Enhanced Analysis of Crashes in the Proximity of Work Zones through Integration of Statewide Crash Data with Lane Closure System Data

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Abstract

Highway work zones interrupt regular traffic flow and lead to safety concerns. Comprehensive knowledge of the crashes and work zones is essential to identify the risk factors. The Wisconsin Lane Closure System (WisLCS), a scheduling and reporting system for highway lane closures statewide, provides a new opportunity to match crashes to specific work zones on a system-wide level. This study conducts an analysis of the safety risks in the proximity of work zones. The WisLCS and the MV4000 Crash Data Retrieval Facility, both part of the WisTransProtal system at the University of Wisconsin-Madison TOPS Laboratory, provide the necessary data for this study. A matching algorithm is used to relate reported work zone crashes with the corresponding work zones, which relies on a common underlying linear referencing system used in the two data systems. Based on the results, it is clear that work zones cause safety concerns outside of the physical boundaries (upstream and downstream) and scheduled time periods (before and after the reported operation hours). In some scenarios, those crashes occurring outside of work zones even have a higher risk of overall and severer injury. Some suggestions are also made based on the findings to improve work zone safety and enhance work zone reporting monitoring in the future. Although developed based on the systems in Wisconsin, the general ideas of this study can also be applied to similar information systems.

INTRODUCTION

Work zones are necessary to maintain and improve our road infrastructure. However, work zones interrupt the regular traffic flow patterns, which cause safety concerns (*1, 2*). Identifying the risk factors and implementing safety countermeasures via work zone safety analysis are essential to improve work zone safety. Effective work zone safety analysis is based on knowledge of crashes, work zones and driver and environmental factors. Fundamental to such knowledge is the ability to match crashes to the corresponding work zones. The traditional approach has relied on a construction zone flag in the police crash report and targeted work zone studies. The crash report usually provides few details about the work zone attributes, except when noted in the officer's narrative description. Even if the narrative description provides some information about the work zone, data preprocessing for safety analysis is very costly in terms of time and human resource. Targeted work zone studies are able to provide a wealth of information for specific work zones, but the covered work zones are limited because of the high demand of time and efforts. Because of the limited available data, the statistical method used in safety analysis needs to be carefully selected (*3*). In addition, only a few studies have investigated the work zone attributes relating to crashes (*4, 5*) and many of the factors are not fully understood, partially because of the insufficient knowledge of the work zone where a specific crash occurred.

Modern transportation information systems have improved the ability to manage and retrieve historical transportation data. However, these systems are often oriented towards specific application areas and not designed for data integration across systems. Because work zone safety analysis requires both work zone and crash details, it is necessary to develop ways to integrate the two data sources across systems, in particular with respect to time and geospatial attributes. The Wisconsin Lane Closure System (WisLCS) provides a statewide scheduling and reporting system for highway lane closures in Wisconsin. Developed through support from the Wisconsin Department of Transportation (WisDOT) Bureau of Highway Operations, the WisLCS provides a new opportunity to match crashes to specific work zones on a system-wide scale.

This paper builds on a previous study by the authors (*5*) that described a matching method to relate crash data to work zone data. The previous study included a preliminary analysis of highway work zone safety based on WisLCS closure attributes that served to validate the methodology (*5*) and indicated several findings of great potential for the method. This study applies the method to investigate crash characteristics in the proximity of work zones, specifically upstream and downstream crashes and crashes occurring near the start and end of a work zone's scheduled operation. This analysis is made possible by the linking detail information from the two databases and is intended to provide insight and potential recommendations on how to improve safety related to work zone operations and scheduling. The following specific questions are addressed:

1. How does location in and around a work zone relate to crashes and work zone safety? Examining crash locations in terms of upstream, within, and downstream of the work zone, plus the associated work zone configuration

and crash data attributes, can provide a lens to systematically identify high risk work zone scenarios.

2. What is the actual impact period of a work zone? The work zone life cycle is typically defined by the scheduled start and end time of operation. However, workers need to arrive at the site earlier than the work actually starts. When the work is finished, there is also extra work after the closure ends. Such buffer time, if exists, should also be considered as the impact period of the work zone. This analysis would also benefit reporting capabilities on traveler information systems, such 511, which in turns impact safety and operations.

3. What measures can be taken to make work zones safer? The results of the two questions above can help predict work zone risks, which would lead to better scheduling and configuration decisions. In addition, this analysis could contribute to automated capabilities in lane closure scheduling systems to identify and monitor risks in a systematic way.

DATA SOURCES

The work zone and crash data used in this study derive from the Wisconsin Lane Closure System (WisLCS) (*6*) and Wisconsin MV4000 crash database (*7*), available through the WisTransPortal system (*8*) at the University of Wisconsin-Madison Traffic Operations and Safety (TOPS) Laboratory.

The Wisconsin Lane Closure System

The WisLCS was designed to streamline work zone operations and scheduling decisions and provide better information to other related real time transportation systems (*9*). Operational since April 2008, the WisLCS facilitates scheduling and monitoring of highway work zone activities at the WisDOT Satewide Traffic Operation Center (STOC) and regional transportation offices. The WisLCS also provides real-time lane closure information to traveler information systems such as the Wisconsin 511, and supports WisDOT Oversize / Overweight permitting activities. All planned or unplanned closures on the Wisconsin highway system are archived in WisLCS in a detailed format. Moreover, the WisLCS fully integrates the WisDOT State Trunk Network (STN) (*10*), a GIS-based linear referencing system, to locate closures to the highway and to provide interoperability with other GIS and map-based systems. In addition to location and time, other work zone attributes are also available. Table 1 shows the major ones. For more detailed introduction, please refer to the system homepage (*6*).

Table 1 Work Zone Details in WisLCS

Attributes	Values
Closure Type	Construction, Maintenance, Permit, Special Event, Emergency
Duration	Long Term, Continuous, Weekly, Daily/Nightly
Facility Type	Bridge, Mainline, Ramp, System Interchange
Restriction	Weight, Height, Width, Speed
Lane Details	Full Closure, 2 Left Lanes Closed, 2 Right Lanes Closed, 3 Left Lanes Closed, 3 Right Lanes Closed, Flagging Operation, Lane Restriction, Left Lane Closed, Left Shoulder Closed, Median Turn Lane Closed, Moving Full Closure, Moving Lane Closure, Off Roadway Left, Off Roadway Right, Passing Lane Closed, Right Lane Closed, Right Shoulder Closed, Single Lane Closed, Various Lanes Closed

Wisconsin MV4000 Crash Data

The Wisconsin MV4000 Traffic Accident Extract database contains information on all police reported crashes in Wisconsin, including the location of each crash, vehicles involved, and general crash attributes from 1994 to the current year. Maintained by the TOPS Lab for research purposes and as a service to the WisDOT, crash records can be accessed via the WisTransPortal Crash Data Retrieval Facility (*7*). Highway crashes are geo-coded by WisDOT Division of Motor Vehicles (DMV) to the Wisconsin STN (*10*) on an annual basis.

RETRIEVING THE CRASH RELATED WORK ZONES

To find the potential work zone associated with a given crash, both time and location attributes should match. The locations of highway crashes and work zones in the two systems are both coded to the Wisconsin STN, the WisDOT GIS-based linear referencing system for state and federal highways in Wisconsin. Because of the common location coding, matching the locations of crashes to corresponding work zones becomes possible. Our previous study described a matching algorithm based on the time and location of the work zones and crashes (*5*). This study adopts a similar matching method with minor modifications to investigate crash characteristics in the temporal-spatial proximity of work zones.

Matching on Time Attributes

In addition to the scheduled begin and end time of the closures, the WisLCS includes four Duration types to capture the different schedule scenarios that may occur:

- *Daily/Nightly*: the time of operation occurs on a daily or nightly basis as specified by the starting and ending times per each day within the start date and end date range;
- *Weekly*: the time of operation occurs on a weekly basis as specified by starting and ending day of week;
- *Continuous*: continuous work zones longer than 24 hours but less than two weeks;
- *Long Term*: work zones longer than two weeks.

The WisLCS also includes the option to assign Schedule Override periods, which indicates inactive periods for work zones. Any work zone can have multiple override periods. A 24 hour buffer is applied in searching for the crashes before and after of a work zone's scheduled hours.

Matching on Location Attributes

The location of a work zone is defined by predefined points, called landmarks, in the STN. Some work zones, referred as segment closures, are defined by a begin landmark and an end landmark. Other work zones, such as bridge maintenance, use only one landmark and are referred as point closures. Because a point work zone is actually a short segment on the road although it is coded as a point in the system, in this study, based on empirical investigation, a length of 0.5 miles is assigned to a point closure. A five mile distance buffer is applied in searching for the crashes upstream and downstream of a work zone.

Because the STN is a linear referencing system, the cumulative mileage of the landmarks (for work zones) and crash locations on their associated highways can be used as the common scale for location matching (*5*). This method also provides the necessary distance from the crash to the work zone for the following location proximity analysis.

Figure 1 shows various cases of the crash locations in the proximity of a work zone. Based on the traffic direction and the work zone area, Crash A and F are considered downstream of the work zone; Crash B and E are within the work zone; Crash C and D are upstream of the work zone. Crashes that occurred on a ramp are less straightforward to characterize. In keeping with the concept that "crash upstream of a work zone" means the crash occurred while approaching the work zone, Crash H in Figure 1 is considered upstream of the work zone. Similarly, Crash G is considered downstream of the work zone.

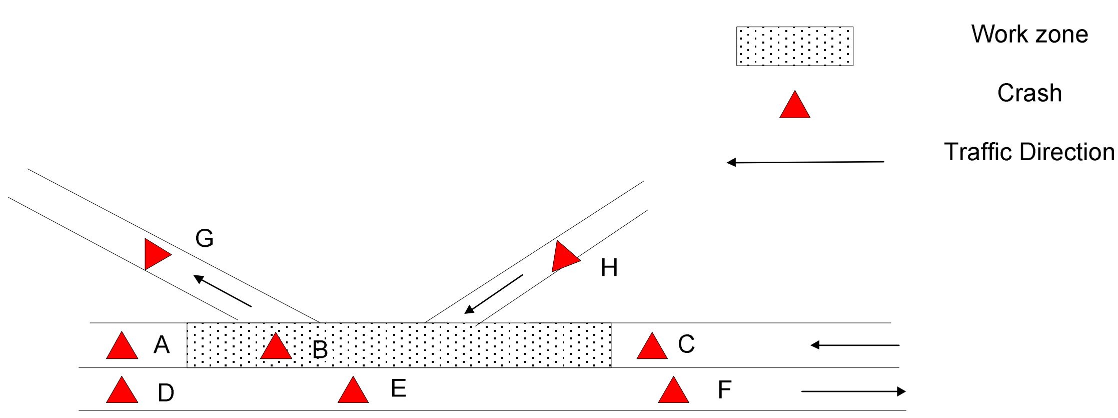

Figure 1 Locations of Work Zones and Crashes

RESULTS SUMMARY AND ANALYSIS

There are 2747 highway work zone crashes recorded in the MV4000 database from 2009 to 2011, of which 2246 crashes can be associated with work zones in the WisLCS using the matching algorithm. The overall matching rate is 81.8%. Crash severity in terms of total matched, work zone crashes as reported on the MV4000 form, non-work zone related crashes, and overall crashes in those three years is shown in Table 2. Crash severity is defined in terms of the National Safety Council "K","A","B" and "C" injury severity categories (*11*): fatal (K), incapacitating injury (A), non-incapacitating injury (B), possible injury (C), and property damage only (PD). Severe crashes are taken as the combination of K+A crashes. The distribution of the matched crashes, which are later used for the analysis, retains basically the same distribution as the construction zone crashes in the MV4000 database. In summary, the overall matching rate and the distributions of crash severity are quite consistent with our previous study based on 2009 and 2010 data (*5*).

Table 2 Crash Severity update

	Matched		Reported Work Zone		Non Work Zone		Overall	
	Count	%	Count	%	Count	%	Count	%
SC (K+A)	97	4.3%	108	3.9%	4414	3.5%	4522	3.5%
INJ (K+A+B+C)	697	31.0%	864	31.5%	33863	26.5%	34727	26.6%
PD	1549	69.0%	1883	68.5%	93897	73.5%	95780	73.4%
Total	2246	100.0%	2747	100.0%	127760	100.0%	130507	100.0%

Crash Location Distribution

This section examines the distribution of crash locations upstream, within, and downstream of work zones in terms of crash severity and other attributes. The objective is to investigate capabilities of the matching algorithm to conduct fine grain analysis of work zone safety based on geospatial attributes and to identify important safety factors related to work zone proximity and configuration.

Table 3 shows the relative locations of work zone crashes in terms of crash severity categories. The results show that the severity of crashes upstream and within work zones, taken as the ratio of injury crashes to the total, is higher than downstream work zone crashes. In particular, the percentage of injury crashes is highest in upstream locations (technically outside of the work zone boundaries) although the percentage of severe crashes is highest within the work zone. The severity of downstream crashes is comparable to overall non-work zone crash severity. As discussed, total work zone crashes in this table and subsequent analysis is based on total matched crashes.

Table 3 Work Zone Crash Severity in Different Areas

	Upstream		Within		Downstream		Total Work Zone		Non Work Zone	
	Count	%	Count	%	Count	%	Count	%	Count	%
SC	17	4.0%	71	4.6%	9	3.2%	97	4.3%	4414	3.5%
INJ	143	34.0%	482	31.1%	72	26.0%	697	31.0%	33863	26.5%
PD	278	66.0%	1066	68.9%	205	74.0%	1549	69.0%	93897	73.5%
Total	421	100.0%	1548	100.0%	277	100.0%	2246	100.0%	127760	100.0%

For further investigation, a distribution of crashes in terms of the crash report Manner of Collision versus location is shown in Table 4. Compared to non-work zone crashes, work zone crashes are much higher in rear-end (REAR) and same direction side swipe (SSS), but much lower in single vehicle crashes (NO). For the work zone crashes, the portion of rear-end crashes are quite high upstream and downstream of work zones, but much lower within work zones. The percentage of same direction side swipe crashes increases from upstream, within to downstream. Based on Manner of Collision, there is evidence that downstream crashes are indeed impacted by the work zone traffic patterns, although the crash severity itself does not appear to be affected. These results validate the expected impact in terms of rear-end crashes at the start of the queue and re-emergence at the end of the work zone, although an in-depth quantification of those impact factors is beyond the scope of this paper.

Table 4 Manner of Collision in Different Areas

	Upstream		Within		Downstream		Total Work Zone		Non Work Zone	
	Count	%	Count	%	Count	%	Count	%	Count	%
REAR	186	44.18%	594	38.37%	117	42.24%	897	39.90%	31019	24.30%
SSS	69	16.39%	288	18.60%	57	20.58%	414	18.40%	11201	8.80%
NO	114	27.08%	479	30.94%	74	26.71%	667	29.70%	62908	49.20%
ANGL	42	9.98%	160	10.34%	24	8.66%	226	10.10%	18885	14.80%
HEAD	3	0.71%	8	0.52%	1	0.36%	12	0.50%	1373	1.10%
SSOP	6	1.43%	17	1.10%	3	1.08%	26	1.20%	2055	1.60%
Total	421	100.0%	1548	100.0%	277	100.0%	2246	100.0%	127760	100.0%

Note:
ANGL: Angle; HEAD: Head On Collision; NO: No collision with another vehicle; REAR: Rear End; RTR: Rear to rear; SSO: Sideswipe/Opposite Direction; SSS: Sideswipe/Same Direction. A few crashes without manner of collision are excluded.

Table 5 correlates Manner of Collision and crash severity at different locations. There are several results worth noting. First, rear-end work zone crashes tend to have a higher percentage of injury crashes compared to overall work zone crashes, with the highest injury ratio occurring upstream from the work zone. However the likelihood of a severe injury crash is lower than the overall average. Angle crashes are generally lower as an overall percentage of crashes compared to non-work zone crashes; however their injury severity is much higher. There are also clear distinctions in severity based on location, with downstream angle crashes having the highest likelihood of severe injuries followed by upstream angle crashes. The authors conjecture that this trend is the result of lane changing and merging behaviors just before and after the work zone.

Table 5 Manner of Collision and Crash Severity in Different Areas

		Upstream		Within		Downstream		Total Work Zone	Non Work Zone
		Count	%	Count	%	Count	%	%	%
NO	SC	2	1.80%	31	6.50%	2	2.70%	4.30%	3.50%
	INJ	23	20.20%	144	30.10%	11	14.90%	31.00%	26.50%
	PD	91	79.80%	335	69.90%	63	85.10%	69.00%	73.50%
	Total	114	100.00%	479	100.00%	74	100.00%		
REAR	SC	7	3.80%	19	3.20%	2	1.70%	4.30%	3.50%
	INJ	84	45.20%	213	35.90%	40	34.20%	31.00%	26.50%
	PD	102	54.80%	381	64.10%	77	65.80%	69.00%	73.50%
	Total	186	100.00%	594	100.00%	117	100.00%		
SSS	SC	2	2.90%	7	2.40%	1	1.80%	4.30%	3.50%
	INJ	13	18.80%	45	15.60%	11	19.30%	31.00%	26.50%
	PD	56	81.20%	243	84.40%	46	80.70%	69.00%	73.50%
	Total	69	100.00%	288	100.00%	57	100.00%		
ANGL	SC	5	11.90%	12	7.50%	4	16.70%	4.30%	3.50%
	INJ	17	40.50%	70	43.80%	8	33.30%	31.00%	26.50%
	PD	25	59.50%	90	56.30%	16	66.70%	69.00%	73.50%
	Total	42	100.00%	160	100.00%	24	100.00%		
HEAD	SC	1	33.30%	1	12.50%	0	0.00%	4.30%	3.50%
	INJ	2	66.70%	4	50.00%	1	100.00%	31.00%	26.50%
	PD	1	33.30%	4	50.00%	0	0.00%	69.00%	73.50%
	Total	3	100.00%	8	100.00%	1	100.00%		
SSOP	SC	0	0.00%	1	5.90%	0	0.00%	4.30%	3.50%
	INJ	3	50.00%	6	35.30%	0	0.00%	31.00%	26.50%
	PD	3	50.00%	11	64.70%	3	100.00%	69.00%	73.50%
	Total	6	100.00%	17	100.00%	3	100.00%		
UNKN		1		2		1			
Total		421		1548		277			

The previous analysis was based on matching crash attributes from the MV4000 database. Table 6 shows the crash severity for different work zone types, based on the WisLCS lane closure database. Construction and Maintenance work zone crashes, which represent the largest subset, have basically the same crash severity within and downstream, but crashes occurring upstream of maintenance work zones are quite dangerous in terms of the likelihood of severe and overall injuries. The sample set for Permit and Emergency closures is too small to draw reliable conclusions, although initial indications suggest a possible increase in the injury ratio for upstream crashes.

Table 6 Work Zone Type and Crash Severity in Different Areas

		Upstream		Within		Downstream		Combined	Non Work Zone
		Count	%	Count	%	Count	%	%	%
Construction	SC	11	3.20%	68	4.60%	7	3.40%	4.30%	3.50%
	INJ	110	32.20%	458	31.00%	59	28.40%	31.00%	26.50%
	PD	232	67.80%	1019	69.00%	149	71.60%	69.00%	73.50%
	Total	342	100.00%	1477	100.00%	208	100.00%		
Maintenance	SC	6	9.80%	2	4.70%	2	3.60%	4.30%	3.50%
	INJ	23	37.70%	13	30.20%	13	23.20%	31.00%	26.50%
	PD	38	62.30%	30	69.80%	43	76.80%	69.00%	73.50%
	Total	61	100.00%	43	100.00%	56	100.00%		
Permit	SC	0	0.00%	1	5.90%	0	0.00%	4.30%	3.50%
	INJ	7	58.30%	7	41.20%	0	0.00%	31.00%	26.50%
	PD	5	41.70%	10	58.80%	8	100.00%	69.00%	73.50%
	Total	12	100.00%	17	100.00%	8	100.00%		
Emergency	SC	0	0.00%	0	0.00%	0	0.00%	4.30%	3.50%
	INJ	3	60.00%	4	36.40%	0	0.00%	31.00%	26.50%
	PD	2	40.00%	7	63.60%	4	100.00%	69.00%	73.50%
	Total	5	100.00%	11	100.00%	4	100.00%		
Special Event	SC	0	0.00%	0	0.00%	0	0.00%	4.30%	3.50%
	INJ	0	0.00%	0	0.00%	0	0.00%	31.00%	26.50%
	PD	1	100.00%	0	0.00%	1	100.00%	69.00%	73.50%
	Total	1	100.00%	0	0.00%	1	100.00%		
Total		421		1548		277			

Table 7 shows the crash severity for different lane details. Full Closure work zones have fewer severe crashes upstream and within work zones, but a higher percentage downstream compared to all work zone crashes. This is likely the result of traffic merging back onto highway from alternate detour routes. Flagging Operation, Lane Restriction and Various Lanes Closed are seen to be the most dangerous in general, which is consistent with the previous study (*5*). However the specific location of risk within the work zone varies by closure type and is visibly captured by the matching algorithm and data. Lane Restriction work zones are quite safe downstream, while Various Lanes Closed has a very high percentage of injury crashes upstream, but much less within and downstream of the work zone. The percentage of overall injury crashes for Flagging Operations is highest within the work zone, although the percentage of severe injury crashes is highest upstream and downstream, with downstream representing the highest risk of severe injury crashes.

Table 7 Work Zone Lane Details and Crash Severity

		Upstream		Within		Downstream		Combined	Non Work Zone
		Count	%	Count	%	Count	%	%	%
Full Closure	SC	2	2.20%	4	1.50%	3	4.80%	4.30%	3.50%
	INJ	22	24.70%	80	29.60%	13	20.60%	31.00%	26.50%
	PD	67	75.30%	190	70.40%	50	79.40%	69.00%	73.50%
	Total	89	100.00%	270	100.00%	63	100.00%		
2 Left Lanes Closed	SC	2	4.90%	1	1.70%	0	0.00%	4.30%	3.50%
	INJ	14	34.10%	8	13.60%	7	35.00%	31.00%	26.50%
	PD	27	65.90%	51	86.40%	13	65.00%	69.00%	73.50%
	Total	41	100.00%	59	100.00%	20	100.00%		
2 Right Lanes Closed	SC	2	6.70%	1	3.70%	0	0.00%	4.30%	3.50%
	INJ	16	53.30%	9	33.30%	4	40.00%	31.00%	26.50%
	PD	14	46.70%	18	66.70%	6	60.00%	69.00%	73.50%
	Total	30	100.00%	27	100.00%	10	100.00%		
Flagging Operation	SC	1	9.10%	4	8.20%	1	14.30%	4.30%	3.50%
	INJ	3	27.30%	19	38.80%	2	28.60%	31.00%	26.50%
	PD	8	72.70%	30	61.20%	5	71.40%	69.00%	73.50%
	Total	11	100.00%	49	100.00%	7	100.00%		
Lane Restriction	SC	3	10.30%	16	6.40%	0	0.00%	4.30%	3.50%
	INJ	10	34.50%	78	31.30%	3	13.60%	31.00%	26.50%
	PD	19	65.50%	171	68.70%	19	86.40%	69.00%	73.50%
	Total	29	100.00%	249	100.00%	22	100.00%		
Left Lane Closed	SC	3	3.30%	11	3.60%	0	0.00%	4.30%	3.50%
	INJ	33	36.70%	103	33.30%	14	28.00%	31.00%	26.50%

	PD	57	63.30%	206	66.70%	36	72.00%	69.00%	73.50%
	Total	90	100.00%	309	100.00%	50	100.00%		
Left Shoulder Closed	SC	0	0.00%	6	2.90%	1	4.80%	4.30%	3.50%
	INJ	7	24.10%	58	28.00%	5	23.80%	31.00%	26.50%
	PD	22	75.90%	149	72.00%	16	76.20%	69.00%	73.50%
	Total	29	100.00%	207	100.00%	21	100.00%		
Median Turn Lane Closed	SC	1	5.60%	0	0.00%	0	0	4.30%	3.50%
	INJ	8	44.40%	1	25.00%	0	0	31.00%	26.50%
	PD	10	55.60%	3	75.00%	0	0	69.00%	73.50%
	Total	18	100.00%	4	100.00%	0	0		
Moving Full Closure	SC	0	0	0	0.00%	0	0.00%	4.30%	3.50%
	INJ	0	0	1	50.00%	0	0.00%	31.00%	26.50%
	PD	0	0	1	50.00%	2	100.00%	69.00%	73.50%
	Total	0	0	2	100.00%	2	100.00%		
Moving Lane Closure	SC	0	0	5	14.30%	0	0.00%	4.30%	3.50%
	INJ	0	0	12	34.30%	5	23.80%	31.00%	26.50%
	PD	0	0	23	65.70%	16	76.20%	69.00%	73.50%
	Total	0	0	35	100.00%	21	100.00%		
Off Roadway Left	SC	0	0.00%	1	9.10%	0	0.00%	4.30%	3.50%
	INJ	0	0.00%	3	27.30%	0	0.00%	31.00%	26.50%
	PD	1	100.00%	8	72.70%	1	100.00%	69.00%	73.50%
	Total	1	100.00%	11	100.00%	1	100.00%		
Off Roadway Right	SC	0	0.00%	3	25.00%	0	0.00%	4.30%	3.50%
	INJ	2	100.00%	5	41.70%	0	0.00%	31.00%	26.50%
	PD	0	0.00%	7	58.30%	2	100.00%	69.00%	73.50%
	Total	2	100.00%	12	100.00%	2	100.00%		
Right Lane Closed	SC	2	2.40%	14	4.30%	2	5.30%	4.30%	3.50%
	INJ	30	36.10%	107	32.90%	16	42.10%	31.00%	26.50%
	PD	53	63.90%	218	67.10%	22	57.90%	69.00%	73.50%
	Total	83	100.00%	325	100.00%	38	100.00%		
Right Shoulder Closed	SC	2	4.20%	11	3.20%	0	0.00%	4.30%	3.50%
	INJ	17	35.40%	106	31.30%	11	35.50%	31.00%	26.50%
	PD	31	64.60%	233	68.70%	20	64.50%	69.00%	73.50%
	Total	48	100.00%	339	100.00%	31	100.00%		
Single Lane Closed	SC	2	4.30%	15	5.80%	2	4.70%	4.30%	3.50%
	INJ	11	23.90%	83	32.20%	9	20.90%	31.00%	26.50%
	PD	35	76.10%	175	67.80%	34	79.10%	69.00%	73.50%

	Total	46	100.00%	258	100.00%	43	100.00%		
Various Lanes Closed	SC	2	9.10%	7	6.50%	1	7.70%	4.30%	3.50%
	INJ	13	59.10%	30	28.00%	3	23.10%	31.00%	26.50%
	PD	9	40.90%	77	72.00%	10	76.90%	69.00%	73.50%
	Total	22	100.00%	107	100.00%	13	100.00%		
Total		539		2264		344			

Crash Time Distribution

This section address the second question from the Introduction by studying crashes that occurred before and after the work zone scheduled hours of operation. In general, this analysis is independent of the previous spatial analysis, but is related by the overall need to review safety risks associated with lane closure scheduling and operations decisions.

Table 8 shows crashes before and after the scheduled hours of work zones for the four closure duration types. If there are actual work zone activities outside of the scheduled hours, and such impacts are independent of the work zone duration, the percentage of the crashes should be similar to the percentage of the work zones. However, it shows that Continuous, Long Term and Weekly closures have relatively fewer crashes before and after the scheduled hours compared to the corresponding work zone percentage. The Daily/Nightly closures have increased portion of crashes before and after the scheduled hours. There are two possible reasons: 1) the reported hours are inaccurate and 2) there are actual work zone activities outside of formal hours such as setup and breakdown activities that have pose a safety risk. For planning purposes, there is safety impact beyond the official hours, especially for short term closures. Travelers are not well informed by 511/media release. For reporting and situational awareness, a buffer time should be suggested.

Table 8 Crash Before and After Work Zone

Work Zone Duration	Number of Work Zones		Crashes Before Work Zone Starts		Crashes After Work Zone Ends	
	Count	%	Count	%	Count	%
Continuous	2399	7.8%	6	6.7%	6	4.9%
Daily/Nightly	26472	85.8%	81	91.0%	110	90.2%
Long Term	1558	5.1%	1	1.1%	5	4.1%
Weekly	409	1.3%	1	1.1%	1	0.8%
Total	30838	100.0%	89	1	122	1

DISCUSSION

This study clearly indicates that work zones impact safety outside of the reported physical boundaries and scheduled hours of operations. Some of the findings would be expected by experienced safety engineers. However, this study demonstrated how the situation it is in a systematic way using quantitative results. Furthermore, the quantitative analysis brings us some new knowledge. In particular, crashes occurring upstream from a work zone in many cases have a higher risk of overall and severe injury. Although crashes downstream from a work zone are less severe in general, some particular types of closures, such as Full Closure (Table 7), have the highest severity level in that category. All these findings would serve as the start point for future safety analysis.

Although identifying crash risk factors in the proximity of work zones still relies on future work, some recommendations can be made now to enhance the current work zone information systems and improve work zone safety. First, work zone information systems could include some spatial and temporal buffering for reporting and monitoring purpose. Second, since crash severities outside of work zones are even higher than within the work zone, enhancing signing and implementing ITS lane control devices upstream and downstream from the work zone would be a cost effective way to improve work zone safety.

CONCLUSIONS AND FUTURE WORK

This study conducts an analysis of safety risks in the proximity of work zones. The Wisconsin Lane Closure System and the MV4000 Crash Data Retrieval Facility, both part of the WisTransProtal system at the University of Wisconsin-Madison TOPS Laboratory, provide the necessary data for this study. A matching algorithm is used to relate work zone crashes with the corresponding work zones, which relies on the underlying linear referencing system used to manage location information in the two datasets. Based on the results, it is clear that work zones do cause safety concerns outside of the physical boundaries (upstream and downstream) and scheduled time periods (before and after the reported operation hours). In some scenarios, those crashes occurring outside of work zones even have a higher risk of overall and severer injury. Some suggestions are also made based on the findings to improve work zone safety and enhance work zone reporting monitoring in the future.

Some future work is suggested. Firstly, the risk factors related to work zone crashes outside of work zones need to be identified. Secondly, although some measures to enhance the work zone reporting and improve work safety are suggested in this study, looking for the best measure or measure combination for different work zone scenarios would be a long term task.

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