Research Report
-566-

INTERSTATE SAFETY IMPROVEMENT PROGRAM

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offered for publication by the
Transportation Research Board

November 1980

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ABSTRACT

The purpose of this paper was to prepare prioritized rankings of recommended improvements which could be implemented for the Interstate Safety Improvement Program in Kentucky. Considerable detail is presented which 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) spots were 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 utilized as the means of developing prioritized rankings for safety improvements totaling approximately $27,500,000. A user's guide for preparation of a safety improvement program was developed.

INTRODUCTION

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 justified and selected under the provisions of Federal Highway Administration Program Manual 6-8-2-1 (Volume 6, chapter 8, section 2, subsection 1) (1).

A previous report dealt with development of procedures for preparation of an Interstate Safety Improvement Program (2). The purpose of this report was to prepare prioritized rankings of recommended improvements which 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 accomplish this, 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: (1) interchange-related, (2) bridge-related, or (3) other highway sections. Each accident was assigned a code based on an analysis of the accident description. Listings of the accident types for the three broad categories are given in Tables 1, 2, and 3. 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 which were classified as either bridge- or interchange-related were assigned to a specific bridge or interchange. Using this procedure, the number of accidents which occurred on each interchange and bridge was obtained. The number of accidents could then be compared to a critical number of accidents. The critical number of an interchange, bridge, or specific length of road was calculated using the following formula (3):

$$Nc = Na + K\sqrt{Na} + 0.5$$

where Nc = critical number of accidents

Na = average number of accidents, and

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

The average number of accidents per interchange, bridge, mile, and spot (0.48 km (0.3 mile)) were calculated for the large urban, medium urban, and rural sections of interstate roads as well as the entire interstate system. Using certain levels of statistical significance, critical numbers of accidents were calculated. Also, using volume data, average and critical accident rates were calculated. For bridges, the length of bridge along with the volume provided vehicle-kilometers (vehicle-miles). The vehicle-kilometers (vehicle-miles) traveled on a particular section of road was calculated directly from the volume and section length. For interchanges, the total interchange volume was estimated using the volume and the number of ramps. Interchange volume counts were used to obtain the percentage of the total interchange volume occurring 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 formula (4):

$$Ac = Aa + K\sqrt{Aa/m} + 1/(2m)$$

where Ac = critical accident rate, in accidents per million vehicle-miles (1.6 million vehicle-kilometers),

Aa = average accident rate, in accidents per million vehicle-miles (1.6 million vehicle-kilometers), and

m = annual vehicle-miles (million vehicle-kilometers).

For spots and interchanges, the total annual volume was used rather than the number of vehicle miles. Thus, the values of Ac and Aa 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 of the accident types. These lists gave general information relating to the types of accidents which occurred most frequently. The severity of each type of accident was also calculated 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 which had a critical number of a particular type of accident. The average number of accidents per kilometer (mile) of a specific type was calculated for each of the three interstate categories. Using the formula given for determining a critical number of accidents, the critical number of accidents per kilometer (mile) was calculated. Some of the specific types investigated included injury and fatal accidents, accidents occurring during darkness, accidents involving guardrail, and accidents involving a rock cut or earth embankment.

A special investigation of fatal accidents occurring on the interstate system was performed. Copies of the accident reports of all accidents involving a fatality were obtained for a 4-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 where several fatal accidents had occurred were summarized. Also, locations where 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 with 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 1,046 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 spots (0.48 km (0.3 mile) sections). 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.

A listing of the general roadway features included in the field inventory is given in Table 4. 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 mounds, and crash cushions have been used. For bridges, the shoulder width, the existence of a curb, 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. The number of 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 feet) to the pavement were tabulated. The rock cuts were divided into those occurring on curves or tangents. Median crossovers were also counted. Crossovers were divided into those which were designed and those which had been created by frequent use. All of the features inventoried, with the exception of bridges, were summarized by mile and mileposts.

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 which would be affected by the improvement and the estimated percentage 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 reductions used were based on previous research findings for the type 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 type.

DYNAMIC PROGRAMMING

Multistage dynamic programming was used as the means of priority ranking the improvements. Using the present worth of the benefits and costs of the improvements along with a specific program budget, the combination of improvements which would yield the greatest benefits was determined. Several hypothetical budgets were input into the program, and the improvement types which 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 5,948 accidents occurring on the interstate system. The largest percentage of accidents occurred in large urban areas (64 percent). Also, the largest percentage of accidents were not related to either a bridge or interchange (74 percent). The percentage of bridge-related accidents was about the same for the three population groups. However, the percentage of interchange-related accdients was much higher for the large urban group, and the percentage of non-bridge or interchange accidents was highest for the rural group.

All of the accidents were classified into the categories shown in Tables 1, 2, and 3. 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 Tables 1, 2, and 3. Summaries of the number of accidents in the categories for interchange accidents, bridge-related accidents, and accidents on other highway sections are also given in Tables 1, 2, and 3, respectively. The number of first events and all events for each category is given as well as the percentage of all accidents in each category. The combined severity index of each category is also given.

Interchange accidents (Table 1) 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 were the rear-end type. On entrance ramps, the frequency of rear-end accidents was followed by angle accidents between a vehicle leaving the ramp and a vehicle on the mainline, indicating 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 not properly slowing when exiting. Some of the most severe accidents involved hitting a fixed object.

Bridge-related accidents (Table 2) commonly involved ice or water on the deck. Bridge-related accidents involved several severe accident types. The most severe types primarily involved hitting a bridge pier or abutment or the bridge curb.

Accidents on other highway sections (Table 3) 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 along with the mileage and average volume (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 5), bridge-related accidents (Table 6), interchange-related accidents (Table 7), and accidents on other highway sections (Table 8).

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 over five times that in rural areas (Table 5). The number of accidents per 1.6 km (mile) 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 (mile) for urban areas to 8 accidents per 1.6 km (mile) for rural areas.

The average rate, expressed as accidents per 160 million vehicle-kilometers (100 million vehicle-miles) was higher on bridges than on the entire interstate system (Table 6). The average and critical number of accidents per bridge was 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 (Table 7). The number of accidents per interchange in large urban areas was over nine times that for rural areas. Also, the number of interchanges per 1.6 km (mile) in large urban areas was over five times for rural areas.

The average accident rate was lower for the "other highway sections" compared to the interstate system (Table 8). The critical number of accidents per spot (0.48-km (0.3-mile)) and per 1.6 km (mile) was calculated for each population group. The number of accidents per 1.6 km (mile) 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 of the computer listings of high-accident bridges, interchanges, 1.6-km (1-mile) sections, and spots (0.48-km (0.3 mile)) were made in descending order of the critical rate factor. 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 location 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 (1-mile) section or 0.48-km (0.3-mile) spot (excluding bridge and interchange accidents) for each population group had been determined previously. A listing of all locations having 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 (1-mile) and 0.48-km (0.3-mile) locations in order by route and mileposts.

In addition to searching for high-accident locations, the accident analysis also included a list of roadway elements which contributed to cause or severity. One method was to obtain 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 (mile) for specific types of accidents. The critical number of accidents per 1.6 km (mile) could then be calculated, and a printout of locations exceeding the critical number was obtained. Critical numbers of accidents per 1.6 km (mile) 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 (mile) involving guardrail was determined. Lists of locations where more than one accident had involved either a bridge, light support or pole, or a sign post were obtained. The most common types of fixed-object accidents involved either a guardrail (most common type), a rock cut, or earth embankment.

A separate analysis was made of fatal accidents occurring in a

4-year period (1974-1977). All of the fatal accidents were placed into one general category. The largest number involved collision 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 9). Data from these tables indicated general types of improvements which could be made to reduce the number of fatal accidents. For example, there were 20 fatal accidents involving wrong-way, head-on collisions. This indicated a need to prevent wrong-way entrance onto the roadway. Other areas needing safety improvements were revealed by the number of fatal accidents involving rock cuts (a total of 13) and blunt guardrail ends (a total of 7). An investigation of seatbelt usage disclosed 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 with full-width shoulders had a 18 percent lower accident rate and 51 percent fewer accidents per bridge compared to bridges without 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 consisting of entrance or exit ramps only and for a T- or trumpet-type interchange. A comparison of bridges based on adequacy ratings was done. It was shown that bridges with 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 were buried (85 percent). Some guardrails have been upgraded to breakaway-cable-terminal (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, guardrail was the only safety device to divert the vehicle. In some cases, the pier had been placed over 30 feet (9 m) from the roadway (9 percent). Also, a few of the shoulder piers were not shielded from traffic (5 percent). 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 guardrail (78 percent). There were various arrangements of guardrails. Some of the older installations provided very little protection. In addition to guardrail, a few installations had shrubs which provided increased protection. Some bridges were at locations where a median barrier was present. In a very few instances on I 264 no protection was provided. For over one-half of the bridges (60 percent), all of 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 light poles 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 non-breakaway type. Approximately 113 km (70 miles) of rock cuts closer than 30 feet (9 m) to the pavement were found. The largest number of rock cuts were on I 75 and I 64. Crossovers were identified as those which were designed and those which had been created by frequent traversing. A total of 290 crossovers was located; 29 percent were not 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 (0.3-mile) spots, 1.6-km (1-mile) sections, bridges, or interchanges. The types of improvements were based partly on guidelines for interstate safety upgrading which were distributed in 1978 by the Federal Highway Administration 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 with abnormally high accident experiences were investigated in the field to determine geometric deficiencies. For 0.48-km (0.3-mile) spots, recommendations were offered for 20 locations. Most of the improvements involved variable message signs to provide advance warning to drivers. There were 12 interchanges where preliminary recommendations include ramp metering, gore improvements, transverse striping, and addition of acceleration lanes. Of the 51 bridges in the listing, no improvements were needed for 15. 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 given also.

A combined list of proposed safety improvements was developed for

(1) high-accident spots,

(2) high-accident sections,

(3) high-accident bridges,

(4) high-accident interchanges,

(5) substandard geometric features,

(6) low adequacy rating (bridges only), and

(7) 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 accident reduction, improvement costs, maintenance costs, average annual benefits, references relating to the improvement, benefit-cost ratio, and service life. The expected percentage reductions in accidents were determined based on one or more of the 42 references. Benefit-cost ratios range from near 0 to 44.

The percentage accident reductions were given separately for fatal, injury, and property damage accidents. Some improvements will reduce severity but not affect number of accidents. In such cases, total accidents remain unchanged, but injury and fatal accidents were reduced. Thus, the number of property-damage accidents show a negative percentage reduction because some injury and fatal accidents are expected to be reduced in severity to property-damage accidents after improvements are 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 over $27 million. Of that total, nearly $20 million in expenditures would result in a benefit-cost ratio of more than 1.0. All of the general improvements would pay for themselves (B-C ratios of 1.0 or higher). Almost all of the ramp improvements would have benefit-cost ratios of 1.0 or higher while less than half of the de-slicking, bridge widening, and spot improvement projects would be cost effective.

PRIORITY RANKING

To prioritize projects, 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 (PDO) accidents for each project location during the previous year. Percentage reductions for these accidents were also used along with improvement costs, annual maintenance costs, and service lives of each project. An interest rate of eight percent was used along with a volume growth rate of five percent per year.

Output from the program included information for each improvement project. The program output also includes a listing of all projects in order of benefit/cost ratio which could be used to determine priority rankings based on benefit-cost ratios alone. The largest benefit-cost ratio was 44.01, which corresponded to the addition of exit signs on the left side of I 65 south of Louisville. Projects with the largest benefit-cost ratios were generally those with the smallest improvement costs. Projects ranged in cost from $2,000 for the left-exit sign to over $5,000,000 for removal of rock cuts. Several other projects had improvement costs over $1,000,000. 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 ratio which 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 with 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

This paper presents the proposed Interstate Safety Improvement Program for Kentucky. Included is a compilation of procedures, results, and priority rankings of the recommended improvements. Considerable detail is presented in this report however, reference should be made to APPENDIX G of 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 with references to details in a companion report (2).

Evaluation of the Interstate Safety Improvement Program was not covered in this report or the earlier report (2). Guidelines for the evaluation are presented in the Federal Highway Administration Program Manual 6-8-2-1 (1). The basic requirements for an evaluation should include the following:

(a) an assessment of the costs and benefits of various means and methods used to eliminate identified hazards.

(b) a comparison of accident data before and after the improvements,

(c) basic cost data used for each type of corrective measure and the number of each type of improvement undertaken during the year, and

(d) methods employed in establishing project priorities.

REFERENCES

1. Federal Highway Administration, Federal-Aid Program Manual, Volume 6, Chapter 8, Section 2, Subsection 1, Highway Safety Improvement Program, July 3, 1974.

2. Pigman, J. G.; Agent, K. R.; and Zegeer, C. V.; "Development of Procedures for Preparation of the Interstate Safety Improvement

Program," Report 495, Division of Research, Kentucky Department of Transportation, February 1978.

3. Agent, K. R.; "Development of Warrants for Left-Turn Phasing," Report 456, Division of Research, Kentucky Department of Transportation, August 1976.
4. Yamane, Taro; "Statistics: An Introductory Analysis," Second Edition, Harper & Rowe Publishers, New York, 1967.
5. Traffic Safety Memo, National Safety Council, Chicago, Illinois, July 1977.
6. Pigman, J. G.; Agent, K. R.; Mayes, J. G.; and Zegeer, C. V.; "Optimal Highway Safety Improvements by Dynamic Programming," Report 412, Division of Research, Kentucky Department of Transportation, April 1974.
7. "Average Unit Bid Prices for All Projects Awarded, Department of Transportation, Bureau of Highways, Division of Design., 1977.
8. Pigman, J. G.; Agent, K. R.; and Zegeer, C. V.; "Interstate Safety Improvement Program," Report 517, Division of Research, Kentucky Department of Transportation, March 1979.

TABLE 1. TYPES OF INTERCHANGE ACCIDENTS

	FIRST EVENT		ALL EVENTS		
TYPE OF ACCIDENT	NUMBER OF ACCIDENTS	PERCENT OF TOTAL	NUMBER OF ACCIDENTS	PERCENT OF TOTAL	SEVERITY INDEX
ENTRANCE RAMP					
Rear-end accident on ramp	193	16.9	199	15.1	1.53
Angle accident between ramp vehicle and mainline 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 mainline 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 mainline 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
Mainline 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	474	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	640	58.6	791	60.1	
Total	1,144	100.0	1,315	100.0	

TABLE 2. TYPES OF BRIDGE-RELATED ACCIDENTS

TYPE OF ACCIDENT	FIRST EVENT		ALL EVENTS		
	NUMBER OF ACCIDENTS	PERCENT OF TOTAL	NUMBER OF ACCIDENTS	PERCENT OF TOTAL	SEVERITY INDEX
Accident on bridge after sliding 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	569	100	

TABLE 3. TYPES OF NON-INTERCHANGE ACCIDENTS

TYPE OF ACCIDENT	FIRST EVENT		ALL EVENTS		
	NUMBER OF ACCIDENTS	PERCENT OF TOTAL	NUMBER OF ACCIDENTS	PERCENT OF TOTAL	SEVERITY INDEX
Rear-end accident in traffic lane	1,544	35.1	1,715	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 non-interchange accident or not-stated	326	7.4	389	6.7	1.78
Vehicle overturned	26	0.6	226	3.9	4.04
Vehicle malfunction - tire blowout, brakes failed, etc.	198	4.5	216	3.7	2.43
Drastic human error - fell asleep while driving, etc.	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 collision	5	0.1	19	0.3	2.50
Total	4,394	100.0	5,797	100.0	

TABLE 4. ROADWAY FEATURES INCLUDED IN FIELD INVENTORY

1 Type of Guardrail End
2 Bridge Pier Protection
3 Bridge Shoulder Width
4 Bridge Safety Features
5 Curb on Bridge
6 Protection of Gap between Bridges
7 Signs
8 Lightpoles
9 Gore Area Features
10 Rock Cuts
11 Crossovers

TABLE 5. ACCIDENT AND VOLUME DATA ON INTERSTATES (ALL ACCIDENTS)

	LARGE URBAN	MEDIUM URBAN	RURAL	TOTAL
Number of accidents	3,809	487	1,652	5,948
Total miles (km)	84.1 (135.3)	63.2 (101.7)	505.6 (813.5)	652.9 (1050.5)
Accidents per mile (1.6 km)	46.5	7.7	3.3	9.1
Critical accidents per mile (P=95.0) (1.6 km)	60	14	7	16
Critical accidents per mile (P = 99.5) (1.6 km)	65	15	8	17
Average AADT	40,623	27,305	15,669	20,528
Million vehicle-miles (km)	1,247	630	2,892	4,892
	(2,006)	(1,014)	(4,635)	(7,871)
Average accident rate*	305	77	57	122

* Accidents per 100 million vehicle-miles (160 million vehicle-kilometers)

TABLE 6. SUMMARY OF ACCIDENTS AND VOLUMES ON BRIDGES

	LARGE URBAN	MEDIUM URBAN	RURAL	TOTAL
Number of accidents	276	23	111	410
Number 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
Critical accidents per bridge (P = 99.5)	6	5	4	5
Average AADT	51,144	29,683	14,137	31,864
Average accident rate (Accidents per 100 million vehicles)	11.2	11.8	15.5	12.3
Average length per bridge (feet) (m)	262 (79.9)	279 (85.0)	284 (86.6)	273 (83.2)
Total bridge length (miles) (km)	6.45 (10.4)	0.95 (1.53)	7.48 (1.20)	14.88 (23.94)
Million vehicle-miles (km)	120.4 (193.7)	10.3 (16.6)	38.6 (62.1)	169.3 (272.4)
Average accident rate*	229	223	288	242

* Accidents per 100 million vehicle-miles (160 million vehicle-kilometers)

TABLE 7. SUMMARY OF ACCIDENTS AND VOLUMES ON INTERCHANGES

	LARGE URBAN	MEDIUM URBAN	RURAL	TOTAL
Number of accidents	948	82	114	1,144
Number 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
Critical accidents per interchange (P = 99.5)	23	10	5	14
Average AADT	68,046	31,678	17,638	40,502
Average accident rate (Accidents per million vehicles)	0.53	0.36	0.22	0.45
Interchanges per Mile (1.6 km)	0.86	0.32	0.16	0.26

TABLE 8. ACCIDENT AND VOLUME DATA ON INTERSTATES (EXCLUDING BRIDGE AND INTERCHANGE ACCIDENTS)

	LARGE URBAN	MEDIUM URBAN	RURAL	TOTAL
Number of Accidents	2,585	382	1,427	4,394
Total Miles (km)	84.1 (135.3)	63.2 (101.7)	505.6 (818.5)	6,529 (1,050.5)
Accidents per Mile (1.6 km)	30.7	6.0	2.8	6.7
Accidents per Spot (0.3-mile (483-m) segment)	9.2	1.8	0.8	2.0
Critical Accidents per Spot (P = 95.0)	16	5	3	5
Critical Accidents per Spot (P = 99.5)	18	6	4	6
Critical Accidents per Mile (1.6 km) (P = 95.5)	42	11	7	12
Critical Accidents per Mile (1.6 km) (P = 99.5)	45	13	8	14
Average AADT	40,623	27,305	15,669	20,528
Million Vehicle-Miles (km)	1,247 (2,006)	630 (1,014)	2,892 (4,653)	4,892 (7,871)
Average Accident Rate*	207	61	49	90

* Accidents per 100 million vehicle-miles (160 million vehicle-kilometers)

TABLE 9. DETAILED ACCIDENT DESCRIPTION OF FATAL ACCIDENTS

DESCRIPTION	NUMBER	PERCENT OF TOTAL
Wrong Way Head-on	20	9.3
Run-off-road (no collision)	14	6.5
Pedestrian (not driver or passenger of another motor vehicle)	8	3.7
Workman	1	0.5
Pedestrian (driver or passenger of other motor vehicle)	3	1.4
Pedestrian -- Disabled Vehicle	8	3.8
Pedestrian -- Previous Accident	2	0.9
Pedestrians (total)	22	10.2
Involving Median Crossover	4	1.9
Motorcycle Lost Control	5	2.3
Hit Guardrail (general)	4	1.9
Blunt Guardrail End Punctured Vehicle	7	3.2
Hit Buried Guardrail End and Overturned	3	1.4
Jumped Guardrail	6	2.8
Went Through Guardrail	1	0.5
Hit Guardrail and Overturned	9	4.2
Jumped Over Buried Guardrail End	1	0.5
Guardrail-Related (total)	31	14.4
Cross Median Head-on	16	7.4
Rear End (general)	15	6.9
Slow Moving Truck	11	5.1
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
Rear End (total)	42	19.4
Hit Bridge Pier	7	3.2
Hit Bridge Abutment	3	1.4
Through Bridge Railing	6	2.8
Icy Bridge	1	0.5
Gap Between Parallel Bridge	2	0.9
Rebounded off Bridge Railing	5	2.3
Bridge-Related (total)	24	11.1
Other Fixed Object (general)	1	0.5
Culvert	2	0.9
Sign	3	1.4
Rock Cut	13	6.0
Light Pole	3	1.4
Earth Embankment	5	2.3
Fixed Object (total)	27	12.5
Sideswipe (general)	1	0.5
Passing	6	2.8
Merging from Entrance Ramp	1	0.5
Sideswipe (total)	8	3.7
U-Turn (no crossover)	3	1.4