Truck Drivers' Concerns in Work Zones: Travel Characteristics and Accident Experiences

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A study was conducted to determine truck drivers' concerns about traffic control in work zones (WZ) and to identify the locations of accidents and risky driving situations. A statewide opinion survey of 930 semitrailer drivers was conducted. The survey contained questions about driver/vehicle characteristics, assessment of WZ traffic control devices, accident and difficult driving situations, and suggestions for improving traffic flow and safety in WZ. The findings on travel characteristics and accident experiences of the truck drivers are discussed. About 90 percent of truck drivers consider traveling through WZ to be more hazardous than nonwork zone areas. About half of them want to see an advance warning sign 5 to 8 kilometers (3 to 5 mi) ahead of WZ. The drivers do not have a clear preference between one-lane closure and median crossover configurations. About two-thirds of them think the speed limit of 89 km/hr (55 mi/hr) is about right, but one-fourth believe it is too fast. Nearly half of them would exceed a speed limit of 72 km/hr (45 mi/hr), and nearly one-fifth would drive at least 8 km/hr (5 mi/hr) faster than the speed limit. About one-third said the flaggers are hard to see, and about half said that directions given by flaggers were confusing sometimes or most of the time. About three-fourths of the drivers indicated that the arrow boards were too bright. For most of the drivers, WZ signs are clear and not confusing, but 14 percent disagreed. About one-fifth of the truck drivers said some signs should be added to the work zones. A relatively small percentage of truck drivers (6.1 percent) said they had accidents in WZ. About one-third of the accidents were in the advance warning area, and about two-thirds were in the transition area. The accident experiences were significantly related to the experience of bad driving situations but not other driver/truck characteristics.

In 1992, there were 9,949 crashes in Illinois work zones: 29 were fatal and 2,422 were injury crashes (*1*). In the past several years, the number of injury and total crashes has steadily increased while the number of fatal accidents has fluctuated from year to year. The exact number of accidents per vehicle miles traveled (VMT) in work zones is not as well known for trucks as it is for cars. In 1992, over all highway types, the fatal accident rate of semitrailers in Illinois (accidents per million VMT) was 2.28, but for all other vehicles it was 1.54. The fatal accident rate of semi-trucks was 1.48 times higher than that of the other vehicles. On the other hand, the ratio for total crashes was 0.74 and for injury crashes it was 0.37. The ratios indicate that, in terms of VMT, semitrailers are underrepresented in the total and injury crashes but are overrepresented in fatal crashes. Accurate data are not readily available to compute the ratios for work zones, but it is reasonable to assume that work zone accidents would include a similar trend. Considering that the average annual miles traveled by trucks are about 10 times that of cars, reducing the frequency as well as the severity of truck accidents would improve work zone safety for all motorists.

Accident records are very helpful in evaluating past performances, but they contain very little information about the emerging problems, those that are not reflected in the accident records yet, and problems that are not directly represented in the accident record (such as "near miss" accidents). Furthermore, the locations of the accidents in work zones are not accurately coded in most of the accident files, so an in-depth work zone accident study has not been conducted. There are a limited number of studies about the location of accidents in work zones, but these studies did not identify where the emerging problems, near-miss-type accidents, or difficult driving situations take place in work zones. The term "bad driving situation" was used to describe situations where truck drivers were exposed to a higher risk of accident such as near-miss situation, difficult driving situations, or situations that a corrective action was needed to avoid an accident. During the pretesting of the survey form, it was realized that truck drivers were using this term to describe the higher risk situations.

This study was conducted to determine the truck drivers' concerns about work zone traffic control and to identify the location of accidents and bad driving situations based on the experience and perception of truck drivers. A statewide survey of 930 semi-truck drivers was conducted. The survey contained questions about driver/vehicle characteristics, assessment of work zone traffic control devices, accident and difficult driving experiences, and suggestions for improving traffic flow and safety in the work zones.

This paper discusses travel characteristics of truck drivers and their relationship to accident experiences of the drivers. It does not include the findings of the survey pertinent to experiences of bad driving situations and their relationship to the travel characteristics.

Truck Accidents

Trucks are involved in a relatively small share of all vehicle accidents, but in a higher share of all fatal accidents. For example, in Illinois, only 16.4 percent of the tractor-trailer crashes took place in rural locations, but they accounted for 52.2 percent of the fatalities in 1992 (*1*). About 84 percent of the persons killed in tractor-trailer accidents were occupants of other types of vehicles.

Based on the VMT, overall truck accidents are underrepresented when compared with accidents of other vehicles. In 1986, the passenger-car accident rate was about 2.21 times higher than combination-truck accident rates in the United States (*2*). However, the combination-truck fatal accident rate was 1.75 times higher than the passenger-car fatal accident rate. Accident involvement rate may

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vary by several factors. For example, Meyers (*3*) compared truck and passenger-car accident rates on limited-access facilities. He found that the overall expressway accident rates for heavy trucks exceeded that for passenger cars by 58 percent. For the bridges and tunnels, overall accident rates for heavy trucks were four times greater than that for the average passenger car.

McGee (*4*) suggested that the key variables that influence truck safety might include truck type, truck length, truck trailer type, truck weight, driver type, driver age, and highway type. Garber and Joshua (*5*) found that the driver-related factors (such as error, speed, handicap, and alcohol) were mostly responsible for large-truck crashes: 75 percent of all large-truck crashes and 91 percent of large-truck fatal crashes on Virginia highways. Driver error was associated with over 50 percent of large-truck fatal accidents, and speeding accounted for 21 percent of these accidents.

Lyles et al. (*6*) reported that the most significant factor associated with truck accidents was the roadway class. Urban accident rates were lower than rural rates, and younger drivers were involved in more accidents than the average.

Hall and Lorenz (*7*) found that the number and rate of accidents increased during construction. The accident rate during construction increased 33 percent on the rural interstate highways in New Mexico compared with before construction.

Nemeth and Rathi (*8*) studied Ohio Turnpike work zone accident characteristics. They found that there was a high accident rate at crossovers, especially at night. Truck accidents constituted 75 percent of the total accidents at crossovers, while truck accidents at other work zone areas made up 52 percent of the total accidents, indicating that the driving task was more demanding here than at other work zones or on highways in general.

STUDY APPROACH

The overall study approach was to develop a questionnaire, conduct a state-wide survey of semi-truck drivers, perform statistical analyses to examine the relationships among responses, and interpret the findings of the study.

Survey Instrument

A survey instrument was developed in collaboration with the Illinois Department of Transportation (IDOT). The questionnaire contained over 40 questions about driver and vehicle characteristics, drivers' assessment of work zones and the traffic control devices, their accident and difficult driving experiences, and their suggestions for improving traffic flow and safety in the work zones. The main questions asked in the survey are listed in Table 1.

Pretesting

A formal pretest of the survey was conducted using about 100 truck drivers. The data collection procedures for the pretest followed, as closely as possible, those planned for the main survey to provide a

TABLE 1 Survey Items in Questionnaire

(1) Driving experience (in years)
(2) VMT during last year in U.S.
(3) VMT during last year in Illinois
(4) Driver age
(5) Type of current truck
(6) Type of current carrier
(7) Number of trucks in current carrier
(8) Preferred time of day to drive
(9) Type of permits for current truck
(10) Preferred distance of advance signs about work zones (miles)
(11) Perceived hazard of driving through work zones compared with nonwork zones
(12) Preferred type of work zones: median crossover versus one-lane closure
(13) Nine items about driving situations and work zone conditions
(14) Opinion about speed limit of 89 km/hr in work zones
(15) Actual speed in work zones with 72 km/hr speed limit
(16) Locations the driver experienced BDS in work zones
(17) Locations of accidents in work zones
(18) Visibility of flaggers
(19) Directions given by flaggers
(20) Seven items about traffic control devices
(21) Height of arrow boards
(22) Brightness of arrow boards
(23) Height of CMB
(24) Brightness of CMB
(25) Unclear or confusing signs in Illinois work zones (if any, specify)
(26) Need for more signs or messages in work zones (if any, specify)
(27) Driving in Illinois work zone(s) today
(28) Suggestions and comments

Note: 1 km = 0.6 mi.

thorough test of the survey procedures and questionnaire. The returned questionnaires were closely examined to determine if there were any unforeseen problems. Their input was used for minor revisions and clarification of the questions or responses.

Data Collection

The main surveys were conducted from 9:00 a.m. to 5:00 p.m. on weekdays in September and October of 1993. The purpose of the survey was also explained to the drivers, and they were assured that their responses would not affect their personal driving records. The survey questionnaires were handed to the truck drivers (excluding pickups) and were collected after they were completed. The data were collected mainly at truck stops and some at rest areas. The data were collected at several locations in Illinois. Approximately one out of every four drivers refused to answer the questionnaire. There was not a common characteristic among those who refused to participate; thus they would not cause a bias in this study. It seemed that these drivers were tired or were in a hurry. In general, the response rates at rest areas were lower than those at truck stops. A total of 930 truck drivers participated in the survey.

The data collection sites were selected such that near every data collection site there was at least one construction zone. Data were collected in the areas of Bloomington (I-55 and I-74), Danville (I-74), Joliet (I-55 and I-80), Springfield (I-55 and I-72), and Peoria (I-74) in Illinois. These locations were spread over Illinois and are expected to represent a good cross section of the truck drivers on the road. Almost all of the surveyed drivers (94 percent) had driven through construction zone(s) the day of the survey.

The responses were coded and checked for completeness, accuracy, and consistency. Incomplete and inconsistent questionnaires were removed from the data set. Out of 930 surveys, 834 surveys were found suitable for further data analysis.

Data Analysis

Data analysis is discussed in two sections. The first section, Travel Characteristics of Truck Drivers, discusses the frequency distribution of the responses. The second section, Accident Experience Versus Travel Characteristics, discusses the statistical analyses of accident experiences of the drivers. The analyses are conducted for the entire work zone (overall) as well as for the advance warning area (AWA), transition area (TRA), buffer space (BFS), work space (WKS), and termination area (TEA).

Different statistical tests were used, based on the distribution characteristics of the responses, for each question, as well as on the number of groups to be compared. For continuous variables, the analysis of variance (ANOVA) was applied, and for the discrete variables, comparisons were made using χ^2 goodness-of-fit tests. All statistical tests were performed, unless otherwise stated, with a 90 percent confidence level.

Statistical Analysis

The general linear model (GLM) procedure in SAS was used for ANOVA because of unbalanced situations (*9*). An unbalanced situation is when there is an unequal number of observations for different combinations of class variables, which is the case in this survey. In this situation, SAS recommends to use the GLM procedure instead of the ANOVA procedure. For continuous variables, the GLM results will indicate whether the average values for all groups are the same or whether there are at least two groups with different mean values. The authors looked at F values in the GLM output to make such judgments. If F values indicated that they were significantly different, the authors examined the results of Duncan's Multiple Range test to identify which groups are different. In the case of two groups, the t-test also can be used to determine the mean difference of two groups.

For the discrete variables, χ^2 goodness-of-fit tests were used. Drivers were grouped into two categories: those who had accident experiences in the work zones and those who did not. Each group was further divided into various travel characteristic subgroups. The test was used to determine if certain drivers were over- or under-represented. These tests would reveal whether an unexpected number of drivers have certain characteristics.

TRAVEL CHARACTERISTICS OF TRUCK DRIVERS

The responses to various questions are summarized in Table 2 and are discussed in the following sections.

Experience and Age

The average age of the truck drivers who responded was 43, and the ages ranged from 20 to 68. Approximately two-thirds of the sample were within the range from 30 to 50 years old. Drivers 61 years and older represented 2.5 percent, and drivers under 25 represented 4.3 percent of the sample. There was a relatively strong correlation between the driver's age and his or her driving experience. Driving experience varied from 0 to 48 years with an average value of 16.1 years. About 10 percent of the drivers had 30 or more years of experience and about 8 percent of the drivers had 2 years or less of driving experience.

Miles Driven

The truck drivers were asked to indicate the total number of miles they drove last year and what portion of that was in Illinois. To increase the accuracy, only those drivers with 1 full year of driving experience were considered in the analysis. The average total kilometers driven was 180,320 (112,000 mi), and the range was from 0 to 466,900 km (0 to 290,000 mi). About 52 percent of them drove between 144,900 and 209,300 km (90,000 and 130,000 mi). About 8 percent of the sample drove less than 80,500 km (50,000 mi), and about 4 percent drove 322,000 km (200,000 mi) or more per year. Values higher than 466,900 km (290,000 mi) were deleted from the analysis because driving more than 466,900 km (290,000 mi) in 1 year appears to be unreasonable.

The drivers response to the miles driven just in Illinois indicated that the average was 40,250 km (25,000 mi) and the range was from 0 to 402,500 km (0 to 250,000 mi). About 36 percent of drivers said it was in the range of 0 to 16,100 km (0 to 10,000 mi). It was found that there is no relationship between the miles driven in the United States and those in Illinois.

TABLE 2 Frequencies of Responses to Travel Characteristics Questions

Items	Proportion			
Type of Carrier	Common (62%)	Contract (18%)	Private (12%)	Others (8%)
Driving Hours	All Hours (88%)	Daytime (10%)	Nighttime (2%)	-
Permit	No (79%)	Hazardous (15%)	Over-dimension (5%)	Combination (1%)
Advance Sign	5-8 km (47%)	2-3 km (34%)	10-16 km (14%)	Others (5%)
Hazard Assessment	More Hazard (90%)	Less Hazard (1%)	Same (8%)	Do not Know (1%)
Type of Work Zone	Median Crossover (36%)	One-Lane Closure (33%)	No Preference (29%)	No Opinion (2%)
Speed Limit of 89 km/hr	About right (62%)	Too Fast (25%)	Too Slow (9%)	No Opinion (4%)
Drive at 72 km/hr Speed Limit	74-81 km/hr (34%)	At 72 km/hr (30%)	< 72 km/hr (19%)	> 81 km/hr (17%)
Visibility of Flagger	OK (44%)	Hard to See (32%)	Very Visible (19%)	No Opinion (5%)
Direction by Flagger	Clear (46%)	Sometimes Confusing (37%)	Most Times Confusing (12%)	No Opinion (5%)
Height of Arrow Board	OK (76%)	Too High (15%)	Too low (5%)	No Opinion (4%)
Brightness of Arrow Board	Too Bright (76%)	OK (22%)	Not Bright Enough (1%)	No Opinion (1%)
Height of Changing Message Board	OK (86%)	Too Low (5%)	Too High (4%)	No Opinion (5%)
Brightness of Changing Message Board	OK (72%)	Too Bright (18%)	Not Bright Enough (7%)	No opinion (3%)
Unclear/Confusing Signs	No (86%)	Yes (14%)	-	-

Note: 1 km = 0.6 mi.

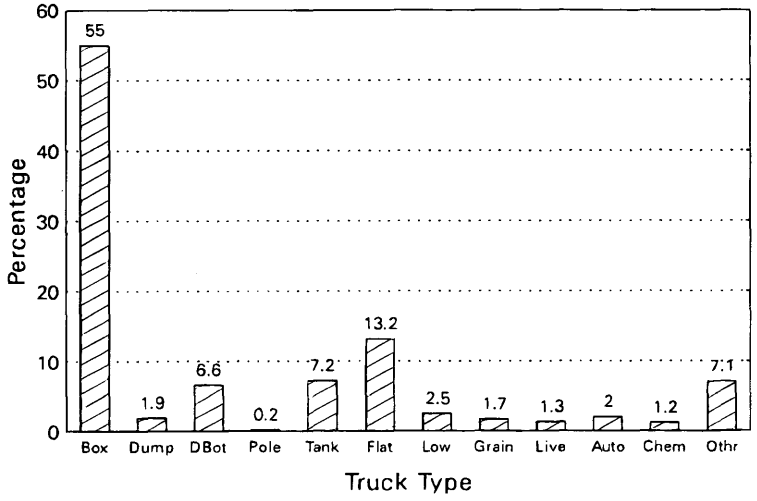
Trucks and Carrier Types

The drivers were asked to indicate what type of trucks they were driving. Figure 1 shows that a box van was the most cited (55 percent) type of truck, followed by a flatbed/platform (13 percent), tanker/hopper (7 percent), and double-bottom (7 percent). Common carrier was the largest carrier type (62 percent) that drivers worked for, followed by contract (18 percent), private (12 percent), and others (8 percent). The average number of trucks per company was approximately 930 trucks, and the range was from 1 to 25,000 trucks. The survey included drivers working for the small as well as large companies. For example, about 12 percent and 22 percent of the drivers responded that their companies have 10 or fewer and 20 or fewer trucks, respectively.

Travel Time and Load Permit

About 88 percent of the drivers answered that they had driven their trucks all hours, which is somehow expected due to the needs of their profession (i.e., schedules, nature of loads). About 10 percent of the drivers responded that they usually drive during the day, and only 2 percent usually drive at night.

Drivers were asked if they were carrying any type of permit at the survey time. About 79 percent responded that they were not holding any type of permit. Among permit types, hazardous-materials-related permits had the highest frequency (15 percent), followed by over-dimension-related permits (5 percent), and both hazardous-materials and over-dimension-related permits (1 percent).



Note: Box(box van), Dump(dump), DBot(double bottom), Pole(pole) Tank(tanker/hopper), Flat(flatbed/platform), Low(lowboy), Grain(grain) Live(livestock), Auto(auto-transport), Chem(chemical), Othr(others)

FIGURE 1 Frequency of truck type.

Hazard Assessment

Drivers were asked to compare the hazard of driving through work zones to nonwork zones. A large majority of truck drivers (90 percent) answered that work zones are more hazardous than nonwork zone areas. This is very high compared with the findings of a previous study (*10,11*) in which 54 percent of drivers (all drivers, not just truck drivers) responded that the work zones were not more hazardous. In the previous study, only 16 percent of the respondents were driving large trucks compared to this survey, which includes only the drivers of large trucks. This indicates that an educational effort to increase drivers' perception of hazard in the work zones should mainly be directed toward car drivers to increase their perception of hazard in work zones.

Truck drivers not only assess the work zones to be more hazardous, but most of them also want to know far ahead about the presence of work zones. Approximately half of the sample (47 percent) responded that work zone signs should be posted 5 to 8 km (3 to 5 mi) ahead, followed by 2 to 3 km (1 to 2 mi) ahead (34 percent), 10 to 16 km (6 to 10 mi) ahead (14 percent). Only 5 percent answered that signs should be posted less than 2 km (1 mi) or more than 16 km (10 mi) ahead.

Work Zone Layout

Drivers were given sketches of a work zone with one-lane closure and another one with a median crossover and were asked to indicate their preferred configuration. The percentage of those drivers who preferred the median crossover was only slightly higher than that of one-lane closure. About 29 percent of drivers responded that they have no preference. These responses indicate that truck drivers do not have a preferred work zone configuration.

Speed Limit

Drivers were asked about the 89 km/hr (55 mi/hr) speed limit in work zones. About two-thirds (62 percent) answered that such a speed limit is about right; 25 percent said that the 89 km/hr (55 mi/hr) speed limit is too fast; and 8 percent responded that it is too slow. It should be noted that the speed limit in Illinois interstate work zones is 89 km/hr (55 mi/hr), unless a 72 km/hr (45 mi/hr) speed limit is put into effect. When workers are present, regulatory 72 km/hr (45 mi/hr) speed limits are activated by turning on the two yellow strobe lights mounted on the speed limit signs. Drivers were asked to indicate how fast they drive in a work zone with a 72 km/hr (45-mi/hr) speed limit. The highest proportion (34 percent) was found for those driving in the range of 74 to 81 km/hr (46 to 50 mi/hr), followed by those driving at 72 km/hr (45 mi/hr) (30 percent) (see Figure 2). However, relatively high percentages were found in the ranges below 72 km/hr (45 mi/hr) (19 percent) and 82 km/hr (51 mi/hr) and above (17 percent). Thus, in a 72 km/hr (45 mi/hr) speed zone nearly half (49 percent) of the drivers would drive at or below the speed limit, and the other half would exceed it. About 17 percent of the drivers indicated that they would drive at least 8 km/hr (5 mi/hr) faster than the speed limit.

Flagger Visibility and Directions

About 63 percent of the drivers responded that the flagger visibility is either okay or they are very visible. However, 32 percent answered that flaggers are hard to see. The reasons for this could be a driver's inattention, inadequate contrast of a flagger's attire, or the position of flaggers in work zones. The reasons for the inadequate visibility indicated by one-third of the drivers should be determined and appropriate action should be taken to improve flagger visibility.

Drivers were then asked about the clarity of the direction given by flaggers in work zones. Half of truck drivers (49 per-

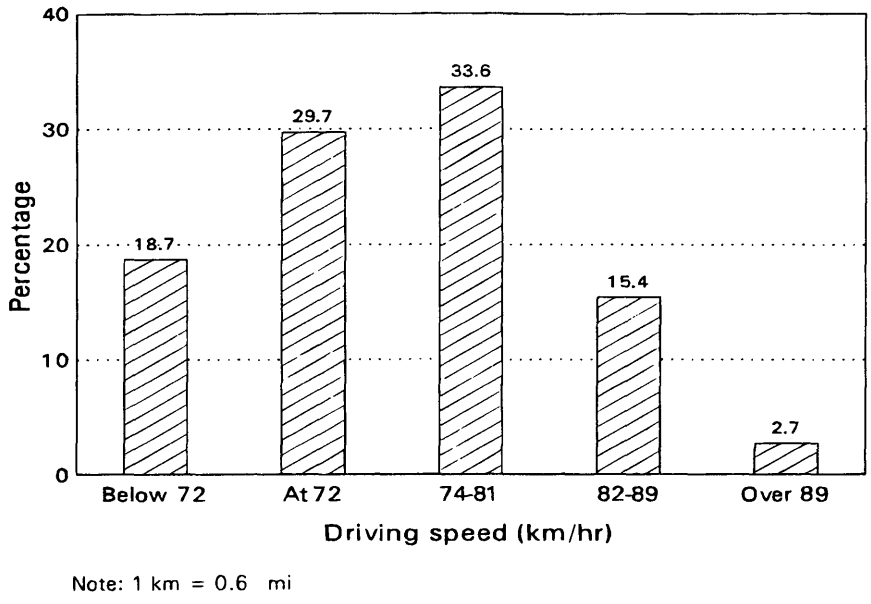


FIGURE 2 Driving speed in work zone with 72 km/hr speed limit.

cent) responded that it was confusing sometimes or most of the time; the other half (46 percent) answered that it is usually clear. Such a high proportion for the flaggers' directions to be confusing surprised the authors because the respondents are professional truck drivers and see a lot of flaggers in work zones. The clarity of the directions given by the flaggers needs to be improved. In a different survey (*10,11*), about 88 percent of the respondents (mostly car drivers) correctly identified the flagger's message from the list of responses. This does not mean that truck drivers do not understand flagger's message; it means that the direction given is not always clear and needs some improvement.

Arrow Board and Changeable Message Board

In the previous study (*10*), some truck drivers complained about brightness and height of arrow boards. In this survey, drivers were specifically asked about brightness and height of arrow board and changeable message boards (CMBs). In general, truck drivers do not have problems with the height of the arrow board, and 76 percent responded that the height is okay. However, 15 percent answered it is too high, and 5 percent replied it is too low.

Drivers seem to indicate that when the arrow boards are at their eye level, the brightness of the board bothers their eyes. About 76 percent responded that the arrow boards are too bright. This shows that truck drivers have a problem with the brightness of the arrow board. Several drivers made comments about the brightness of arrow boards. The brightness concern needs to be examined to increase the effectiveness of arrow boards and/or reduce their disturbing effects. A similar pair of questions were asked about CMBs. Contrary to arrow boards, both the height and brightness of CMBs seem to be well accepted by the truck drivers. About 86 percent and 72 percent responded that the height and the brightness are okay, respectively. Only 18 percent said that CMBs are too bright.

Confusing and Unclear Signs

Drivers were asked to indicate if they think there are any confusing or unclear signs in the work zones. They were also asked to indicate if there is a need to add any more signs to work zones. Most of the truck drivers (86 percent) responded that they did not have any confusing or unclear signs to indicate. However, 14 percent replied that there were confusing and/or unclear signs. About 6 percent, 3 percent, and 2 percent responded that there were confusing, unclear, and both confusing and unclear signs, respectively, in the work zones. The remaining 3 percent replied that there are confusing or unclear signs, but did not specify whether the signs were confusing or unclear.

Comments about confusing and unclear signs were directed toward lane closure, CMBs speed limits, exit ramps, and work zones without actual work. Drivers commented that it is unclear or confusing when a sign states that one lane is closed, but actually the other lane is closed. When a sign states that a lane is closed ahead, drivers want to know which one. Truck-only lanes changing too often also troubled drivers. Some drivers complained that CMBs didn't always work or the messages flashed too fast.

Some drivers stated that speed limit signs in work zones are unclear and confusing. Alternate 72 km/hr (45 mi/hr) and 89 km/hr (55 mi/hr) speeds in work zones also caused problems for drivers. Some drivers find that exits in construction zones are not marked clearly. Drivers found signs posted when there was no work being done confusing and unclear. Drivers also complained about signs that remain after construction is completed, when conditions have changed, and when construction has not yet begun. There were also complaints about 72 km/hr (45 mi/hr) speed zones when no workers are present.

Additional Signs

About 78 percent responded that there is no need to add signs or messages to Illinois work zones. However, 22 percent replied that

some signs should be added. Drivers suggested adding signs about early merging, early notification of work zones, road conditions, construction length, and speed limits. Drivers suggested adding signs to force the car to merge immediately to prevent the last-minute merging. There were also suggestions for putting more merge signs, merge signs accompanied by law enforcement officers, and signs to make drivers aware of trucks trying to merge.

Drivers want to see more signs before the work zones, and they want to see these signs sooner. A few drivers suggested that work zone notification begin 5 to 8 km (3 to 5 mi) before the work zones. Several drivers think merge signs are placed too close to the work zones and there is not enough time to merge. Drivers would also like to see that Lane Closed Ahead signs specify which lane is closed. Some drivers want to see signs displaying the distance to the lane closure. There were also suggestions for no-passing zones when a lane is closed ahead.

Some drivers suggested adding signs for the road conditions of the temporary lane in the work zones such as width, uneven pavement, and shoulder drop-offs. There were also suggestions for notification of what type of work is being performed. Seven drivers want signs stating the length of zone before the zone, and signs within the zone stating the distance left to travel. Drivers recommended signs instructing drivers to slow down in work zones, and some proposed more speed limit signs.

ACCIDENT EXPERIENCE VERSUS TRAVEL CHARACTERISTICS

Locations of the accidents in work zones are not accurately coded in the accident files. Thus, an in-depth work zone accident study has not been possible. This study attempted to find the location of accidents by tapping the experience of truck drivers. Drivers were given a sketch of the work zone and asked to identify the locations where they have experienced accidents. The sketch was divided into five parts: advance warning area, transition area, buffer space, work space, and termination area. The drivers were also asked to indicate how many times they had experienced accidents. Thus, the number of drivers who experienced accidents and the number of accidents were determined for each part of the work zone.

Overall Experience of Accidents in Work Zones

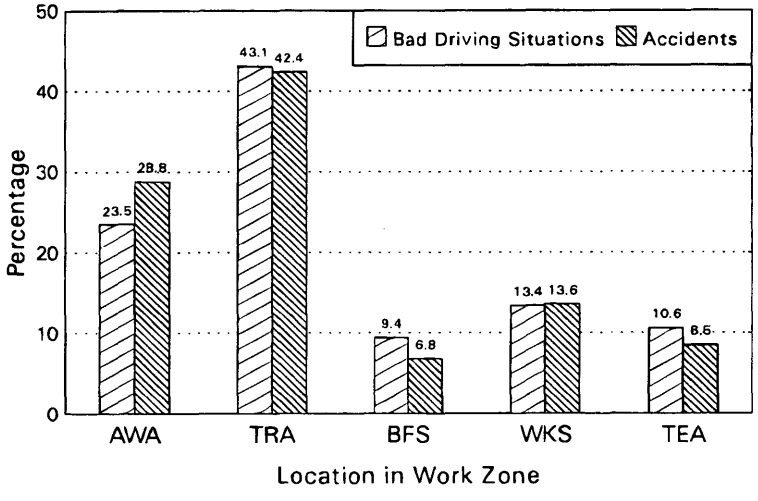
A relatively small percentage of all truck drivers (6.1 percent) said that they have had accidents in one or two locations in work zones. About 1 percent have experienced accidents in two locations, and all of them included either the AWA or the TRA. The accidents were distributed among the five areas, but were mainly in AWA (2 percent) and TRA (3 percent). In the buffer space, 0.5 percent of the respondents have had accidents; in the work space, 1 percent; and in the termination area, 0.6 percent. These numbers may seem small, but actually they are not. For instance, 5 out of every 100 drivers surveyed had accident(s) on the AWA and/or TRA. This is more than twice the number of accidents in the remaining areas of the work zones. The accident experiences support the bad driving experience of the respondents.

Considering the number of accidents, 42 percent of them happened in the TRA, and 29 percent happened in the AWA (see Figure 3). Comments and suggestions of truck drivers revealed that most of the accidents happened between passenger vehicles and trucks mainly due to lane changes and rapid speed reductions. About 14 percent happened in the WKS, 9 percent in the TEA, and only 7 percent in the BFS.

Considering the number of drivers who had accidents and the number of accidents in work zones, work zone improvement should focus on the TRA and the AWA.

Categories of Analyses

To examine the correlations between the experience of bad driving situations (BDS) and/or accidents in work zones and other truck/



Note: AWA(advanced warning area), TRA(transition area), BFS(buffer space), WKS(work space), TEA(termination area)

FIGURE 3 Frequency of bad driving situations and accidents among the number of bad driving situations and accidents.

drivers characteristics, statistical analyses were conducted in the following four categories:

1. Correlation of accidents with travel characteristics,
2. Correlation between accident experience and BDS,
3. Correlation of BDS with travel characteristics, and
4. Correlation of BDS in each work zone areas with travel characteristics.

Categories 1 and 2 are discussed in this paper.

Correlation of Accidents with Travel Characteristics

A small portion of drivers (6.1 percent) indicated that they had one or more accidents in the work zones. For the purpose of the statistical analyses, drivers were grouped into two categories; those who had experienced an accident at any point in a work zone and those who had not. Possible correlations between driver and/or vehicle characteristics and the experience of accident were examined.

ANOVA shows that none of the driving experience, age, and miles driven were related to the accident experience. The summary of χ^2 goodness-of-fit tests is given in Table 3. Detailed accident analysis for each area in the work zones was not possible because of the small number of drivers who had accidents. The χ^2 tests show that accident experience was significantly related to the experience of bad driving situations, but not other driver/truck characteristics. Some trends also emerged indicating relation, though not statistically significant, between accident experience and advance signs, a speed limit of 89 km/hr (55 mi/hr), and unclear/confusing signs. These trends can be characterized as follows: in a group of drivers who had accidents in work zones, those who wanted to know about work zones 3 km (2 mi) or less in advance were overrepresented and 5 to 8 km (3 to 5 mi) in advance were underrepresented; those who mentioned unclear or confusing signs in work zones were overrepresented, and those who think the speed limit of 89 km/hr (55 mi/hr)

TABLE 3 Results of Chi-Square Goodness-of-Fit Tests: Accidents in Work Zones Versus Travel Characteristics

Items	Degree of Freedom	χ^2-value	Prob. for $\geq \chi^2$ Value	Interpretation (With 90% Confidence Level)
type of truck	4	2.395	0.664	Not significant
type of carrier	2	0.904	0.636	Not significant
time of driving	1	0.689	0.406	Not significant
type of permit	2	0.343	0.843	Not significant
location of advance sign	3	5.286	0.152	*Not significant
hazard of work zones	1	0.414	0.520	Not significant
type of work zones	2	0.118	0.943	Not significant
speed limit of 89 km/hr	2	3.359	0.186	Not significant
speed of 72 km/hr zone	4	3.207	0.524	Not Significant
bad driving experience	1	13.097	0.000	Significant
visibility of flagger	2	2.875	0.237	Not significant
direction by flagger	2	2.134	0.344	Not significant
height of arrow board	2	0.703	0.703	Not significant
brightness of arrow board	1	0.000	1.000	Not significant
height of CMB	1	0.011	0.917	Not significant
brightness of CMB	2	3.049	0.218	Not significant
unclear/confusing sign	1	2.559	0.110	*Not significant
addition of sign/message	1	0.512	0.474	Not significant

Notes:

When χ^2 tests were not valid because of the low expected frequencies of cells, grouping of each question was performed.

When the degree of freedom is 1, continuity-adjusted χ^2 values were used.

* May indicate a strong trend although it is not significant.

1 km = 0.6 mi.

in work zones is too fast were underrepresented, and strangely those who said the speed limit is about right were overrepresented.

It should be noted that Table 3 indicates that the drivers' accident experiences were unrelated to most of the other responses. It would be an oversimplification if one concludes from Table 3 that accidents happen regardless of characteristics of drivers, vehicles, and/or geometric of work zones. This oversimplification would not be an accurate statement. Stoke and Simpson (*12*) found that new drivers are more likely to be involved in truck crashes than experienced drivers.

Some relationships between travel characteristics and accidents in work zones revealed interesting results, although the results of the χ^2 test did not indicate these to be statistically significant with a confidence level of 90 percent. It was noticed that more than the expected number of truck drivers who had accidents in work zones responded that they drive double-bottom trucks, they want to find out about work zones far ahead [e.g., 10 to 16 km (6 to 10 mi)], they drive faster than 81 km/hr (50 mi/hr) in work zones with a 72 km/hr (45 mi/hr) speed limit, they think the CMBs are too bright, and they think some signs are unclear/confusing in work zones. On the other hand, more than the expected number of truck drivers who had not had any accidents in the work zones responded that the speed limit of 89 km/hr (55 mi/hr) in work zones is too fast, they drive slower than 81 km/hr (50 mi/hr) in work zones with a 72 km/hr (45 mi/hr) speed limit, they think flagger visibility is okay, but the direction by flaggers is confusing.

In addition to this interpretation, the following may also be interesting findings: type of carrier, time of driving, type of permit, assessment of hazard, preference of a certain type of work zone, height and brightness of arrow boards, and height of CMB were unrelated to accidents in work zones.

Correlation Between Accident Experience and Bad Situations

For statistical analysis purposes, drivers were grouped into two categories: those who had BDS in work zones and those who did not. The drivers in one category were further divided into two subcategories: those who had accidents and those who did not. There was a very close relationship between the experience of bad situations and accidents in work zones. A higher than expected proportion of drivers who had experienced BDS have also had accidents in work zones. Conversely, among the drivers who had accidents in work zones, those with BDS experience were overrepresented.

The synopsis of the relationships between accidents and BDS experiences at different areas of work zones is as follows. Those who have had accidents in work zones have also experienced more bad situations in work zones. Those drivers who had experienced BDS in AWA and TRA also showed a significant correlation to accident experience. Accident experience at WKS was also related to BDS experience and was significant at an 89 percent confidence level. However, buffer space and termination areas did not show a significant relationship between accident and bad driving experience.

CONCLUSIONS AND RECOMMENDATIONS

The findings of this study are based on a survey of 930 truck drivers. Truck drivers indicated that they are aware of the hazard of driving through work zones, and 90 percent of them consider it be more hazardous than driving in nonwork zone areas. This perception is, however, low among car drivers. Truck drivers want to know far ahead about work zones and about half of them want to see a sign 5 to 8 km (3 to 5 mi) ahead. The drivers do not have a clear preference between one lane closure and median crossover configurations. About two-thirds of them think the speed limit of 89 km/hr (55 mi/hr) is about right, but one-fourth think it is too fast. Nearly half of them would exceed a speed limit of 72 km/hr (45 mi/hr), and nearly one-fifth would drive at least 8 km/hr (5 mi/hr) faster than the speed limit. Some drivers have difficulty in seeing flaggers and/or understanding the directions given by them. About one-third responded that the flaggers are hard to see, and about half replied that directions given by flaggers were confusing sometimes or most of the time.

Arrow boards seem to be too bright for most truck drivers. About three-fourths of the drivers indicated that the arrow board was too bright but that the height was okay. For a great minority of truck drivers, some signs were unclear/confusing and additional signs should be placed in the work zones. For most of the drivers, work zone signs are clear and not confusing, but 14 percent disagreed. About one-fifth of the surveyed drivers responded that some signs should be added to the work zones.

A relatively small percentage of truck drivers had accidents in the work zones. About one-third of the accidents happened in AWA and two-thirds in TRA. Efforts to improve traffic safety in work zones should mainly focus on these two locations. Accident experience significantly correlated to the experience of bad driving situations but not other driver/truck characteristics. A higher-than-expected proportion of drivers who experienced BDS also had accidents in work zones. The BDS experience is a good indicator of the problem areas in work zones.

Educational efforts should be initiated to increase driver perception of hazards in work zones. They should mainly be directed toward car drivers to increase their perception of the hazards of driving in work zones. Effectiveness of additional signs to be placed a few miles before the work zones so that drivers can get to the proper lane and avoid late lane changes should be examined. Methods of improving flagger visibility and clarity of direction given should also be explored. The brightness of arrow boards needs to be examined to improve their effectiveness and/or reduce their disturbing effects. Further studies should be conducted to improve signing lane closures, exit ramps, merging, road conditions notification, and speed limits.

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