.

The fatal accident rates for controlled-access expressways are provided in Figure 1 and show that the fatal accident rates for light and heavy trucks were significantly greater than that for passenger cars. On the average, light trucks were involved in 2.35 times more fatal accidents than were passenger cars for the same distance traveled. Heavy trucks were also found to be overinvolved; there were 2.10 times more fatal accidents for heavy trucks than for passenger cars for the same exposure.



**Table 2. Expressway and turnpike injury accident rates.**

Facility	Accident Rate/100 Million VMT <sup>a</sup>								
	Passenger Cars			Light Trucks			Heavy Trucks		
	1976	1977	1978	1976	1977	1978	1976	1977	1978
California									
Interstate 15	[Data provided did not include specific information on injury accidents.]								
Florida									
Florida's Turnpike	17.9	24.0	29.0	20.5	18.1	16.1	31.9	19.9	37.2
Airport Expressway	74.9	85.4	115.9	94.8	139.8	205.5	246.5	582.4	0.0 <sup>b</sup>
East-West Expressway	66.3	72.5	74.3	52.6	91.4	83.7	198.6	532.9	463.1
Everglades Parkway	212.6	239.5	319.8	184.3	175.4	127.7	84.7	128.8	178.8
West Dade Expressway	17.5	22.5	22.9	4.3	14.1	4.3	6.9	10.1	14.9
Illinois Turnpike	48.5	52.3	N/A	86.1	87.1	N/A	30.8	28.4	N/A
Kansas Turnpike	42.5	50.5	52.4	109.7	128.1	108.6	56.2	76.0	78.6
Kentucky									
Bluegrass Parkway	31.2	40.4	16.0	65.1	123.1	30.1	20.2	47.4	45.1
Cumberland Parkway	18.3	24.5	22.7	59.3	42.5	0.0	43.7	17.9	51.3
Daniel Boone Parkway	65.2	63.3	96.0	80.9	0.0	224.1	0.0	72.2	66.1
Green River Parkway	24.7	33.6	17.1	36.8	0.0	34.5	31.2	26.7	49.6
Purchase Parkway	14.8	36.1	63.5	107.8	98.4	87.3	26.9	62.9	0.0
Mountain Parkway	45.9	49.5	40.4	165.7	201.3	133.4	82.6	77.0	30.3
Pennyrile Parkway	81.4	64.6	68.6	144.2	65.3	60.8	40.8	102.7	44.0
Western Kentucky Parkway	27.5	30.9	35.4	18.7	34.0	50.9	36.4	40.4	31.2
Ohio Turnpike	N/A	40.8	36.3	N/A	91.2	67.6	N/A	67.2	62.1
New Jersey Turnpike	23.6	24.5	24.4	— <sup>c</sup>	— <sup>c</sup>	— <sup>c</sup>	55.0 <sup>c</sup>	66.2 <sup>c</sup>	71.7 <sup>c</sup>
New York State Thruway		26.0 <sup>d</sup>			19.0 <sup>d</sup>			54.8 <sup>d</sup>	
Pennsylvania Turnpike	25.2	25.1	26.6	— <sup>c</sup>	— <sup>c</sup>	— <sup>c</sup>	38.8 <sup>c</sup>	45.0 <sup>c</sup>	50.0 <sup>c</sup>
West Virginia Turnpike	40.4	73.4	50.4	310.9	235.4	85.4	46.1	85.4	120.8

Note: N/A = not available.

<sup>a</sup>Includes injury and fatal accidents.<sup>b</sup>Data provided are questionable.<sup>c</sup>Light and heavy truck data were combined.<sup>d</sup>1976, 1977, and 1978 data were combined.**Table 3. Expressway and turnpike fatal accident rates.**

Facility	Accident Rate/100 Million VMT <sup>a</sup>								
	Passenger Cars			Light Trucks			Heavy Trucks		
	1976	1977	1978	1976	1977	1978	1976	1977	1978
California									
Interstate 15	N/A	4.0 <sup>a</sup>	—	N/A	3.2 <sup>a</sup>	—	N/A	8.0 <sup>a</sup>	—
Florida									
Florida's Turnpike	0.3	0.7	1.3	2.0	0.0	4.6	1.0	1.4	3.2
Airport Expressway	2.6	1.8	2.5	0.0	0.0	0.0	0.0	0.0	0.0
East-West Expressway	0.3	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Everglades Parkway	3.1	4.5	6.3	0.0	0.0	16.0	4.7	17.6	15.8
West Dade Expressway	0.4	0.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Illinois Turnpike	0.9	1.2	N/A	2.5	1.4	N/A	1.1	0.9	N/A
Kansas Turnpike	2.7	1.7	2.3	5.9	8.5	7.9	0.0	8.7	2.3
Kentucky									
Bluegrass Parkway	1.1	0.0	0.0	0.0	0.0	0.0	10.1	0.0	0.0
Cumberland Parkway	2.6	4.9	2.3	0.0	0.0	0.0	0.0	0.0	0.0
Daniel Boone Parkway	2.6	7.3	10.9	0.0	0.0	56.0	0.0	0.0	13.2
Green River Parkway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.8
Purchase Parkway	0.0	0.0	4.0	0.0	0.0	87.3	0.0	0.0	0.0
Mountain Parkway	1.0	4.0	3.8	0.0	22.4	44.5	0.0	9.6	0.0
Pennyrile Parkway	12.5	1.4	0.0	0.0	0.0	0.0	13.6	0.0	0.0
Western Kentucky Parkway	2.8	2.8	2.1	0.0	17.0	0.0	0.0	0.0	0.0
Ohio Turnpike	1.0	1.2	0.8	0.0	3.0	1.0	3.0	3.9	2.0
New Jersey Turnpike	0.6	0.5	0.4	— <sup>b</sup>	— <sup>b</sup>	— <sup>b</sup>	3.0 <sup>b</sup>	2.2 <sup>b</sup>	2.7 <sup>b</sup>
New York State Thruway		1.0 <sup>c</sup>			1.0 <sup>c</sup>			2.8 <sup>c</sup>	
Pennsylvania Turnpike	0.3	0.5	1.0	— <sup>b</sup>	— <sup>b</sup>	— <sup>b</sup>	1.8 <sup>b</sup>	2.5 <sup>b</sup>	2.8 <sup>b</sup>
West Virginia Turnpike	6.7	12.5	11.0	13.5	94.2	32.5	11.5	2.0	29.8

Note: N/A = not available.

<sup>a</sup>1977 and 1978 accident data were combined and are listed under 1977.<sup>b</sup>Light and heavy truck data were combined.<sup>c</sup>1976, 1977, and 1978 accident data were combined.

The dramatically disproportionate involvement of light and heavy trucks in fatal accidents can be attributed to the fact that when big trucks were involved, the results unfortunately were not just property-damage accidents but instead fatal accidents.

As shown in Figure 2, light trucks were involved in 1.55 times more injury accidents than were passenger cars, whereas heavy trucks were involved in 1.37 times more injury accidents than were passenger cars.

The overall accident-involvement rate presented in Figure 3 shows that, compared with passenger cars, light and heavy trucks were involved in 1.72 and 1.58 times more accidents, respectively, than were cars. Light trucks and heavy trucks were thus involved in 72 and 58 percent more accidents, respectively, than were passenger cars for the same distance traveled under the same driving conditions.

Figure 4 shows that, whereas all trucks account for only 20.3 percent of the highway exposure (a product of the number of vehicles and the miles they

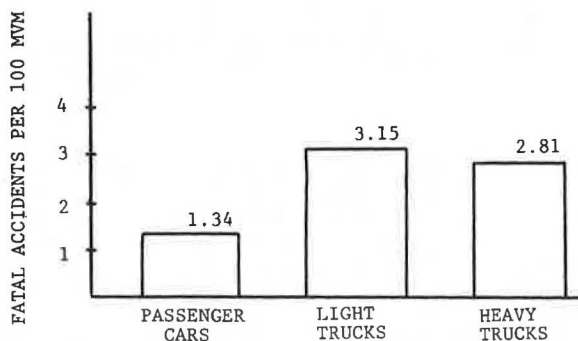
Table 4. Bridge and tunnel overall and injury accident rates.

Facility	Passenger Cars			Light Trucks			Heavy Trucks		
	1976	1977	1978	1976	1977	1978	1976	1977	1978
Bridge and Tunnel Overall Accident Rate/100 Million VMT <sup>a</sup>									
California									
Carquinez Bridge, Solano County	189.1	127.9	168.2	0.0	378.5	1383.6	838.9	1355.0	1500.6
Golden Gate Bridge, San Francisco	155.3	178.7	170.8	849.8	951.5	1267.9	4732.8	3702.7	4481.4
San Francisco-Oakland Bay Bridge	191.4	186.3	200.0	202.0	80.3	316.8	2543.6	2893.6	2360.5
San Mateo Bridge	78.5	74.1	85.1	243.9	548.5	172.5	1058.8	1074.8	945.7
Delaware									
Delaware Memorial Bridge	117.7	95.8	99.4	408.1	302.1	626.6	170.7	205.0	214.2
Florida									
Warren Bridge	361.8	511.1	632.3	206.2	873.4	292.2	429.6	315.4	519.0
Maryland									
Baltimore Harbor Tunnel	379.3	276.9	274.6	— <sup>b</sup>	— <sup>b</sup>	— <sup>b</sup>	1316.7 <sup>b</sup>	897.5 <sup>b</sup>	886.4 <sup>b</sup>
New York									
Bronx Whitestone Bridge	N/A	225.0	233.0	N/A	3864.0	3017.0	N/A	4147.0	4049.0
George Washington Bridge	861.0	1054.0	1057.0	2690.0	3368.0	3024.0	2238.0	3316.0	3121.0
Throgs Neck Bridge	N/A	186.0	172.0	N/A	1155.0	858.0	N/A	2826.0	1982.0
Triborough Bridge	N/A	253.0	242.0	N/A	2381.0	2379.0	N/A	3036.0	2933.0
Verrazano Narrows Bridge	N/A	187.0	199.0	N/A	1564.0	1516.0	N/A	1554.0	2938.0
Virginia									
Chesapeake Bay Bridge and Tunnel	101.4	159.6	161.5	— <sup>b</sup>	— <sup>b</sup>	— <sup>b</sup>	188.1 <sup>b</sup>	283.5 <sup>b</sup>	325.6 <sup>b</sup>
Bridge and Tunnel Injury Accident Rate/100 Million VMT									
California									
Carquinez Bridge, Solano County	55.9	64.0	44.9	0.0	0.0	691.8	0.0	338.7	300.1
Golden Gate Bridge, San Francisco	29.3	34.8	38.6	255.0	173.0	338.1	364.1	0.0	344.7
San Francisco-Oakland Bay Bridge	68.3	70.6	72.0	40.4	40.2	79.2	514.8	661.8	442.6
San Mateo Bridge	36.7	25.5	36.8	0.0	274.2	86.3	302.5	286.6	337.7
Delaware									
Delaware Memorial Bridge	26.4	23.3	24.5	N/A	151.1	289.2	22.2	29.3	35.7
Florida									
Warren Bridge	99.5	163.9	273.7	0.0	249.5	146.1	0.0	0.0	0.0
Maryland									
Baltimore Harbor Tunnel	83.3	65.3	68.3	— <sup>c</sup>	— <sup>c</sup>	— <sup>c</sup>	246.1 <sup>c</sup>	180.2 <sup>c</sup>	123.6 <sup>c</sup>
New York									
Bronx Whitestone Bridge	N/A	53.0	73.0	N/A	601.0	670.0	N/A	444.0	675.0
George Washington Bridge	105.0	121.0	136.0	247.0	124.0	182.0	90.0	104.0	96.0
Throgs Neck Bridge	N/A	43.0	42.0	N/A	495.0	241.0	N/A	491.0	375.0
Triborough Bridge	N/A	78.0	68.0	N/A	729.0	870.0	N/A	479.0	800.0
Verrazano Narrows Bridge	N/A	54.0	54.0	N/A	512.0	497.0	N/A	473.0	1079.0
Virginia									
Chesapeake Bay Bridge and Tunnel	40.6	61.4	61.4	— <sup>c</sup>	— <sup>c</sup>	— <sup>c</sup>	47.0 <sup>c</sup>	87.2 <sup>c</sup>	101.7 <sup>c</sup>

Note: N/A = not available.

<sup>a</sup>Includes property-damage and injury accidents.<sup>b</sup>Light and heavy truck data were combined.<sup>c</sup>Light and heavy truck data were combined.

Figure 1. Fatal accident rates for controlled-access expressways.

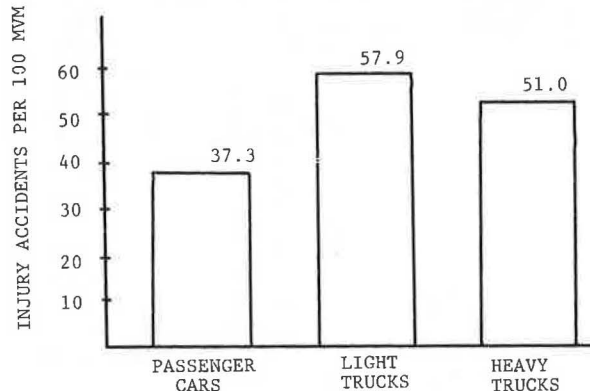


traveled), they represented 35.3 percent of the vehicles involved in fatal accidents.

Moreover, Figure 5 shows that, although light and heavy trucks made up 29 percent of all the vehicles involved in accidents, they were involved in more than one-third of the fatal accidents.

The analysis also showed that, although 1 in 85 car accidents is fatal, 1 in 63 heavy-truck accidents results in a fatality. This suggests the ef-

Figure 2. Injury accident rates for controlled-access expressways.



fect of a truck's substantially greater size and weight on accident severity.

The number of trucks involved in fatal accidents was also found to have risen disproportionately when compared with increases reported for truck exposure. This is shown in Figure 6, which illustrates that between 1976 and 1978, truck exposure increased

Figure 3. Overall accident rates for controlled-access expressways.

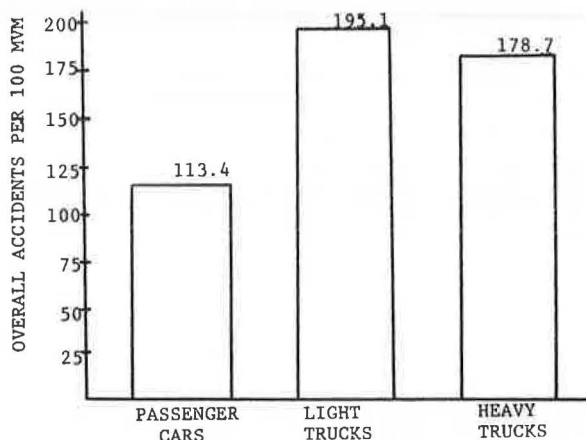


Figure 4. Fatal truck accidents in relation to vehicle exposure.

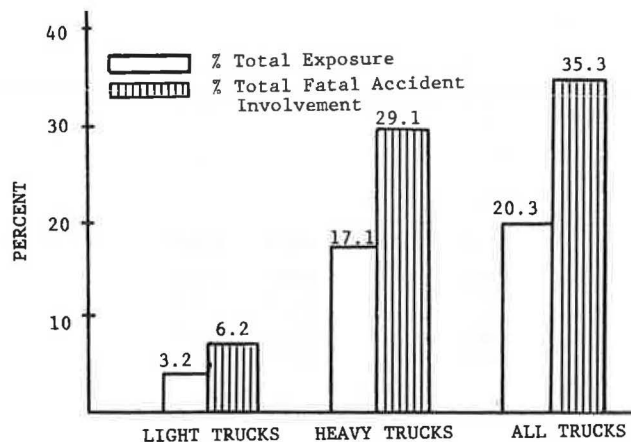
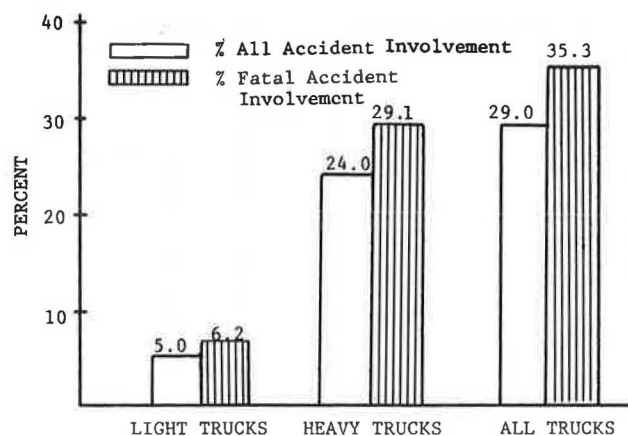


Figure 5. Fatal truck accidents in relation to all truck accidents.



by 58 percent, whereas fatal truck accidents on the highways studied increased by a staggering 96 percent.

Accident rates for the toll bridges and tunnels in the study are provided in Figure 7 and show that the differences in the overall accident rates for light and heavy trucks compared with those for the

Figure 6. Changes in truck accident involvement, 1976-1978.

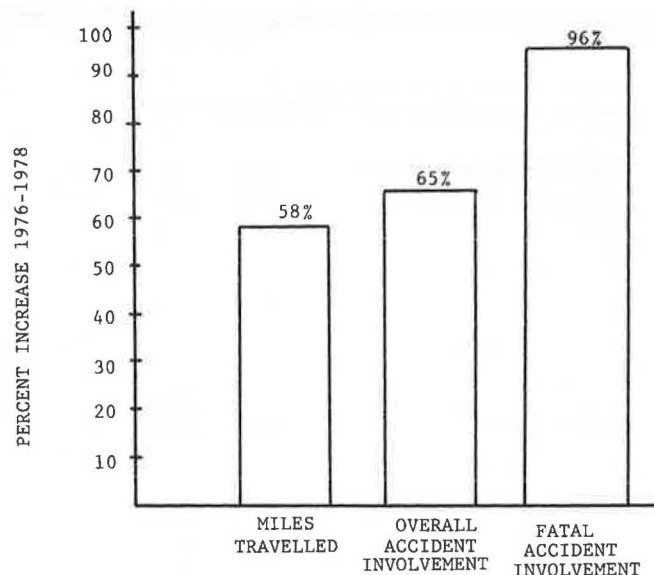
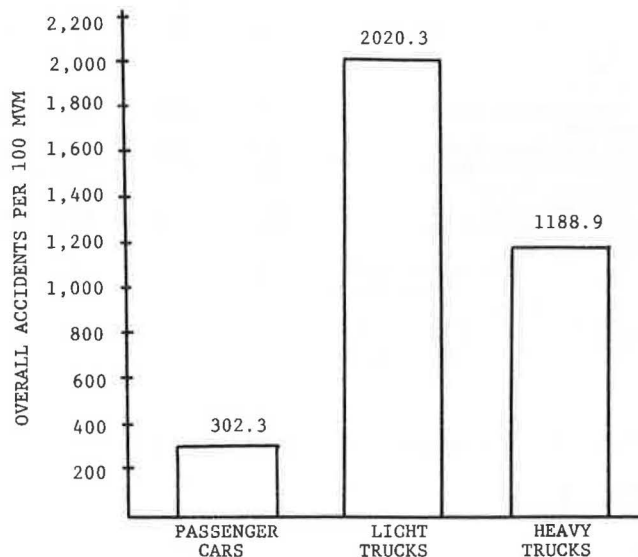


Figure 7. Overall accident rates for bridges and tunnels.

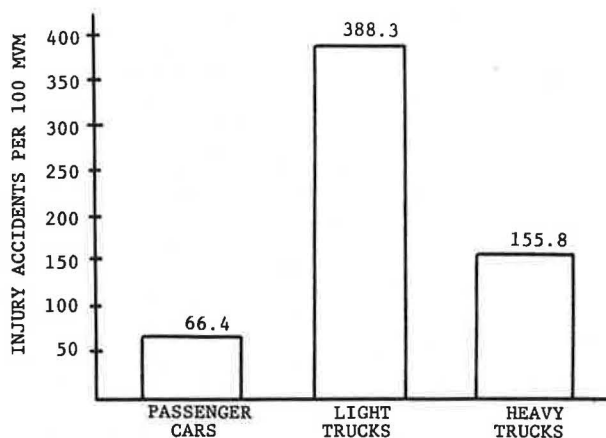


passenger cars were even greater than those for expressways. On the average, light trucks were involved in 6.7 times more accidents than were passenger cars for the same distance traveled. Heavy trucks were found to be involved in 3.9 times as many accidents as were passenger cars for the same exposure.

As shown in Figure 8, light trucks were involved in 5.8 times more injury accidents than were passenger cars for the bridges and tunnels, whereas heavy trucks were involved in 2.3 times the number of injury accidents for the same distance traveled.

The overall bridge and tunnel accident rates for light and heavy trucks were 10.4 and 6.7 times greater, respectively, than those for expressways. The accident rate for passenger cars for bridges and tunnels was, on the other hand, only 2.7 times greater than that for expressways.

Figure 8. Injury accident rates for bridges and tunnels.



## SUMMARY

The findings may be summarized as follows:

1. The fatal accident rate of trucks is more than two times greater than the accident rate for passenger cars for the same exposure on the highway.
2. Other accident rates for light and heavy trucks, which include injury and property-damage accidents, are also disproportionately greater compared with those for passenger cars for the same distance traveled under identical conditions.
3. Big trucks are involved in a significantly greater share of fatal accidents than might be expected for their mileage and population on the highway.
4. A substantially higher number of truck accidents result in a fatality than do passenger-car accidents, which suggests that the trucks' size and weight influence accident severity.
5. As the VMT of the big truck increases, there has been a disproportionate increase in fatal truck accident involvements.
6. Although trucks now account for 20 percent of the vehicle exposure on expressways and turnpikes, they are involved in 35 percent of the fatal accidents. On some major thoroughfares, such as the Pennsylvania, Ohio, and New Jersey Turnpikes, about 50 percent of all fatal accidents involve a truck.

## CONCLUSIONS

This study presents, perhaps for the first time, accident rates based on accurate exposure data that document the serious overinvolvement of trucks in traffic accidents. The results are based on accident and exposure data that have been provided for facilities that make up what are generally regarded as the nation's safest highways.

Although the study obviously can only account for the traffic mix as it currently prevails, the situation can only be expected to worsen as the disparity between weight and size of the passenger car and the truck continues to increase.

Unfortunately, there is every indication that the future will present a bleak picture for the motoring public. Because of the concern about fuel economy, automobiles are getting smaller and lighter, whereas trucks are getting bigger and heavier.

In addition to the growing disproportion in size and weight of the traffic mix, the number of large vehicles in the traffic stream has grown rapidly in recent years. In 1977, trucks carried three times

the number of ton miles of intercity freight as they did in 1950 (3).

As a result, all this would seem to indicate that as far as big-truck safety is concerned, the worst is yet to come.

## ACKNOWLEDGMENT

I would like to express appreciation to the AAA Foundation for Traffic Safety for developing and coordinating this project; to the following AAA clubs who participated in the collection of accident information: Automobile Club of Kansas, Automobile Club of Maryland, Automobile Club of New York, Automobile Club of Oklahoma, Automobile Club of Rhode Island, Automobile Club of Southern California, California State Automobile Association, Chicago Motor Club, Delaware Motor Club, East Florida Division AAA, Hoosier Motor Club, Louisville Automobile Club, Maine Automobile Association, Ohio Automobile Club, Pennsylvania AAA Federation, Tidewater Automobile Association, and West Virginia State Association; and to Paul Petrillo and Richard Newhouse for their counsel and support.

## Discussion

John Brennan

The stated purpose of the paper presented by Meyers of AAA was to determine whether large trucks were involved in a disproportionate number of accidents. At the outset, Meyers criticized the practice of using estimated vehicle miles as opposed to known levels of exposure for each vehicle group in question. Thus the AAA foundation set out to collect actual numbers of vehicle miles and accident occurrences. From that point on, the Meyers study appears to rely on selective, incomparable, and even estimated data.

By confining the inquiry to toll roads, Meyers focuses on only one particular roadway type. Originally, 52 facilities were to be analyzed, and these were broken down into expressway, turnpike, bridge, and tunnel facilities. However, the objectivity of the data from 18 facilities was questionable and as a result not used. From the remaining 34, Meyers narrowed the analysis to 21 facilities after excluding bridges and tunnels due to their operational uniqueness. Beyond asserting that the original 52 facilities encompass a representative mix of highways in rural and urban areas, the degree to which these remaining 21 road segments represented the situation on all toll roads, let alone all roadways, was not examined.

Some criticisms of Meyers' study result from our effort at the American Trucking Associations (ATA) to trace through the data selected for the study and to validate the conclusions. In the course of this checking, we contacted each of the toll facilities recognized in the Meyers study. The Illinois State Toll Highway Authority wrote us that they had given the AAA figures that were used to calculate accident rates. However, the Illinois authority was unclear as to how their figures could be used to calculate accident rates for specific vehicle classes because Illinois does not collect vehicle miles by various classes of vehicles. Similarly, the New York State Thruway Authority responded to our inquiry with a copy of their letter to the Automobile Club of New York that stated that their data-collection system



precludes determination of vehicle mileage by vehicle type or class.

Even for toll facilities that did record miles by vehicle class, the data were presented only in the form of accident rates. By banning the actual numbers from the study, Meyers' position might be misleading interpretations of the accident situation. An example of this is illustrated by the results Meyers cited for the Bluegrass Parkway in Kentucky (Table 3). The only fatal accident rate for trucks for that facility was 10.1/100 million VMT in 1976. Yet, that rate is based on one fatal truck accident for 9 934 306 VMT. This single accident was the only fatal heavy-truck accident on that facility during the three years covered by the study. In addition, 6 of the 21 turnpikes had no fatal truck accidents during any of the three years.

Given the facts in our discussion, the heavy-truck accident situation does not appear to compare with Meyers' study. In our opinion, the conclusions reached in Meyers' study are not representative of the heavy-truck accident situations throughout the country.

## Author's Closure

This study was undertaken to make comparisons of the accident rates of trucks and passenger vehicles traveling under the same conditions on the same highways. Further, in order to get actual mileage figures and avoid any criticism that has been made in the past, toll-road information was collected from a total of 54 turnpike, bridge, and tunnel facilities because of the accuracy in the statistics available from these types of facilities from the standpoint of miles traveled, accidents, and types of vehicles on the road. The data were refined to 21 turnpikes and 13 bridge and tunnel facilities in order to meet the criteria of having unchallengeable mileage and accident data for cars and trucks.

The American Trucking Associations has repeatedly scoffed at statistics provided by the Bureau of Motor Carrier Safety and other state and federal agencies on the basis that the fatal accident rates do not consider the true exposure of trucks accurately. It is their contention that trucks travel more than cars and that estimates of miles traveled based on gasoline sales, vehicle registrations, and travel characteristics do not accurately reflect the situation that prevails.

As far as data collection is concerned, no estimates were made in the study--all rates were determined from actual mileage figures and accident data provided by the reporting agencies. The toll authorities were specifically requested to provide the number of vehicles of each class involved in property-damage, injury, and fatal accidents as well as the miles they traveled. In this connection, in correspondence dated May 16, 1980, from their traffic engineer, the Illinois State Toll Highway Authority provided the actual number of VMT and the number of vehicles involved, by type, in fatal, injury, and property-damage accidents from which accident rates reported in my paper were determined. In essence, the Illinois State Toll Highway Authority complied with the request for specific information as described previously.

Similarly, in the case of the New York State Thruway Authority, a special printout that provided the volumes of each vehicle class that traveled from interchange to interchange for both directions of

the toll-ticket portion of the Thruway was obtained. The traffic volumes between interchanges were multiplied by the exact distance between each two interchanges, which provided a measure of the VMT for each vehicle class. The procedure was successively repeated for the entire length of the toll-ticket portion of the Thruway until a total measure of VMT for each vehicle class was obtained.

One indication that the data used were not selectively chosen is the fact that on six of the turnpikes included in the study, no fatal accidents were reported for trucks and the fatal accident rates for trucks were (as might be expected) zero. However, it is important to note that the inclusion of these six facilities did not significantly change the overall outcome of the study because the truck mileage for these six facilities represented only 3.8 percent of the total truck exposure for all turnpikes.

Accident and fatality rates are commonly accepted measures by the engineering community for comparisons of accident involvement. This practice relates the number of accident involvements by type for a specified distance of travel, generally 100 million VMT. The study abided by that practice and presented truck as well as passenger-vehicle accident experience expressed as a rate in order to permit direct comparisons of the accident involvement for the two types of vehicles.

In short, this study is based on accident rates calculated on actual miles traveled (not estimates) for trucks and passenger vehicles for the same highway environment.

## Discussion

Paul Ross

Meyers calculates the truck accident rates on 34 toll facilities for which the VMT by each type of vehicle are quite accurately known. This calculation shows that trucks are involved in a greater percentage of the accidents than their proportion of the total VMT, from which the conclusion is drawn that trucks have a greater accident risk than do other vehicles.

This conclusion seems valid if only single-vehicle accidents are reported, since the exposure of vehicles to single-vehicle accidents is clearly proportional to their miles of travel. However, Meyers is silent as to accident type and it is not unreasonable to assume that all accidents--single-vehicle and multiple-vehicle--are included. The exposure of vehicle types to multiple-vehicle accidents is not proportional to their VMT as may be seen by a simple example.

We take the distribution of VMT as given in Figure 4, namely, 3.2 percent light trucks and 17.1 percent heavy trucks, which leaves 79.7 percent non-trucks. Assume that all vehicle types are identical in accident potential. With two-vehicle accidents, we would expect the 3.2 percent of the light-truck traffic to hit another light truck 3.2 percent  $\times$  3.2 percent = 0.10 percent of the time. Similarly a light truck should hit a heavy truck 3.2 percent  $\times$  17.1 percent = 0.547 percent, and light trucks should be hit by heavy trucks in 17.1 percent  $\times$  3.2 percent = 0.547 percent of the two-vehicle accidents. The total number of accidents involving light trucks and heavy trucks should be about 1.09 percent of all two-vehicle accidents. Similarly, if

we allow for the times that a light truck hits one of the 79.7 percent of the vehicles that are not trucks or is hit by one of these vehicles, we should expect about 5.10 percent of all two-vehicle accidents to involve a light truck and a nontruck in one way or another. The total involvement of light trucks in two-vehicle accidents should be about 6.29 percent, which is not significantly different from the 6.2 percent of fatal accidents reported in the paper but somewhat greater than the 5.0 percent of all accidents actually attributed to light trucks.

There is a general formula for the expected distribution of types in  $n$ -vehicle collisions. If  $A, B, C, \dots$  represents vehicle types and  $a, b, c, \dots$  represents their relative proportions in the traffic stream, the expected fraction of collisions of vehicle types  $XYZ \dots$  is the coefficient of  $XYZ \dots$  when the expression  $(aA + bB + cC + \dots)^n$  is multiplied out. If we work out the expected distribution of two-vehicle accidents by using the VMT distribution given in Figure 4, we get the following:

Vehicles in Accident	Distribution (%)
Light truck-light truck	0.10
Light truck-heavy truck	1.09
Light truck-nontruck	5.10
Heavy truck-heavy truck	2.92
Heavy truck-nontruck	27.26
Nontruck-nontruck	63.52

We see that light trucks, heavy trucks, and nontrucks should be expected to be involved in 6.29, 31.27, and 95.88 percent, respectively, of all two-vehicle accidents. Meyers reports that light trucks were actually involved in 6.2 percent of the fatal accidents and 5.0 percent of all accidents; heavy trucks were involved in 29.1 percent of the fatal accidents and 24.0 percent of all accidents. If all the accidents involved two vehicles, it would appear that trucks are not significantly different from other vehicles in their fatal accident experience and are better than other vehicles for nonfatal accidents. However, a firm conclusion on this subject cannot be reached without knowing what proportion of the accidents were single-vehicle, two-vehicle, three-vehicle accidents, etc.

Accident rates cannot be compared (except for single-vehicle accidents) simply on the basis of VMT, since this always overstates the accident rates of individual components of the traffic stream, especially those components that constitute very small proportions of the traffic stream. For example, suppose that ordained ministers drove about 1 per-

cent of the total vehicle miles. Then they can be expected to be involved in almost 2 percent of the two-vehicle accidents. If in fact ordained ministers were involved in only 1.5 percent of all two-vehicle accidents, it would indicate exceptionally safe behavior on their part. A comparison on the basis of VMT would, nevertheless, make it appear that ordained ministers were 50 percent more dangerous than average drivers.

## Author's Closure

With regard to Ross's assumption that "all vehicle types are identical in accident potential," this is, unfortunately, a research-classroom type of supposition. The condition assumed does not exist on the road: All vehicles have varying steering, braking, and other operational characteristics and not every driver has the same driving proficiency. Further, it is generally recognized that statistical probability theory should not be used as a substitute for factual data.

On the other hand, Ross may have been misled by the labeling of Figures 4 and 5 in the preprint paper. I hope that any misunderstanding has been corrected by the refined labeling of Figures 4 and 5 in this paper and that this will show more adequately that the comparisons in these figures are for the percentage of vehicles actually involved in the fatal accidents.

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# Relationship of Accident Frequency to Travel Exposure

WERNER BRÖG AND BERND KÜFFNER

An attempt is made to determine the accident risk for persons who use various modes of transportation. The number of persons injured or killed in traffic not only is calculated in proportion to the total population but also is related to three different factors that pertain to travel exposure: the number of trips made, the number of kilometers traveled, and the amount of time spent traveling. The results of a survey done in the Federal Republic of Germany in 1976 (KONTIV) were the data base. The survey technique is shown that was applied to use data on the behavior of individuals on random sampling days to determine yearly values for traffic exposure. The accident rates for different modes vary according to the factors used to determine traffic exposure. Thus, by using kilometers traveled, the accident risk is least for persons who travel by

car. However, by using number of trips made and time spent traveling, the accident risk is least for pedestrians. The evaluation shows that the individual accident rate does not give a complete and accurate picture of accident risk. Only the combined analysis of all three accident rates can do this. An increased international exchange of data and experiences that pertain to this subject would be desirable.

In transportation safety research, it is very important to identify the accident risks for specific

groups of persons as well as for persons who use different modes. Accident rates are an important criterion by which to pinpoint the target groups at which transportation safety work should be aimed. The absolute number of accidents does not show the accident rates for specific groups or modes. In order to determine different accident rates that can be used as the measure of the accident risk, different statistical indicators of accident risk must be taken into consideration.

#### STATISTICAL INDICATORS OF ACCIDENT RISK

The first accident rate is the relationship of the number of persons who have had accidents to the total population. This correlation makes it possible to judge the risk for an average person; it thus reflects the general risk of having an accident while traveling.

Another indicator that can be used to determine the accident risk is the total travel exposure. Total travel exposure consists of the number of trips a person has made, the distance traveled, and the amount of time spent traveling (1).

Each of the accident rates for the above indicators is a meaningful measurement of accident risk. When combined, they are a good basis for comparative evaluations:

1. The rate of accidents per trip shows the risk a person runs when participating in an out-of-home activity;
2. The rate of accidents per kilometers traveled shows that the greater the distance is that a person travels, the greater the risk is that there will be an accident; and
3. The rate of accidents related to travel time is especially useful to measure exposure to risk in cases in which (for example, pedestrians) the number of kilometers traveled is less important as a risk factor than is the amount of time a person is exposed to a potentially dangerous situation.

Since each of the four accident rates referred to above (including the general accident rate for an average person) shows only one particular aspect of the problem, it is usually advisable to combine all four as a basis for forecasting.

The problem is, however, that the data needed on travel behavior are rarely available and, when they are available, their quality and precision are often imperfect. This paper uses a specific data source to attempt to calculate the complete set of the four accident rates and to thereby identify accident risk.

#### DETERMINATION OF BEHAVIORAL DATA

##### Methodological Requirements

In order to calculate the accident rate, one needs data on accidents (in this case, the number of persons injured and fatalities in 1976 in the Federal Republic of Germany) as well as data on travel behavior.

Data on traffic accidents is readily available from the statistical data on accidents collected by local police departments. (However, it is important to note that since a certain percentage of accidents are not reported, the actual number of persons who have had accidents is larger than the number recorded in the statistical records.)

Although fairly accurate statistical data are thus available for accidents, this is not the case for data on travel behavior. If surveys that collect data on travel behavior are to be valid, they must meet certain minimal qualitative requirements.

However, the question of the validity of the survey method is frequently neglected (2). Although it is not possible to discuss here all the possible sources of error that result from the use of inadequate methods (3), the following list (which includes the most important prerequisites for the collection of valid data on out-of-home activity patterns) gives some idea of what to look for in a survey (4):

1. The entire activity pattern of the interviewees must be recorded. Thus, all trips, including pedestrian trips, must be registered (5).
2. The interviewee's actual behavior during a specific period of time must be recorded. If one asks persons to report their "average behavior" (e.g., when preprinted multiple-choice lists are used), the result is that the responses reflect the interviewee's subjective self-estimation and not actual behavior (6).
3. Only when diarylike techniques are used can the problem of subjective self-evaluation be kept to a minimum (7).
4. It is preferable to use written questionnaires to collect data on travel behavior. Oral responses generally lead to greater distortions than do written questionnaires, and the distortions cannot be controlled (8).
5. Every survey appeals more to some persons and less to others. The problem of nonresponse leads to a systematic bias in survey results that must be taken into consideration when the results are processed (9-11).
6. Whenever possible, behavior should be continuously recorded over the period of an entire year in order to take seasonal differences in traveling into consideration (12).

##### Available Data Sources

The Continuous Survey of Travel Behavior (KONTIV) was used as the basis for the present evaluation. KONTIV was conducted at the request of the Federal Ministry of Transportation in 1976 and is representative of the Federal Republic of Germany. In this written survey, all out-of-home activities of 54 000 persons were recorded for 107 000 random sampling days throughout an entire year. The survey's return rate was 72 percent (13).

##### Necessary Corrective Measures

Although all the conditions necessary to ensure that the survey methodology was adequate were complied with in KONTIV, corrective measures were nonetheless necessary since, when behavioral data are processed, a number of factors can influence the quality of the survey. In KONTIV, as in all empirical surveys, the method of measurement used influences the results of the survey, for it is practically impossible to consider simultaneously all the factors that might influence the results of the survey and to weigh all of these factors equally.

However, this is not necessary. It is possible to neglect specific factors if the manner and degree to which these factors influence the results are known and can be corrected. When corrective measures are used, it becomes possible to use data on individual travel behavior measured on certain random sampling days to calculate valid statistical universal data such as number of trips made per year, number of kilometers traveled per year, and amount of time spent traveling per year.

The final correction of the KONTIV data was done in the four steps summarized below (14):



1. The basis is the trips that the individual made on the day of random sampling. The number of trips was then calculated on a yearly basis for each individual. For this calculation, the following corrections are important:

a. In surveys that take place on several consecutive days, the number of entries in the questionnaires falls off after the first day. (For the second day, about 4 percent fewer trips are reported.) This underreporting is corrected.

b. In samples where the return rate is less than 100 percent, the samples contain a systematic bias. Special surveys have shown that persons who do not respond to surveys make fewer trips than those who do respond. This insight is used to correct the resulting data (15).

c. Reported length and distance of trips are subjected to systematic errors in estimation. In special surveys, corrective measures that deal with specific modes of transportation were determined and used to correct the data (16).

2. As a next step, the foreign residents who had not been included in the survey were considered. Other surveys had shown that the travel behavior of foreign residents is different from that of Germans (17). These surveys were used as a basis for corrective measures.

3. Certain types of trips were purposely not fully recorded in the survey: private long-distance trips, especially vacation trips, and business and goods-movement trips. For these trips, specific sums were added to the calculations. At the same time, it was noted that some persons were not at home because they were on vacation (18).

4. Another problem was that prior to and following the use of a vehicle (especially public transportation), persons necessarily walk a certain distance. However, these pedestrian trips are usually not listed separately by the interviewees. Therefore, for trips made by using public transportation, estimations are made concerning the length of the walk to and from the public transportation stop

(19). The sums calculated for the distance covered and time needed for these walks were then added to the number of pedestrian trips. [This interpretation of such trip segments leads to some conflicts among specialists. Without being able to spend more time in this paper defending the approach used, it should be noted that the attempt to have all these trip segments recorded in the diaries is not a better alternative, at least not in large-scale surveys. The approach used here (which could be improved technically) still seems to be the best solution to the problem.]

#### ACCIDENT RATES FOR SPECIFIC TYPES OF TRIPS

##### For Yearly Travel Exposure

The corrective measures described above make it possible to calculate yearly participation in travel, number of trips made, number of kilometers traveled, and the length of time spent traveling (Table 1).

Thus it becomes possible to determine the accident risks for different types of travel. [For public transportation, no accident rates were determined since some of this traffic is not considered to be street traffic. Therefore, only a portion of the accidents that involve public transportation vehicles (e.g., buses) is included in the accident statistics for street traffic.] The accident rates for the four remaining types of vehicles are shown in Table 2.

Table 2 shows that the number of accidents per capita is highest for persons that use cars. More than half of all traffic injuries were sustained by persons who were either driving cars or riding as passengers in cars. The relationship of the number of accidents to data on traffic participation (accident/mobility rate) gives a very different picture of the accident risk while using a car. The accident risk when walking is relatively small, that when using a car is average, and that when using a moped or motorcycle is relatively large. In the accident/distance rate, persons who use cars are less prone to accidents than are pedestrians, since the speed traveled by car is naturally much greater. The high rate of accidents for persons who use motorcycles is remarkable; the risk of having an accident is 30 times higher per kilometer than it is for cars. The amount of time spent traveling is the last factor to be taken into consideration (and completes the picture) when accident risk is calculated. Using a car presents a more-or-less average risk as far as travel time is concerned. Persons in cars have three times as many accidents as do pedestrians in the same time span.

##### Comparative View

In Table 2, the values of the accident rates are also compared by using indices. The accident rates differ according to factors taken into consideration in the calculation. Thus, it is not possible to say

Table 1. Total amount of travel per person per year.

Mode	Avg No. of Trips <sup>a</sup>	Avg Distance <sup>a</sup> (km)	Avg Time Spent <sup>a</sup> (h)
Walking	251	364	96
Bicycle or mofa <sup>b</sup>	77	179	19
Motorcycle or moped <sup>c</sup>	7	48	2
Car	434	6811	171
Public transportation	106	1847	55
Total	875	9249	343

<sup>a</sup>Per person more than 10 years old per year.

<sup>b</sup>Mofa is a small motorcycle that has a maximum speed of 25 km/h.

<sup>c</sup>Moped is a small motorcycle that has a maximum speed of 40 km/h.

Table 2. Accident rate according to mode of transportation.

Mode	Accidents per 10 000 Persons	Accidents per Million Trips		Accidents per Million Kilometers		Accidents per Million Hours Traveled	
		Absolute Number	Index <sup>a</sup>	Absolute Number	Index <sup>a</sup>	Absolute Number	Index <sup>a</sup>
Walking	8.3	3.3	34	2.3	248	8.6	35
Bicycle or mofa	11.8	15.3	158	6.6	715	62.0	251
Moped or motorcycle	11.0	157.1	1624	22.9	2489	549.7	2226
Car	50.3	11.6	120	0.7	80	29.4	119
All <sup>b</sup>	84.8	9.7	100	0.9	100	24.7	100

<sup>a</sup>Total value = 100.

<sup>b</sup>Includes public transportation.

which form of travel is safest simply by quoting one accident rate. However, all persons who use two-wheeled vehicles show a particularly high accident rate. This is especially true for those who use mopeds and motorcycles.

#### ACCIDENT RATES FOR DIFFERENT DEMOGRAPHIC GROUPS ACCORDING TO AGE AND SEX

Additional data can be collected for the evaluation of accident risks when interviewees are divided into different sociodemographic groups. There are gross differences among the groups in the rate of accidents and the exposure to situations in which accidents might occur. By using the available data, it is possible to depict accident rates for these different groups.

However, this causes a special problem. The method described earlier, in which aggregate data on individual behavior were collected on certain days, could not be used analogously in this situation, because the coefficients used have variable effects depending on sociodemographic group (this is assuming that vacation trips, business trips, errors in estimating distances, etc., vary for different age groups). Since no sufficiently differentiated data were available in this stage of the research, it was not possible to use the approach described earlier to calculate accident/time rates for the different age groups and sexes. Rather, only behavioral data determined for an average weekday were used, and the only corrective measure used pertained to the pedestrian trips to and from public transportation.

Although this approach is certainly not completely satisfactory, we feel that we are justified in presenting the results of the data processing and in discussing them. Although the absolute degree of

the corrective measures is considerable (the yearly kilometers traveled in the Federal Republic of Germany was 108 billion in 1979), the individual factors can have opposite effects and can thus balance one another (the relative corrective measure for the yearly distance traveled is only 17 billion km).

To get an idea of the extent of accidents, these findings can be compared with the pertinent shares for the entire population. The results for 1976 in the Federal Republic of Germany for the characteristics considered are shown in Table 3, which shows that the accident risk for individual sociodemographic groups varies greatly according to the mode used.

In Tables 4-6 the accident risks for different groups is related to their traffic exposure.

In order to simplify the use of the tables, the average values for the number of trips, the time needed to make the trips, and the distances traveled were made equal to 100 and the pertinent index was determined for each age group.

This shows that younger and older persons travel more on foot than do others, that younger persons use bicycles and mopeds much more frequently than the average, and that persons between 14 and 24 years use more mopeds and motorcycles whereas middle-aged persons and men as a group tend to use cars more frequently than the average. These results already give one a more in-depth view of the relationship between the frequency with which specific modes are used and the accident rate related to this use.

However, accident statisticians are confronted not only with the problem that sufficient behavioral data are not yet available but also with the fact that it is important that statistics be kept so that they can be used and understood by as broad a base of interested persons and users as possible.

Table 3. Percentage of fatalities and injuries by age and sex for different modes.

Characteristic	Fatalities and Injuries (%)					
	Total Population (N = 5 369 000)	All Modes (N = 455 510 000)	Walking (N = 44 705 000)	Bicycle <sup>a</sup> or Mofa (N = 63 416 000)	Moped <sup>a</sup> or Motorcycle (N = 59 159 000)	Car (N = 270 248 000)
Age						
10-14	9.6	6.1	14.7	21.2	1.5	2.4
15-17	5.2	13.0	6.0	23.6	46.5	5.0
18-24	11.1	27.6	9.5	10.0	34.8	33.8
25-64	57.3	46.1	41.8	36.1	15.4	54.5
64 and older	16.8	7.2	28.0	9.1	1.7	4.3
Sex						
Male	47.1	66.0	49.0	NS	NS	61.7
Female	52.9	34.0	51.0	NS	NS	38.3

Note: NS = not shown in accident statistics.

<sup>a</sup>As driver or passenger.

Table 4. Accidents and amount of travel according to age and sex for all persons.

Characteristic	Total Population		Injuries and Fatalities		Avg No. of Trips per Day	Avg Travel Time per Day (min)	Avg Distance per Day (km)	Index <sup>a</sup>		
	N	Percentage	N	Percentage				Trips	Time	Distance
Age										
10-14	51 284 000	9.6	27 885 000	6.1	2.35	48.6	14.1	97.1	89.8	62.0
15-17	28 168 000	5.2	59 143 000	13.0	2.66	60.1	17.0	109.9	111.0	74.6
18-24	59 699 000	11.1	125 890 000	27.6	2.73	63.0	24.5	112.8	116.4	107.8
25-64	307 690 000	57.3	209 873 000	46.1	2.61	58.0	27.1	107.9	107.2	119.0
64 and older	90 048 000	16.8	32 719 000	7.2	1.54	37.0	9.2	63.6	68.4	40.3
Sex										
Male	253 078 000	47.1	300 679 000	66.0	2.66	62.8	30.4	109.9	116.1	133.4
Female	283 812 000	52.9	154 831 000	34.0	2.21	46.1	15.8	91.3	85.2	69.5
Total	536 890 000		455 510 000		2.42	54.1	22.8			

<sup>a</sup>For computation of index in the last three columns, the total average values of the previous three columns were made equal to 100.

Table 5. Accidents and amount of travel according to age and sex for persons walking and using bicycles and mopeds.

Characteristic	Total Population (%)		Injuries and Fatalities (%)		Index					
					Trips		Time		Distance	
	B	C	B	C	B	C	B	C	B	C
Age										
10-14	9.6	9.6	14.7	21.2	114.9	322.5	116.5	262.9	116.8	241.4
15-17	5.2	5.2	6.0	23.6	108.1	334.8	126.2	340.0	127.1	389.7
18-24	11.1	11.1	9.5	10.0	75.7	100.0	82.3	105.7	83.2	119.0
25-64	57.3	57.3	41.8	36.1	97.3	73.9	92.7	68.6	94.4	69.0
64 and older	16.8	16.8	28.0	9.1	112.2	43.5	122.6	48.6	106.5	48.3
Sex										
Male	47.1	47.1	49.0	NS	79.7	NS	86.6	NS	88.8	NS
Female	52.9	52.9	51.0	NS	118.9	NS	112.2	NS	109.3	NS

Notes: B = persons walking; C = persons using bicycles and mopeds.  
NS = not shown in accident statistics.

Table 6. Accidents and amount of travel according to age and sex for persons using mopeds and motorcycles and using cars.

Characteristic	Total Population (%)		Injuries and Fatalities (%)		Index					
					Trips		Time		Distance	
	D	E	D	E	D	E	D	E	D	E
Age										
10-14	9.6	9.6	1.5	2.4	29.1	30.2	27.0	35.1	11.6	40.4
15-17	5.2	5.2	46.5	5.0	515.0	28.4	460.3	31.9	406.7	32.2
18-24	11.1	11.1	34.8	33.8	315.5	126.7	365.0	121.8	465.8	118.2
25-64	57.3	57.3	15.4	54.5	58.3	128.4	56.6	128.5	50.4	128.3
64 and older	16.8	16.8	1.7	4.3	34.5	31.0	32.6	31.9	21.8	27.7
Sex										
Male	47.1	47.1	NS	61.7	NS	132.8	NS	139.7	NS	140.5
Female	52.9	52.9	NS	38.3	NS	69.0	NS	64.2	NS	61.8

Notes: D = persons using mopeds and motorcycles; E = persons using cars.  
NS = not shown in accident statistics.

Table 7. Accident rates according to age and sex for all persons, persons walking, and persons using bicycles and mopeds.

Characteristic	Index Value for Injuries and Fatalities											
	Per Inhabitant			Per Number of Trips			Per Distance Traveled			Per Time Spent Traveling		
	A	B	C	A	B	C	A	B	C	A	B	C
Age												
10-14	64.1	153.8	222.1	66.0	133.9	68.9	103.4	131.7	92.0	71.4	132.0	84.5
15-17	247.3	114.5	450.2	225.0	105.9	134.5	331.5	90.1	115.5	222.8	90.7	132.4
18-24	248.5	85.1	89.7	220.3	112.4	89.7	230.5	102.3	75.4	213.4	103.4	85.0
25-64	80.4	73.0	63.0	74.5	75.0	85.3	67.6	77.3	91.3	75.0	78.8	91.8
64 and older	42.8	167.0	54.1	67.3	148.8	124.4	105.7	156.8	112.0	62.6	136.2	111.3
Sex												
Male	140.8	103.9	NS	128.1	130.4	NS	105.6	117.0	NS	121.3	120.0	NS
Female	64.3	96.5	NS	70.4	81.2	NS	92.5	88.3	NS	75.5	86.0	NS

Notes: Index values for A, all persons; B, persons walking; C, persons using bicycles and mopeds. For the computation of the indices, the average value of the given accident rate was made equal to 100.  
NS = not shown in accident statistics.

Thus, Tables 7 and 8 are designed to be as understandable as possible. These tables compare the frequency of accident involvement with the degree of travel participation and enable one to summarize more adequately the accident risk.

Table 7, for example, shows that persons more than 64 years old do not have even half as many accidents as the average for all age groups (index = 42.8). However, this must be seen in relation to the fact that this age group travels much less than do other age groups. The risk of this group's having accidents increases very rapidly in relation to the number of trips made and the amount of time spent traveling (indices = 67.3 and 62.6). When the distance traveled is considered (which is comparatively low), the index is 105.7, an above-average value.

When these figures are differentiated according to mode, other important insights are gained. Thus, among pedestrians (Table 7), younger and older persons run an average risk of having an accident (indices = 153.8 and 167.0), but this risk is "relativized" when one considers the fact that more older and younger persons tend to walk to their destinations than do other age groups. On the other hand, those aged 18 through 24 only appear to take less than an average risk in having accidents when they walk, since they walk so rarely and for such short stretches. Actually, they therefore run an above-average risk of having an accident while walking (20).

This shift is even more obvious when one considers persons who use bicycles and mopeds (Table 7). Children 10-14 years old who use bicycles and



Table 8. Accident rates according to age and sex for all persons, persons using mopeds and motorcycles, and persons using cars.

Characteristic	Index Value for Injuries and Fatalities											
	Per Inhabitant			Per Number of Trips			Per Distance Traveled			Per Time Spent Traveling		
	A	D	E	A	D	E	A	D	E	A	D	E
Age												
10-14	64.1	15.7	24.8	66.0	54.0	82.1	103.4	135.3	61.4	71.4	58.2	70.7
15-17	247.3	886.1	94.3	225.0	172.1	332.0	331.5	217.9	292.9	222.8	192.5	295.6
18-24	248.5	313.2	304.1	220.3	99.3	240.0	230.5	67.2	257.3	213.4	85.8	249.7
25-64	80.4	26.9	95.1	74.5	46.1	74.1	67.6	53.4	74.1	75.0	48.4	74.0
64 and older	42.8	10.2	25.9	67.3	29.6	83.6	105.7	46.8	93.5	62.6	31.3	81.2
Sex												
Male	140.8	NS	130.8	128.1	NS	98.5	105.6	NS	93.1	121.3	NS	93.6
Female	64.3	NS	72.5	70.4	NS	105.1	92.5	NS	117.3	75.5	NS	112.9

Notes: Index values for A, all persons; D, persons using mopeds and motorcycles; E, persons using cars. For the computation of the indices, the average value of the given accident rate was made equal to 100.  
NS = not shown in accident statistics.

mofas are more than two times as likely as other age groups to have an accident. But when one considers the fact that they use these modes much more than other age groups do, they actually have less than an average number of accidents. Thus, although the risk that persons 15-17 years old would have an accident seems to be very high at first, it lessens when viewed in the light of their heavy use of bicycles and mopeds. The opposite is the case with the group 64 years and older. At first it appears that the chance of their having an accident with a bicycle or mofa is very low, but this is because they use these modes so rarely. When one accounts for the frequency with which this age group uses these modes, the length of the trips, and the time of the trips, then this group actually has the second greatest risk of the different age groups in having an accident when using a bicycle or mofa.

Table 8 shows the same tendency for moped and motorcycle users. Persons aged 15-24 appear to run a very high risk of having accidents by using these modes. However, this is once again simply caused by the fact that they use these modes most frequently. Thus, the actual risk that members of this age group will have an accident is not so great as it appears to be at first. For all other age groups, the risk is greater than the relationship between the number of accident victims and the population.

As is true with other modes, when one looks at the figures that pertain to car drivers and car passengers, simple accident statistics differ from the results attained when behavioral data are used.

This is especially obvious when one compares the number of men who have accidents with the number of women who have accidents: 62 percent of all car passengers injured and killed are men (Table 4). But when accident rates are based on total travel exposure in cars, the accident rate is lower for men than for women.

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## Bicycle as a Collector Mode for Commuter Rail Trips

WILLIAM FELDMAN

This study was designed to identify the potential of the bicycle as a collector mode for commuter rail trips and the conditions or circumstances that inhibit or fulfill realization of this potential. The study consisted of the development and distribution of a survey questionnaire to commuter rail passengers at five target stations and an analysis of the survey results. It was discovered that there is considerable potential for the bicycle to serve as a collector mode for commuter rail trips. Of all respondents, 46.6 percent claimed that they would consider commuting from home to rail station by bicycle. This would result in alleviation of parking congestion or freeing of parking spaces, which would permit increased rail ridership. The improvement that apparently would do the most to foster increased use of the bicycle for these trips is the provision of secure bicycle-parking facilities at rail stations. In some situations, this would have to be accompanied by improvements to the roadway system that leads to the station to make it more compatible to bicycles.

In this age of increasing cost and diminishing availability of fuel resources, American society in general and residents of New Jersey in particular must turn to energy-efficient modes when possible, not merely to extend scarce fuel supplies but also to reduce costs to individual consumers of transportation so they can maintain their mobility. The bicycle is potentially well suited to short-distance utilitarian trips such as collector-distributor trips between home and long-distance commuter rail transit. The bicycle is indeed an energy-efficient mode. It has, however, been an underused mode (1). Generally, it has been believed that one of the primary reasons for this underuse has been the lack of facilities, both bicycle-compatible roadways that lead to rail stations and devices at stations to secure bicycles from theft and vandalism.

In New Jersey, the New Jersey Department of Transportation (NJDOT) and New Jersey Transit (NJ Transit) wish to promote the increased use of the bicycle as a collector mode for commuter rail transit trips. In addition to the energy implications of this increased use, other objectives could conceivably be served. These include reduction in parking demand at commuter rail stations, alleviation of congestion, improved air quality (2), and equity considerations (i.e., the provision of rail services to those who for a variety of reasons cannot use other modes to reach the rail stations).

In order to proceed with a rational program of facilities (or other improvements) to foster the increased use of the bicycle, NJDOT and NJ Transit needed to know what conditions or circumstances inhibit use of the bicycle, what changes would best promote increased bicycle use, and what potential exists for increased levels of bicycle use.

### METHODOLOGY

This study was designed to satisfy the needs listed

above. The study consisted of the development and administration of a questionnaire distributed to rail passengers at selected commuter rail stations in New Jersey and the analysis of questionnaire responses.

The questionnaire was designed to determine the potential use of the bicycle as a collector mode for commuter rail transit stations and to identify those conditions or circumstances that inhibit the full realization of that potential. The questionnaire (Figure 1) was constructed to determine some characteristics of passengers at the target stations that might have a bearing on their predilection to use a bicycle for the trip to that station (questions 1 through 5). Such characteristics included sex, age, distance from station, length of time to station, and current modal choice for the trip to the station.

Additional questions were designed to elicit any tendencies in current modal-choice selection and to ascertain potential bicycle trip makers. Question 10 was designed to elicit the range and relative magnitude of improvements that might foster increased bicycle use. Questions 11 and 12 were designed to determine commuter preferences toward and potential use of various secure bicycle-parking facilities. Previous analysis by NJDOT personnel had indicated that having secure bicycle-parking facilities at rail stations was likely to be a necessary condition to expanded use of the bicycle for trips to commuter rail stations.

A number of criteria were postulated as having some relationship to the level of potential bicycle ridership and the level of potential demand for bicycle-parking facilities at rail stations. These are the following:

1. Condition of roads that lead to stations,
2. Availability of parking or deficiency of parking at the station,
3. Population clusters within 4 to 5 miles from the station,
4. Station ridership,
5. Existing bicycle use, and
6. Proximity to populations that do not use automobiles (e.g., college students).

By applying these criteria loosely and with the assistance of Stephen Hochman, senior planner of NJDOT's Bureau of Environmental Analysis (in charge of environmental work for NJ Transit's Rail Station Improvement Program), the following rail stations were identified as having significant potential for increased bicycle ridership: Metropark, Metuchen,

Figure 1. Survey questionnaire.

The purpose of this questionnaire is to measure the potential of the bicycle to serve as a means of getting passengers to and from rail stations in New Jersey. Please answer the questions and return.

1. Sex: ☐ Male ☐ Female
2. How old are you? (Check one)
 

10 - 20	<input type="checkbox"/>
20 - 30	<input type="checkbox"/>
30 - 40	<input type="checkbox"/>
40 - 50	<input type="checkbox"/>
50 - 65	<input type="checkbox"/>
over 65	<input type="checkbox"/>
3. How far do you live from this train station? (Check one)
 

0 - 1 mile	<input type="checkbox"/>
1 - 4 miles	<input type="checkbox"/>
4 - 7 miles	<input type="checkbox"/>
7 - 10 miles	<input type="checkbox"/>
10+ miles	<input type="checkbox"/>
4. How do you usually get to this train station? (Check one)
 

walk <input type="checkbox"/>	dropped off by car <input type="checkbox"/>
bike <input type="checkbox"/>	carpool <input type="checkbox"/>
bus <input type="checkbox"/>	car - parks in lot <input type="checkbox"/>
5. How long does it usually take you to get to the train station from home? (Check one)
 

0 - 5 minutes	<input type="checkbox"/>
5 - 15 minutes	<input type="checkbox"/>
15 - 25 minutes	<input type="checkbox"/>
6. If you do not (ever) ride a bike to this train station why not?
 

<input type="checkbox"/> convenient, affordable alternatives are available
<input type="checkbox"/> unsafe roads leading to station
<input type="checkbox"/> motorists don't respect bicyclists' rights
<input type="checkbox"/> lack of secure bicycle parking at the station
<input type="checkbox"/> other (identify) _____
7. Would you ever (even part-time) consider commuting from home to this station by bicycle?
 

yes <input type="checkbox"/>
no <input type="checkbox"/>
8. If not, why not?
 

<input type="checkbox"/> convenient, affordable alternatives are available
<input type="checkbox"/> unsafe roads leading to station
<input type="checkbox"/> motorists don't respect bicyclists' rights
<input type="checkbox"/> lack of secure bicycle parking at the station
<input type="checkbox"/> other (identify) _____
9. Can you foresee any circumstances which would encourage you to consider riding a bike to the station?
 

<input type="checkbox"/> no
<input type="checkbox"/> yes (identify) _____
10. What one improvement might encourage you most to ride your bike to the train station? (Check one)
 

<input type="checkbox"/> improved roads (more bicycle compatible) leading to the station
<input type="checkbox"/> secure bike storage facilities at the station
<input type="checkbox"/> education of motorists to the rights of bicyclists
<input type="checkbox"/> other (identify) _____
<input type="checkbox"/> none
11. What, in your opinion, are secure bike parking facilities?
 

<input type="checkbox"/> designated space for bicycles
<input type="checkbox"/> bike racks
<input type="checkbox"/> bike lockers
<input type="checkbox"/> other (identify) _____
12. Would you be willing to pay a nominal fee to reserve a bike locker for your use at this station?
 

<input type="checkbox"/> yes	<input type="checkbox"/> no
------------------------------	-----------------------------

Princeton Junction, West Trenton, Cranford, Montclair, Ramsey, Ridgewood, Westwood, Summit, Red Bank, Matawan, Long Branch, Westfield, South Orange, Short Hills, Oradell, Radburn, Glenrock, Convent, Madison, Morristown, and Bound Brook.

#### SURVEY SITES

Based on the preliminary analysis cited above, five target stations were selected for the dissemination of the survey questionnaire. These were Princeton Junction, Morristown, Red Bank, Westfield, and Metropark.

A description of the stations selected for the survey, including physical and ridership characteristics, is given in the following paragraphs.

#### Princeton Junction

Princeton Junction is located in Mercer County and is served by the Northeast Corridor Line, which has a ridership here of 1570 passengers daily (3). Existing parking for 1071 automobiles in three separate parking lots is fully used on both sides of the track. There is overflow parking on undeveloped lots and on surrounding access roads. Land is available for parking expansion but it would have to be acquired. A fee is charged for parking in two of the lots, and a monthly permit (acquired by fee) is required to park in the third lot. There is no dense residential development immediately adjacent to the station. This station was selected primarily because of its relatively high ridership and high parking deficiency.



### Morristown

Morristown, New Jersey, is in Morris County (4). The station facility is located two blocks from "the green," which is the centroid of the central business district (CBD) in Morristown. The Morristown Line has a ridership of 1428 passengers daily from Morristown. There are 256 parking spaces located in four small lots on either side of the tracks for which a fee is charged or permit (acquired by fee) is required. Space for the expansion of parking facilities is essentially nonexistent. This station was selected because of its extreme parking deficiency, large number of daily patrons, and accessibility to dense residential and commercial areas. In addition, it was noted that there is limited opportunity to expand ridership by expansion of automobile parking facilities.

### Red Bank

Located in Monmouth County, Red Bank is served by the North Jersey Coast Line, which has a ridership here of 1467 passengers daily (5). There are 711 existing parking spaces in five small lots scattered about the station site, and parking for the trains has scattered beyond the immediate area of the station to residential side streets. Land owned by the Central New Jersey Railroad is available for parking expansion. The station is located in an area of light industry and commerce and the Red Bank CBD is located to the northeast. There are numerous residential areas in the general vicinity of the station on the periphery of the commercial areas. The station was selected because of the relatively high ridership, parking deficiency, and its proximity to residential areas within a relatively short distance from the station.

### Westfield

Westfield, New Jersey, is located in Union County on the Raritan Valley Line; the ridership from here is 1989 passengers daily (6). There are 543 parking spaces in three lots immediately adjacent to the station buildings. A fee is charged for parking. Potential for increasing the number of spaces is limited due to existing development. The station complex is one of the focal points of the town of Westfield. It is located within the CBD and is surrounded by commercial enterprises and numerous residential areas in peripheral locations not far from the station. This station was selected because of its high ridership, parking deficiencies, limited opportunity to increase automobile parking, and the proximity of residential areas to the station.

### Metropark

Metropark is in Iselin, Middlesex County, on the Northeast Corridor Line, which carries a ridership of 2089 passengers daily from this station. There are 1300 free parking spaces for cars. The park-and-ride lot is currently operating at 110 percent of capacity, and there are numerous illegally parked cars in every conceivable space in the lot. Parking spills onto adjacent roads. Opportunities to expand parking significantly are limited. The station is surrounded by an office complex and one small and one moderately sized low-density residential area. Access to the station from the moderately sized residential area is somewhat circuitous. This station was selected primarily because of its high ridership and parking deficiency.

### DISTRIBUTION PROCEDURE

One hundred questionnaires were distributed at each

of the selected stations. The questionnaires were distributed on a weekday between 7:00 and 9:00 a.m. The distribution procedure was as follows.

Approximately 10-15 min prior to the arrival of the train, as passengers began to congregate on the platform or in the vicinity of the station in anticipation of the train's arrival, the individual distributing the questionnaire stood at one end of the platform. Approximately 5-10 min prior to the scheduled arrival of the train, the distributor would pass along the station platform. As individuals or small groups were approached, they were offered a questionnaire. This offer was accompanied by an explanatory statement that the individual distributing the questionnaire was carrying out a survey for NJDOT/NJ Transit on the use of this station and a request that the commuter please fill out the questionnaire and drop it in the mailbox. (It was immediately mentioned that the questionnaire was preaddressed and prestamped.) No additional statements were made to convince or coerce commuters to take or fill out the questionnaire. Acceptance of the questionnaire was therefore essentially a voluntary act, and those who accepted the folded questionnaire had no knowledge that the questionnaire dealt primarily with bicycle transportation to and from commuter rail stations.

If any resistance to taking the questionnaire was encountered for any reason whatsoever, the distributor withdrew the questionnaire and moved on to the next commuter. An estimated 98 percent of those offered the questionnaire accepted it.

No attempt was made to screen out individuals or to select individuals to whom questionnaires were presented. In fact, great care was taken to avoid any conscious selection. Once the distributor had presented one questionnaire, he or she moved on to the next available person on the platform. This procedure was followed to eliminate (as much as possible under the circumstances) a sampling bias, e.g., in which those who appeared unlikely to be bicycle riders or potential bicycle riders due to apparent age or physical condition were passed over and questionnaires were distributed only to those who appeared to be potential bicycle riders.

As the train pulled into the station area and passengers began to move toward the cars, distribution of the questionnaire ceased. For the next train, the distributor would begin to pass along the platform from the opposite end.

By following this procedure, the distributor could hand out approximately 20 questionnaires prior to the arrival of each train. It therefore took four to six train arrivals to complete the distribution of 100 questionnaires.

Since the rail lines on which these stations exist serve primarily patrons whose workplace is in the North Jersey/New York City area, the overwhelming majority of questionnaires was distributed to eastbound commuters. Less than five questionnaires were distributed at each station to westbound passengers.

Questionnaires were distributed on the following dates:

<u>Station</u>	<u>Date</u>
Princeton Junction	May 5, 1980
Morristown	May 7, 1980
Red Bank	May 12, 1980
Westfield	May 14, 1980
Metropark	May 15, 1980

Questionnaires received in the mail within two weeks of the distribution date were included in the survey tally. Those (relatively few) received after this length of time were not included. The vast majority

Table 1. Questionnaire return rate and percentage of ridership surveyed.

Station	Questionnaires Distributed			Ridership		
	Total	No. Returned Within Two Weeks	Percentage of Total	Total	Percentage Surveyed	Percentage Responding
Princeton Junction	100	43	43	1570	6.4	2.7
Morristown	100	44	44	1428	7.0	3.1
Red Bank	100	38	38	1467	6.8	2.5
Westfield	100	57	57	1989	5.0	2.9
Metropark	100	41	41	2089	4.8	2.0
Total	500	223	44.6	8543	5.9	2.6

of returns occurred within three days of distribution.

#### SURVEY RESULTS

For each station surveyed, the rate of return of the 100 questionnaires and the percentage of ridership surveyed are presented in Table 1.

Table 2 presents the responses to the survey questionnaire by station as a percentage of the sample and the totals. Some percentages may not add up to 100 due to the failure of some respondents to answer all questions; some may add up to more than 100 percent due to multiple selections by some respondents. The responses to questions 7, 9, and 12 extrapolated to the total ridership for each station are given in Table 3. [Specific answers to questions 6, 8, 9, 10, and 11 are available from the author.]

#### DISCUSSION OF QUESTIONS

##### Questions 1 and 2 (Sex and Age)

Characteristics by sex and age vary little by station. Analysis of responses by age and sex characteristics was not attempted in this study.

##### Question 3 (Distance from Station)

It is generally conceded that utilitarian trips by bicycle are quite feasible up to a range of 4 miles. Although some recent surveys indicate that this range is increasing, it is assumed that for this study the distance limit for bicycling trips to rail stations (as only one part of a combined bicycle-train-walk commute) would be 4 miles. This question therefore identifies essentially the upper limit of potential bicycle trip makers in terms of a distance constraint. The proportion of respondents who claim to live within 4 miles of the station represents for all practical purposes the pool of potential bicycle trip makers to the rail station.

This figure varies considerably from station to station (from 34.9 percent at Princeton Junction to 96.5 percent at Westfield); the sample mean is 68.6 percent. This indicates that the effective upper limit of potential bicycle trip makers to rail stations would vary considerably by station and is due to factors or conditions particular to each station.

##### Question 4 (Mode to Station)

For all stations except Westfield, the majority of commuters arrived at the station by an automobile that was parked in the station lot. If one postulates that reduction in parking demand and fewer vehicle miles of travel (VMT) are goals to be achieved, it is this pool of commuters from which it is desirable to draw and shift to other modes such as the bicycle for trips to the rail station. Table

4 presents the number of car drivers by station who answered affirmatively to questions 7 and 12; i.e., they claimed that they would consider commuting from home to the station by bicycle and that they would be willing to pay a nominal fee to reserve a bicycle locker. This indicates a considerable potential for alleviating parking deficiency, freeing parking spaces for additional transit patronage, or reducing demand for costly additional parking spaces.

As with question 3, the responses to this question indicate that the particular mode-arrival characteristics of the station are an important consideration in the potential of the bicycle to serve as a collector mode and to serve in a socially useful fashion, i.e., by reducing parking congestion and VMT by substituting for trips made by automobile.

##### Question 5 (Time to Station)

Responses to question 5 show pronounced variability by station; however, responses to this question were not analyzed or considered in this study.

##### Question 6 (Reason for Not Riding Bicycle to Station)

The most common reason given by those who never ride a bicycle to the train station was the availability of convenient affordable alternatives. This was closely followed by the lack of secure bicycle parking at the station. Again, the rank order of reasons varied considerably by station. At two stations, Princeton Junction and Metropark, unsafe roads that led to the station were the prime impediment to bicycle use.

##### Question 7 (Willing to Consider Bicycle for Trip to Station)

A total of 46.6 percent of all respondents claimed that they would consider commuting from home to the station by bicycle. This ranged from 36.6 percent at Metropark to 64.9 percent at Westfield. Coupled with the responses to question 3, an estimate can be derived of potential bicycle users who claim they would consider commuting to the station by bicycle and who live within the critical distance. This is shown in Table 5. This derived figure represents an estimate of the maximum number of commuters who would conceivably make some trips to the station by bicycle if given essentially perfect bicycling conditions.

##### Question 8 (Reasons Not to Bicycle)

The responses to this question essentially mirror the responses to question 6. Those who assert that they would never consider riding to the station by bicycle do so in roughly the same proportion and for the same reasons as do those individuals who do not currently ride.

Table 2. Survey results.

Question	Princeton Junction (N = 43)		Morristown (N = 44)		Red Bank (N = 38)		Westfield (N = 57)		Metropark (N = 41)		Total (N = 223)	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
1. Sex												
Male	34	79.1	31	70.0	30	78.9	48	84.2	30	73.2	173	77.6
Female	9	20.9	13	30.0	8	21.1	9	15.8	11	26.8	50	22.4
2. Age												
10-20	0	0	5	11.4	0	0	0	0	0	0	5	2.2
20-30	14	32.5	9	20.5	9	23.7	19	33.3	18	43.9	69	30.9
30-40	20	46.5	17	38.6	12	31.6	19	33.3	15	36.6	83	37.2
40-50	6	14.0	8	18.2	7	18.4	13	22.8	6	14.6	40	17.9
50-65	3	6.9	4	9.1	10	26.3	6	10.5	2	4.8	25	11.2
65+	0	0	0	0	0	0	0	0	0	0	0	0
3. Distance from station (miles)												
0-1	4	9.3	9	20.5	6	15.7	23	40.4	3	7.3	45	20.2
1-4	11	25.6	21	47.7	20	52.6	32	56.1	24	58.5	108	48.4
4-7	16	37.2	9	20.5	10	26.3	2	3.5	5	12.2	42	18.8
7-10	8	18.6	3	6.8	1	2.6	0	0	0	0	12	5.4
10+	4	9.3	2	4.5	0	0	0	0	9	22.0	15	6.7
4. Current modal choice												
Walking	2	4.7	10	22.7	4	10.5	22	38.6	3	7.3	41	18.4
Bicycle	1	2.3	0	0	0	0	5	8.8	0	0	6	2.7
Bus	1	2.3	1	2.3	3	7.9	0	0	2	4.8	7	3.1
Car driven by other	13	30.2	10	22.7	4	10.5	12	21.0	6	14.6	45	20.2
Carpool	2	4.7	0	0	0	0	0	0	3	7.3	5	2.2
Own car	26	60.5	22	50.0	26	68.4	19	33.3	27	65.9	120	53.8
5. Length of time to station (min)												
0-5	6	14.0	5	11.4	12	31.6	21	36.8	4	9.8	48	21.5
5-15	25	58.1	30	68.2	26	68.4	29	50.9	24	58.5	134	60.1
15-25	10	23.3	8	18.2	0	0	7	12.3	13	31.7	38	17.0
6. Reason for not riding bicycle to station												
Convenient alternatives	11	25.6	12	27.2	16	42.1	25	43.9	14	34.1	78	35.0
Unsafe roads	15	34.9	12	27.2	6	15.8	5	8.8	17	41.5	55	24.7
Disrespect by motorists	4	9.3	2	4.5	6	15.8	4	7.0	10	24.4	26	11.7
Lack of secure bicycle parking	11	25.6	21	47.7	12	31.5	15	26.3	15	36.6	74	33.2
Other	21	48.8	20	45.4	13	34.2	12	21.1	16	39.0	82	36.8
7. Willing to consider bicycle for trip to station												
Yes	16	37.2	20	45.4	18	47.3	37	64.9	15	36.6	106	47.5
No	26	60.5	21	47.7	20	52.6	17	29.8	25	60.1	109	48.9
8. Reasons												
Convenient alternatives	6	14.0	8	18.2	9	23.7	10	17.5	7	17.1	40	17.9
Unsafe roads	10	23.3	6	13.6	3	7.9	2	3.5	8	19.5	29	13.0
Disrespect by motorists	4	9.3	1	2.3	3	7.9	1	1.8	7	17.1	16	7.2
Lack of secure bicycle parking	3	6.9	8	18.2	4	10.5	7	12.3	7	17.1	29	13.0
Other	17	39.5	10	22.2	8	21.1	7	12.3	15	36.6	57	25.6
9. Availability of encouraging factor to use bicycle												
No	20	46.5	18	40.9	20	52.6	21	36.8	21	51.2	100	44.8
Yes	15	34.9	21	47.7	17	44.7	30	52.6	20	48.8	103	46.2
10. Improvement to encourage use of bicycle												
Improved roads	11	25.6	9	20.1	7	18.4	7	12.3	14	34.1	48	21.5
Secure bicycle parking	13	30.2	22	50.0	18	47.2	30	52.6	12	29.3	91	40.8
Education of motorists	3	6.9	1	2.3	3	7.9	3	5.3	3	7.3	13	5.8
Other	0	0	0	0	1	2.6	2	3.5	3	7.3	6	2.7
None	17	39.5	13	29.5	10	26.3	17	29.8	13	31.7	70	31.4
11. Opinion of secure bicycle parking												
Designated space	9	20.9	5	11.4	7	18.4	6	10.5	8	19.5	35	15.7
Bicycle rack	19	44.2	18	40.9	13	34.2	25	43.9	15	36.6	90	40.4
Bicycle locker	15	34.9	24	54.5	21	55.3	24	42.1	21	51.2	105	47.1
Other	2	4.7	4	9.1	3	7.9	9	15.8	5	12.2	23	10.3
12. Willing to pay for bicycle locker												
Yes	19	44.2	22	50.0	20	52.6	20	35.1	14	34.1	95	42.6
No	20	46.5	17	38.6	15	39.5	34	59.6	26	63.4	110	49.3

Note: Total ridership was as follows: Princeton Junction, 1570; Morristown, 1428; Red Bank, 1467; Westfield, 1989; Metropark, 2089; total, 8543.

Table 3. Responses to questions 7, 9, and 12 extrapolated to ridership.

Item	Princeton Junction (R = 1570)	Morristown (R = 1428)	Red Bank (R = 1467)	Westfield (R = 1989)	Metropark (R = 2089)	Total (R = 8543)
Question 7						
Yes	584	648	695	1291	764	4058
No	949	681	772	593	1274	4176
Question 9						
No	730	584	772	733	1070	3831
Yes	548	681	656	1047	1019	3945
Question 12						
Yes	693	714	772	698	713	3639
No	730	552	579	1186	1324	4214

Note: R = total ridership for each station.



**Table 4. Potential of automobile drivers to transfer to bicycle.**

Station	N	No. Car Drivers	Affirmative Response to	
			Question 7 (consider bicycling)	Question 12 (pay locker fee)
Princeton Junction	43	26	7	10
Morristown	44	22	8	10
Red Bank	38	26	11	12
Westfield	57	19	12	9
Metropark	41	27	11	10
Total	223	120	49	51

**Table 5. Pool of potential bicycle riders.**

Station	N	Affirmative Response to Question 7			
		No.	No. Within 4 Miles	Percentage of Sample	Extrapolated Total
Princeton Junction	43	16	9	20.9	328
Morristown	44	20	18	40.9	584
Red Bank	38	18	13	34.2	501
Westfield	57	37	36	63.2	1256
Metropark	41	15	13	31.7	662
Total	223	106	89	39.9	3409

**Question 9 (Encouraging Factor to Use Bicycle)**

Roughly one-half (46.2 percent) of all respondents claimed that certain circumstances might encourage them to ride a bicycle to the train station as part of their commute. Again, this figure varied considerably by station, ranging from 36.6 percent at Metropark to 64.9 percent at Westfield. The factors most commonly mentioned are lack of fuel availability, increased fuel costs, and improvement of one or more aspects of the bicycling environment.

**Question 10 (Improvement to Encourage Use of Bicycle)**

Provision of secure bicycle-storage facilities at the station was mentioned overwhelmingly as the one improvement that might encourage bicycle trips to the train. In the overall sample and at all stations except Metropark, improvement of roads leading to the station (i.e., making them more bicycle-compatible) was a distant second. Relatively few respondents identified any other improvements, physical or otherwise, that might encourage them to ride bicycles.

**Question 11 (Opinion of Secure Bicycle Parking)**

Bicycle lockers and racks were mentioned with roughly equal frequency as providing suitable security while bicycles are parked at the station, and they were the overwhelming choice of respondents. Designated spaces for bicycles was a distant third. Provision of a security guard was another method mentioned specifically by respondents almost as frequently as the designated spaces.

**Question 12 (Willing to Pay for Bicycle Locker)**

A total of 42.6 percent of all respondents claimed that they would be willing to pay a nominal fee (amount not specified) to reserve a bicycle locker for their use at the station. There was reasonable consistency in this response. The low figure for Metropark may be explained by the fact that automo-

bile parking is currently free at this station and commuters are reluctant to agree to pay a fee for bicycle parking when they do not now pay for automobile parking.

**CONCLUSIONS AND RECOMMENDATIONS**

Based on the analysis of questionnaire responses, there appears to be considerable potential for increased use of the bicycle to serve as a collector mode for commuter rail trips. Of the total respondents, 47.5 percent claimed that they would consider at least part-time commuting to rail stations by bicycle; 39.9 percent of the respondents who live within 4 miles of the station said that they would use the bicycle at least part-time. Extrapolating this percentage yields a pool of 3409 potential bicycle-using commuters at the five target stations. Even if only one-tenth of this pool used their bicycles part-time, this would represent an astounding increase over the number of passengers who now use bicycles to get to the station.

Of the 223 respondents, 120 now arrive by automobile and park at the station. Of these passengers, 40.8 percent claimed that they would consider at least part-time use of the bicycle. This indicates that fostering increased use of the bicycle might have a considerable impact on the socially desirable objectives of reducing VMT and alleviating parking congestion (or freeing parking spaces and permitting increased ridership) at the various commuter rail stations.

Roughly one-half (44.8 percent of all respondents) claimed that they could foresee circumstances that would encourage them to ride a bicycle to the station. The most commonly mentioned reasons were the increase in gasoline prices or lack of availability of fuel. In addition, the provision of improved facilities (secure parking and improved roads to stations) or provision of multiple improvements was frequently mentioned.

These tendencies hold true for all stations, although there is a considerable variability in degree at individual stations due to local conditions.

Of those (roughly one-half) respondents who stated that they would never consider riding to the station by bicycle, a plurality claimed that the reason was convenient affordable alternatives. Unsuitable roads leading to the station and lack of secure parking each garnered 13 percent of the responses. Of the other reasons specified by respondents, the most commonly mentioned was distance to the station. Surprisingly, relatively few respondents (7.2 percent) claimed that failure of motorists to respect bicyclists' rights was a consideration in their refusal to use the bicycle. These responses essentially mirror the reasons given by those who do not currently ride a bicycle to the station.

The one improvement mentioned most frequently (by 40.8 percent of the respondents) that might encourage passengers to bicycle to the station was the provision of secure bicycle-storage facilities at the station. Provision of improved roads (i.e., bicycle-compatible) leading to the station was mentioned next most frequently (21.5 percent). At the Metropark station, however, improved roads were mentioned most frequently, which suggests that the specific conditions at each station should be investigated prior to the implementation of any plan to foster increased bicycle use. Secure bicycle parking may be a necessary but not sufficient improvement to foster such increased use at some locations. No other improvements (not even education of motorists about the rights of bicyclists) were mentioned with significant frequency.

Bicycle lockers were mentioned most frequently (by 47.1 percent of the respondents) as the facility that constituted secure bicycle parking. Bicycle racks followed closely (mentioned by 40.4 percent of the respondents). At two stations--Westfield and Princeton Junction--bicycle racks were mentioned most frequently. Surprisingly, a designated space for bicycles (a relatively insecure facility) was mentioned by 15.7 percent of the respondents. Essentially all those (10.3 percent) who specified other facilities mentioned security guards. The variability of response by station suggests that the security problem varies (or at least the perception of it varies) by locality. This may be due to several factors, such as the existence of security personnel, the level of pedestrian traffic in the vicinity of the station, the accessibility of the station to noncommuters, the history of or perception of vandalism at the station, etc. This suggests, in turn, that varying mixtures of bicycle-parking facilities might suffice at varying locations.

Bicycle lockers provide the high level of security required by the plurality of potential bicycle users. Racks do not provide the same anti-theft and antivandalism characteristics that an enclosed locker does. At stations in which space and the existence of full-time personnel permits, a check-a-bicycle system could provide secure parking. For the occasional bicycle rider or for short-term (not all-day) storage, bicycle racks should suffice.

Of the total respondents, 42.6 percent claimed that they would be willing to pay a nominal fee (amount not specified) to reserve a bicycle locker for their use at the train station. If this is extrapolated to total ridership, it yields a total of 3639 passengers at the five target stations. Again, if even one-tenth of these passengers actually followed through on their claim, this would represent a considerable demand for installing bicycle lockers.

It is concluded that the most likely and most cost-effective method of realizing the potential use of the bicycle as a commuter rail collector mode is through the provision of secure bicycle-parking facilities at commuter rail stations. If purchased in quantity, two-bicycle locker units cost approximately \$500 each. Two hundred such units, which provide parking for 400 bicycles, plus racks that accommodate an equal number of bicycles could be purchased and installed for roughly the same cost as that for constructing approximately 1.5 miles of class 1 bikeway and at considerably less cost than that for a typical intersection improvement (intersection modification plus signalization). A minimum of 10 bicycles can be accommodated in the space needed for one car. Providing additional parking costs a minimum of \$1200 per space (often more). Thus, provision of five two-bicycle units at \$2500 in a parking-deficient situation may save at least part of the cost of providing nine additional spaces (minimum cost \$10 800) or it will free parking

spaces to permit more commuters to use the station.

Where lockers are installed, they should be rented on a moderate-term to long-term basis, for example, in 3-month increments. Regular bicycle commuters must be assured that a locker will be available for their use. The fee should not exceed the actual cost of the administration of the rental procedure. In fact, it might not be unreasonable to defray or subsidize the rental cost in light of the socially desirable benefits that are likely to accrue.

It is recommended that prior to the installation of lockers at each station, a preinstallation survey be carried out. Such a survey would help determine an appropriate fee structure. Passengers who express interest in renting a locker could be required to pay a preinstallation deposit to ensure use of the lockers. The deposit would be credited against the rental fee once the locker was installed and in service.

The bicycle-locker installation program should be carried out in concert with an effort to improve the bicycle suitability of roadways leading to those rail stations at which the unsuitability of such roads has been identified as a significant impediment to bicycle use (such as Metropark). Discovery of such conditions as well as the determination of the level of potential bicycle use, demand for secure bicycle parking, or other facilities and programs to achieve the potential bicycle use identified could be accomplished by the administration of a survey questionnaire similar to that used in this study. This procedure could be supplemented by coordination with local transportation planners and bicycle-interest groups.

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# Public Policy and Decision-Analysis Methods: Development of the National Comprehensive Bicycle Program

C. WILLIAM RYAN AND R. STEPHEN SCHERMERHORN

The National Energy Conservation Policy Act of 1978 mandated that the U.S. Department of Transportation (DOT) conduct a study of the energy conservation potential of bicycling. One of the expressed objectives of the study was that a comprehensive bicycle transportation program be developed to address current obstacles to bicycle use. This paper describes and analyzes the approach taken to develop that program. The primary problem encountered in developing the program was that there are a multitude of obstacles to increased bicycle use and, similarly, a multitude of experts' opinions about which obstacles are the most important. To aid in gaining an overview of the issues and experts' opinions, a formal decision-analysis method called worth assessment was employed. During the application of worth assessment, experts organized problem issues into a hierarchy of program objectives and numerically evaluated the relative importance of those objectives for achieving increased bicycle use. A comprehensive bicycle program was then synthesized to respond to those objectives identified as most important. Difficulties were encountered in using the worth-assessment technique, e.g., determination of the level of detail for which discussion was appropriate, semantics problems, and a lack of consensus among experts on certain issues. However, through the use of worth assessment the following benefits were derived: (a) a comprehensive overview of the bicycling problem was synthesized, (b) experts throughout the country for the first time concurrently dealt with identical subject material to identify key obstacles to bicycling, and (c) DOT and Congress were given direction for policy priorities based on experts' quantitative rankings of issues.

In the fall of 1978, Congress passed the National Energy Conservation Policy Act. Section 682 of that act deals with the potential energy conservation and other benefits of increased bicycle use in the United States. In that section Congress stipulated that obstacles to increased bicycle use be studied, that a target for commuting bicycle use be established, and that the U.S. Department of Transportation (DOT) "develop a comprehensive program to meet these goals."

DOT contracted with Mountain Bicyclists' Association (MBA) of Denver, Colorado, to complete the mandated study. Six months later, MBA produced a technical report detailing its findings for each assigned task as well as a recommended comprehensive program (1). DOT incorporated those findings into a report delivered to Congress on May 1, 1980 (2).

The tasks undertaken by MBA and DOT representatives were not easy. The charge to build a comprehensive program to attack obstacles to increased use was particularly intimidating, since in bicycling, as in any field, an array of obstacles and problems could be identified. These included unskilled riders, indifferent policymakers, defective products, poorly maintained facilities, and hateful motorists, to name just a few. In addition, almost everyone contacted had solutions for each problem (MBA developed a list of more than 500 individual strategies during this project). This situation required that the most important obstacles be identified and isolated and that a balanced program be built to address those obstacles. This paper examines and analyzes the approach used by the MBA project team to accomplish these ends.

## WORTH-ASSESSMENT METHOD

To develop an optimal comprehensive program, a systematic approach must be employed. Impact, Ltd., was commissioned by the MBA project staff to evaluate the applicability of decision theory techniques. Within this field there are numerous mathematical methods specifically designed to aid in the

development of optimal strategies and allocate limited resources. Decision-analysis methods model the decision-making process, i.e., the mental process of defining and organizing objectives, determining their relative importance, and evaluating alternatives in terms of those objectives. (In the past, decision-analysis methods have been primarily used to evaluate complex alternatives; a classic example is site selection for nuclear power plants. In contrast, the bicycle study need was to generate a comprehensive program, which thus required a rather unique application of decision-analysis methods.)

After reviewing several candidate methods of varying complexity, Impact selected the worth-assessment method, which was developed by J.R. Miller for the U.S. Air Force Systems Command in 1967 (3). As applied, this method enabled the project team to organize the obstacles and factors that affect bicycle use into a logical framework, achieve a consensus of bicycle and institutional experts on the relative importance of each of those factors, statistically evaluate the level of agreement among the experts, and use this information to frame a comprehensive bicycle program.

## ORGANIZATION OF THE PROBLEM

As applied in the context of the DOT charter, the worth-assessment method was used primarily to develop a hierarchical structure to describe the bicycling problem (Figures 1-5). A primary objective was identified, which was then divided into four secondary objectives. Those objectives in turn were divided into criteria, and criteria were divided into subcriteria, etc. This process facilitated analysis of the problem at several levels of detail and allowed translation of general objectives into detailed criteria for analyzing problem solutions. An analysis of the evolution of that structure and its eventual use follows.

Organization of the myriad factors that influence bicycle use was accomplished by a panel of bicycling experts. During an intensive workshop, the panel, equipped with a list of previously identified obstacles, was guided through the worth-assessment process and produced a problem structure.

The first task of the workshop was to develop categories of the factors that influence bicycle use. The following list was drawn up:

1. Personal perceptions,
2. Environmental conditions,
3. Multimodal opportunities,
4. Bicycle and bicycle equipment design,
5. Support facilities,
6. Implementation considerations,
7. Behaviors,
8. Attitudes,
9. Personal skills,
10. Motor vehicle design, and
11. Institutional context.

For each of the categories the workshop participants, by means of a brainstorming exercise, identified obstacles or factors that influence each cate-



Figure 1. Worth-assessment structure:  
primary and secondary objectives.

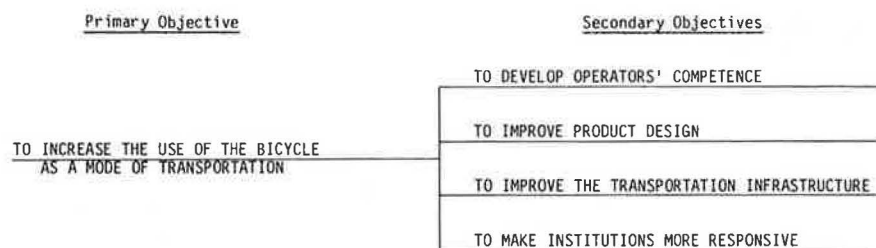


Figure 2. Worth-assessment structure:  
operators'-competence branch.

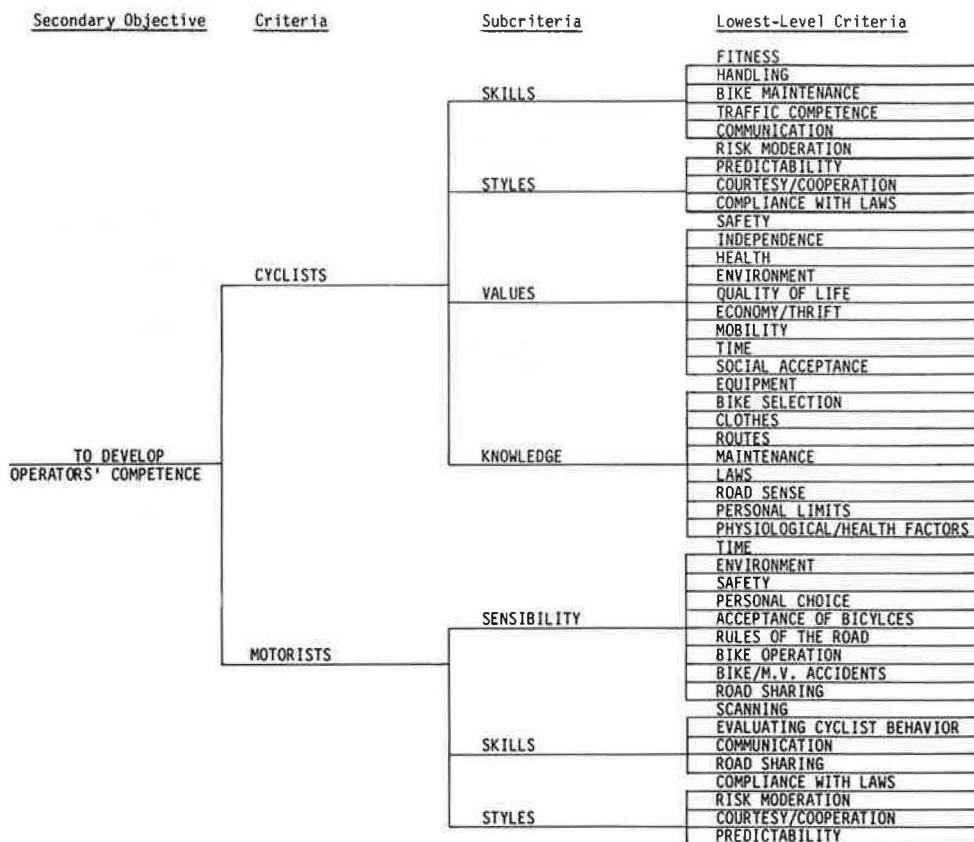


Figure 3. Worth-assessment structure:  
product-design branch.

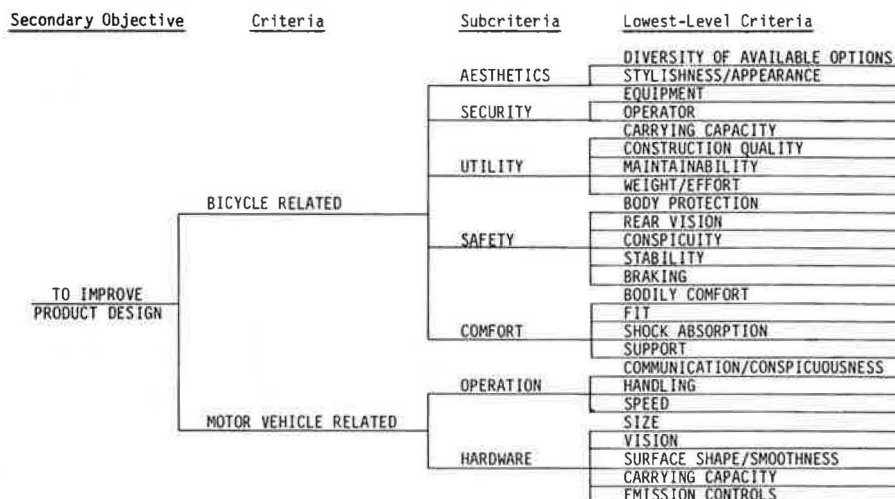


Figure 4. Worth-assessment structure: transportation-infrastructure branch.

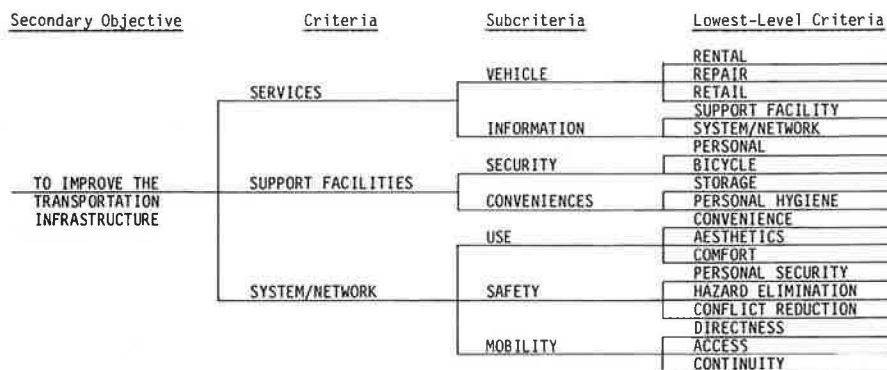


Figure 5. Worth-assessment structure: institutions branch.

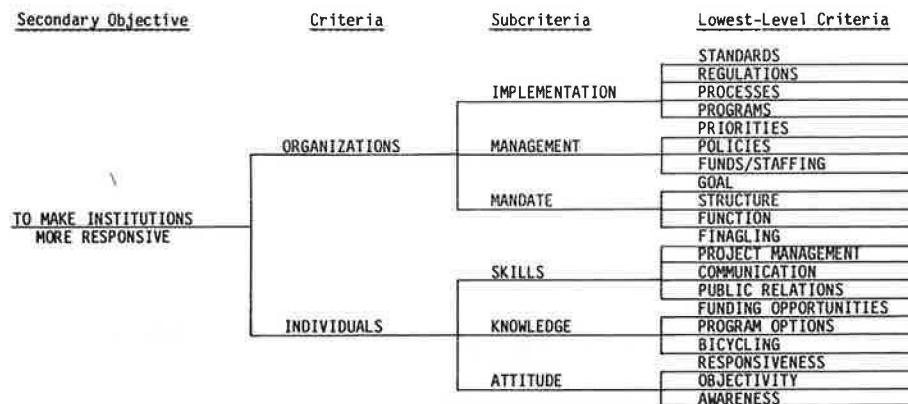
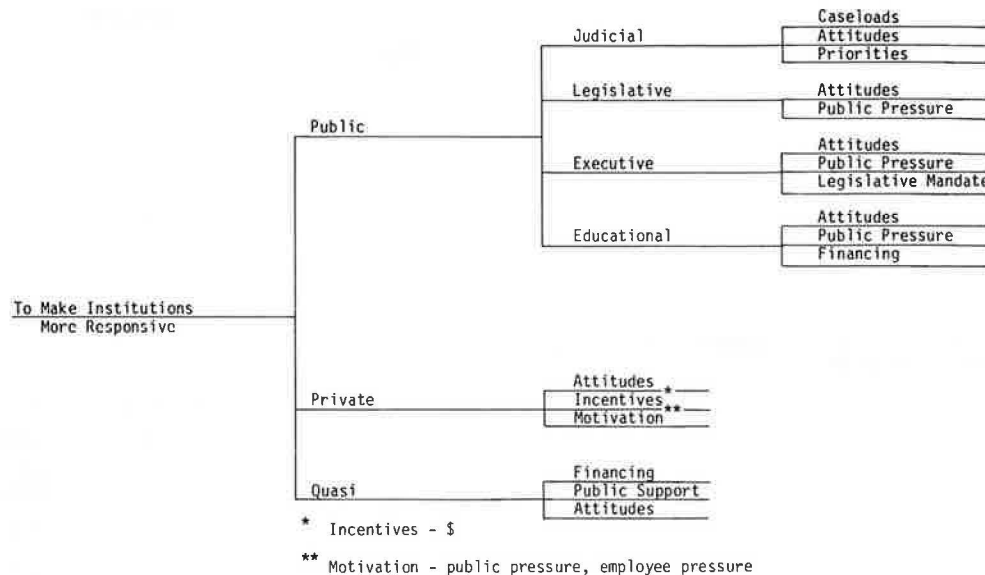


Figure 6. Preliminary hierarchical structure for institutions.



gory, for example, those for the category of environmental conditions: existing street; street design; street maintenance; land use patterns; weather and climate; air quality; topography; barriers; special facilities; bikeways; traffic level, speed, and type; continuity; roadway hazards; accidents; intermodal conflicts; signs and signals; distribution (time and geographical); and traffic control.

Participants were then separated into teams of two and assigned a group of categories that ad-

ressed similar subjects. Each team's charge was to translate its listed obstacles and factors into a hierarchy of objectives, which was to be combined with others to form the overall problem hierarchy. The process of developing the hierarchy was an iterative one that required input from all panel members before agreement was reached. An example of one of the interim hierarchies is presented in Figure 6.

The category listings and problem structures presented in Figures 1 through 6 provide excellent

illustration of some of the difficulties experienced when attempting to structure a complex problem. Some of the problems experienced were as follows:

1. Problem specificity: One of the most difficult aspects is to determine an appropriate level of problem specificity. Through the development process, however, this problem resolves itself. For example, the tendency of the group that developed the structure in Figure 6 was to divide general categories into more specific parts, e.g., institutions were divided into public, private, and quasi-sectors. At the next hierarchy level, however, it became evident that those sectors had common problems, i.e., attitudes, priorities, financing, etc. In sequential iterations of the structure development, the three institutional distinctions were dropped and only the general attributes were included. This level of detail was deemed appropriate for specifying a national program.

2. Solution orientation: Another difficulty encountered was that experts often try to define problem factors in terms of a solution. In Figure 6 one of the problem attributes most often noted is public support or public pressure. Public support or pressure is a means to an end and was eventually generalized to the more-global expression "making institutions more responsive." Public pressure is only one alternative means for altering that responsiveness.

3. Semantics: Semantics difficulties are common to all definition exercises. Terms that have high emotional content present particular difficulty. One of the advantages of the worth-assessment approach is that a term used at one level is defined by the subsequent terms into which it is divided.

A comparison of the final worth-assessment hierarchy and the figures from which it was derived reveals that the group's initial category concepts were generally maintained, although the order was often altered. For example, "environmental conditions" proved to be an awkward term and was dropped in favor of "system network". As another example, it became easier to assign skills to several types of persons rather than to group persons under skills as was initially done.

The final structure was developed in the context of a specific application, development of a comprehensive national bicycle program. It is not claimed to be the only possible problem structure; another panel would have derived a different one. The point is that it is comprehensive--at some level all the obstacles to increased bicycle use that were identified are addressed.

There are some limitations to the structure and the method used to derive it. An assumption inherent in the structure is that of static conditions, i.e., that the economic conditions, political situation, people's values, etc., that existed when the structure was developed will continue to prevail. As a result, neither the dynamic interaction of the objectives nor the influence of exogenous factors is modeled. For example, improved institutional response may eventually result in an improved transportation infrastructure, and fuel availability and cost may alter perspectives. One must be aware of these limitations.

The worth-assessment method met the objectives of this application. The structure developed provides a concise overview of the problems that inhibit bicycle use in the United States today. The framework has been established so that, as conditions change, the structure can be altered accordingly.

As a final observation about the process leading to the structure, it was interesting to note the

relative ease with which the operator-competence branch was developed and the relative difficulty encountered in formulating the institutional branch. This may have been due to the fact that the experts participating were primarily bicycle program experts.

#### IDENTIFICATION OF CRITICAL OBJECTIVES

The next step toward developing a national program was to assess the relative importance of major objectives and criteria that influence bicycle use. The team's approach was to solicit opinion from recognized experts throughout the country. Those experts were divided into two classifications according to their expertise. Bicycle program experts (persons who have particular bicycling-related skills and who are involved in implementing bicycle programs) were asked to evaluate numerically the relative importance of issues that relate to operators' competence, product design, and the transportation infrastructure. Institutions experts (primarily administrators involved with bicycling at an institutional or policy level) were requested to evaluate institutional-response issues. Both groups were asked to evaluate the relative importance of the four secondary objectives. Workbooks that presented the overall problem structure and instructions for assigning numerical weights were sent to each expert.

The hierarchical worth-assessment approach allows one to systematically evaluate the relative importance of problem elements in a manageable fashion. Rather than having to address the entire problem at once, one addresses only one section of the structure at a time. For example, all decision makers were asked to consider initially only the relative importance of the four secondary objectives. Then institutions experts were asked to evaluate the criteria immediately underlying the objective "to make institutions more responsive," and bicycle experts were asked to consider criteria sets underlying the other secondary objectives. Experts were then asked to continue through their parts of the structure one discrete set at a time until all criteria sets were numerically evaluated.

Response to the workbook was mixed. Of the bicycle program experts, 75 percent completed their workbooks. One person declined to participate due to objections to the method. Of the institutions experts, 70 percent completed their workbooks at least in part, and two persons objected to the method. The primary objections focused on semantics. Considering the problems encountered in the workshop, this was not surprising.

For each objective or criterion, the mean (average) and SD (variability) of numerical values derived by experts were calculated. These values are presented in Figures 7-11. For each pair of numbers, the first value presented is the mean and the second is the SD, which indicates the variability of values submitted and therefore the degree of unanimity among the experts. For each group of associated criteria or objectives the sum of the mean values equals 1. Individual values can be interpreted as percentages that reflect the relative importance of each criterion in satisfying the more-global objective or criterion to which it relates.

Of particular interest was the comparison of bicycle program experts' assessments of the four secondary objectives with those of the institutions experts (Figure 7). These values are also compared in Table 1.

Bicycle program experts seem to agree that efforts to increase bicycle use should focus on opera-



Figure 7. Experts' importance weights: secondary objectives.

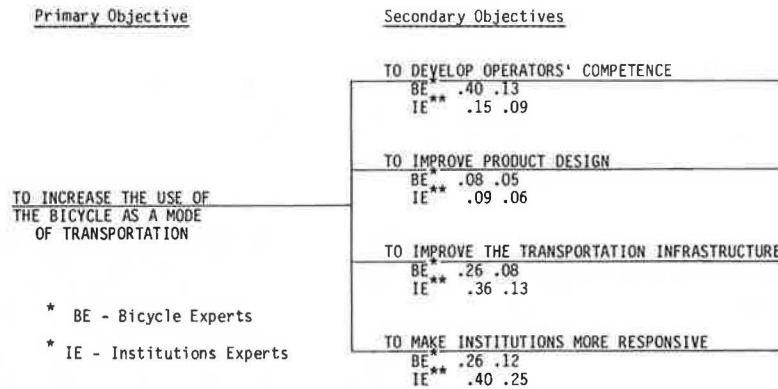


Figure 8. Experts' importance weights: operators'-competence branch.

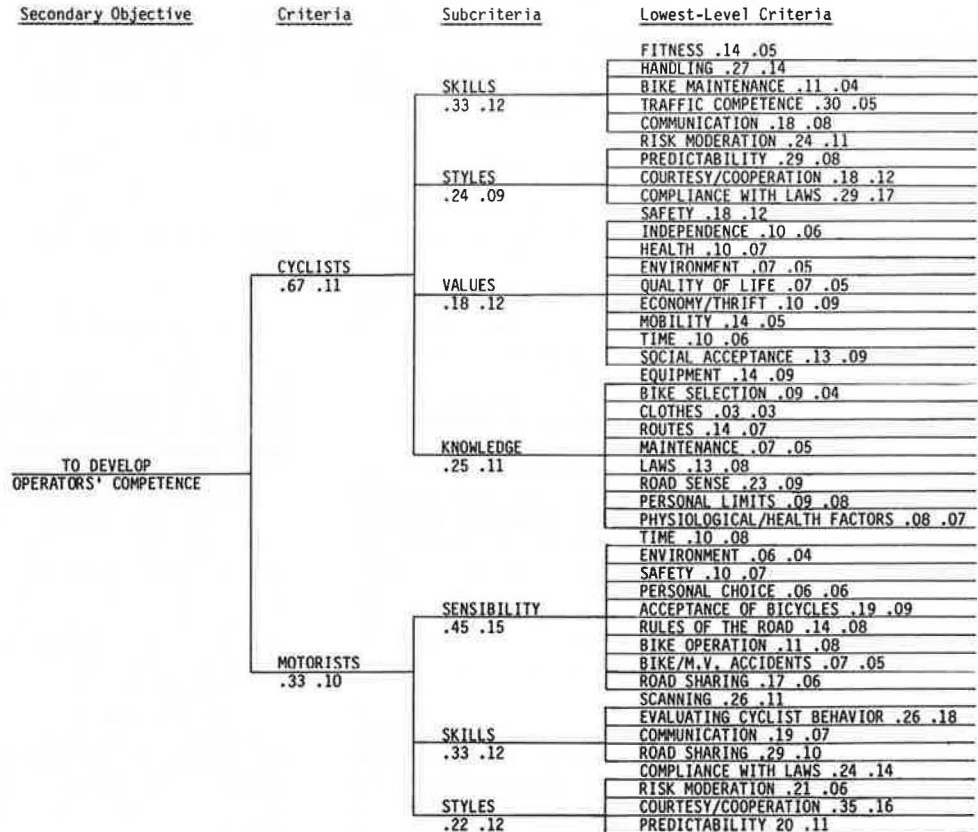


Figure 9. Experts' importance weights: product-design branch.

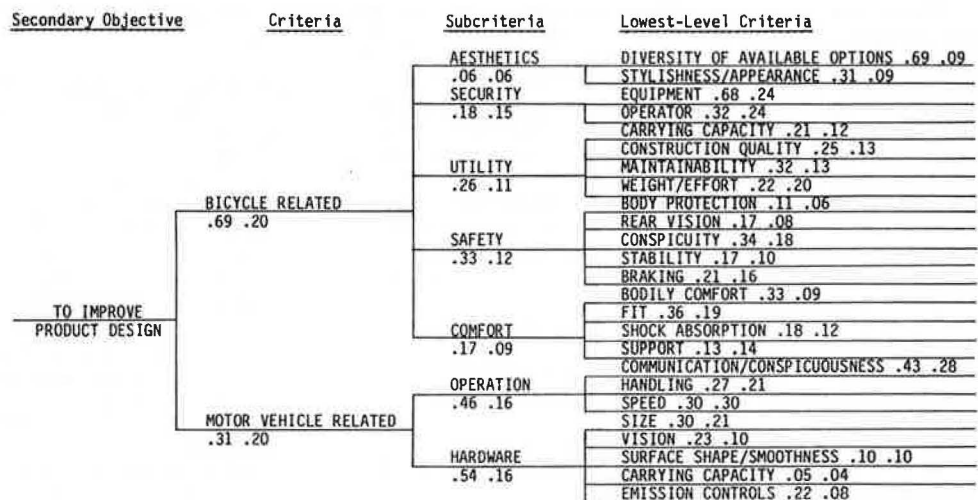


Figure 10. Experts' importance weights: Secondary Objective transportation-infrastructure branch.

	Criteria	Subcriteria	Lowest-Level Criteria
TO IMPROVE THE TRANSPORTATION INFRASTRUCTURE	SERVICES .20 .09	VEHICLE	RENTAL .29 .22
			REPAIR .42 .28
		INFORMATION	RETAIL .29 .18
			SUPPORT FACILITY .42 .12
	SUPPORT FACILITIES .34 .10	SECURITY	SYSTEM/NETWORK .58 .12
			PERSONAL .39 .22
		CONVENIENCES	BICYCLE .61 .22
			STORAGE .57 .18
	SYSTEM NETWORK .46 .12	USE	PERSONAL HYGIENE .43 .18
			CONVENIENCE .62 .18
		SAFETY	AESTHETICS .12 .09
			COMFORT .26 .09
		MOBILITY	PERSONAL SECURITY .18 .15
			HAZARD ELIMINATION .56 .28
			CONFLICT REDUCTION .26 .16
			DIRECTNESS .36 .22
			ACCESS .37 .12
			CONTINUITY .27 .13

Figure 11. Experts' importance weights: Secondary Objective institutions branch.

	Criteria	Subcriteria	Lowest-Level Criteria
TO MAKE INSTITUTIONS MORE RESPONSIVE	ORGANIZATIONS .49 .20	IMPLEMENTATION	STANDARDS .20 .09
			REGULATIONS .19 .08
			PROCESSES .18 .11
			PROGRAMS .43 .06
	MANAGEMENT .34 .13	PRIORITIES	PRIORITIES .33 .14
			POLICIES .30 .05
		FUNDS/STAFFING	FUNDS/STAFFING .37 .19
		MANDATE	GOAL .44 .11
	INDIVIDUALS .51 .20	SKILLS	STRUCTURE .22 .11
			FUNCTION .34 .04
			FINAGLING .13 .10
		KNOWLEDGE	PROJECT MANAGEMENT .33 .18
			COMMUNICATION .27 .15
		ATTITUDE	PUBLIC RELATIONS .27 .12
			FUNDING OPPORTUNITIES .39 .18
			PROGRAM OPTIONS .38 .09
			BICYCLING .23 .15
			RESPONSIVENESS .43 .12
			OBJECTIVITY .28 .12
			AWARENESS .29 .19

Table 1. Comparison of secondary-objective importance weights.

Rank	Objective	Weight	SD
Bicycle Program Experts			
1	Operators' competence	0.39	0.13
2	Institutional response	0.27	0.12
3	Transportation infrastructure	0.27	0.08
4	Product design	0.07	0.05
Institutions Experts			
1	Institutional response	0.38	0.25
2	Transportation infrastructure	0.38	0.15
3	Operators' competence	0.15	0.10
4	Product design	0.09	0.04

tor competence and that the secondary emphasis should be split equally between institutional response and transportation infrastructure. Product design is considered to be of negligible importance. In contrast, the institutions experts view institutional response as the major obstacle to increased use and rate operator competence a low third.

Possible interpretations are interesting. The results seem to support one of the obstacles to increased bicycle use often cited, i.e., that institutions experts do not really understand the bicycling problem and therefore often devote funds only to highly visible facility projects instead of to educational programs. On the other hand, it may be argued that the bicycle experts do not truly understand the importance of dealing within system constraints. For this study's purposes, MBA officials felt that bicycle program experts probably had a

better overall perspective and chose to use their evaluations.

The experts' evaluations were used to identify the critical factors of the bicycling problem that should be addressed in the comprehensive national program. The detail that seemed appropriate for the formulation of a national bicycling program was that of the fourth structure level, subcriteria. Thus it was necessary to evaluate the importance of each subcriterion relative to the overall objective of increasing bicycle use. Each subcriterion's weighting factor was derived by calculating the product of the weights assigned to the secondary objective, the criterion, and the subcriterion itself along the path leading from the overall objective to that subcriterion.

Subcriteria are listed in Table 2 in order of descending importance as determined by the calculated importance weights (only the top 20 are listed). Again a "total-equals-one" percentage format was maintained. A natural division seemed to occur between the 19th and 20th criteria. Key aspects of the first 19 (as identified by the experts' weights) were chosen as priority items for the national bicycling program. Although these values indicate that the top-weighted criteria should receive greater emphasis than others, it was decided that, given the variability among the responses from bicycle-program and institutions experts and the general nature of the program, the 19 items would be accorded equal emphasis.

The decision to emphasize a broad range of policies represents a shift in DOT policy. Prior to this study, DOT had been concerned primarily with improving the transportation infrastructure. This study served to spur the department to pay more attention to questions of operator competence and institution responsiveness.

Table 2. Subcriteria importance weights.

Rank	Objective and/or Criterion	Subcriterion	Weight
1	Cyclists	Skills	0.088
2	Institutions/individuals	Attitude	0.068
3	Cyclists	Knowledge	0.067
4	Cyclists	Styles	0.064
5	Motorists	Sensibility	0.059
6	Support facilities	Security	0.054
7	System/network	Safety	0.049
8	Cyclists	Values	0.048
9	Organizations	Implementation	0.046
10	System/network	Mobility	0.045
11	Organizations	Management	0.043
12	Motorists	Skills	0.043
13	Organizations	Mandate	0.038
14	Services	Information	0.037
15	Institutions/individuals	Knowledge	0.035
16	Support facilities	Conveniences	0.034
17	Institutions/individuals	Skills	0.030
18	Motorists	Styles	0.029
19	System/network	Use	0.025
20	Bicycle-related product design	Safety	0.018

As a final note, the experts' SD values were evaluated in an attempt to interpret the significance of the demonstrated differences of opinions. Some possible interpretations are as follows:

1. Operator competence: The experts seem to be in general agreement on the important elements of improving operator competence at all levels of specificity. This indicates that operator-competence problems do not vary according to locale and are commonly encountered throughout the nation. Thus programs should easily cross geographical boundaries and be amenable to treatment at the federal level.

2. Transportation infrastructure: The experts were in fair agreement on critical elements when differentiating among general categories. However, as the criteria became more specific, less agreement was demonstrated. This may indicate that, in general, infrastructure improvements are needed in all communities but that the more-specific provisions of a program should be locality-specific.

3. Institutional responsiveness: Institutions experts did not generally agree on the critical elements. This may reflect the complexity of the problem and the difficulty encountered in defining it. The results may also support the concept that every institution has characteristics peculiar to it and therefore should be approached as a unique entity.

#### CONCLUSIONS

Prior to the DOT-MBA study, promotion of increased bicycle use was characterized by a multitude of obstacles, varying experts' opinions, and a multitude of possible solutions. Now that this study has been completed, the federal government has an indication based on a survey of expert opinion of what tasks should be undertaken to increase bicycle use in the United States. Problem organization and acquisition of expert opinion were provided through the use of the decision-analysis method, worth assessment. The following benefits were derived from the use of worth assessment:

1. A comprehensive overview of the bicycling problem was synthesized,

2. Experts throughout the country for the first time concurrently dealt with identical subject material to identify the key obstacles inhibiting bicycling, and

3. DOT and Congress were given direction for policy priorities based on experts' quantitative

rankings of issues. The result has been a shift in DOT bicycle policy.

Similar benefits could be realized through use of decision-analysis methods in developing local community bicycle programs or in other transportation policy fields.

#### ACKNOWLEDGMENT

The research that formed the basis for this paper was sponsored by the U.S. Department of Transportation. The prime contractor for the project was Mountain Bicyclists' Association of Denver, Colorado. We would like to thank Katie Moran, Tom O'Hara, and Bill Wilkinson for their support and to acknowledge all the experts who gave their time to participate in the study.

#### Discussion

Michael D. Everett

The study by Ryan and Schermerhorn attempts to identify the obstacles to increased bicycling for transportation in the United States as part of a congressional and DOT effort to increase bicycling to save energy. Unfortunately, the paper provides us few, if any, sound insights on the obstacles to bicycling or how to actually increase bicycling. The study uses a panel of experts to develop hypothesized obstacles to bicycling. This represents an exploratory research strategy appropriate when the investigators know little or nothing about a subject. But well-refereed replicable research and theory on the determinants of and obstacles to bicycling already existed and would have provided testable hypotheses. For example, we knew that costs, including time related to distance, constitute very important determinants in most modal choices. Articles had developed models that applied time costs and distance to explain lack of bicycling (4). Ryan and Schermerhorn virtually ignore time costs or distance as obstacles to bicycling.

Reasonably well-designed and implemented surveys consistently find that bicyclists and potential bicyclists consider motor vehicle traffic a major obstacle, and they state that separate facilities would increase their propensity to use the bicycle (5,6). Also, studies have confirmed the observed correlations between levels of traffic, separate facilities, and incidence of bicycle transportation (7,8). Finally, anyone familiar with the bicycle movement knows that some very strident voices have proclaimed lack of bicyclist competence to be an important obstacle to bicycling. Thus, the authors could have generated testable hypotheses without assembling an expensive panel survey. They then would have had time and resources to test the hypotheses.

For example, a serious study, even one done on a crash basis with limited funding, could have tested the already known hypotheses on the barriers to bicycling--costs (including time), lack of competence, and fear of traffic--by running correlations across communities. Even mail-back surveys could have obtained crude but usable data on incidence of bicycling, traffic conditions, infrastructure and facilities, existence of training programs, and distances of origins and destinations to calculate time costs. Collecting these data for communities that have perceived high rates of bicycling--Davis and Santa Barbara, California; Madison, Wisconsin; Eugene, Oregon; Tallahassee and Gainesville,



Florida; Urbana, Illinois; and, to a much lesser extent, Northwest Washington, D.C., and Denver, Colorado--and similar communities that have little perceived bicycling would have provided data for useful multiple-regression analyses to test the various hypotheses.

Rather than testing well-known and for the most part well-developed hypotheses on the barriers to bicycling, this study at best tells us what bicycle program experts think constitute the obstacles to bicycling. But even here the study suffers from a number of methodological and factual shortcomings and distortions:

1. In Table 1 why does the study put transportation infrastructure after institutional response? The mean responses are equal and the infrastructure has a tighter SD. Changing these positions makes infrastructure look very important. But the paper never clearly defines infrastructure. Does it include separate facilities or just improvements to the road or some combination of factors?

2. Why does the study summarily throw out the opinions of the institutions experts, who, under the above logic, rank infrastructure first? Surely we cannot accept the reason stated in the paper that the major contractor, MBA, "felt bicycle program experts probably had a better overall perspective and chose to use their evaluations." Why should we not reason that institutions experts, who presumably do not bicycle to work, more closely represent the mass of potential bicyclists whom we must attract to have any appreciable effect on energy use, air pollution, congestion, levels of exercise and health, or other important social variables? But why throw out either set unless we have a preconceived position we are trying to support?

3. How was the panel selected, what was their knowledge of the literature, and what were their bicycling experiences and tastes? The study tells us virtually nothing about the sample of experts. Remember, the panel of bicycle program experts apparently drew up the basic questionnaire, which was then sent out to institutions experts. In that questionnaire, facilities apparently were given a vague and low-ranking position, and costs, theoretically the most important determinant, were virtually ignored.

4. Were the bicycle experts really responding to the question, "What will increase bicycling" or were they also addressing the question, "What ought a good bicycling program to contain?" The problem with using practitioners to develop predictive models is that practitioners tend to become entrapped in their values and policies and may have less ability than more-detached observers to objectively predict events.

5. Why did the study fail to mention other readily available studies done on obstacles to bicycling and attempt to reconcile the conflicting conclusions? Were the authors aware of the other studies?

In conclusion, the present study tells us little about the determinants of bicycling. It does tell us that bicycle program experts (assuming the sample is representative) believe that education and bicyclist competence play or should play an important role in bicycle programs. Most bicycle analysts would probably agree with that conclusion and support responsible education, which also indicated the risks of bicycling, particularly for increasing safety. But wide gaps may exist between values and actual determinants of bicycling. Concentrating on values may cause us to miss some of the important hypothesized determinants such as distance and time costs. We need objective reviews of studies that

have tested these determinants (7,8) and further testing, such as cross-community studies, if we want to understand the obstacles to and determinants of bicycling.

## Authors' Closure

We thank Everett for his comments and welcome the opportunity to respond. Feedback invariably indicates points that have been omitted and points that have been inadequately explained. In this case we appear to have been guilty of a few of the former and several of the latter.

Prior to responding to Everett's concerns point by point, a general comment should be made that apparently was not adequately explained in the paper. Although it was stated in the abstract and the introduction to the paper, we should have more clearly stressed the fact that our purpose in writing this paper was not to provide detail of bicycling problems nor the specifics of the DOT study. Our purpose was to present a methodology that had proved useful so that others could be aware of it and possibly adapt it for their use. The paper should be read in that context. For more details of the DOT study, the reader is referred to the report by Moran (1).

Everett's first comments criticize the use of a panel-of-experts approach. He implies that an alternative approach would have been what we term a basic research study. The choice of an approach was not ours but that of DOT. In general, the first step in a policymaking procedure is to determine whether adequate basic research has been conducted in the subject area. If so, experts are consulted who know the field and the studies to date and who help analyze and synthesize available information. If not, a basic research study is conducted. Then, once the study has been completed, the results should be synthesized with other study results by experts, so experts should be polled in either case. For this study DOT apparently concluded that sufficient basic research data were available and that expert appraisal and synthesis were needed. Expert surveys, however, are usually not very rigorous or explicitly comprehensive. The uniqueness of this study was that a large group of experts was systematically and objectively surveyed and the problem was comprehensively treated.

The second set of comments made by Everett deal with time and cost considerations. These comments make clear our failure to provide adequate study background information. As explained in the introduction, there were several study tasks, of which ours was one. During the obstacles-identification task, time and costs were identified as bicycle use determinants. However, DOT officials decided that policies that address these determinants were not within the purview of the study. Thus, the study was constrained in its scope. Time considerations were considered during the bicycle-use target development task through the use of a modal-split model.

Everett next returns to the theme of a basic research study as an alternative approach. This time his implication is that such a study would have been less demanding on limited time and resources. As discussed above, even if such a basic research study had been conducted, an experts-synthesis stage would still have been necessary. As it was, our study required only an initial meeting with a small group of experts and a mail-back workbook exercise in which some 50 experts were polled. All this was accomplished within less than three months. All of the testable hypotheses mentioned by Everett were

explicitly or implicitly addressed. One can imagine the time, cost, and accuracy concerns associated with the kind of community sampling that he intimates as appropriate.

Everett continues with the observation that our study "at best tells us what bicycle program experts think constitute the obstacles to bicycling." We would amend this to read "the most important obstacles." Then the sentence would succinctly state the objective and achievement of the study.

In response to Everett's specific numbered comments,

1. He is correct about the ranking, although a better manner in which to present Table 1 would have been to assign both objectives a ranking of 2 and list the infrastructure objective first. Since the numerical ratings are listed, the impact of such a change would have been minor. As discussed in the organization of the problem section, hierarchy terms are provided definition by subsequent terms into which they are divided. This is true for the infrastructure term.

2. Everett raised a good point, which was a subject of debate at MBA. A counterargument was that if the masses understand themselves so well, why do we have so many expert psychoanalysts? Bicycle program experts are experts because they have studied the subject. DOT did keep this source of uncertainty in mind, however, when actually using the results to develop a program. As is discussed in the last part of the section on identification of critical objectives, "given the variability among bicycle program and institutions experts' responses," specific rankings were not used in formulating the program. Rather, experts' rankings were used as indicators, and the weaknesses of the survey, as exemplified by Everett's point, were known. Thus Everett's charge that we attempted to substantiate a preconceived notion is unwarranted and inaccurate.

3. As stated above, the purpose of the paper was to profile the methodology, not to present specifics. For more information on expert participants, readers are referred to the report by Moran (1). Also in this comment, Everett inaccurately characterizes the process used. As discussed in the paper, a small group of bicycle and institutions experts formulated an assessment structure, which was then used as the basis for the workbook sent to

a larger group of bicycle and institutions experts.

4. Everett's implication is that persons heavily involved in a field cannot be objective. We agree to an extent but also realize the importance of insights that are provided through experience and involvement. Thus we always recommend that panel representatives differ in background, degree of involvement, and perspective. Then results are evaluated and used and the biases of the panel and limitations of the survey are known.

5. For a discussion of the studies reviewed during the objectives identification task, please refer to the task description and the bibliography in the report by Moran (1).

In conclusion, we again thank Everett for his comment and hope that our responses cause the paper to be better understood.

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## Bicycle Task Analysis: Development and Implications

MAUREEN WIRTH, ELLEN CONE, AND KATIE MORAN

Agreement as to what the critical tasks in bicycling are is essential to the development of valid bicycling educational programs. The bicycle task analysis (BTA) represents a significant first effort to describe what is involved in safe and efficient bicycle operation. In general, it follows the format of the motorcycle task analysis and the moped task analysis. A panel of 15 nationally recognized bicycling specialists reviewed the first draft of the BTA to check for inaccuracies, errors of omission, and organizational design. Following a complete revision of the first draft, the same review panel completed a criticality rating. This was a process by which specific tasks were rated in three categories: efficiency of operation, accident prevention, and accident severity. It is this criticality scoring that does the most to further one's understanding of what tasks are most important in bicycling for safe and efficient operation. The BTA provides a more reliable basis for developing a bicycling education program than that used by any existing bicycling curriculum.

A task analysis is a complete description of the behaviors, knowledge, and skills necessary for the successful completion of a particular task. Task analyses have been written for automobile, motorcycle, and moped operation, and their most common use is in the development of instructional programs. The reason for this is that a task analysis breaks a gross skill, e.g., motorcycle operation, into its component parts (such as turning left and operating alongside parked vehicles) and also sequences the behaviors into teachable segments (e.g., approaches in center of lane, observes roadway for traffic, proceeds with turn, operates at reduced

speed and maintains adequate separation, and looks for indications that vehicle will enter roadway). In addition to its use in developing educational programs, a task analysis can also be used for the evaluation of educational programs, the development of educational materials, and the understanding of correct operational procedures.

The bicycle task analysis (BTA) recently completed by Mountain Bicyclists' Association (MBA) represents the first effort to systematically catalog what is involved in successful and efficient bicycle operation. The BTA is similar in format and organization to other task analyses.

The underlying philosophy used in the development of the BTA is also important, since this directly affected content. Our philosophy is based on two premises. First, we believe that the bicycle is a legitimate transportation mode that enjoys the rights and responsibilities of highway use. Second, we support the concept that competent bicyclists and motorists must share the road system and that behaviors must be developed by both groups to facilitate that sharing. We have been criticized by some for being too aggressive and by others for being too conservative. Perhaps that means we were successful in finding a middle-of-the-road approach. Also, it was decided that safety, although certainly an important element to be considered in any bicycling program, must be integrated with efficiency and comfort.

But the BTA was not done as an independent project as were previous task analyses. Instead, it was completed as the first step in the development of a comprehensive bicycling curriculum, an identification and analysis of what is involved in bicycling. Indeed, MBA is using information from the BTA in the formulation of the Comprehensive Bicyclist Education Program that was pilot-tested by using 1000 fourth, fifth, and sixth graders in several Colorado school districts (including Denver) in May 1981. An adult program had already been developed.

In our opinion, the information in the BTA provides a more reliable basis for developing a bicycling education program than that used by any existing bicycling curriculum. Rather than relying solely on common sense and intuition, we were able to obtain judgments from nationally recognized bicycling specialists as to exactly what is most critical. This judgment and the most recent accident data give a firm foundation for curriculum content.

A complete description of the methodology used in writing the BTA as well as an analysis of the results obtained from the criticality scoring and a discussion of future implications follow.

#### METHODOLOGY

Writing a task analysis is somewhat like writing one's personal memoirs. There are so many details in such a jumble of recollections that it is necessary first of all to establish a framework with which to organize the information.

#### Organizational Framework

Our organizational effort for the BTA began with a thorough review of the motorcycle task analysis (1) and the moped task analysis (2). These provided a cumulative structure that started with the most basic tasks and built to the more complex ones.

The first section of the BTA deals with basic control tasks--the fundamental bicycle-handling skills as they would be performed in an off-road environment. This section includes mounting the bicycle, balancing, pedaling, turning, stopping, and

dismounting. The second section, tasks related to the roadway, describes how to negotiate the most common roadway configurations (e.g., intersections, traffic circles, curves, and downgrades) without taking surrounding traffic into account. The third section, tasks related to traffic conditions, introduces the specific tasks needed to accommodate surrounding traffic. To explain further, the basic turning maneuver is described in section 1, correct lane position for a left turn through an intersection is described in section 2, and the process of negotiating for a gap in traffic in order to make a left turn is described in section 3. The most frequently used behaviors are presented in the first three sections.

Sections 4-7 deal with the tasks related to the environment, to the operator, to passengers and packages, and to special bicycle facilities.

The key to locating a specific task is determining what situation creates the need for the behavior. For example, scanning is covered most completely in section 3 (traffic conditions), since scanning is designed to detect overtaking or cross traffic. But scanning is also referred to in sections 1 and 2 because it is an important habit to develop.

We did differ somewhat from the moped and motorcycle task analyses when we attempted to describe specific situations frequently encountered by bicyclists but not covered in one or both of the earlier works. The moped task analysis, for example, does not contain behaviors related to negotiating interchanges or traffic circles. Although there may be a general perception that bicycles do not belong in what is viewed as demanding traffic environments, it cannot be denied that the average bicyclist is very likely to encounter both traffic circles and interchanges in normal urban bicycling. We therefore modeled our treatment of these two conditions after the motorcycle task analysis. We also added a section entitled "Surveillance" to the beginning of section 3 because we believe that observing for traffic is perhaps one of the most important behaviors to be considered in a traffic context. We also added an entire section on special bicycle facilities because of their unique significance to bicycle operation and dropped a section on tasks related to the vehicle (moped or motorcycle) because of the relative simplicity of maintaining a non-motorized vehicle as compared with a motor vehicle.

Within each of the sections we created a hierarchical structure of headings and subheadings to provide the most complete coverage of situations bicyclists encounter. Each task was assigned a number, which reflected the hierarchical level at which it occurred. For example, reducing speed is a major heading in section 1 (basic control tasks). There are three topics to be discussed under speed reduction: normal speed reduction, rapid speed reduction, and emergency speed reduction. These three subheadings were structured and numbered as follows:

16. REDUCING SPEED
  - 16.1 Normal Speed Reduction
    - 16.11 Prepares to Reduce Speed
    - 16.12 Decreases Speed
  - 16.2 Rapid Speed Reduction
  - 16.3 Emergency Speed Reduction

The specific tasks under each subheading could then be addressed in sequence, expanding the hierarchy as appropriate.

To conserve space, information that was presented in an early section was not repeated in later sections. Instead, the appropriate task was listed and



a reference provided for more-detailed information. For example, hand signals for left and right turns and speed reductions are detailed in section 1. In later sections in which a signal is required, the BTA indicates when it should be given but does not repeat how to make the signal.

### Content

Once the overall structure was designed to ensure that everything could be covered under the headings and subheadings, it remained to provide the details of bicycle operation in each situation presented. Two categories of information are provided in the task analysis: behaviors and knowledge or skills. "Behaviors" refers to the actual tasks involved, for example, "insert foot into toe clips"; behaviors are listed in a column on the left-hand side of the page. The knowledge-skills section provides information needed to complete the task effectively, such as, "toe clips are used to increase pedaling efficiency," and these are written in paragraph form on the right. The knowledge-skills section also presents background information on accident data, variations in bicycle design or handling, technical specifications, and techniques for performing the behavior in question. The knowledge-skills section was also used to identify restrictions on the use of a behavior and to describe alternatives to the recommended approach; for example, novices should avoid congested traffic circles.

The content of the first draft was drawn from a variety of sources (1-8), including issues of the magazines *Bicycle Forum* and *Bicycling*. We also relied heavily on our own personal bicycling experiences and on informal observations of bicyclists. We were not able to collect formal observational data on bicycle operations because of severe time and cost limitations.

The tasks described focus on the general rules of safe operation that can be applied in most situations. Naturally, there are many differences of opinion regarding the correct way to handle a particular traffic situation. Frequently the differences of opinion reflect the various operating styles and levels of proficiency exhibited by bicyclists. Novice bicyclists will frequently opt for the course that keeps them as far removed from traffic as possible and will always yield to motorists no matter what the traffic configuration is. Very experienced bicyclists, on the other hand, will frequently operate in the midst of traffic and follow all vehicular traffic laws. Both these styles reflect the bicyclist's perception of what is safe. We were required to examine the variety of options for dealing with a specific situation and choose one that is most substantiated by the literature and corresponds most with the abilities of an average bicyclist. It also had to be consistent with the practice that the bicyclist obeys the rules of the road. For example, an in-depth analysis of data from the National Electronic Injury Surveillance System by the Consumer Product Safety Commission in 1976 revealed that loss of control is one of the leading factors in all bicycle accidents. This is supported by accident data collected by Bike-Centennial, which reveals that road-surface hazards contribute significantly to that loss of control. The rock or obstacle dodge is an effective way of avoiding a potential hazard such as a rock or a pothole without swerving into possible traffic. Although the average bicyclist may not be familiar with this maneuver, instructors for the effective-cycling course and the Missoula bicyclist training program indicate that it is not difficult for their students to learn. Therefore, it is included as a

behavior for bicyclists. Not included, however, is the bicyclist behavior of jumping his or her bicycle over lateral obstructions such as expansion joints or railroad tracks. Although successfully used by experienced bicyclists, this behavior seems to be beyond the average skill level (especially since most bicyclists do not use toe clips), and there is no indication in the literature that this is the only or best approach. Therefore, we chose a more conservative method for dealing with lateral obstructions.

In those cases in which we could not determine the best way of handling a particular situation, we turned to the moped and motorcycle task analyses to determine whether there was any similarity in behaviors. In many cases we found that the tasks required for mopeds seemed to relate well to the norms for bicycle use. If anything, they reflected a more conservative approach than we were using for bicycles. (This could possibly be a result of the relative inexperience of moped users as compared with bicyclists.) The motorcycle task analysis was used infrequently because of the tremendous difference in speed capabilities between motorcycles and bicycles; however, it was used in the sections on negotiating interchanges and negotiating traffic circles because it constituted the only written documentation of how any two-wheeled vehicle should handle these situations. Adjustments were made to these references to eliminate any behaviors that were irrelevant to bicycles, such as use of acceleration lanes.

Clearly, there were many instances in which we used our best professional judgment to determine how a bicyclist should handle a particular situation. There are numerous aspects of bicycle operation that have never been considered in a formal fashion; they range from the best side of the bicycle to use for mounting to which side to use in passing a wrong-way oncoming bicyclist. It was our intent to choose a particular method, indicate the alternatives in the knowledge-skills section, and use our reviewers to identify the errors, inconsistencies, and gaps of information.

### Level of Detail

A recurring problem in the preparation of the first draft was determining the appropriate level of detail. We wanted to describe behaviors in such a way that a person unfamiliar with bicycle operation would be able to understand them. Therefore, rather than say that the bicyclist "shifts gear," we stated that the bicyclist "moves gear shift lever until it clatters and then moves it further until it becomes quiet." But the problem then arises of where to limit detail. That same task could be described in several subtasks that could identify which hand should be used, how fast the lever is moved, or the sequence of shifts required to reach a particular gear. We avoided this level of detail because of two problems. First, the more detail provided, the more attention that needs to be paid to the variations in bicycle design, age of bicycle operator, and operating conditions. Not only different styles of bicycles (e.g., single speed, three speed, five speed, and ten speed), but also different manufacturers and components would have to be considered. To ignore these factors while providing highly specific detail would make the task analysis invalid. Another problem to be avoided was the differing information needs of the various audiences for the increased detail. If the detailed information needs of an engineer are met by describing the degree of lean and pounds of pressure required for a turn, the needs of educators would also have to be

met through such information as the exact position for starting a turn, the frequency of a hand signal, etc. The increased volume of information would make the document unwieldy. A very pragmatic concern was also the limitations of our own information. There were many situations in which our information was sketchy at best. We tried to restrict our level of detail to that which we could firmly support with documentation or consensus of expert opinion.

We also tried to provide general rules of operation that could be applied in a variety of situations rather than describe how to handle every possible traffic condition. Therefore, we have described how to make a left turn in moderate and in fast-moving traffic, but we have not established special cases for two-lane, three-lane, and four-lane streets or for turns into driveways or alleys. Similarly, we described a recommended maintenance check, but we did not describe how to repair any of the problems that might be found. We believe that the level of detail provided is sufficient to meet the needs of our primary audience--those who want to teach and measure safe bicycling behavior--and to provide direction for those who need to conduct more-detailed analyses.

The preliminary draft was our best effort to collect all the information available and organize it into a working document. Its primary purpose was to elicit comment on the nature of information that should be included in a BTA. We then set up a two-stage review process--the first a general review and commenting procedure, the second an actual rating that used a predetermined scale of the criticality of each task to safe and efficient bicycling. Through the first stage of the review we hoped to develop a consensus concerning what should be included in each task and each section in order to produce a complete and accurate BTA. The second stage would then pinpoint which tasks were considered the most critical, so that priorities could be established for choosing the material to include in a bicycling education program. In the next section, we shall discuss reaction to the first draft.

#### Initial Review

The review process was a means of substantiating and refining the information collected for the first draft of the BTA. We selected 15 professionals from around the country, who have each developed expertise in at least one area of bicycling (e.g., law, accident research, planning, expert bicycling, education, traffic engineering, and technical writing) to participate on the evaluation panel. We chose each reviewer for his or her knowledge, experience, and ability to review the BTA as a technical document. A list of reviewers and their affiliations is presented below:

Bruce Burgess, executive director, Bicycle Touring Group of America;

Ken Cross, vice president, Anacapa Sciences, Santa Barbara, California;

John English, director of research, National Committee on Uniform Traffic Laws and Ordinances;

Steve Faust, planner, Urban Mass Transportation Administration, Region II;

John Fegan, research psychologist, Office of Research and Development, Federal Highway Administration (FHWA);

John Forester, cycle transportation engineer, author of *Effective Cycling*;

Richard Jow, contributing editor, *Bicycling* magazine;

Eileen Kadesh, bicycle coordinator, District of

Columbia Department of Transportation;

Josh Lehman, bicycle program coordinator, Seattle, Washington, and contributing editor, *Bicycling* magazine;

James McKnight, president, National Public Services Research Institute, Alexandria, Virginia;

Mary Meletiou, assistant bicycle coordinator, North Carolina Department of Transportation;

Dick Rogers, chief, Office of Bicycle Facilities, California Department of Transportation;

Alex Sorton, associate director, research and development, Northwestern University Traffic Institute, Evanston, Illinois;

William C. Wilkinson, program coordinator, U.S. Department of Transportation; and

John Williams, editor, *Bicycle Forum*, and bicycle coordinator, Missoula, Montana.

We encountered one problem immediately in communicating to the reviewers the purpose and organization of the BTA. The idea of a comprehensive listing of tasks involved in an activity had been encountered by only a few of the reviewers; this is not surprising in that only three task analyses have ever been written for highway vehicles. The reviewers tended to think in terms of a bicycle education program. Their comments reflected the fact that they were reviewing the BTA as a curriculum or program in itself, to be used intact by teachers or students rather than as a first step in curriculum development. Their immediate reaction, therefore, was that the BTA was too long and detailed. The organization of the BTA also confused many reviewers. They could conscientiously comment that a task or series of behaviors had been omitted from a section when actually the tasks belonged, and had appeared, earlier or later.

The other major issue we dealt with was the injection of personal style and opinion into the comments. This was not a factor we wanted to avoid, since we were requesting individual perceptions of optimal bicycling behavior. The reviewers' comments merely reinforced our belief that different people have different bicycling philosophies concerning, for instance, assertiveness, bicyclists' right to the road, and types of equipment. Although there was strong agreement in such areas as helmet use, the reviewers differed widely in areas such as lane position. This also served to highlight the need for a document such as the BTA to describe the consensus.

#### Revision Process

We received approximately 2500 separate comments, which included a comment by several reviewers on almost every single task in the BTA. We proceeded through the analysis task by task. The tasks that received several similar comments were changed according to the consensus. We accepted the validity of the reviewers' comments and tended to go ahead and revise the tasks accordingly unless a distinct conflict appeared between reviewers or between reviewers' comments and the philosophical guidelines we had developed of viewing the bicycle as a legitimate transportation mode. In these cases, a resolution was achieved through discussion among the three authors of the BTA after having reviewed the literature available and having consulted other reviewers.

The revision process of the first draft also revealed some sections that needed reorganization. This was accomplished pursuant to specific comments generated by the reviewers. One major change in organization was made, for example, in section 22, (negotiating intersections). Whereas we had pre-

viously included an initial segment entitled "Approaching Intersections," by using the format from the motorcycle and moped task analyses, we omitted this in the revised BTA because the tasks in this and subsequent sections appeared repetitious and confusing. Instead we included them under segments on traversing an intersection, turning right, and turning left.

Another change was that in the first draft of the BTA we tended to analyze alternative behaviors and recommend one, but in the revised draft we presented the viable behavioral choices along with the knowledge relevant to each behavior; the task was then written as a choice between those behaviors. For instance, the first draft of the BTA stated in section 8, "avoids bike lanes separated by parked cars," whereas the revised edition states, "chooses whether to ride in bike lanes separated by parked cars." This change of tone was in response to the variety of our reviewers' opinions concerning the best bicycling behaviors. By stating the various problems involved in a situation and the alternatives available, we allow a bicyclist to modify his or her behavior according to a specific situation or personal consideration.

Also revealed by the review of the first draft was the need for a format that was easier to read and comprehend. We followed the format of the motorcycle task analysis by indenting, in an outline form, each subordinate task. The revised BTA constituted our final draft; the assignment of criticality scores remained as the second stage of the review process.

#### Criticality Procedure

The rating of bicycling tasks is essential to the development of valid priorities concerning material to be taught in a bicycling education program. Any program will be operating under time constraints from other school courses or from the busy lives of adult participants. The bicycling education programs developed to this point have selected material to teach without benefit of any specific research concerning which tasks are actually most important to bicycling. Only recently have several studies of bicycle accidents appeared (9), which give a solid background for deciding which tasks are most crucial to the prevention of commonly occurring accidents.

The criticality procedure used for the motorcycle task analysis was our main source of information. However, two issues proved unique in our situation. The first and most important was that the criticality procedure of the motorcycle task analysis was designed solely to choose the tasks that were most critical to the prevention of an accident. Although we are concerned with teaching safe bicycling, our education and bicycling philosophies dictate that safety be integrated with efficiency and comfort on a bicycle to produce optimal bicycling.

We therefore realized the need for a system with which we could ascertain the tasks that are critical to the prevention of accidents and bicycling efficiency; it will be explained in detail under the description of our criticality procedure.

Our other concern with the criticality procedure of the motorcycle task analysis was its complexity, both for the raters and for the tabulators. There were four scores to produce for each task: behavior frequency, error probability, accident likelihood, and accident severity. The four were multiplied together to form an overall indication of criticality. These factors provided the combination of the potential frequency and severity of an accident attributable to a particular behavior on a motorcycle. However, since we did not have hard observa-

tional data on behavior frequency and error probability, our reviewers would essentially have to guess the scores for these two factors. Therefore, we felt that it would be much more valid and satisfying to the raters to have them estimate one general score concerning the importance of each task to the prevention of an accident. This eased the tabulation procedure as well as eliminated the need to round off individual scores, as was done for each of the scores in the motorcycle task analysis.

In summary, the scoring procedure we developed was tailored to

1. Produce scores relevant to the information we needed in order to prioritize educational materials,
2. Fit with our philosophy that optimal bicycle riding includes safe as well as efficient riding, and
3. Be satisfying to raters who were using their experience, knowledge, and personal observational data to make judgments on scores.

The scoring procedure itself involved rating each task as to its importance to the following categories:

1. Efficiency of operation,
2. Accident prevention and avoidance, and
3. Accident severity.

The efficiency of operation category set up an ideal of efficiency, and the rater was then requested to score the correct performance of the task as to its effect in reaching or hindering that ideal. The ideal reads as follows: The efficient bicyclist should operate confidently and skillfully and be able to enjoy bicycling, which entails

1. Functioning as a normal element of the traffic flow (obeying traffic laws and rules and recognizing the bicyclists' right to the road);
2. Operating smoothly and without interruption (except by normal traffic-control devices);
3. Operating a vehicle that is a viable mode of transportation or recreation (solving problems of baggage, weather, environment, etc.);
4. Maintaining total control of the bicycle (operating the bicycle as an extension of self); and
5. Maintaining riding comfort (pedaling style, gearing skills, and riding position).

The rating scale for this category goes from -5 to +5; +5 means "very significant to reaching the ideal"; 0 means "irrelevant to reaching the ideal"; and -5 means "great hindrance to reaching the ideal."

The second category, accident prevention and avoidance, requests the raters' estimate of the chance or probability of having an accident due to the correct performance of a task. An accident is defined in the following way. A bicyclist falls off the bicycle or falls with the bicycle due to (a) collision between a bicycle and a motor vehicle, (b) collision between two bicycles, (c) collision between a bicycle and a pedestrian or an animal, (d) collision between a bicycle and a stationary object, or (e) loss of control by bicyclist.

Some tasks apply to the prevention of an accident, and some apply to the avoidance of an accident. For example, scanning is more important in accident prevention, whereas emergency stopping is more closely related to accident avoidance. However, both types of tasks were scored in this category on the same scale. The scale ranges from -5 to +5; +5 indicates that the chance of an accident is greatly reduced; 0 means that the behavior would have no effect on the chance that an accident might occur; and -5 indicates that the correct performance



of the behavior greatly increases the chance of an accident.

The negative scale was included as a necessary option. Although we felt that all the behaviors in the BTA were important for both efficiency of operation and accident prevention, we wanted to allow for differences of opinion. Also, we wanted to determine what tasks, if any, might hinder efficiency but be critical in terms of accident prevention, and vice versa.

The accident severity category defines how severe an accident would be if it were to occur in conjunction with the correct performance of the task that is being scored. To increase rating consistency, the assumption was made that a helmet and bicycling gloves are worn in all cases. The scale used was that of the National Safety Council (10). The scale, approved by the American National Standards Institute (ANSI), ranges from 1 to 5:

- 1, no injury;
- 2, possible injury (injury that is reported or claimed by the victim but is not evident to observers);
- 3, evident injury that is not incapacitating (any injury other than one that is fatal or incapacitating and is evident to observers at the scene of the accident);
- 4, incapacitating injury (any injury other than a fatal one that prevents the person from walking, bicycling, driving, or normally continuing activities she or he was capable of performing before the accident);
- 5, fatal.

We did not request the reviewers to rate every task in the BTA; we omitted many of the basic handling skills that were described in much detail. These tasks (such as maintaining vertical balance on a bicycle, mounting, and dismounting) are so fundamental to bicycling that no other maneuvers could occur without them. We also felt that, in many cases, it was adequate to collect ratings for superordinate behavior instead of requesting ratings for each detailed subordinate task. For example, reviewers were asked to rate "prepares to change lanes," a superordinate behavior under which are included "signals intention to change lanes" and "checks roadway again before initiating lane change." But since our purpose was for the reviewers to decide which tasks were most critical, we felt that most of the tasks should be rated, both to furnish a complete data base and to avoid our biasing of the procedure.

The criticality scores were recorded on a microcomputer that calculated means and SDs for each task. A discussion of the results follows.

## RESULTS

The final draft of the BTA was read by 12 of the 15 original reviewers. (Three did not participate because of personal time constraints.) Reactions were given in two forms: narrative comments from the reviewers and the actual criticality ratings.

### Narrative Comments

The most obvious difference between the comments on the first and the final drafts of the BTA was quantity. The final version elicited only 200 or so comments, and almost no two comments concerned the same item. Though the primary purpose of this second review was not general response, as it had been for the first version when approximately 2500 comments were made, the reduced response seems to

indicate that many of the changes made in the BTA were acceptable to the reviewers.

There were some errors pointed out. For example, we stated in the BTA that using the right arm straight out as a right-turn signal was permitted in several states, but one of our reviewers pointed out that it is a legal signal only in Minnesota. And two reviewers suggested that longitudinal (pavement) markings are considerably more complex than described in the BTA and referred us to the FHWA Manual on Uniform Traffic Control Devices.

Most opinions expressed concerned lane position. Generally, the BTA advises the bicyclist to control the lane when at an intersection, i.e., assume a center-lane position. Several reviewers took exception to this. One decried the zig-zag approach at intersections that would be required for a bicyclist riding in the right-lane position who had to move to the center and then back again to the right for making either a right turn or for traversing the intersection. One was very concerned at the prospect that right-turning vehicles would pass on the bicyclist's right, although that is exactly why we described the maneuver in this manner; i.e., if the bicyclist is going to go straight through an intersection, why should she or he be in a right-lane position that would prevent motorists and even other bicyclists from making a legal right-turn-on-red? Some took exception to the fact that we recommended that bicyclists yield the right-of-way to motorists who were obviously not cognizant of the bicyclist's rights. Several suggested that the use of diagrams might help to clarify some of these complex traffic operations.

Interestingly, one reviewer recommended a slow-and-scan approach rather than a complete stop when dealing with stop signs. Although many bicyclists, adults in particular, confess to using that approach, few have suggested teaching that method, especially to children. (Stopping at stop signs received one of the highest scores in the criticality rating for accident prevention and a fairly low score in efficiency.)

### Criticality Ratings

Differing philosophies widely affected the scores given to a particular task. For example, one reviewer gave negative scores in the accident prevention category every time a bicyclist left a right-lane position, even when he or she was preparing to turn left. The same reviewer also gave negative scores to the perimeter, or two-stage, left turn. Another reviewer gave negative scores in the efficiency category every time the bicyclist was to stop. Stopping can certainly be inefficient, but the criticality instructions had indicated that the ideal of efficiency included stopping at traffic-control devices.

Throughout the following discussion on criticality scores, numbers given refer to the mean, or average score. Every behavior that received a particular score is not always discussed. This editorial judgment is exercised because we want to highlight the most worthwhile findings and because the statement "uses emergency braking technique if parked car door is opened in bicyclist's path" is so closely related to the statement "uses emergency braking technique" that the repetition seems pointless.

One of the most easily recognized groups of scores is the highest. In the efficiency category, scores of 4.5 and above were given to the tasks that describe gear selection on upgrades. Scores of 4.0-4.4 were given to tasks that detail proper pedaling and accelerating, proper body position, the

importance of knowing when to shift gears, and the ability to select an appropriate lane. Other high scores (3.6-3.9) in the efficiency category were given to the following tasks:

1. Operates in a right lane in a lane-sharing position;
2. Operates in the left position of the lane when preparing to make a left turn;
3. Moves to a center-lane position when merging;
4. Does not ride facing traffic;
5. Obeys traffic-control devices on bicycle routes;
6. If oncoming vehicle is yielding, maintains speed and position;
7. Builds endurance prior to long rides; and
8. Performs regular maintenance checks.

In other words, according to our reviewers, the most critical tasks in terms of bicycling efficiency involve gearing, pedaling, maintenance, and lane positioning.

Next are the tasks that received the highest scores in the accident prevention category. (Remember, it was assumed here that all bicyclists are wearing a helmet and gloves.) Scores of 4.5 and above were given to the following:

1. Scans left, right, and left again;
2. Responds to red lights and stop signs;
3. Does not ride facing traffic;
4. Crosses intersection only when safe; and
5. Maintains an adequate stopping distance between the bicycle and a preceding vehicle on a downgrade.

Scores of 4.1-4.4 were given to the following:

1. Reduces speed in emergency;
2. Scans to rear and side before changing lane position;
3. Scans surroundings on and off the roadway continuously, shifting gaze frequently;
4. Continuously scans roadway ahead and to the sides;
5. Scans behind prior to any lane changes;
6. Signals left turns;
7. Maintains safe speed on downgrades;
8. Observes road surface more closely on downgrades;
9. If a passing vehicle attempts to return to the lane prematurely, slows quickly, moves to the right, and leaves the roadway if necessary;
10. Yields the right-of-way to cross traffic when required;
11. Even if cross traffic should yield, yields if necessary;
12. Reduces speed if necessary to avoid conflict with a left-turning vehicle;
13. Makes independent judgments when riding with a group;
14. Determines whether gap between oncoming vehicles is sufficient for a left turn; and
15. Uses a headlight and taillight if riding at night or on dark roads.

In summary, our experts are telling us that the most critical tasks in terms of accident prevention are scanning, stopping at stop signs and red lights, riding with the traffic, being able to stop quickly without losing control of the bicycle, knowing which lane to be in, using lights at night, and yielding when necessary to avoid conflicts (defensive driving strategies).

The reviewers have clearly indicated the most critical tasks in terms of both efficiency of opera-

tion and accident prevention. Of interest is an examination of the differences between the two and of whether there were times when accident prevention scores were higher than those for efficiency. This was found to be so. Tasks that received a score of 2.5-2.9 higher in accident prevention than in efficiency include "responds to red light," "responds to flashing red light or stop sign," and, "leaves roadway if necessary if vehicle pulls in front of bicyclist." Other tasks that were rated 1.5-2.4 higher in accident prevention than in efficiency are "uses hand signal for normal speed reduction," "reduces speed rapidly," "reduces speed normally," "responds to yellow light, flashing yellow light, and yield sign," "signals left turn," "makes a perimeter (two-stage) left turn," and "selects an alternate route or avoids riding in conditions of limited visibility."

The accident severity category proved difficult because accident severity is a function not only of bicyclist behavior but also of environmental conditions, motor vehicle speed, etc. But in general, the highest accident severity scores tend to parallel the highest accident prevention scores. Also, there were several unique factors in this category that affected the average score. First, several reviewers gave a range for a score; i.e., 3-5 rather than one particular score. And second, if a reviewer recorded a zero for accident prevention, accident severity was automatically recorded as a blank; this meant that often the accident severity score was an average of fewer than 12 scores.

The SD revealed some interesting findings. Remember that the efficiency of operation and accident prevention categories could be rated from +5 to -5 (although very few minus scores were recorded), whereas the accident severity category was scored from +1 to +5. This difference in the range of scores would create the appearance of more reviewer agreement on accident severity. Despite this bias, consider the following variations of the SD. In the efficiency of operation category, the SD ranged from 0.7 to 4.8; in accident prevention, from 0.4 to 3.8; and in accident severity, from 0.5 to 1.7. An SD of 0.9 or less was scored for only five of the tasks (out of 627 rated) in the efficiency of operation category, 102 of the tasks in accident prevention, and 303 of the tasks in accident severity. Conversely, an SD of 3.0 or higher was recorded for 15 of the tasks in efficiency of operation, four of the tasks in accident prevention, and none of the tasks in accident severity. This seems to indicate that there is more agreement as to what is important in terms of accident prevention and accident severity than in efficiency of operation. This may be because of the amount of accident research that has been completed during the past 10 years, whereas bicycling efficiency has not been so well documented.

Not surprisingly, the greatest agreement (SD of 0.9 or less) for tasks in efficiency of operation parallels that for the most critical tasks: uses gears to maintain cadence and performs a regular maintenance check. There was also widespread agreement that using eye protection is not particularly important. There was less agreement (SD of 3.0 or higher) about dismounting and backtracking to alternate routes if signing prohibits bicycles and if necessary walking the bicycle on sidewalk bicycle paths.

In terms of accident prevention, the greatest agreement (SD of 0.5 or less) concerned scanning, riding with traffic, and maintaining lane position while proceeding through a curve. There was less agreement (SD of 2.5 or higher) about using a leg or belt light if one is infrequently caught in the dark for a short time and well-lighted routes are avail-

able and about operating in a center-lane position. The most disagreement (SD of 3.8) concerned the following task: "when traversing an intersection, moves to left position of lane if there is heavy right-turning traffic."

### Summary of Results

An array of numbers and list after list of tasks can be disconcerting. In an effort to place our findings in a simpler format, we prepared the following summary:

1. Some tasks limit efficiency but are important in terms of accident prevention.
2. There is greater agreement as to what is critical in terms of accident prevention than as to what is critical in terms of efficiency of operation.
3. The most critical tasks in terms of efficiency of operation include (a) uses gears properly; (b) pedals with pressure on ball of foot, uses toe clips, and maintains a steady cadence; (c) performs regular maintenance checks; (d) selects appropriate lane; and (e) builds endurance prior to long rides.
4. The most critical tasks in terms of accident prevention include (a) scans continuously, (b) responds to stop signs and red lights, (c) rides with traffic, (d) uses emergency speed reduction when required, (e) signals left turns, (f) selects appropriate lanes, (g) yields when necessary to avoid a conflict or collision, (h) makes independent judgments when riding with a group, and (i) uses a headlight and taillight when riding at night or on dark roads.

The results also indicate that, although there is agreement that lane position is important to both efficient operation and accident prevention, there is no consensus as to what the best lane position actually is. For example, the task "operates in the right of the lane (right lane or lane-sharing position) on roads that have wide lanes, and when there is a safe (defined as maintaining an adequate lateral separation from hazards that occur on the right side of the road, such as sewer grates and doors of parked cars, as well as from hazards to the left, such as overtaking vehicles) or right-lane position" received a 3.9 for efficiency and a 3.8 for accident prevention. But a lower rating (2.9 for efficiency and 2.0 for accident prevention) was given to the task "operates in the center of the lane (center lane or lane-occupation position) on roads that have narrow lanes when no safe right-lane position exists, when operating at the speed of traffic, when traveling through an intersection, when crossing narrow bridges, when preparing to change lanes to the left, and when in a center or left lane." There was, however, more agreement about "operates in left position of lane when preparing to turn left," which also received higher scores (3.6 for efficient operation and 2.5 for accident prevention).

Lane position is, of course, especially important when the rider negotiates intersections. The BTA recommends moving to the center position of the lane when it is clear in order to go straight through or traverse an intersection. This received a higher score for efficiency (2.5) than for accident prevention, with an SD of 2.1 and 2.7, respectively. However, moving to the left lane or left-lane position to prepare for a vehicular left turn in moderate traffic received a 2.3 for efficient operation and a 3.1 for accident prevention.

### CONCLUSIONS

The BTA has significance in several areas. First,

it clearly highlights the most critical tasks (such as scanning), which obviously should be included in the development of any educational program. It also points to the fact that on-bicycle training, especially to teach skills such as emergency stopping, is essential. Second, it provides a basis by which existing programs may be evaluated. This is important because, in our opinion, many bicycling curricula available today do not include adequate instruction on scanning, emergency stopping, proper gearing and pedaling techniques, etc. (11). Third, the detailed description of bicycle operation may also be used to evaluate bicycle facilities.

What are the successes of the BTA? For the first time, an effort has been made to describe the consensus of leading bicycle specialists. Also, it is an attempt to focus on bicycling as a whole and to integrate safety aspects with considerations of efficiency. In addition, the BTA provides an overall structure for reviewing the field of bicycling; it can easily be used as a general resource or reference document, perhaps as an introduction for new people in the growing field of bicycling. But most important, it begins the major task of identifying what is truly critical in bicycle operation.

In spite of the successes of the BTA, there are also some limitations, which suggest future research needs. First, there is an obvious need for more formal observational data. In particular, more work needs to be done to determine the optimal lane position for bicyclists in different situations. In addition to an analysis of accident data to determine the bicyclists' lane position in a variety of situations, field observations could be conducted to describe the lane position assumed by most bicyclists negotiating intersections; bicyclists trained in the procedure detailed in the BTA could also be observed. Another need is to collect data concerning what lane positions to recommend to bicyclists based on both their age and skill level. The question of judgment must also be addressed--i.e., the bicyclist asks not simply "Is this maneuver safe?" but "What maneuver is safest at my skill level in this particular traffic situation?" And more empirical data are needed to back up the criticality ratings in both the accident prevention and accident severity categories. It must be pointed out that any educational program based on the BTA, which does a thorough job of describing what is involved in bicycle operation, must also include information on basic traffic concepts. In general, it seems vital that those involved in bicycling come to some sort of agreement on the "how to's" of bicycling. If there is discord among those in the field and more and more people are deriving both a career and a livelihood from bicycling, how can our needs be adequately presented to decision makers in government and education?

There is increasing concern for energy conservation and continuing interest in the importance of physical exercise, both of which are well served by bicycling. A document such as the BTA represents a significant and timely first step in consolidating information about bicycling that can be used in developing educational programs for bicyclists. But in many respects, the BTA raises as many questions as it answers. It is our sincere hope that the BTA will serve as an impetus for further research, for we view the BTA not as an end, but as a beginning.

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#### *Abridgment*

## Engine Tune-Ups and Passenger Car Fuel Consumption

PAUL J. CLAFFEY

The effect of engine tune-up on passenger car fuel consumption, including criteria for determining when tune-ups are needed for achieving good fuel economy, was investigated as part of a 1975 Federal Highway Administration study. A sample of 22 recent-model family cars was selected for the study. Each car was operated at a series of uniform speeds on a level straight test road, both immediately before and immediately after a major engine tune-up. Road, weather, and speed conditions were identical for the test runs before and after engine tune-up. Fuel consumption data were recorded for all test runs. A table was prepared that shows the percentage of change in fuel consumption that resulted from the tune-up for each of the 22 test cars. This table also lists for each car the age at the time of the study, the accumulated mileage, and the distance traveled since the last tune-up. The principal conclusion of the study is that passenger car tune-ups for cars less than six years old are unlikely to improve on-the-road fuel economy unless there is some evidence of actual fuel loss or waste. Out of the sample of 22 cars, only a third operated with better fuel economy in the normal range of running speeds after tune-up than before. Fourteen percent consumed more fuel per mile of travel after tune-up than they did before.

The improvement in passenger car fuel economy that can be expected from a major engine tune-up for cars in use less than six years was investigated for the Federal Highway Administration in 1974 and 1975. The purpose of the study was to develop on-the-road data on the fuel economy benefits of engine tune-ups for family cars during their first five years of service. Study details on which this paper is based were given in a report by Claffey (1).

Reports of two recent investigations to determine the effect tune-ups have on passenger car fuel economy are available. However, neither study involves the direct measurement of on-the-road passenger car fuel economy before and after full engine tune-ups. Walker and others (2) report that in diagnosing a random selection of 5666 cars in service they found that only about a third needed engine maintenance to improve fuel economy. These researchers also arranged for tune-ups for a small sample of the cars that were found by inspection to need engine maintenance to save fuel. Laboratory fuel economy measurements that used a dynamometer before and after the tune-up of each of these cars indicated that the tune-ups improved fuel economy by about 10 percent. A study by Bayler and Eder (3) found from an extensive review of the records of engine tune-ups to correct emissions deficiencies for 322 cars and of

the corresponding fuel economy data that such tune-ups resulted in an average improvement in fuel economy of 4.7 percent. They also arranged for engine tune-ups for a random sample of 26 compact cars and for a random sample of 31 intermediates. In each case fuel economy was determined both before and after the tune-up by using laboratory measurements with the dynamometer. They found that tune-ups improve the average fuel economy of the compacts by 2.7 percent and that of the intermediates by 1.6 percent for a pattern of highway speeds.

The study reported on here involved measuring the fuel consumption rates of a selection of 22 cars from the population of family cars in normal use both before any change was made in the vehicle and again after a complete tune-up. Before and after fuel consumption rates were determined for each car while it was idling and for uniform on-the-road running speeds of 16.1 km/h (10 mph), 32.2 km/h (20 mph), 48.3 km/h (30 mph), 64.4 km/h (40 mph), 80.5 km/h (50 mph), and 96.4 km/h (60 mph) on a section of paved level straight road. All test runs were made when air temperature was between 23.3°C (80°F) and 26.0°C (90°F), humidity was between 60 and 70 percent, there was no wind, and the pavement was dry. All before-and-after test runs for each car were made by the same test-car driver and always in the same manner. Tire-inflation pressures were noted when each car was received from the owner. These were not changed.

#### SELECTION OF TEST VEHICLES

Each of the 22 vehicles used in the study was a family car less than six years old at the time of the study. Fifteen were standard or luxury-type cars and seven were small cars or compacts. Twelve were customarily operated in a rural area (the vicinity of Potsdam, New York) and 10 in an urban area (Utica, New York). No attempt was made to select one car model rather than another.

A 22-car sample is, of course, too small to represent adequately the millions of cars registered in this and other countries if each car in the population is unique. However, each car is not unique. Only a few manufacturers produce all the cars and car parts in use. The test sample includes vehicles

Table 1. Change in fuel consumption for 22 passenger cars after major engine tune-up.

Car Model and Year	Age (years)	Odometer Reading (km)	Distance Since Last Tune-Up (km)	Change in Fuel Consumption (%)			
				Idling in Gear	At Uniform Speeds of		
					16.1 km/h	48.3 km/h	80.5 km/h
1970 Chevrolet	4	46 661	11 263	+4.3	-10	-15	-20
1971 Mercury	3	97 713	8 045	+3.5	NC	-10	-14
1973 Nova	1	19 308	11 263	+25.0	NC	NC	-8
1973 Oldsmobile	1	16 090	16 090	+27.4	-9	-11	-12
1973 Plymouth	1	27 353	27 353	-26.0	-10	-4	NC
1973 Chevrolet	1	27 353	27 353	-5.8	+6	-3	-3
1973 Plymouth	1	32 180	27 353	NC	+4	-6	-5
1970 BMW	4	115 848	16 090	-13.6	NC	NC	NC
1970 Pontiac	4	157 682	40 223	NC	NC	NC	NC
1971 Dodge	3	48 270	20 917	-1.7	NC	NC	NC
1971 Ford	3	65 969	32 180	NC	NC	NC	NC
1972 Oldsmobile	2	74 014	8 045	+27.4	NC	NC	NC
1974 Matador	½	8 850	8 850	-40.7	NC	NC	NC
1970 Volvo	4	65 969	16 090	-27.2	NC	NC	NC
1970 Valiant	4	96 540	16 090	+32.3	NC	NC	NC
1971 Vega	3	54 706	25 744	+11.6	NC	NC	NC
1972 Oldsmobile	2	57 924	57 924	+27.4	NC	NC	NC
1973 Buick	1	20 917	20 917	+3.3	NC	NC	NC
1974 Mustang II	½	16 090	16 090	NC	NC	NC	NC
1970 Plymouth	4	54 706	11 263	NC	+14	NC	+10
1973 Ford	1	37 007	37 007	NC	+16	+7	+8
1972 Chevrolet	2	48 270	24 135	-20.1	NC	+4	+4

Note: 1 km = 0.6 mile; NC = no change.

produced by each of the three major motor companies of the United States and by two foreign firms. The tune-up needs of the sample cars reflect the durability and service characteristics of the tune-up parts produced by parts manufacturers from all over the country. Tune-up parts (spark plugs, carburetor kits, distributor caps and points, for example) are standardized mass-produced items that can be adequately represented for the purposes of this study by a small sample of cars.

#### TEST PROCEDURE

The test procedure for determining the effect of a tune-up on a passenger car's fuel consumption was identical for each of the 22 test cars. Just before the tune-up the fuel consumption while the car idled in gear was recorded. Following this, the fuel consumption for operation at a set of uniform speeds that varied from 16.1 km/h (10 mph) to 96.4 km/h (60 mph) was measured for operation over a 1219-m (4000-ft) section of straight level test road. Then the vehicle was taken to a service station at which a mechanic skilled in tuning the particular model being tested gave the car a complete tune-up. After the tune-up, the fuel consumption of the car was again determined for exactly the same operating conditions and procedures as before the tune-up.

Fuel consumption measurements were made by using the photoelectronic fuelmeter developed for the Transportation Research Board (TRB) in 1964 in connection with fuel consumption studies carried out for TRB from 1964 to 1970. This fuelmeter has been fully described (4). All fuel consumption data were recorded in the field in units of 0.001 gal.

The tune-up performed on each of the 22 cars is commonly called a major tune-up and consists of the following operations:

1. Replacement of all spark plugs;
2. Replacement of breaker points;
3. Replacement of condenser;
4. Replacement of air cleaner;
5. Inspection and replacement, if necessary, of distributor case, distributor cap, distributor rotor, and spark-plug wires;

6. Inspection and adjustment, if necessary, of heat riser, automatic choke, carburetor, and pollution controls; and
7. Performance of compression test.

#### STUDY RESULTS

The results of the study are summarized in Table 1. In this table each test car is identified by model and year of manufacture. The age of each car is also given, along with the total mileage (odometer reading) and the mileage since the last tune-up. The percentage of change in the rate of fuel consumption as a result of the tune-up is given for each vehicle while it is idling in direct gear and for running speeds of 16.1, 48.3, and 80.5 km/h.

The test vehicles that benefited most from the tune-up for on-the-road operations are the first two cars listed in Table 1. In the case of each of these vehicles, fuel consumption rates were very erratic and varied widely on the test runs before tune-up. After tune-up, their fuel consumption rates were stable and repeatable. The erratic fuel consumption rates before tune-up indicated a definite breakdown somewhere in the fuel systems or ignition systems of these cars that resulted in random losses of fuel. The first car listed in the table was actually leaking gasoline around the carburetor. One of the findings of this study is that there is often evidence of fuel waste when a vehicle really needs a tune-up to save fuel. Erratic fuel consumption rates usually mean leaking fuel lines or other directly observable phenomena related to fuel loss.

Neither the overall mileage (odometer reading) nor the distance traveled since the last tune-up seem to relate to the fuel economy benefits of an engine tune-up. Neither of the two sample cars that had the highest accumulated mileage (the 1970 BMW and the 1970 Pontiac) gained improved fuel economy as a result of being tuned up. Similarly, neither of the two cars that had traveled the greatest distance since the previous tune-up (the 1970 Pontiac and the 1972 Oldsmobile) had any better fuel economy after the tune-up than before. The implication of this finding is that owners should have some reason

for believing that a tune-up will result in improved fuel economy other than accumulated mileage or mileage traveled since the last tune-up before investing in an expensive tune-up to save fuel.

#### CONCLUSIONS AND RECOMMENDATIONS

The principal conclusion is that passenger car tune-ups for cars less than six years old are unlikely to improve fuel economy unless there is some evidence of actual fuel loss or waste. Out of a random sample of 22 cars, only about a third operated with better on-the-road fuel economy after tune-up than before. Over half of the test cars showed no change in on-the-road fuel economy as a result of the tune-up, whereas three of the 22 test cars actually used more fuel. Two of the cars that operated with improved on-the-road fuel economy as a result of engine tune-up had very erratic fuel consumption patterns before tune-up. The erratic fuel consumption patterns were eliminated by the tune-up. In the case of these two cars, the tune-up corrected a particular engine malfunction that was wasting fuel. One operated with better fuel economy after tune-up than before because a fuel leak around the carburetor was corrected by using a new carburetor kit. The other achieved improved fuel economy through replacement of a spark-plug wire. A third vehicle got better fuel economy through replacement of the distributor rotor. The remaining four test cars that had better on-the-road fuel economy after tune-up than before benefited from carburetor and timing adjustments.

There was no evidence that replacement of spark plugs, points, and condensers improved fuel economy in any of the test cars. This does not mean that it did not help in some of the cars, but fuel economy improvement was due principally to other elements of the tune-up work, especially engine adjustments and replacement of malfunctioning engine parts.

It is suggested that diagnostic service stations be established at convenient locations where car owners can take their cars for analyses of engine fuel economy characteristics. Such stations, by using precise fuelmeters and a dynamometer, could identify cars that had poor fuel economy attributes and suggest tune-up work needed to improve fuel economy. Whether or not such stations are made available to the motoring public, all automobile mechanics should be given specific training on how to spot evidence of engine malfunctioning that results in poor fuel economy. Furthermore, drivers themselves should have available some kind of instruction sheets that explain how to recognize the more easily observable engine conditions associated with

poor fuel economy. These include such conditions as fuel-line leaks and erratic overall fuel consumption rates. Fuel economy diagnostic centers, special training for mechanics, and instruction sheets for car owners are all suggested as means of identifying cars that have engines that are wasting fuel and the reasons for the waste so that corrective measures can be taken.

Neither major nor minor tune-ups are recommended for recent-model cars to improve fuel economy unless there is evidence of an engine malfunction of some kind that is causing a waste of fuel. Fifteen of the 22 test cars in the study sample (68 percent) either gained no improvement in on-the-road fuel economy from the tune-up or had poorer economy after the tune-up than before. There is only approximately one chance in three that a recent-model car will gain improved on-the-road fuel economy as a result of the tune-up. Since such tune-ups are expensive, they should be resorted to only when there is evidence that they will produce a fuel economy improvement.

#### ACKNOWLEDGMENT

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