

Highway Accidents in Construction and Maintenance Work Zones

JERRY G. PIGMAN AND KENNETH R. AGENT

Statewide accidents in which road under construction was listed as a contributing factor were documented for the period 1983 through 1986. Accident data and traffic control devices used at 20 case study locations were analyzed. Accident data at these locations for a 3-year period before construction were compared with accident data for the period during construction. Approximately 500 accidents per year were reported as occurring in work zones for the period 1983 through 1986. In general, work zone accidents are more severe than other accidents. There are high percentages of rear end and sideswipe accidents; following too close is the most frequently listed contributing factor. There is a high percentage of accidents involving trucks. The analysis of 19 case study locations revealed that at 14 sites the accident rates during construction exceeded those before construction. Of the 14 sites, 10 had rates during construction that exceeded statewide averages and six exceeded statewide critical rates. Similar characteristics (types of accidents and contributing factors) were found to exist at the same study locations when compared with statewide work zone accidents. Traffic control at case study sites was generally found to be in conformance with specified standards.

Construction and maintenance work zones have traditionally been hazardous locations within the highway environment. Studies show that accident rates at construction and maintenance work zones are higher than similar periods before the work zones were set up (1-3). Factors that have been cited as reasons for the increase in accident rates include (a) inappropriate use of traffic control devices, (b) poor traffic management, (c) inadequate layout of the overall work zone, and (d) a general misunderstanding of the unique problems associated with construction and maintenance work zones.

Proper interpretation of traffic control details and usage of traffic control devices is necessary to alert drivers of impending conditions and hazards and direct them through work zones.

A significant amount of research has been completed in the area of safety associated with construction and maintenance work zones. Proper use of traffic control devices, work activity scheduling, and personnel training have been areas of emphasis in previous studies. Training courses developed and presented by FHWA have addressed many of the problems. In addition, most state highway agencies have devoted considerable attention to their work zone traffic control policies and training of their employees.

Even with the work zone safety problems being addressed, there is still a distinct need for improvement. This need is related to the shift from building new facilities to the improvement of existing facilities. There have also been recent increases

in the volumes of traffic and changes in the composition of the traffic stream. On the Interstate system, major reconstruction and resurfacing projects have had to contend with overall increases in volumes of traffic and percentages of trucks. The size, weight, and handling characteristics of trucks require that additional consideration be given to these vehicles in work zones. Large trucks are involved in fewer accidents per mile of travel than passenger cars; however, their involvement rate in fatal accidents is almost twice that of passenger cars (4,5).

Training of personnel involved with construction and maintenance work zones has also been given a significant amount of attention. Varying levels of training have been offered and benefits have been realized. Development of traffic control plans is usually the responsibility of the design and traffic engineers. These engineers, along with the resident engineers on the job site, need to be completely familiar with the proper usage of appropriate traffic control devices. The devices are necessary to alert drivers of impending conditions and hazards and direct them through the proper path. Highway agency employees, responsible for traffic control during maintenance operations, and construction company employees, responsible for providing traffic control, are also involved in work zone safety. The efforts of this research were directed at identifying and offering solutions to problems that confront personnel involved with traffic control for construction and maintenance operations.

DATA COLLECTION

Statewide Work Zone Accidents

Accident data were collected from the Kentucky Accident Reporting System (KARS) computer file for the time period of 1983 through 1986. Only those accidents with road under construction listed as an environmental contributing factor were identified and summarized. In addition, copies of the accident reports were obtained for more details about the accident.

Case Study Locations

The objective of this phase of the study was to collect data to document the types of traffic control being used and to follow up with the collection of accident data both in the field and through computer accident records at 20 case study locations. Field inspections were accomplished in the summer construction seasons of 1986 and 1987. Existing traffic control

was documented by written descriptions and photographs at 18 of the 20 case study locations. The case study locations included projects ranging from construction of a bridge on County Road 5001 in Harrison County to a spot pavement replacement project of over 50 mi of I-75 in Whitley and Laurel counties.

A request was made for the resident engineer on each project to provide accident report forms when an accident occurred in the field; however, few reports were received and it became necessary to rely on centralized computer accident records. Computer searches were made and output was produced during a 3-year period before the work zone was in place and then during the time work was occurring.

Additional traffic control information was obtained from the contract proposal. Bid tabulations for each project were examined and both lump sum and incidental bid items relating to maintaining and controlling traffic were summarized.

ANALYSIS AND RESULTS

Statewide Work Zone Accidents

The total number of statewide accidents in Kentucky for 1983 through 1986 in which road under construction was given as an environmental contributing factor is presented in Table 1. There were some variations over the 4-year period, with an average of about 500 accidents per year. These are the accidents in which the investigating officer listed road construction as a contributing factor and, therefore, would not include all accidents occurring in work zones. In the 4-year period, there were 19 fatalities resulting from 18 fatal accidents and 883 injuries, or about 220 injuries per year. Of the 18 fatal accidents, 8 were single vehicle, 8 were multiple vehicle, and 2 involved pedestrians (1 was a construction worker).

Most accidents (about one-third) occurred on Interstates with the largest number occurring on I-75, which is a high-volume Interstate with a large amount of construction activity. Of the accidents, 14 percent occurred on non-state-maintained streets.

Several characteristics of work zone accidents and total statewide accidents were compared (see Table 2). There was a substantially higher percentage of work zone accidents between June and October compared with statewide accidents. This increase was expected because those months corresponded to the construction season. There was no general trend when time of day was compared. The largest difference was for the 9:00 to 11:59 a.m. time period, which had a higher

percentage of work zone accidents. There was a smaller percentage of work zone accidents occurring on the weekend compared with statewide accidents, which was related to less work zone activity on the weekend. Work zone accidents involving injury or fatality were more severe than statewide accidents. The percentage of work zone accidents occurring in rural areas was much higher and the percentage in business and residential areas much lower than for all accidents. The percentage of work zone accidents during wet, snow, or ice roadway conditions was low, which was related to less activity during such conditions. When road character was considered, it was found that a higher percentage of work zone accidents than statewide accidents involved a curve. This shows the importance of providing adequate sight distance. There was a smaller percentage of work zone accidents occurring during nondaylight hours, which again relates to the amount of activity.

A comparison of work zone and all accidents by type of accident is presented in Table 3. A much higher percentage of work zone accidents occurred on a roadway section or midblock and a lower percentage at an intersection compared with all accidents. The most common work zone accident was a rear-end or same-direction sideswipe accident on a roadway section or midblock. There were also higher percentages of single-vehicle ran off the road and collision with a nonfixed object types of accidents.

Contributing factors, as given on the police report, of work zone accidents compared with statewide accidents are presented in Table 4. When human factors were considered, the largest difference was a higher percentage of work zone accidents involving following too close as a contributing factor. The percentage of accidents involving unsafe speed was slightly higher for work zone accidents compared with all accidents. There was a lower percentage of accidents involving alcohol in the work zone accidents. The vehicular factors were similar with slightly lower percentages generally noted for work zone accidents. There were also generally lower percentages for environmental factors (other than road construction) for work zone accidents, especially for the slippery surface factor. Exceptions where the percentage was higher for work zone accidents included debris in roadway, shoulders defective, and holes/deep ruts/bumps.

An attempt was made to classify each accident by type of work zone (see Table 5). The work zone categories were construction, maintenance, and utility. The most common type of work zone involved construction, although it could not be determined in many accidents. Maintenance work zones followed, with only a small percentage of accidents identified

TABLE 1 WORK ZONE ACCIDENTS IN KENTUCKY BY YEAR

YEAR	TOTAL ACCIDENTS	FATALITIES	INJURIES
1983	449	2	214
1984	551	7	257
1985	493	5	185
1986	520	5	227

TABLE 2 COMPARISON OF WORK ZONE AND STATEWIDE ACCIDENTS FOR SEVERAL VARIABLES

VARIABLE	CATEGORY	PERCENT OF TOTAL	
		WORK ZONE ACCIDENTS	STATEWIDE ACCIDENTS
Month	January	2.3	8.2
	February	1.8	7.4
	March	4.1	7.4
	April	6.1	7.9
	May	8.9	8.8
	June	12.9	8.2
	July	11.8	8.0
	August	14.0	8.4
	September	11.0	8.1
	October	12.6	8.9
	November	9.4	8.8
	December	5.0	9.8
Time of Day	Midnight - 2:59 am	4.9	5.3
	3:00 am - 5:59 am	3.7	2.6
	6:00 am - 8:59 am	11.1	10.1
	9:00 am - 11:59 am	19.2	14.7
	Noon - 2:59 pm	22.0	20.2
	3:00 pm - 5:59 pm	22.5	24.2
	6:00 pm - 8:59 pm	10.4	13.7
	9:00 pm - 11:59 pm	6.3	9.2
Day of Week	Monday	9.3	10.3
	Tuesday	14.0	14.2
	Wednesday	16.0	13.9
	Thursday	16.2	13.8
	Friday	15.7	14.2
	Saturday	17.1	18.3
	Sunday	11.7	15.2
Severity	Fatal	0.9	0.5
	Injury	27.4	21.7
	Property Damage Only	71.7	77.8
Land Use	Rural	54.9	30.1
	Business	28.8	41.4
	Industrial	1.9	0.9
	Residential	13.3	21.6
	School	0.7	2.2
	Park	0.3	0.4
	Private Property	0.2	3.3
Surface Condition	Dry	84.7	72.8
	Wet	14.1	20.1
	Snow-Ice	0.6	6.8
	Slush	0.2	0.2
	Muddy	0.4	0.1
Road Character	Straight-Level	56.3	62.4
	Straight-Grade	21.8	17.9
	Straight-Hill Crest	2.2	3.0
	Curve-Level	9.9	7.6
	Curve-Grade	8.4	8.0
	Curve-Hill Crest	1.3	1.2
Light Condition	Daylight	76.3	70.4
	Dawn	1.2	1.2
	Dusk	1.8	2.5
	Dark-Lights On	6.5	13.3
	Dark-No Lighting	14.1	12.5

TABLE 3 COMPARISON OF ACCIDENT DESCRIPTION

DIRECTIONAL ANALYSIS	PERCENT OF TOTAL	
	WORK ZONE ACCIDENTS	STATEWIDE ACCIDENTS
Intersection		
Angle	8.6	14.0
Rear End	2.0	6.2
Opposing Left Turn	1.2	1.1
Opposite Direction	0.5	0.9
Fixed Object	0.2	1.1
Single Vehicle	0.3	0.1
Pedestrian	0.1	0.2
Vehicle Backing	0.7	0.6
Same Direction Sideswipe	0.9	2.0
Roadway Section or Mid-Block		
Rear End	27.3	10.1
Head-On	1.5	1.4
Same Direction Sideswipe	14.2	4.8
Opposite Direction Sideswipe	3.2	4.5
Entering or Leaving Entrance	2.5	5.7
Pedestrian	0.6	0.9
Fixed Object	5.8	10.4
Collision - Not Fixed Object	5.9	0.8
Single Vehicle - Ran Off Road	9.6	4.7
Overturned in Roadway	0.8	0.8
Bridge Related Accidents	1.1	0.3
Interchange Ramp Accidents	2.2	0.4
Miscellaneous Accidents	0.6	13.4
Parking Lot	0.0	13.3

as occurring in a utility work zone. Most of the construction work zone accidents were on Interstates. The high percentage of accidents in construction work zones, compared with maintenance and utility work zones, related to higher exposure (both in terms of length of work and traffic volume).

The description of each accident was reviewed to determine the work zone-related factor that contributed to the accident. Factors were identified in about three-fourths of the accidents (see Table 6). The most common factor was congestion, which agrees with the previous finding that rear end accidents are the most common type of work zone accidents. Restricted lane width was the second most common factor found. There were several accidents involving either hitting or being hit by construction equipment. Another common factor related to the condition of the pavement surface and involved either a material such as gravel or oil on the roadway, an uneven pavement (including potholes and pavement removal), and a pavement (shoulder) dropoff. There were several accidents related to a flagger or construction worker; the most common involved a communication problem between the driver and flagger. Another common factor involved a vehicle merging too late.

The severity of the accidents associated with each factor presented in Table 6 was related using a severity index (SI). The SI is calculated by dividing the number of equivalent property-damage-only (EPDO) accidents by the total number

of accidents. As average accident severity increases, the SI increases. EPDO is equal to 9.5 times the number of fatal or incapacitating injury accidents plus 3.5 times the number of nonincapacitating or possible injury accidents plus the number of no injury accidents. The highest severity involved the water pooling and shoulder dropoff accidents. Accidents involving running off the road in a detour were also severe.

The accident severity of the work zone accidents was related to several variables (see Table 7) using the severity index, the percentage of fatal or serious injury accidents, and the percentage of injury or fatal accidents. When work zone type was considered, the most severe accidents were in construction work zones with the least severe in utility work zones. This effect probably related to the traffic speeds. When location in the work zone was considered, the most severe accidents occurred in the advance warning area. The most severe type of accident involved a pedestrian. Other severe types of accidents were head-on, overturning in the roadway, single-vehicle ran off the road, and fixed object. The most common accident types (rear end and same direction sideswipe) were not as severe. Accidents involving trucks were more severe than those in which a truck was not involved. Accidents during darkness, with no lighting, were more severe than accidents during daylight hours or darkness with roadway lighting. Accidents in rural areas were more severe than those in business or residential areas, which related to traffic speeds.

TABLE 4 COMPARISON OF WORK ZONE AND STATEWIDE ACCIDENTS BY CONTRIBUTING FACTOR

CONTRIBUTING FACTORS	PERCENT OF TOTAL	
	WORK ZONE ACCIDENTS	STATEWIDE ACCIDENTS
Human		
Unsafe Speed	10.4	8.0
Failed to Yield Right-of-Way	14.9	16.3
Following Too Close	11.6	4.3
Improper Passing	1.2	1.3
Disregard Traffic Controls	3.0	2.7
Turning Improperly	1.8	2.7
Alcohol Involvement	3.9	6.2
Drug Involvement	0.1	0.2
Sick	0.0	0.1
Fell Asleep	1.4	1.0
Lost Consciousness	0.1	0.2
Driver Inattention	31.5	29.1
Distraction	2.7	1.9
Physical Disability	0.1	0.3
Vehicular		
Brakes Defective	1.4	2.0
Headlights Defective	0.0	0.1
Other Lighting Defects	0.2	0.3
Steering Failure	0.3	0.4
Tire Failure/Inadequate	0.7	0.9
Tow Hitch Defective	0.3	0.1
Over or Improper Load	0.2	0.2
Oversized Load	0.1	0.1
Environmental		
Animal's Action	0.0	1.8
Glare	0.3	0.7
View Obstructed/Limited	2.0	3.6
Debris in Roadway	0.7	0.4
Improper/Non-Working Traffic Controls	0.2	0.2
Shoulders Defective	0.6	0.3
Holes/Deep Ruts/Bumps	0.8	0.2
Road Under Construction/Maintenance	100.0	0.4
Improperly Parked Vehicle	0.3	0.5
Fixed Object	0.1	0.2
Slippery Surface	1.7	10.3
Water Pooling	0.3	0.6

TABLE 5 ACCIDENTS BY TYPE OF WORK ZONE

TYPE OF WORK ZONE	NUMBER OF ACCIDENTS	PERCENT OF TOTAL	PERCENT OF KNOWN
Construction	1104	54.8	69.4
Maintenance	297	14.8	18.7
Utility	62	3.1	3.9
Maintenance or Utility	127	6.3	8.0
Undetermined	423	21.0	-

TABLE 6 FACTORS CONTRIBUTING TO WORK ZONE ACCIDENTS

FACTOR	NUMBER OF ACCIDENTS	PERCENT	SEVERITY INDEX
Congestion	484	24.0	2.12
Restricted Lane Width	188	9.3	1.76
Struck or Avoiding Construction Equipment	113	5.6	1.71
Material such as Gravel or Oil on Roadway	108	5.4	2.47
Related to Flagger (such as Communication Problem) or Construction Worker	107	5.3	2.23
Vehicle Merging Too Late	104	5.2	1.64
Uneven Pavement (including Potholes and Pavement Removal)	78	3.9	2.58
Vehicle Travelling on Lane Closed to Traffic	54	2.7	2.19
View Obstructed	53	2.6	1.74
Pavement Dropoff (Shoulder)	52	2.6	3.11
Lane Blocked	51	2.5	1.41
Struck by Construction Vehicle or Equipment	45	2.2	1.47
Lack of Proper Traffic Control	34	1.7	1.74
Ran off Road in Detour	30	1.5	2.92
No Merge Lane	25	1.2	2.28
Manhole Cover	12	0.6	1.62
Water Pooling	9	0.4	3.61

When adequate information was available, the location of the accident in the work zone was determined (see Table 8). The majority of accidents occurred in the work area, followed by accidents in the transition.

In the 4-year study period, there were 18 accidents involving a pedestrian or construction worker. Five of these accidents involved a pedestrian, nine involved a construction worker, and four involved a flagger. These 18 accidents resulted in 2 fatalities.

A high percentage of accidents occurred in work zones involving trucks—either a single unit or combination truck. The percentage of work zone accidents involving trucks was 25.7 percent compared with 9.6 percent of all accidents. A work zone was listed as a factor in 0.4 percent of all accidents compared with 1.0 percent of all truck accidents. The severity of accidents involving trucks in work zones was higher than statewide truck accidents. The percentage of injury or fatal accidents was about 29 percent for work zone accidents compared with 19 percent for all truck accidents.

Case Study Locations

As previously noted, 20 case study locations were selected from a wide range of projects. Even though the types of projects varied considerably, most traffic control operations were categorized as either single-lane closures on multilane roadways (eight projects) or two-lane, two-way operations (five projects). Two of the eight projects involving single-lane closures also included multilane closures on multilane roadways. There were three bridge construction projects with two-lane detours, and four projects involving two-lane roadway reconstruction, which necessitated diversion of the traffic from old to new sections of road and then back to the old sections at various times in the project. Two of the four projects involving two-lane reconstruction also included single-lane closures

with the use of temporary traffic signals. The project beginning and ending dates showed that work was accomplished between July 1985 and July 1988.

Additional information relating to maintaining and controlling traffic was obtained. The contract bid proposals showed that maintenance and control of traffic was bid as a lump sum item on all contracts with incidental traffic control devices also included for several projects. Incidental traffic control devices bid separately in the various contracts included flashing arrows, pavement markings, temporary traffic lights, temporary guardrail, concrete barrier walls, variable message signs, and tubular separation devices.

The analysis of accidents at case study locations included the review and summary of accidents for 3 years before construction and the time period during construction. An effort was also made to extend the appropriate roadway section length to include accidents in the advance warning area. This made it necessary to extend the project limits 1 mi in each direction for the purpose of accident data collection.

One of the basic means of evaluating the overall effectiveness of traffic control at a work site is to compare accident statistics for some period before the work begins with a similar period during the work activity. The periods of analyses were 3 years before and during the construction work. In some cases, the time period of work zone activity was greater than 1 year, hence, the before period of analysis was limited to three complete years of before data. Table 9 presents a summary of accident rates for each of the case study locations.

Accident rates for the 19 case study locations (data were not available for CR-5001 in Harrison County), as presented in Table 9, vary from 35 accidents per 100 million vehicle miles (acc/100 mvm) at Location 15 (Audubon Parkway in Henderson County) to 1,603 acc/100 mvm at Location 11 (KY-1974 in Fayette County). Table 9 also presents statewide average and critical accident rates for each highway type, which were determined previously (4). In general, the critical rate

TABLE 7 ACCIDENT SEVERITY VERSUS SEVERAL VARIABLES

VARIABLE	CATEGORY	PERCENT FATAL OR SERIOUS INJURY	PERCENT INJURY OR FATAL ACCIDENTS	SEVERITY INDEX
Type of Work Zone	Construction	8.2	29.4	2.25
	Maintenance	6.4	30.0	2.13
	Utility	3.2	29.0	1.92
Location in Work Zone	Advance Warning	8.8	37.2	2.46
	Transition	6.3	22.6	1.94
	Work Area	8.2	31.5	2.28
Type of Accident	Intersection	4.0	17.7	1.68
	Road Section or Mid-Block	7.7	29.7	2.21
	Rear End	6.0	30.4	2.12
	Head On	31.3	61.2	4.47
	Same Direction Sideswipe	2.8	10.5	1.43
	Opposite Direction Sideswipe	6.2	26.2	2.02
	Enter or Leave Entrance	2.0	18.0	1.57
	Pedestrian	66.7	100.0	7.50
	Fixed Object	12.0	44.4	2.83
	Collision-Not Fixed Object	6.8	22.9	1.98
	Single Vehicle-Run Off Road	15.0	55.4	3.29
	Overtuned in Roadway	11.8	70.6	3.47
	Vehicle Backing	0.0	8.3	1.21
	Bridge Related	8.7	30.4	2.22
	Interchange Ramp	8.9	28.9	2.26
Miscellaneous	0.0	0.0	1.00	
Vehicle Type	Truck Involved	8.7	28.9	2.25
	Truck Not Involved	6.5	28.1	2.10
Light Condition	Daylight	6.2	25.3	2.00
	Dawn-Dusk	11.5	37.7	2.63
	Darkness-Lighted	5.3	24.4	1.93
	Darkness-No Lights	12.0	43.8	2.82
Land Use	Rural	9.8	35.2	2.47
	Business	2.6	20.6	1.67
	Residential	6.7	21.8	1.95
Year	1983	7.8	28.1	2.17
	1984	8.3	30.3	2.26
	1985	5.3	27.8	2.01
	1986	6.9	26.7	2.08

TABLE 8 ACCIDENTS BY LOCATION IN WORK ZONE

LOCATION IN WORK ZONE	NUMBER OF ACCIDENTS	PERCENT OF TOTAL	PERCENT OF KNOWN
Advance Warning	113	5.6	8.3
Transition	159	7.9	11.7
Work Area	1,089	54.1	80.0
Unknown	652	32.4	-

TABLE 9 ACCIDENT RATES FOR CASE STUDY LOCATIONS COMPARED TO STATEWIDE AVERAGE AND CRITICAL RATES

LOCATION NUMBER	ROUTE	COUNTY	HIGHWAY TYPE	ACCIDENT RATES (ACC/100 MVM)				PERCENT CHANGE BEFORE-DURING
				BEFORE	DURING	STATEWIDE AVERAGE	STATEWIDE CRITICAL	
1.	I65	Hardin	Rural, Interstate	48	56	69	84	16.6
2.	I65	Hardin	Rural, Interstate	94	99	69	81	5.3
3.	I75	Whitley Laurel Rockcastle	Rural, Interstate	50	66	69	74	32.0
4.	Nt. Pkwy.	Clark Powell	Parkway	68	88	78	96	29.4
5.	CR 5001	Harrison	Rural, Two-Lane	-	-	-	-	-
6.	US 31E	Nelson	Rural, Two-Lane	249	470	302	428	88.8
7.	US 27	McCreary	Rural, Two-Lane	220	76	302	401	-65.5
8.	US 42	Boone Gallatin	Rural, Two-Lane	527	1322	302	613	150.9
9.	KY 90	Metcalfe	Rural, Two-Lane	186	284	302	397	52.7
10.	KY 90	Barren	Rural, Two-Lane	131	97	302	351	-26.0
11.	KY 1974	Fayette	Urban, Undivided Four-Lane	946	1603	802	963	69.5
12.	US 27	Harrison	Rural, Two-Lane	146	211	302	422	44.5
13.	KY 80	Floyd	Rural, Divided Four Lane	370	542	166	215	46.5
14.	Nt. Pkwy.	Powell	Parkway	83	105	78	105	26.5
15.	Adbn Pkwy.	Henderson	Parkway	50	36	78	118	-28.0
16.	WK Pkwy.	Ohio	Parkway	74	137	78	115	85.1
17.	I75	Scott	Rural, Interstate	44	73	69	88	66.0
18.	I75	Whitley Laurel	Rural, Interstate	59	56	69	82	-5.1
19.	WK Pkwy.	Muhlenburg Ohio	Parkway	76	117	78	97	54.0
20.	BG Pkwy.	Nelson Washington	Parkway	87	66	78	115	-24.1

for a highway type is calculated using statistical tests to determine whether the accident rate for a specific class of highway is abnormally high compared with a predetermined average for highways with similar characteristics. For the types of highways included as case study locations, the statewide average rates ranged from 69 acc/100 mvm for rural Interstates to 802 acc/100 mvm for four-lane, undivided roads in urban areas. Critical rates ranged from 74 acc/100 mvm for a section of I-75 in Whitley and Laurel counties to 963 acc/100 mvm for KY-1974 (Tates Creek Road) in Fayette County.

At 14 of the 19 case study locations where accident rates were calculated, rates were less for the 3-year before period than during the time of construction. The five locations where rates were greater before than during construction included

1. Location 7, US-27 in McCreary County,
2. Location 10, KY-90 in Barren County,
3. Location 15, Audubon Parkway in Henderson County,
4. Location 18, I-75 in Whitley and Laurel counties, and

5. Location 20, Bluegrass Parkway in Nelson and Washington counties.

There were not large differences when before rates exceeded during rates except at the site on US-27 in McCreary County. Here, the accident rate before construction was 220 acc/100 mvm as compared with 76 acc/100 mvm during construction. The project covered 3.8 mi and the average number of accidents in the before period was 11/year compared with 5/year during construction. This project was the only location of the five where numbers of accidents before were much greater than during construction. Of the five locations where before rates exceeded during rates, only the Bluegrass Parkway site had rates greater than the statewide average. However, the rate at the Bluegrass Parkway site was less than the statewide critical rate for parkways. Numbers of accidents were tabulated for total days of construction, which in some cases exceeded a complete year.

Of 14 locations where accident rates during construction exceeded those before construction, 10 had rates during construction that exceeded statewide averages for their respective highway type. In addition, 6 of the 14 locations had rates during construction that exceeded statewide critical rates. Of those 10 locations where rates during construction exceeded statewide averages, there were also five sites where rates before construction exceeded statewide averages. This indicates that there were some problems at these locations before construction began. In addition, there were two locations (I-65 in Hardin County and KY-80 in Floyd County) where the accident rate before construction also exceeded the critical accident rate for similar highway types. Part of the accident problem at the I-65 location could have been related to construction activity that apparently took place during the before period of analysis. In the before period, there were 29 construction-related accidents (average of 10 per year) as compared with 9 during the period of construction.

Only four case study locations had accident rates during construction that exceeded the statewide critical rate and the comparable before period that did not exceed the statewide critical rate. These locations were

1. Location 6, US-31E in Nelson County,
2. Location 8, US-42 in Boone and Gallitin counties,
3. Location 11, KY-1974 in Fayette County, and
4. Location 19, Western Kentucky Parkway in Muhlenburg and Ohio counties.

At Locations 6 and 8, there were no work zone accidents in either the before or during periods of analysis. Problems thus related to factors other than construction activity. However, at Location 11 (KY-1974 in Fayette County), there were 10 construction-related accidents identified from a total of 102 accidents during the construction period. This location was the only urban site among the 20 locations and most of the accidents were related to congestion. At Location 19 (Western Kentucky Parkway in Ohio County), 9 of 34 accidents were identified as construction-related during the construction period. In both cases, there were no construction-related accidents during the before period.

Additional analyses were performed with emphasis on accidents related to work zones. Those accidents with road under construction listed as a contributing factor were tabulated for each case study location. Most work zone accidents occurred during the day when road surfaces were dry. There were 69 property damage accidents, 37 injury accidents, and 1 fatal accident. Total vehicles involved were 180, which means that most collisions involved multiple vehicles. Of the 99 work zone accidents, 78 (79 percent) occurred on sections of the road categorized as straight and level or straight and grade. Of the 180 vehicles involved in 99 accidents, 131 were cars and 32 were trucks.

The analysis of types of accidents showed that the most frequently occurring were sideswipes and rear-end collisions. There were also a large number of collisions with fixed or nonfixed objects. Driver inattention was the most frequently listed contributing factor, followed by failure to yield right-of-way and following too close.

Previously discussed were case study locations where accident rates during construction exceeded the statewide critical accident rate. Location 11 (KY-1974 in Fayette County) and

Location 19 (Western Kentucky Parkway in Ohio County) were cited as possible problem locations because of the relatively large number and high rate of work zone accidents. KY-1974 in Fayette County is in an urban area with high volumes of traffic and the types of accidents are representative of that type of congested area (rear end collisions, sideswipes, vehicles leaving private drive). Somewhat in contrast is the location on the Western Kentucky Parkway, which is representative of a low-volume, rural road. Most work zone accidents at this location were run off road, or collisions with an object.

Traffic control at the work zone was documented for 18 of the 20 sites. Signs and markings appeared to be in general conformance with the *Manual on Uniform Traffic Control Devices* (MUTCD) and the Kentucky Department of Highways' Standard Drawings. Results from the field inspections included (a) a list of signs and devices used, (b) photographs showing the sequence of control devices approaching the projects, and (c) applicable standard drawings or figures from the MUTCD as referenced in the project traffic control plan.

The most common type of project included in this analysis was the single-lane closure on a multilane roadway (Locations 3, 4, 11, 18, 19, and 20). An example of this type of operation was the spot pavement replacement and joint sealing projects on I-75 in Whitley and Laurel counties (Location 3).

Another type of traffic control operation that was used on the two I-65 projects in Hardin County (Locations 1 and 2) was multilane closures on a multilane roadway. These two projects were a combination of single-lane and multiple-lane closures. Less frequently used, but requiring considerable attention in terms of traffic control, is the two-lane, two-way operation (TLTWO). Included as case study locations were five of this type (Locations 13, 14, 15, 16, and 17). A wide range of devices was used to separate the two directions of traffic flow at the locations inspected. At a culvert failure repair site on KY-80 in Floyd County (Location 13), metal drums were used as channelizing devices and a concrete barrier as the separation device. At the interchange reconstruction project on Mountain Parkway in Powell County (Location 14), Type II barricades were used as channelizing devices and a concrete barrier was used for separation. Flexible tubular markers were used as separation devices in conjunction with metal drums for channelization at Location 15 (Audubon Parkway in Henderson County) and Location 16 (Western Kentucky Parkway in Ohio County). A unique procedure for a TLTWO project was used on I-75 in Scott County (Location 1). Because two interchanges were being reconstructed near the Toyota development, it was necessary to close one direction of I-75 when the bridge overpasses had to be rebuilt. A decision was made to perform the work during daylight hours and use traffic cones as channelization and separation devices. When work on the bridge required closure of both lanes in one direction on I-75, the cones were set and removed during the same day. Over a 4-month period at one of the interchanges, TLTWO was put in place in 22 days.

Another type of traffic control used on projects evaluated in this study was a two-lane detour. There were three bridge construction projects on two-lane roads that used detours as traffic control (Locations 5, 6, and 8).

The last major type of traffic control evaluated was single-lane closures and traffic diversion on two-lane roadways (Locations 7, 9, 10, and 12). A variety of traffic control

strategies were required to accommodate the necessary lane closures and detours on these projects. This location was somewhat unique in that temporary traffic signals were used at lane closures over bridges.

SUMMARY OF RESULTS AND CONCLUSIONS

That numbers and rates of accidents increase in work zones has been assumed. This may be the case under some conditions; however, there appears to be indications that efforts to create safer work zones have been successful in recent years. Even though the level of construction and maintenance activity is higher and traffic volumes have increased, there have not been significant increases in work zone accidents.

The following is a list of conclusions reached from the analysis of work zone accidents for the period 1983 through 1986:

1. The number of accidents coded on police reports as occurring in work zones has remained at approximately 500/year.

2. Most work zone accidents occur on Interstate routes, which apparently have increased levels of maintenance and construction activity and higher traffic volumes.

3. Work zone accidents are more severe than other accidents. Those types involved water pooling and shoulder-dropoff accidents. Additional analyses showed that accidents during darkness and those involving trucks were more severe. Also more severe were those accidents occurring in the advance warning area.

4. The percentage of work zone accidents involving rear end or same-direction sideswipe was almost three times the statewide percentages.

5. The greatest difference in contributing factors, as recorded by the investigating officers, compared with statewide accidents was the higher percentage of work zone accidents with following too close as a contributing factor.

6. A separate analysis of factors contributing to work zone accidents revealed congestion as the most common factor. Other frequently occurring factors were struck or avoiding construction equipment, material such as gravel or oil on roadway, related to flagger, and vehicle merging too late.

7. In the 4-year period of analysis, there were 18 accidents and two fatalities involving a pedestrian or construction worker.

8. There was a high percentage of accidents in work zones involving trucks (25.7 percent) as compared with all accidents (9.6 percent).

The second phase of the study involved evaluation of traffic control and accident analysis at 20 case study locations. The following is a summary of results and conclusions from the analysis of case study locations:

1. The 20 case study work zone sites were categorized as single-lane closures on multilane roadways (6 sites), multilane closures on multilane roadways (2 sites), two-lane, two-way operations (5 sites), two-lane detours (3 sites), and single-lane closures and route diversions (4 sites).

2. For all 20 projects, traffic control was bid as a lump sum item with several projects also having bids for incidental traffic control devices.

3. Accident analyses included a 3-year period before construction and the time period during construction.

4. Accident rates during construction were calculated and varied from 36 acc/100 mvm on the Audubon Parkway in Henderson County to 1,603 acc/100 mvm on KY-1974 in Fayette County.

5. At 14 of the 19 locations where accident rates were calculated, rates during construction exceeded those in the before period.

6. Of the five locations where before rates exceeded during rates, only Location 20 on the Bluegrass Parkway had rates greater than the statewide average.

7. When analyzing the 14 locations where accident rates during construction exceeded those before construction, 10 had rates during construction that exceeded statewide averages for their respective highway type. In addition, 6 of the 14 locations had rates during construction that exceeded statewide critical rates.

8. Only four case study locations had accident rates during construction that exceeded the statewide critical rate and the before period that did not exceed the statewide critical rate. At two of these locations, there were no work zone accidents, which indicates problems other than construction activity.

9. Numbers and rates of accidents at two locations (KY-1974 in Fayette County and Western Kentucky Parkway in Ohio County) indicated possible work zone problems; however, the traffic control appeared to be standard in both cases.

10. Analysis by accident type showed that the most frequently occurring were sideswipes and rear end collisions.

11. Contributing factors most frequently listed were driver inattention, failure to yield right-of-way, and following too close.

12. Documentation of traffic control at 18 of the 20 locations revealed general conformance with the MUTCD and the Kentucky Department of Highways' Standard Drawings.

13. TLTWOs were used successfully at five case study locations. Of particular interest were the three types of devices (concrete barrier, traffic cones, and flexible tubular markers) used to separate opposite directions of traffic flow.

REFERENCES

1. J. L. Graham, R. J. Paulson, and J. C. Glennon. Accident Analyses of Highway Construction Zones. In *Transportation Research Record 693*, TRB, National Research Council, Washington, D.C., 1978.
2. J. J. Wang and C. M. Abrams. *Planning and Scheduling Work Zone Traffic Control—Technical Report*. Report No. FHWA/RD-81/049. FHWA, U.S. Department of Transportation, 1981.
3. Z. A. Nemeth and D. J. Migletz. Accidents Characteristics Before, During, and After Safety Upgrading Projects on Ohio's Rural Interstate System. In *Transportation Research Record 672*, TRB, National Research Council, Washington, D.C., 1978.
4. K. R. Agent and J. G. Pigman. Analysis of Accident Data in Kentucky (1982–1986). Report UKTRP-87-23. Transportation Research Program, University of Kentucky, Lexington, 1987.
5. J. D. Crabtree and K. R. Agent. Accident Rates by Vehicle Type. Report UKTRP-82-12. Transportation Research Program, University of Kentucky, Lexington, 1982.