SPATIAL AND TEMPORAL ANALYSES OF CRASHES AT TWO WORK ZONES WITH DIFFERENT TRAFFIC CONTROL DEVICES: BARRELS AND JERSEY BARRIERS

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ABSTRACT

Work zone safety is one of the highest priorities for traffic engineers. In order to guide the motorists safely and efficiently through the activity areas of work zones, construction types and work procedures must be studied in advance to select and install appropriate traffic control devices. Traffic engineers will benefit in evaluating cost effectiveness of installing certain types of traffic control devices if any relationships can be identified between traffic control devices and work zone crashes. Two case study work zones with different main traffic control devices (barrels and New Jersey barriers) were selected and their crash records were analyzed in detail, along with the five-mile sections both upstream and downstream of the activity areas, using the crash records available from the Utah Department of Transportation. One of the study sites was located on a rural US route and the other on a rural interstate. The former study site used barrels and the latter used concrete Jersey barriers as their main traffic control devices. It was found that the transition area upstream of the activity area was most crash prone than the activity area itself, regardless of the types of main traffic control devices used in the activity areas of the work zones. Inside the activity area, the entry and exit ends were found to be most crash prone at both study sites. Notable differences were not found in the crash occurrence patterns at these study sites.

Key words: Work zone safety, Traffic control device, Crash rate analysis, Crash severity level

INTRODUCTION

Highways in the United States are undergoing maintenance, rehabilitation, and/or reconstruction work due to continual need for upgrades to meet the ever-increasing demand on existing highways. Safety in work zones, for both the motorists and the workers, is one of the top priorities for many state departments of transportation (DOTs). However, the relationship between work zone crashes and traffic control devices and the relationship between highway improvements and reductions in crash occurrence have not been clearly understood.

The Manual of Uniform Traffic Control Devices (MUTCD) discusses four types of temporary traffic control devices related to work zones, including signs (regulatory, warning, and guidance), signals, hand-signaling devices, and channelization devices. (*1*). The MUTCD describes the size, installation place, type, characteristics, function, maintenance, and design of each traffic control device; however, these traffic control devices are not necessarily specifically designed to deal with the crash characteristics and operational conditions of the work zones where they are installed.

Many of the existing research studies on work zone crashes have focused on such topics as crash occurrences in work zones and their sub areas, fatal crashes in work zones, and nighttime crash characteristics. Research studies on traffic control devices and their specific effects on traffic safety in work zones have been limited. Hence, in-depth spatial and temporal analyses on crashes related to work zones are needed in order to find out if there is any relationship between certain traffic control devices and the reduction in accident proneness. Findings from such analyses will help traffic safety engineers plan accordingly for the use of particular traffic control devices. The research team initially decided to focus on various highways in Utah, their traffic control devices, and the crash occurrences associated with them. The research team, however, quickly found that records of work zone traffic control plans for the works that had taken place in several years back were difficult to locate because the Utah Department of Transportation (UDOT) has not always kept traffic control data systematically. Eventually, two work zone projects that had adequate records were selected and analyzed.

This paper presents the findings from a study that performed detailed analyses of work zone–related crashes for UDOT. The analyses included crashes that took place within five miles upstream and downstream of the activity areas of work zones as well as the crashes that happened inside the activity areas. The paper briefly presents the study objectives, the scope of the study, and a summary of the literature review, followed by the findings from in-depth spatial and temporal analyses of the work zone–related crash records.

STUDY OBJECTIVES AND SCOPE OF THE STUDY

The objectives of the study were (a) to review the characteristics of crashes in work zones through spatial and temporal analyses, with a goal of finding any relationship between work zone–related crashes and the main traffic control devices used at the work zones, and (b) to suggest directions for setting up traffic safety and traffic control plan for work zones. As mentioned in the introduction section, it was difficult to get records of traffic control devices and plans for work zones that had taken place several years back. Out of the thirteen work zones identified by the members of the Technical Advisory Committee (TAC) of the study, the research team were able to locate enough information on traffic control devices and plans for only two work zones that would meet the objectives of the study: one work zone using barrels and the other using concrete Jersey barriers as the main traffic control devices.

LITERATURE REVIEW

The literature review had a focus on the effectiveness of certain traffic control devices at maintaining traffic safety in work zones. Carlson et al. (*2*) discussed the characteristics of traffic control devices used in work zones through reviewing the past research studies. They summarized the advantages and the disadvantages of the traffic control measures and prioritized them as high priority and low to medium priority for the Texas Department of Transportation.

Fontaine et al. (*3*) reviewed innovative traffic control devices in order to determine which devices may be appropriate for specific work zones. Through the literature review, they chose nine traffic control devices to further evaluate the effect of their use on work zone traffic safety and summarized their levels of effectiveness on work zone traffic safety.

Rose and Ullman (*4*) found that dynamic speed display signs (DSDS), which detect and display a vehicle's current speed back to the driver, have been shown to have significant speed-reduction effects during temporary applications, such as in work zones or during neighborhood speed-watching programs. They found that overall average speeds dropped by nine miles per hour (mph) on average at school zones with reduced speed limits. Elsewhere, the effect of the DSDS was less dramatic, with average speeds dropping by five mph or less, depending on the locations tested. They found that the influence of a DSDS differed depending on how fast the motorists approached the DSDS. The results of their study suggested that DSDS could be effective at reducing speeds in permanent applications, although their effectiveness may depend on the conditions of the locations where they are placed.

Controlling traffic speed in work zones to improve safety has long been a major concern for highway agencies. Shaik et al. (*5*) tested three traffic control devices for their effectiveness on improving merging maneuvers and reducing speed and speed variance at an interstate highway work zone in Missouri, including white lane drop arrows, orange rumble strips, and the citizens band (CB) wizard alert system. They found that the white lane drop arrows and the CB wizard alert system were able to decrease the percentage of vehicles remaining in the closed lane, the mean speed, and the speed variance.

Maze et al. (*6*) conducted an interview on speed reduction systems with employees working in state agencies in order to evaluate the effects of work zone speed reduction measures, and then suggested speed reduction strategies based on their interviews.

Quantifying the effects of traffic control devices on safety is difficult at best because the purposes of placing traffic control devices in work zones are for both better managing traffic flow and improving safety; that is, their effects are overlapped. The choice of traffic control device depends on the characteristics of the projects, including traffic control costs, construction time, construction duration, construction location, etc.

Research surveys revealed that the majority of the work zone–related studies focused on the effect of traffic control devices on speed control though work zones. Research that would evaluate the effect of control devices on reduction of work zone–related crashes has been lacking. This research was conducted to gain further insight into the effectiveness of traffic control devices on traffic safety, viewed in terms of the reduction in frequency and severity of crashes.

METHODOLOGY

Selecting Two Case Studies

With the help of the TAC members, two of the thirteen work zones that were initially recommended for analysis were selected as case study sites for in-depth analysis. Table 1 shows the summary of the two case studies. There were two major reasons for selecting only two work zones. One reason was that employee turnaround at UDOT is high, making it difficult to locate the engineers who were in charge of the work zones. The other reason was that construction records were not kept systematically for many years. Once they were sent to UDOT's archive, it was very difficult to find them.

The first case study work zone was located on U.S. Route 6 (US-6), which is a major rural arterial connecting such cities as Spanish Fork, Price, and Green River in Utah. The work zone spanned from milepost (MP) 196.79 to MP 200.51, a total of 3.72 miles in length. The work zone involved rehabilitation and reconstruction, including widening, hot-mix asphalt paving, and chip sealing. The work was done from April 2002 to August 2003. The total cost of this project was about $10.8 million (*7*). The traffic control cost of this work zone was $150,000, which accounted for 1.4% of the total construction cost.

The second case study work zone was located on Interstate 15 (I-15), south of Nephi in Utah. The work zone spanned from MP 200.07 to MP 211.17, a total of 11.1 miles in length. The work zone involved reconstruction and rehabilitation of the roadway, including dynamic compaction of pavement substructures and repaving. The construction was done from April 2002 to June 2003. The total cost of this project was about $19.85 million *(8)*. The traffic control cost of this work zone was $1.33 million, which accounted for 7.0% of the total construction cost.

TABLE 1 Summary of the Two Case Study Sites

	US-6 Case Study Site	I-15 Case Study Site
Main Control Device Type	Plastic Barrel	Concrete Jersey Barrier
Construction Duration	16.5 months (April 2002–August 2003)	15.0 months (April 2002–June 2003)
Span of Work Zone	3.72 miles (MP 196.79–MP 200.51)	11.0 miles (MP 200.07–MP 211.17)
Main Works	Rehabilitation & Reconstruction	Rehabilitation & Reconstruction
Traffic Control Cost ($/mile) (Percent Cost Share, $)	$40,323 (1.4%, $150,000)	$120,909 (6.7%, $1,330,000)

Interview Survey

In order to collect the detailed data of the two work zones, interviews were conducted with the resident engineer or the project inspector of each project. Main questions asked in the interviews involved information about the outline of the project; construction type and cost; traffic control plans and devices; traffic condition before, during, and after construction; crash history during construction; roadway types; and other relevant topics.

Crash Data Collection

Crash data used in this study were extracted from UDOT's CARS website (*9*). Note that all crash rates of "before" and "after" periods mentioned in this paper were annual average crash rates for the number of years used for the analyses before or after the construction.

The typical recommended length of a safety study analysis period for the "before" and "after" is three years. However, because of the insufficient crash records available at the time of the study for the "after" construction period (about two years), the analysis results should be interpreted with caution. Also, the "during" construction period lasted for sixteen months for the US-6 work zone and fourteen months for the I-15 work zone. Nevertheless, this method was the best available at the time of the study.

Calculation of Crash Rates

In order to calculate crash rates using Vehicle Miles Traveled (VMT), Annual Average Daily Traffic (AADT) and the length of the two selected study sites were estimated. The number of crashes at each work zone was collected from UDOT's CARS website by severity level. The unit of crash rate used for the analysis was the number of crashes per 100 Million Vehicle Mile Traveled (MVMT). Each crash rate was categorized by crash severity level: NI (No Injury), PI (Possible Injury), BA (Bruises and Abrasion), BBBB (Broken Bones and Bleeding Blood), or Fatal.

Analysis of Crash Characteristics

Crash data collected from the CARS website were sorted, summarized, and analyzed using Microsoft Excel (*10*). General and special crash analyses by direction, construction phase, and season of the two work zones were then carried out. The results of the analyses of the two work zones were summarized in terms of crash rate versus contribution factors, including light condition, traffic control measure, alignment, weather condition, surface condition, and so forth, which will be discussed shortly.

Traffic Control Cost Analysis

Major factors for determining direct construction cost, including traffic control costs, are construction type, construction duration, construction scale, construction phasing, highway type, construction location, construction time, and other conditions, such as detour and bypass arrangements. Especially, construction type, construction scale, construction location, and construction phasing affect the type and quantity of traffic control devices used for work zones. In this study, many limitations existed on calculating or estimating the traffic control costs of various projects. Based on the results of the interviews, total construction costs and traffic control costs of the two work zones analyzed in this study were estimated.

ANALYSIS RESULTS

General Crash Characteristics of the Two Work Zones

Table 2 shows crash rates by severity for the before, during, and after analysis periods at the US-6 work zone. The average number of crashes per year and crash rates per 100 MVMT decreased as the analysis period progressed through the before, during, and after analysis periods. In the "before" period there was an average of 22.00 crashes per year and 244.61 crashes per 100 MVMT. In the "during" period, there was an average of 19.35 crashes per year and 210.80 crashes per MVMT. In the "after" period, there was an average of 6.00 crashes per year and 66.88 crashes per MVMT. It appears that the construction done in the work zone analyzed in the study significantly helped to reduce crashes in this stretch of US-6. Note that due to the limited duration of the construction and the limited availability of "after" data, the reader should be cautious about this outcome. As shown in Table 2, the rate of fatal crash was the highest during construction (8.43 crashes per 100 MVMT).

TABLE 2 Crash Rates by Severity in the Before, During, and After Construction at the US-6 Study Site

	Before			During			After		
	Num. of Crashes	Num. of Crashes per year	Num. of Crashes per 100 MVMT	Num. of Crashes	Num. of Crashes per year	Num. of Crashes per 100 MVMT	Num. of Crashes	Num. of Crashes per year	Num. of Crashes per 100 MVMT
NI	29	9.67	107.48	20	15.48	168.64	14	10.50	117.04
PI	17	5.67	63.01	2	1.55	16.86	0	0.00	0.00
BA	11	3.67	40.77	1	0.77	8.43	1	0.75	8.36
BBBB	8	2.67	29.65	1	0.77	8.43	2	1.50	16.72
Fatal	1	0.33	3.71	1	0.77	8.43	1	0.75	8.36
Total	66	22.00	244.61	25	19.35	210.80	18	6.00	66.88

Table 3 shows crash rates by severity for the before, during, and after analysis periods at the I-15 work zone. Crash rates per 100 MVMT decreased as the analysis period progressed through the before, during, and after analysis periods. In the "before" period, there was an average of 38.33 crashes per year and 80.00 crashes per 100 MVMT. In the "during" period, there was an average of 40.80 crashes per year and 79.01 crashes per 100 MVMT. In the "after" period, there was an average of 79.01 crashes per year and 40.72 crashes per 100 MVMT. Note that due to the limited duration of the construction and the limited availability of "after" data, the reader should be cautious about the outcome of the analysis—just like the US-6 case study site. As shown in Table 3, the rate of fatal crash was the highest during the construction (3.10 crashes per 100 MVMT).

TABLE 3 Crash Rates by Severity in the Before, During, and After Construction at the I-15 Study Site

	Before			During			After		
	Num. of Crashes	Num. of Crashes per year	Num. of Crashes per 100 MVMT	Num. of Crashes	Num. of Crashes per year	Num. of Crashes per 100 MVMT	Num. of Crashes	Num. of Crashes per year	Num. of Crashes per 100 MVMT
NI	63	21.00	43.83	32	25.60	49.58	21	14.00	26.72
PI	22	7.33	15.30	6	4.80	9.30	5	3.33	6.36
BA	11	3.67	7.65	5	4.00	7.75	5	3.33	6.36
BBBB	17	5.67	11.83	6	4.80	9.30	1	0.67	1.27
Fatal	2	0.67	1.39	2	1.60	3.10	0	0.00	0.00
Total	115	38.33	80.00	51	40.80	79.01	32	21.33	40.72

Spatial and Temporal Crash Analysis

In order to investigate spatial and temporal crash characteristics upstream and downstream of the activity areas of the work zones, crashes within 5 miles upstream and downstream of the activity areas were analyzed. Crash rates per 100 MVMT by severity were determined for time and location. Figure 1 and Figure 2 show the spatial and temporal trends by severity of the US-6 work zone and the I-15 work zone, respectively. These crash rates were computed for each one-mile section. For instance, "west 4 mile" in Figure 1 means the fourth one-mile section from the west end of the US-6 work zone activity area.

Table 4 summarizes the comparison of the results of the spatial and temporal crash analyses of the two work zones. As seen in the table, the sections with the highest rates of BBBB or Fatal crashes at the two sites were not the activity areas themselves but their downstream or upstream sections, except for the Fatal crashes after the construction at the US-6 activity area. After the construction, the sections with the largest increase in crash rate of BBBB or Fatal crashes at the two work zones were the one-mile section from both ends of the activity areas or inside the activity area. The one-mile sections with the highest crash rate in the two work zones were the end sections for each of the three analysis periods. Spring and summer were the most dangerous seasons, with the highest crash rates observed according to the monthly crash rate analysis in the four seasons.

As shown in table 4, many crashes, and the most dangerous crashes, happened in the transition areas but not in either of the two activity areas. Hence, the transition area of work zones should receive special attention. Also, both end sections of the activity areas were of concern for traffic safety engineers because those sections had the highest crash rates at the two work zones. For these work zones, the most dangerous seasons of the year were spring and summer.

TABLE 4 Comparison of Spatial and Temporal Crash Analyses of the Two Work Zones

<table>
<tr><td colspan="2"></td><td>US-6</td><td>I-15</td></tr>
<tr><td rowspan="2">Section with the Highest Crash Rates (Before→During→After)</td><td>BBBB*</td><td>West 5 mile→
East 4 mile→
West 5 mile/East 1 mile</td><td>North 3 mile→
South 2/3 mile→
North 2 mile</td></tr>
<tr><td>Fatal</td><td>West 4mile→
West 1mile→
Activity area</td><td>North 2/3 mile→
North 2 mile→
South 1/2/4 mile</td></tr>
<tr><td rowspan="2">Section with the Largest Increase in Crash Rate</td><td>BBBB*</td><td>East 1mile</td><td>North 1mile</td></tr>
<tr><td>Fatal</td><td>Activity area</td><td>South 1/2/4 mile</td></tr>
<tr><td colspan="2">Section with the Highest Crash Rates by Milepost (Before-During-After)</td><td>West Ends
(Three Periods)</td><td>Mid-parts (Before/During Construction)→
North End</td></tr>
<tr><td colspan="2">Month with the Highest Crash Rates</td><td>Spring (Apr. 2002, Apr./May 2003)</td><td>Summer (June 2003)</td></tr>
</table>

* BBBB: Broken Bones or Bleeding Blood

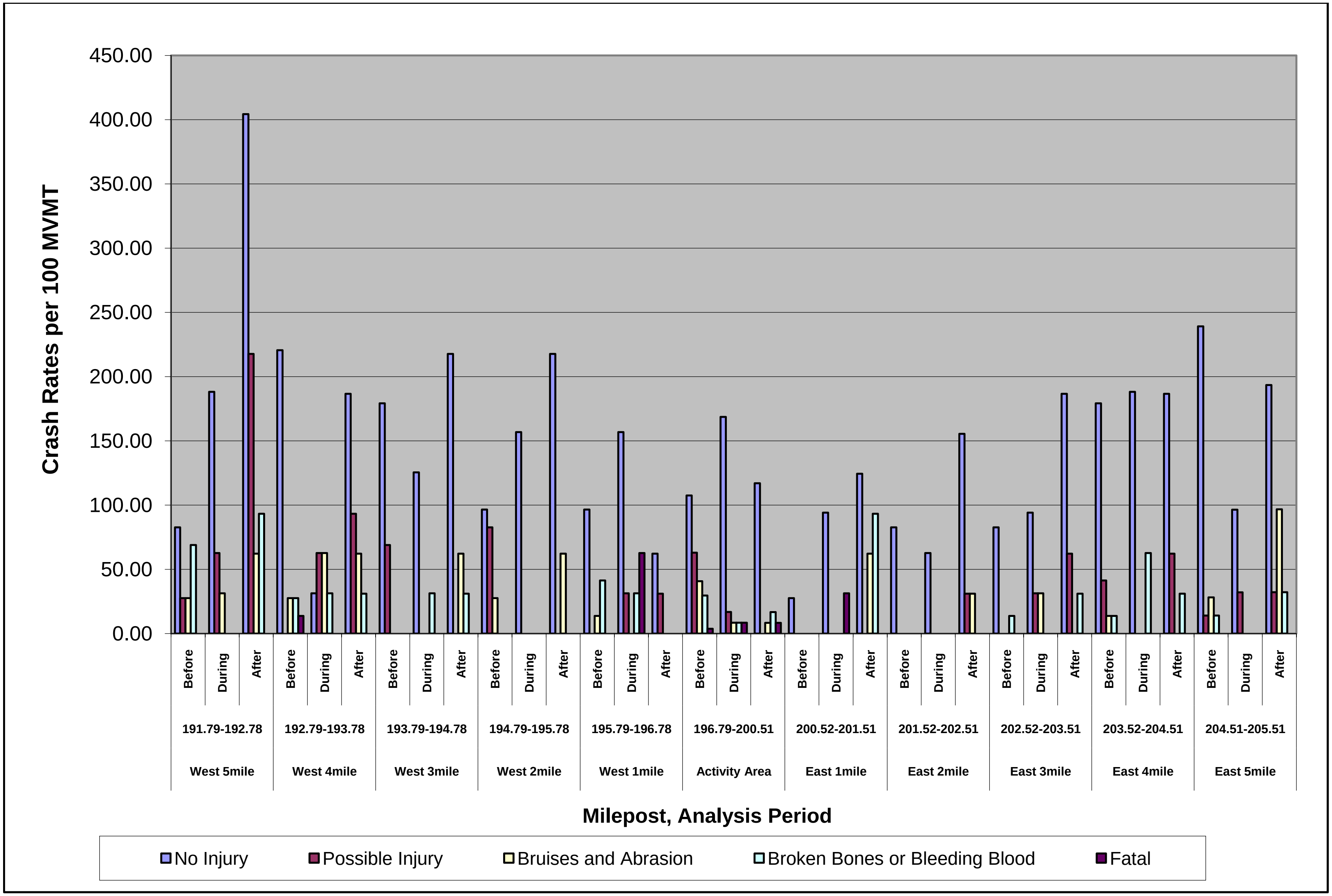

FIGURE 1 Spatial and temporal crash rate by severity at the US-6 study site.

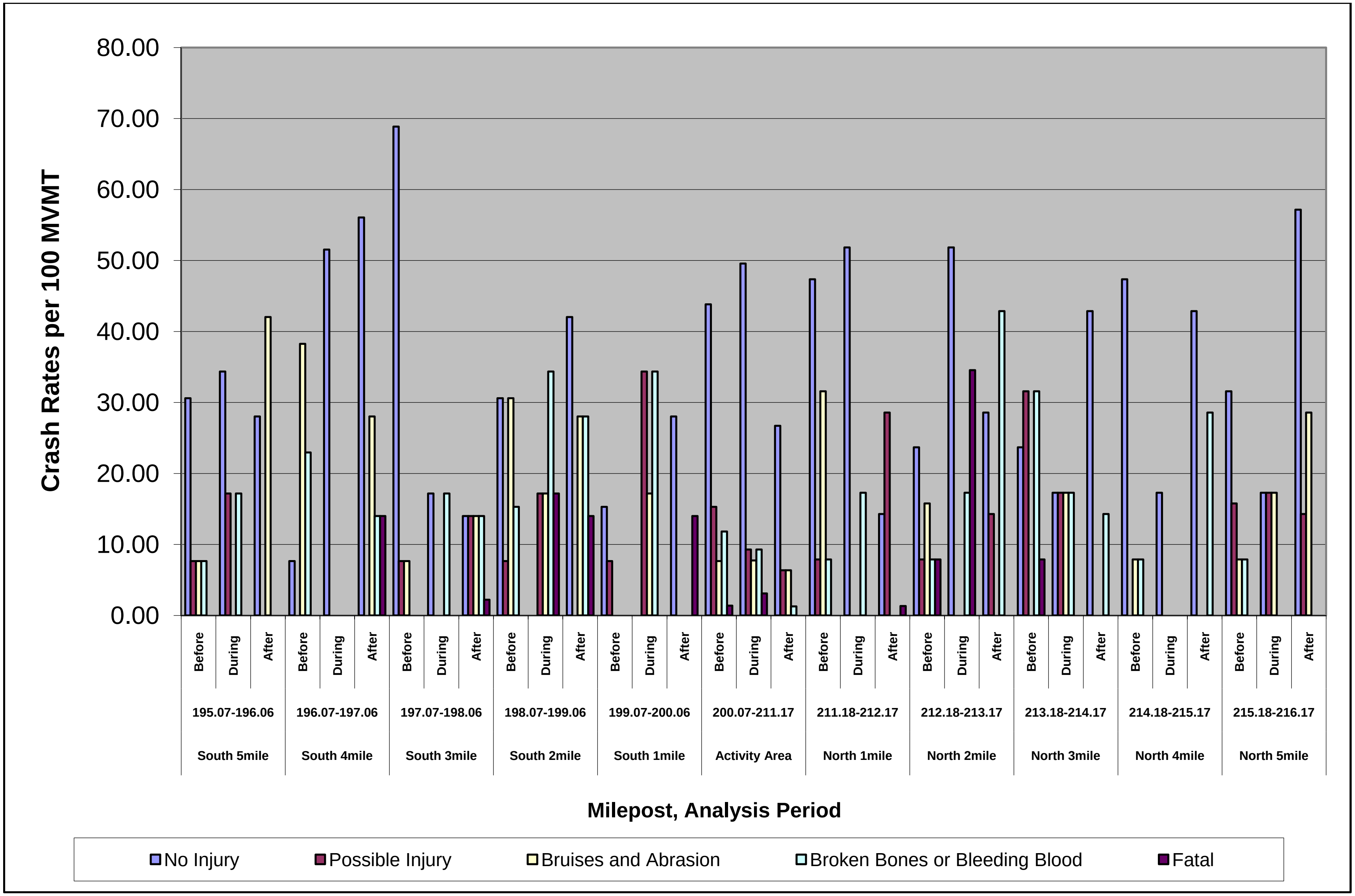

FIGURE 2 Spatial and temporal crash rate by severity at the I-15 study site.

Analysis of Other Contributing Factors

Table 5 compares the results of various other analyses of the work zones in terms of crash rate versus a contributing factor, including light condition, traffic control measure, alignment, weather condition, surface condition, and so forth. Most of the severe crashes (BBBB and Fatal) and the majority of crashes (90%) happened in 'daylight' and 'dark street or highway not lighted' light conditions, implying that daytime driving may be giving motorists a false sense of safety while nighttime driving forces the motorists to concentrate as they drive.

TABLE 5 Comparison of Other Analyses of the Two Work Zones

		US-6	I-15
Crash Rate Analysis by Severity and Light Condition	BBBB*	Daylight	Daylight, Dark Street, or Highway Not Lighted
	Fatal	Dark Street or Highway Not Lighted	Daylight, Dark Street, or Highway Not Lighted
The Largest Percentage Share of Light Condition		Dark Street or Highway Not Lighted (56%)	Daylight (72.5%)
Crash Rate Analysis by Analysis Period and Traffic Control (Before→During→After)		Traffic Lanes Marked (Three Periods)	Traffic Lane Marked→ Construction or Work Area→Traffic Lane Marked
Traffic Control with the Largest Increase in Crash Rate		No Passing Lanes	Traffic Signal
Crash Rate Analysis by Analysis Period and Alignment (Before→During→After)		Curve Grade for Three Periods	Straight and Level for Three Periods
Alignment with the Largest Increase in Crash Rate		Curve Level	Dip Straight
Crash Rate Analysis by Analysis Period and Weather Condition (Before→During→After)		Snowing-Clear-Clear	Clear for Three Periods
Weather Condition with the Largest Increase in Crash Rate		Raining	-
Crash Rate Analysis by Analysis Period and Surface Condition (Before→During→After)		Dry for Three Periods	Dry for Three Periods
Surface Condition with the Largest Increase in Crash Rate		Wet	-
The Highest Crash Type during Construction		MV-Wild Animal	MV-MV

* Broken Bones or Bleeding Blood; - No consistent trend

Crash rates were the highest at the two work zones in the 'traffic lanes marked' condition for the three construction periods, except for the "during" construction period of the I-15 study site where crash rates were the highest in the 'construction or work area.' But the traffic control type with the largest increase in crash rate as time progressed was different between the two work zones: the 'no passing lane' control type at the US-6 study site and the 'traffic signal' control type at the I-15 study site. The latter control type sounds awkward, but this is what was recorded in the traffic control field of crash records.

As for horizontal alignment, the 'curve grade' section at the US-6 study site had the highest crash rate while the 'straight and level' section at the I-15 study site had the highest crash rate. Also, the alignment with the largest increase in crash rate as time progressed was different at the two work zones: in the ‘curve level’ section at the US-6 study site and in the ‘dip straight’ section at the I-15 study site.

Weather conditions in which the two work zones took place were similar for the three construction periods. Highest crash rates happened in the ‘clear’ condition for the two work zones. The US-6 study site had the largest increase in crash rate during rainy weather, while no special trend existed at the I-15 study site.

As for pavement condition, highest crash rates took place on the ‘dry’ surface condition at the two work zones as time progressed, from the before construction period to the after construction period. The US-6 study site had the largest increase in crash rate when the surface condition was “wet.”

As for crash type, the highest number of crashes was different between the two work zones: ‘Multi-vehicle (MV)-wild animal’ type at the US-6 study site and the ‘MV-MV’ crash type at the I-15 study site.

Crash rate analyses by light condition (‘daylight’ or ‘dark street or highway not lighted’), traffic control (‘traffic lane marked’), weather condition (‘clear’), and surface condition (‘dry’) resulted in similar trends between the two work zones; however, crash rate analyses by alignment and by crash type produced different results at the two work zones, as indicated in Table 5.

Directional Analysis

Table 6 shows a comparison of directional crash analyses of the two study sites. Directional analysis was based on the occurrences of traffic crash by direction. Results of the crash analyses of traffic control type, alignment, weather condition, surface condition, and crash type of both directions were similar between the two work zones. On the other hand, other analyses, such as crash rate analysis, spatial and temporal crash analysis, and crash analysis by severity of the work zones of both directions produced different results, as shown in Table 6. The directional analyses showed that the westbound direction was more dangerous than the eastbound direction at the US-6 study site, while both the northbound and southbound directions had similar crash experiences at the I-15 study site.

Crash Analysis by Construction Phase

Table 7 shows a comparison of crash analyses by construction phase at the two work zones. Construction work in the two work zones was divided into three phases; the types of work done in each phase and its duration were different between the two work zones. Phase II of both projects turned out to have the highest crash rates. Crash analyses by traffic control, surface condition, and crash type by construction phase produced similar results at the two work zones. On the other hand, other analyses by crash rate, spatial and temporal crash rate, crash analysis by severity, alignment, and weather condition of the two work zones produced different results by phase, as shown in Table 7.

According to the results of the crash rate analysis by construction phase, Phase I (widening) was the most dangerous phase of three phases at the US-6 study site, while Phase III (inside lane construction) was the most dangerous phase of the three phases at the I-15 study site. Severe crashes, such as BBBB and Fatal crashes, happened only in Phase I at the US-6 study site and only in Phase III at the I-15 study site.

TABLE 6 Comparison of Directional Crash Analyses of the Two Work Zones

	US-6 (East-West) (MP 196.79 to MP 200.51)	I-15 (North-South) (MP 200.07 to MP 211.17)
Crash Rates for Three Analysis Periods	Westbound had a higher crash rate.	Both directions had similar crash rates.
Spatial and Temporal Crash Rate Comparison (Section with the Highest Crash Rates)	- Different by direction and time. - Section of MP 197.0–MP198.0 had the highest crash rate for westbound direction. - During and after construction both directions had the highest crash rates in the same section (MP 197.0–MP198.0).	- Different by direction and but time. - Before construction, both directions had the highest crash rate in the same section (MP206.01–MP 207.80).
Crash Analysis by Severity	Westbound had severe crashes	- Both directions had similar crashes. - Before and during construction, southbound had more severe crashes. - After construction, northbound had more severe crashes.
Month with the Highest Crash Rates	Different by direction.	Month is the same with different year.
Severity and Light Condition	- Different by direction. - Westbound direction had more severe crashes in ‘daylight’ or ‘dark street or highway not lighted.’	- Different by direction. - Both directions had similar level of severity; northbound ‘daylight’ and southbound ‘dark street or highway not lighted.’
Traffic Control	Both directions had same (‘traffic lanes marked’) except during construction of the westbound (‘no control present’).	Same for both direction and time—‘traffic lanes marked.’
Alignment	Both directions had the same trends (‘curve grade’) except during construction of the eastbound (‘straight and level’).	Both directions had the same trends (‘straight and level’) except before construction of the northbound (‘grade straight’).
Weather Condition	Both directions had the same category (‘snow’ for before construction and ‘clear’ for after construction) except for during construction (‘clear’ for eastbound direction and ‘snowing’ for westbound direction).	Same by direction and time under ‘clear’ weather condition.
Surface Condition	Same by direction and time: ‘dry.’	Same by direction and time: ‘dry.’
Crash Type	‘MV-Wild Animal’ had the highest number of crashes in both directions.	‘MV-MV’ had the highest number of crashes in both directions.

TABLE 7 Comparison of Crash Analyses by Construction Phase of Two Work Zones

		US-6 (East-West) (MP 196.79–MP 200.51)	I-15 (North-South) (MP 200.07–MP 211.17)
General Outline			
	# of Phases	3	3
	The Highest Phase with the Highest Crash Rate	Phase II	Phase II
	The Longest Phase	Phase I (13 months)	Phase III (7.3 months)
Crash Analysis (The Main Factor with the Highest Crash Rate)			
	Section with the Highest Crash Rate	- Same section for Phase I and Phase III (MP 197.0–MP 198.0). - Phase II (MP 198.0–MP 199.0).	- Same section for Phase II and III (MP 211.01–MP 211.17). - Phase I (207.01–MP 208.00).
	Crash Severity by Phase	Phase I	Phase III
	Crash Rate Analysis by Day of the Week and Phase	Different by phase.	Different by phase.
	Crash Rate Analysis by Light Condition and Phase	- Same light condition for Phase I and Phase II ('dark street or highway not lighted'). - Phase III ('daylight').	Same for all phases ('daylight').
	Crash Rate Analysis by Traffic Control and Phase	Same for all phases ('traffic lanes marked').	Same for all phases ('construction or work area').
	Crash Rate Analysis by Alignment and Phase	- Same alignment condition for Phase I and Phase III ('curve Grade'). - Phase II ('straight and level').	Different by phase.
	Crash Rate Analysis by Weather Condition and Phase	Different by phase.	- Same weather condition for Phase I and II ('clear'). - Phase III ('cloudy').
	Crash Rate Analysis by Surface Condition and Phase	Same for all phases ('dry').	Same for all phases ('dry').
	Crash Type	- Same crash type for Phase I and Phase II ('MV-wild animal'). - Phase III ('MV-fixed object').	Same for all phases ('MV-MV').

Cost Analysis of the Two Case Study Sites

Traffic control costs of work zones depend on the length of construction zone, the type of construction, the circumstances of construction area, the duration of construction work, and so on. Thus, the research team focused on the total construction cost and traffic control cost in the traffic control analysis, not the costs by traffic crash reduction. Table 8 shows general information of the two work zones and the costs of the traffic control. The US-6 work zone used barrels (drums) and the I-15 work zone used concrete Jersey barriers as their main traffic control devices. Traffic control for the study sites cost $0.04 million per mile at the US-6 work zone and $0.12 million per mile at the I-15 work zone. Also, traffic control for the work zones cost $2,440 per month per mile for the US-6 work zone and $7,990 month per mile at the I-15 work zone.

TABLE 8 Information on Construction and Traffic Control Costs of the Two Work Zones

		Unit	US-6	I-15
Construction Duration		Months	16.5	15.0
Span of Work Zone		Miles	3.72	11.1
Main Works			Rehabilitation & Reconstruction	
			Widening, hot-mix asphalt paving, chip seal	One lane open in on each direction, partial closing
Main Traffic Control Devices			Barrel (Drums)	Concrete Barriers
Total Construction	Cost	M$	10.80	19.85
	Cost per mile	M$/mile	2.90	1.79
	Cost per year	M$/year	7.85	15.88
	Cost per month	M$/month	0.65	1.32
	Cost per month and mile	M$/month, mile	0.18	0.12
Traffic Control	Cost	M$	0.15	1.33
	Cost per mile	M$/mile	0.04	0.12
	Cost per year	M$/year	0.11	1.06
	Cost per month	K$/month	9.09	88.67
	Cost per month and mile	K$/month, mile	2.44	7.99

M = million; K = thousand

CONCLUSIONS

This paper presented results of a series of crash rate analyses of the two work zones. The goal of the study was to conduct spatial and temporal analyses on records of work zone crashes available at UDOT in order to evaluate the characteristics of such crashes and investigate if there were any relationships between work zone crashes and traffic control devices used at work zones. Through interviews of resident and project engineers and upon consultation with the members of the TAC for the study, two work zones were selected for an in-depth analysis: one on US-6 and the other on I-15.

The spatial and temporal analyses of crash records of the two work zones indicated that the transition area upstream of the work zone activity area was found to be most crash prone and not the activity area itself. Hence, when traffic safety improvement works are planned, transition areas to and from activity areas should be carefully evaluated and proper traffic control devices should be placed to ensure safety in transition areas. The end sections of activity area were found to be most crash prone; hence, it is recommended that care be exercised to improve safety at the end areas of activity areas.

The seasonal analysis showed that spring and summer months experienced higher crash rates than the rest of the year. The comparison of crash rates at the two work zones in terms of factors including light condition, traffic control measure, alignment, weather condition, and surface condition indicated that the two work zones showed similar trends for these factors. However, the effects of alignment and crash type on the two work zones were significantly different. Most of the crashes happened in the 'curve grade' and 'grade straight' sections at the US-6 study site and in the 'straight and level' and ' grade straight' sections at the I-15 study site.

The directional analysis of crashes showed that the westbound direction was more dangerous than the eastbound direction at the US-6 study site, while the northbound and the southbound directions showed similar trends in crash occurrence at the I-15 study site. The directional analysis is affected by the geometry of work zone; hence, these results pertain only to the two work zones analyzed. Each work zone should be evaluated case by case.

As for construction phase, Phase I (widening) was found to be the most dangerous of the three phases at the US-6 study site, while Phase III (inside lane construction) was the most dangerous of the three phases at the I-15 study site. This result is an indication that traffic engineers should consider phasing and work type when they plan traffic control measures for work zones.

Similar to the results of the crash rate analyses of the entire crash data, the highest crash rates for light condition (‘daylight’ or ‘dark street or highway not lighted’), traffic control (‘traffic lane marked’), weather condition (‘clear’), and surface condition (‘dry’) showed similar trends at the two work zones; however, trends in crash rates by alignment and by crash type were found to be significantly different between the two work zones.

Obviously, using concrete Jersey barriers is more expensive than using barrels, but the lack of detailed cost data prohibited detailed cost analyses. Hence, if detailed cost analyses on traffic control devices are desired to evaluate their cost effectiveness, it is recommended that details of traffic control devices used in work zones and their costs be continuously gathered and maintained for future analyses. It was found that crash occurrence was probabilistic and crashes scattered over the entire period of the construction at the two work zones.

Even though this study had the limitations on the number of work zones with different traffic control devices for which detailed traffic control plans were available, the spatial and temporal analyses of the available crash data for the two work zones revealed some trends. For instance, highway sections upstream or downstream of the work zones may be more crash prone than the sections within the work zones. Also, more crashes may happen during daylight hours, at locations where alignment is favorable and pavement is dry than under inferior conditions. Reminding the drivers of potential dangers in these areas of work zones is an important step toward the reduction of crashes related to work zones.

The lack of traffic control records limited the scope of the study. It is essential to keep records of work zone traffic control devices and their use if a comprehensive analysis of topics such as those that were dealt with in this study is sought. It is also recommended that work zone–related traffic control data be shared among the state departments of transportation for conducting analyses of the cost-effectiveness of certain traffic control devices on the reduction of crashes at and near work zones.

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