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

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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):

$$Nc = Na + K\sqrt{Na} + 0.5 \quad (1)$$

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, 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.

Type of Accident	First Event		All Events		
	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):

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

where

Ac = critical accident rate [accidents per 1.6 million vehicle-km (1.0 million vehicle miles)],
Aa = 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 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 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).

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

Item	Type of Area Large Urban	 Medium Urban	 Rural	Total
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[a]	305	77	57	122

Note: 1 km = 0.6 mile; 160 million vehicle-km = 100 million vehicle miles.
[a]Accidents per 160 million vehicle-km.

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

Item	Type of Area 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[a]	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[b]	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[c]	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[a]	207	61	49	90

Note: 160 million vehicle-km = 100 million vehicle miles; 1 m = 3.2 ft; 1 km = 0.6 mile.
[a]Accidents per 100 million vehicles.
[b]Accidents per 160 million vehicle-km.
[c]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 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 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

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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