Enhanced Analysis of Work Zone Safety Through Integration of Statewide Crash and Lane Closure System Data

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Highway work zones interrupt regular traffic flow and lead to more severe types of crashes, as shown by many studies. In 2009 alone, more than 600 fatalities nationally were work zone related. Analysis of work zone safety can help to identify the risk factors and improve safety; such an analysis requires the consideration of a variety of data sources, including the frequency of crashes in and around a work zone and specific work zone characteristics. The traditional approach, in Wisconsin and many other states, has relied on the presence of a construction zone flag in the crash report and information from targeted work zone studies. The crash report provides a macroscopic view of work zone crashes but does not provide details about the work zones, except when noted in the police officer's narrative description. Targeted work zone studies provide a wealth of information for specific work zones but are limited in number and scope. The Wisconsin Lane Closure System (WisLCS), a centralized scheduling and reporting system for highway lane closures statewide, provides a new opportunity to match crashes to specific work zones on a systemwide level. This paper investigated the ability to match highway crash records from the Wisconsin Department of Transportation to WisLCS lane closure records. A preliminary analysis of work zone safety based on WisLCS closure attributes is presented and verifies the benefits of integrating work zone information. This knowledge can lead to safer work zone operations and planning decisions. The general ideas of this study can also be applied to any similar sets of crash and work zone data.

The presence of work zones interrupts regular traffic flow patterns. Many researchers recognize that such impacts can lead to safety concerns (*1, 2*). Work zone safety analysis can help to identify the risk factors and improve work zone safety. Effective work zone safety analysis requires the consideration of a variety of data sources, including the frequency of crashes in and around a work zone, driver and environmental factors, and work zone characteristics. Current research has used a variety of statistical methods to investigate the relationship between recorded work zone crashes and work zone attributes (*3–5*). The results from several crash characteristic studies demonstrate that human errors, such as following too closely, inattentive driving, and misjudging, can increase the risk of work zone crashes (*3*). These methods rely on a comprehensive knowledge of the crashes and the work zones. However, many of these factors are not fully understood, partially because of the insufficient knowledge of the work zone situations. Only a few studies have investigated the work zone attributes related to the crashes (*5*).

Fundamental to work zone safety analysis is the ability to match crashes to work zones. The traditional approach in Wisconsin, as in many states, has relied on the listing of a construction zone flag in the police crash report and on information from targeted work zone studies. The crash report provides a macroscopic view of work zone crashes but does not provide details about the work zones themselves, except when noted in the police officer's narrative description. Targeted work zone studies provide a wealth of information about specific work zones but are limited in number and scope. The deployment of modern transportation information systems, many of which have geospatial capabilities, has improved the ability to manage and retrieve historical transportation data. However, these systems are often oriented toward specific application areas, such as crash data or construction project planning information. An investigation of work zone safety needs work zone and crash details. Therefore, it is necessary to develop ways to integrate data across systems, in particular with respect to the time of day and the geospatial attributes. Matching crash data to work zone data is a fundamental first step in this broader analysis.

The Wisconsin Lane Closure System (WisLCS) provides a centralized scheduling and reporting system for highway lane closures statewide (*6*). The system was developed through funding from the Wisconsin Department of Transportation (DOT) Bureau of Highway Operations. The WisLCS provides a new opportunity to match crashes to specific work zones on a systemwide scale. This paper investigates the ability to match manually located highway crashes from the Wisconsin DOT MV4000 crash database (*7*) to lane closure records in the WisLCS. The underlying methodology is based on the Wisconsin DOT state trunk network (STN) linear referencing system, which provides a common geographic information system (GIS) network of state-maintained highways for both data sets. A preliminary analysis of highway work zone safety based on WisLCS closure attributes is presented to demonstrate the methodology. This study addresses three questions that are basic to this analysis:

1. How can WisLCS work zone records be properly correlated to Wisconsin DOT MV4000 crashes? Although WisLCS closure records and MV4000 highway crash records are located in the STN, retrieving the correct work zone for a specific crash is not always

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Transportation Research Record: Journal of the Transportation Research Board, No. 2291, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 17–25.
DOI: 10.3141/2291-03

straightforward. A variety of factors, including data quality, work zone scheduling, and the physical proximity of a crash to the work zone, affect the overall matching algorithm.

2. Can the WisLCS provide useful details about work zone characteristics for the purpose of crash analysis? Work zone information in the crash report is currently limited to a construction zone check box and potential narrative information in the crash report description. In some cases, (e.g., for larger work zones), it is also possible to review the work zone engineering project plan and the Wisconsin DOT traffic management plan, if one exists. The WisLCS, however, captures a variety of location, scheduling, and lane impact attributes for all closures, regardless of duration or type, which could provide valuable information to a postcrash analysis.

3. Can the WisLCS provide a way to monitor work zone safety on a systematic level? The automation of the linkage between the crash data and lane closure databases provides an enhanced capability to monitor work zone safety, especially for long-term work zones and construction projects, for which the initial crash report data may become available while the project is still active. This linkage also provides an opportunity to improve traffic safety surveillance at a traffic operations center by integrating crash risk factors into the lane closure data (e.g., to enable a real-time traffic operations system to detect areas of risk based on real-time work zone conditions and characteristics).

DATA SOURCES

The work zone and crash data used in this study derive from two sources: the WisLCS and the Wisconsin MV4000 crash database, both of which are available through the WisTransPortal system at the University of Wisconsin–Madison Traffic Operations and Safety Laboratory (*8*).

Wisconsin Lane Closure System

The WisLCS serves as a central acceptance and reporting system for all highway lane closures and restrictions statewide. Operational since April 2008, the WisLCS facilitates the monitoring of work zone activities at the Wisconsin DOT Statewide Traffic Operation Center and regional transportation offices, provides real-time lane closure information to the Wisconsin 511 traveler information system, and supports Wisconsin DOT oversize–overweight permitting activities. All construction, maintenance, utility, and other planned or unplanned closures on the Wisconsin highway system are recorded in the WisLCS in a detailed format. The WisLCS fully integrates the Wisconsin DOT's STN GIS linear referencing system to locate closures on the highway and to provide interoperability with other GIS- and map-based systems.

All WisLCS records are archived in the WisTransPortal for research and planning purposes. This archive includes detailed work zone information for each closure. In addition to location and time, other work zone attributes are also available, as shown in Table 1.

Although most of the terms in Table 1 are self-explanatory, a few bear further explanation. For the closure type attribute, "permit" closures refer to utility work, and "emergency" closures refer to unplanned infrastructure repair caused by incidents such as bridge hits. "Special event" closures, which refer to road closures from planned events such as parades, were not covered in this analysis. The duration attribute, which describes the hours of operation of a work zone, is described in further detail later.

TABLE 1 Work Zone Details in WisLCS

Attribute	Values
Closure type	Construction, maintenance, permit, special event, emergency
Duration	Long term, continuous, weekly, daily or 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

The WisLCS was designed to streamline work zone operation and scheduling decisions and provide better information to 511, oversize–overweight truck permitting, and related real-time systems (*9*). As an acceptance system, all highway closures and restrictions must be entered into the WisLCS before the closure start date. Updates to closure schedules and other details are also entered into the system in near real time. As such, the WisLCS is believed to provide a comprehensive, highly accurate database of statewide highway lane closures in Wisconsin.

Wisconsin MV4000 Crash Data

Wisconsin MV4000 traffic accident data from 1994 onward can be accessed via the WisTransPortal crash data retrieval facility (*7*). This database contains information on all police-reported crashes in Wisconsin, including the location of each crash, the vehicles involved, and the general crash attributes. The Traffic Operations and Safety Laboratory maintains this database for research purposes and as a service to the Wisconsin DOT. The WisTransPortal crash database is updated on a monthly basis from extracts provided by the Wisconsin DOT Division of Motor Vehicles.

Highway-related MV4000 crashes are manually geocoded by the Wisconsin DOT Division of Motor Vehicles to the STN on an annual basis. The Wisconsin MV4000 police report also has a check box to indicate whether a crash occurred in a work zone. This attribute is stored with each crash record as a construction zone flag in the crash database.

Location Coding of WisLCS and MV4000

The locations of highway crashes and work zones in the two systems are coded to the Wisconsin STN, the Wisconsin DOT's GIS-based linear referencing system for state and federal highways in Wisconsin. The common location coding makes it possible to match the locations of crashes to corresponding work zones.

Location Fundamental: STN

To describe the matching algorithm developed in this paper, it is worthwhile to first introduce the STN. "The STN is a collection of State, Interstate, and National Highways that support the Roadway Infrastructure of . . . [the] State of Wisconsin" (*10*). The STN is maintained by the Wisconsin DOT as a linear referencing system in a collection of ESRI spatial data files and database tables (*11, 12*).

STN source data are organized into two categories: the location control management (LCM) tables and the STN inventory tables. The LCM tables contain the core STN spatial information—links, chains, and routes—that define the basic network structure. A roadway link is a logical connection between two reference sites (nodes) and represents a measured, real world distance along a linear feature (roadway). A roadway link is also directional and is defined by the "from" and "to" reference sites. A reference site is a physically identifiable position along a linear feature (roadway) that represents an at-grade intersection or a location at which a traffic path can merge or diverge. Whereas links are straight-line representations of the highway network, chains capture the cartographic representation of the system. Routes include the list of all U.S., Interstate, and state highways in the STN.

The STN inventory tables contain data that include roadway intersections (access points), mile posts, bridges, and county boundaries. The STN GIS was designed as a linear referencing system. In particular, all information in the STN is related through association with one or more LCM links. The LCM roadway route link table describes the linear path of a route through the network by defining the ordered sequence of links that a given route traverses. For example, the location of a bridge record in the bridge table is defined with respect to a particular LCM link and link offset. With link and link-offset information, inventory data can be fully described with respect to roadway route, county, and proximity to other inventory data.

How Work Zones Are Located in WisLCS

Location information is a required attribute of every closure record in the WisLCS. Closures can be modeled either by a single control point or by two control points. Closures that can be modeled by a single point include ramp and bridge repairs. Closures that are modeled by two control points include mainline closures that have identified beginning and end locations along a highway segment (e.g., US 63 southbound from 80th Avenue to 55th Avenue). Therefore, the location of closures in the WisLCS comes down to assigning control points on the roadway.

In the WisLCS, control points are implemented through a system of fixed landmarks. A landmark is defined as a physical, identifiable point on a highway, such as an intersection, milepost, bridge, or a virtual point, such as a county boundary line over a highway. The WisLCS landmarks are generated from the STN inventory (access points, mileposts, bridges, etc.) to provide end users with a set of recognizable locations by which to enter closure extents. The set of landmarks is updated on an annual basis to capture changes to the underlying STN.

The essential idea is that WisLCS landmarks, which are derived from the STN inventory, have distinct LCM link and link-offset values. As such, all lane closure extents in the WisLCS are described within the STN in terms of their beginning and ending LCM link and offset values based on their associated beginning and ending landmark locations.

In most cases, the use of fixed landmark locations provides highly accurate STN locations for lane closures. However, since landmark control points are used as reference points in the WisLCS, the notion of "offset" from a landmark is also important. In the WisLCS, offsets comprise a direction and a distance associated with a specific landmark. Offset information is optional and would be used when there is no suitable landmark by which to locate a closure.

How MV4000 Highway Crashes Are Mapped

As noted above, the MV4000 crash report provides location information in terms of relative offset from an intersection on the basis of on- and at-street name information, which identifies the intersection as well as the direction and distance information. Highway crashes are subsequently hand mapped to STN links (offsets on links are also defined) by Wisconsin DOT Division of Motor Vehicle personnel. The crash mapping process is similar to how the WisLCS lane closures are located: the Wisconsin DOT maintains an internal set of reference points that model physical attributes along the highway system (generally access points and ramps). Each reference point is located within the STN by assignment to a distinct LCM link and offset. MV4000 highway crashes are coded in terms of highway, direction, and relative offset to a reference point. This in turn resolves to specific LCM link and offset values for a given crash. Although there may be some highway crashes that cannot be mapped, the proportion is quite low.

RETRIEVAL OF CRASH-RELATED WORK ZONES

To find the potential work zone associated with a given crash, the time and location attributes should match. Obtaining a match for either attribute is not as straightforward as might be expected.

Matching Time Attributes

The WisLCS includes four duration types to capture the different schedule scenarios that may occur:

- Daily or nightly. The time of operation occurs on a daily or nightly basis as specified by the starting and ending times on each day within the start date and end date range. For example, if a daily or nightly work zone is listed as being from October 1, 2010, to November 15, 2010, from 2:00 to 5:00 p.m., the cones are dropped at 2:00 p.m. each day and picked up at 5:00 p.m. each day.
- Weekly. The time of operation occurs on a weekly basis as specified by the starting and ending day of the week. For example, if a weekly work zone is listed as being from October 1, 2010, to November 15, 2010, from Monday at 2:00 p.m. to Friday at 5:00 p.m., the cones are dropped at 2:00 p.m. every Monday and picked up at 5 p.m. every Friday for each week within the start date and end date range.
- Continuous. The time of operation is a 24-h work zone lasting less than 2 weeks. For example, if a continuous work zone is listed as being from October 1, 2008, at 9:00 a.m. to October 4, 2008, at 2:00 p.m., the cones are dropped at 9:00 a.m. on October 1 and picked up at 2:00 p.m. on October 4.
- Long term. The time of operation is a 24-h work zone lasting longer than 2 weeks. Because start time and end time are difficult to determine in practice, if a crash occurs on the first or last day of the work zone period, there is a gray area for determining whether the crash occurred when the work zone was active.

The WisLCS is also able to assign schedule override periods. A schedule override adds an exception to the duration element by indicating specific times during which the work zone will not be in effect. For example, a continuous work zone from July 1 to July 20 may have a schedule override on July 4 to indicate that the work zone will not be in effect on the July 4 national holiday. Any work zone can have multiple override periods.

Matching Location Attributes

A work zone is defined by a beginning landmark and an ending landmark; some work zones, such as those for bridge maintenance, use only one landmark. The landmarks are predefined points in the STN. The location of the crash, relative to the work zone, can be categorized as (*a*) on the same highway, (*b*) on the intersecting highway, or (*c*) on the ramp, as demonstrated in Figure 1.

A common scale is needed to compare the locations; the cumulative mileage of the landmarks (for work zones) is used for this scale, as well as the crash location on the associated highways. Another consideration is that the queue that forms before a work zone is one of the contributing factors to work zone crashes; the scale should include this distance. Because the STN is a linear referencing system, the calculation of cumulative mileage is possible:

$$M_p = M_L + L_{\text{offset}} \tag{1}$$

where

- M_p = mileage of any point in STN, such as landmarks and crash location points;
- M_L = mileage of beginning point of corresponding STN link; and
- L_{offset} = link offset, distance from beginning of link to point.

The mileage of the beginning point of an STN link is

$$M_L = \sum_{\{i\}} L_i \tag{2}$$

where L_i is the travel distance of STN link *i*, and $\{i\}$ is the set of all the links upstream of the target link. The STN contains the information to order these links in the traveling direction on a specific highway.

Case 1. On Same Highway

If the crash and the work zone are on the same highway, the case is straightforward. For a segment work zone to be related to a specific crash, it needs to satisfy

$$\begin{cases} M_{\text{begin}} - b_u \le M_{\text{acc}} \\ M_{\text{end}} + b_d \ge M_{\text{acc}} \end{cases} \tag{3}$$

where M_{begin}, M_{end}, and M_{acc} are the mileages of the beginning landmark, the ending landmark, and the crash, respectively, and b_u and b_d are the distance buffers, upstream and downstream, respectively.

For a point work zone

$$\begin{cases} M_w - l_u - b_u \le M_{\text{acc}} \\ M_w + l_d + b_d \ge M_{\text{acc}} \end{cases} \tag{4}$$

where M_w is the mileage of the work zone location, and l_u and l_d are the estimated impact areas of the work zone, upstream and downstream, respectively. A point work zone is a short segment on the road, although it is coded as a point in the system. In this study, based on empirical investigation, $l_u = l_d = 0.25$ mi.

Case 2. On Intersecting Highway

When the crash occurs near an intersection, the crash and the work zone are often located on the two intersecting roads. In this case, for a segment work zone

$$\begin{cases} M_{\text{begin}} \le M_{\text{int}} \\ M_{\text{end}} \ge M_{\text{int}} \end{cases} \tag{5}$$

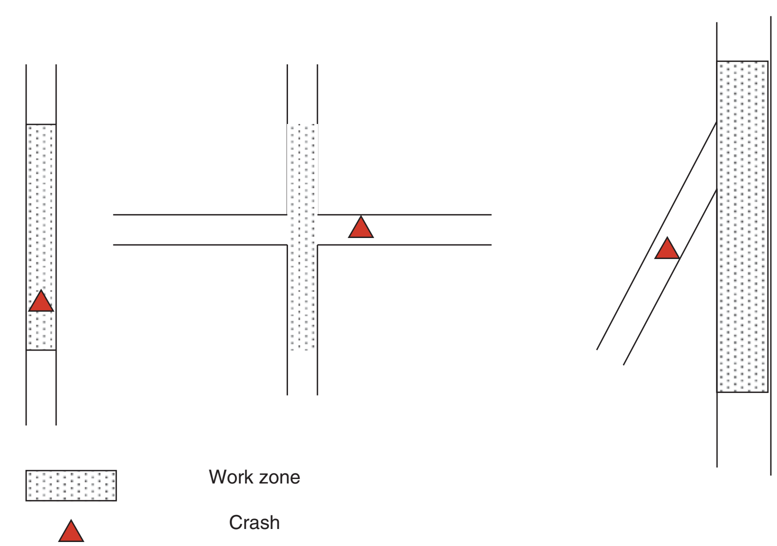

FIGURE 1 Locations of work zones and crashes.

where M_{int} is the mileage of the intersection of the two highways. No buffer area is used in this case.

For a point work zone

$$\begin{cases} M_w - l_u \leq M_{int} \\ M_w + l_d \geq M_{int} \end{cases} \tag{6}$$

Case 3. On a Ramp

If the crash occurs on a ramp close to the work zone, then for a segment work zone

$$\begin{cases} M_{begin} \leq M_{ramp} \\ M_{end} \geq M_{ramp} \end{cases} \tag{7}$$

where M_{ramp} is the mileage of the point at which the ramp connects to the highway. No buffer area is used in this case.

For a point work zone

$$\begin{cases} M_w - l_u \leq M_{ramp} \\ M_w + l_d \geq M_{ramp} \end{cases} \tag{8}$$

RESULTS: SUMMARY AND ANALYSIS

This section presents the results of the matching algorithm, along with a systematic analysis of work zone safety.

Matching Results

There were 1,517 work zone crashes recorded in the MV4000 database for 2009 to 2010, of which 1,262 crashes could be associated with work zones in the WisLCS through the matching algorithm. The overall matching rate was 83.2%. The categories of these crashes are shown in Table 2.

Most work zone crashes happened within a work zone, which was consistent with the expectation. In addition, crashes that occurred upstream of a work zone were about four times more frequent than crashes that occurred downstream. This finding may be related to the fact that the queue or abnormal traffic flow pattern before work zones is one of the most important contributing factors to work zone crashes.

TABLE 2 Summary of Crash Geometry

Geometry with Work Zone	Crash Frequency
Upstream (1–2 mi)	42
Upstream (within 1 mi)	173
Within work zone	830
Downstream (within 1 mi)	40
Downstream (~2 mi)	31
Crossing	116
Ramp	30
Total	1,262

The severity category for all crashes, work zones crashes, and matched work zone crashes is shown in Table 3. Severe crashes, defined as the combination of fatal (K) and incapacitating (A) crashes, comprised less than 5% of the total for all three categories, but the severity of work zone crashes (in terms of severe crashes) was higher than was the general case. This table also demonstrates that the distribution of the matched crashes, which were the focus of the analysis, retained basically the same distribution as the construction zone crashes in the MV4000 database.

The causes of unmatched work zone crashes may include

1. Crash mapping errors: local road crashes that happened on a local road near a highway that were hand mapped to an STN highway;
2. Local work zones: crashes that happened on ramps that the police officers judged to be work zone related; and
3. Report coding errors: the MV4000 record does not match the original report.

Work Zone Safety Analysis

The following analysis covers three primary closure attributes from the WisLCS:

- Duration: the hours of operation of a work zone,
- Closure type: the type of work zone or construction project, and
- Lane details: specific work zone configurations from an operational context.

Each of the work zone attributes was analyzed in two ways. In the first case, work zone attributes were compared with respect to

TABLE 3 Crash Severity

Severity Category	All Crashes		Work Zone Crashes		Matched Crashes	
	Count	Percentage	Count	Percentage	Count	Percentage
K	447	0.6	10	0.7	8	0.6
A	2,482	3.1	52	3.4	46	3.7
B	7,335	9.0	141	9.3	107	8.5
C	11,540	14.2	263	17.3	207	16.4
PD	59,621	73.2	1,051	69.3	894	70.8
Total	81,425	100.0	1,517	100.0	1,262	100.0

NOTE: K = fatal; A = incapacitating; B = nonincapacitating; C = possible; PD = property damage.

TABLE 4 Crash Severity by Work Zone Duration

Duration	K (%)	A (%)	B (%)	C (%)	PD (%)	Total	K+A (%)
Continuous	1.2	3.3	8.2	16.8	70.5	244	4.5
Daily or nightly	0.4	4.0	9.2	14.4	72.0	250	4.4
Long term	0.4	3.7	8.3	17.6	70.0	709	4.1
Weekly	1.7	3.4	8.5	8.5	78.0	59	5.1
Combined	0.6	3.7	8.5	16.4	70.8	1,262	4.3

crash severity. In the second case, work zone attributes were compared based on three proposed rate categories; each of the rates is defined below.

Analysis of Crash Severity for Different Types of Work Zones

Table 4 shows the crash severity in terms of work zone duration. All four duration groups have similar proportions of fatal plus incapacitating (K + A) crashes, although weekly work zones may have higher chances of crash occurrence.

All severe work zone crashes are related to construction and maintenance work zones, as shown in Table 5. Maintenance work zones have the largest percentage of both K and A crashes, which may indicate that this type of zone is the most dangerous. Possible explanations could be that construction work zones are usually long term, and the traffic would get familiar with the work zones, whereas maintenance work zones are usually short term and could be a totally new driving environment for drivers. In addition, work zone safety countermeasures may be better conducted for construction work zones because, intuitively, those work zones are considered more dangerous. Permit closure zones have the lowest percentage of property damage but make up for that in terms of minor injury crashes.

Because one crash may be matched to more than one work zone, the combined number of total crashes shown in Table 6 is more than the totals in Tables 4 and 5. The distinct crashes are the same, however, and the proportions indicate reliable information.

In this analysis, moving lane closures, off-roadway (right), and flagging operation closures stand out as the most dangerous in terms of the K and A crash categories. Why these closure types show a higher crash severity is worthy of further investigation. In general, moving lane closures and flagging operations do not have a fixed work zone area and may lead to more unpredictable traffic patterns. Off-roadway (right) closures may give work zone personnel a false sense that these closures are safer than those on the road. The crash reports and WisLCS closure records provide an opportunity to further investigate the details and nature of these types of work zones to identify potential causes and develop countermeasures.

Analysis of Crash Occurrence Rates

In this section, the safety levels of different types of work zone are investigated. Because different types of work zones have different average time periods and lengths, the simple number of crashes in each type of work zone may not be an accurate indicator of safety. Therefore, three types of crash occurrence rates are defined and used: Rate 1 is the number of crashes per thousand work zones; Rate 2 is the number of crashes divided by the total duration (years) of the work zones; Rate 3 is the number of crashes divided by the total duration (years) and the total length (thousand miles) of the work zones. A higher rate indicates a more dangerous work zone category in terms of overall crash risk.

In Table 7, the Rate 1 column shows that long-term work zones have the highest rate of crash occurrence. This leads to an implication that long-term work zones are the most unsafe work zones, which is consistent with the findings in Table 4. However, long-term work zones have more traffic and exposure because of their much longer operating times and longer segment lengths. The Rate 2 and 3 columns indicate that these zones are not as dangerous as they appear at first inspection. The Rate 1, 2, and 3 columns in Tables 8 and 9 also show different aspects about the safety of each type of work zone.

Table 8 shows the rates of crashes for different types of work zone. Construction work zones are usually long term and located on long segments of roads. Similar to long-term zones, as shown in Table 7, the Rate 1 of construction zones is much higher than for the other zones; however, the Rate 2 column indicates that construction work zones are not that dangerous, and the Rate 3 column even implies that they may be quite safe.

Median turn lane closed, off-roadway (left), and off-roadway (right) closures represent the closure configurations with the highest crash risk with respect to Rate 3. The inconsistency of the three rates of crash occurrence is an interesting finding; the evaluation of work

TABLE 5 Crash Severity by Type of Work Zone

Duration	K (%)	A (%)	B (%)	C (%)	PD (%)	Total	K+A (%)
Construction	0.6	3.7	8.5	16.1	71.2	1,084	4.2
Emergency	0.0	0.0	0.0	14.3	85.7	14	0.0
Maintenance	1.5	4.4	8.0	16.7	69.6	138	5.8
Permit	0.0	0.0	15.4	30.8	53.9	26	0.0
Combined	0.6	3.7	8.5	16.4	70.8	1,262	4.3

TABLE 6 Crash Severity by Work Zone Lane Details

Lane Condition	K (%)	A (%)	B (%)	C (%)	PD (%)	Total	K+A (%)
Full closure	0.3	3.8	6.8	17.7	71.5	368	4.1
Two left lanes closed	0.0	0.0	7.9	14.3	77.8	63	0.0
Two right lanes closed	0.0	0.0	3.5	10.3	86.2	29	0.0
Flagging operation	4.2	4.2	20.8	16.7	54.2	24	8.3
Lane restriction	0.9	3.0	9.8	11.5	74.9	235	3.8
Left lane closed	0.4	3.4	8.9	16.6	70.6	235	3.8
Left shoulder closed	0.5	1.8	7.3	21.4	69.1	220	2.3
Median turn lane closed	0.0	0.0	0.0	0.0	100.0	3	0.0
Moving full closure	0.0	0.0	0.0	0.0	0.0	0	0.0
Moving lane closure	0.0	18.2	9.1	9.1	63.6	22	18.2
Off roadway (left)	0.0	7.1	7.1	7.1	78.6	14	7.1
Off roadway (right)	0.0	14.3	7.1	7.1	71.4	14	14.3
Right lane closed	0.7	3.1	8.5	18.3	69.5	295	3.7
Right shoulder closed	1.0	1.5	8.1	19.8	69.5	197	2.5
Single lane closed	0.4	3.5	9.1	13.9	73.2	231	3.9
Various lanes closed	0.0	4.8	11.3	16.1	67.7	62	4.8
Combined	0.6	3.2	8.4	16.6	71.3	2,012	3.7

TABLE 7 Crash Rates by Work Zone Duration

	Total Work Zone		Crash Number		Crash Rate		
Duration	Count	Percentage	Count	Percentage	1	2	3
Continuous	1,719	7.5	244	19.3	141.94	2.58	0.89
Daily or nightly	19,551	85.0	250	19.8	12.79	2.00	0.04
Long term	1,363	5.9	709	56.2	520.18	2.09	0.91
Weekly	380	1.7	59	4.7	155.26	3.08	1.83

TABLE 8 Crash Rates by Type of Work Zone

	Total Work Zone		Crash Number		Crash Rate		
Type of Work Zone	Count	Percentage	Count	Percentage	1	2	3
Construction	14,293	62.1	1,084	85.9	75.84	2.11	0.09
Emergency	347	1.5	14	1.1	40.35	1.50	2.63
Maintenance	7,071	30.7	138	10.9	19.52	4.60	0.25
Permit	964	4.2	26	2.1	26.97	1.01	1.38

zone safety levels would require a very comprehensive knowledge about all of the important attributes of the work zone. Thanks to the integration of the lane closure operation data and crash reports, more information than usual is available in this study.

DISCUSSION: OTHER ISSUES OF NOTE

Unmatched Crashes

There is a small portion of work zone crashes with no matched work zone. By manually checking the original police report, some causes of the lack of matching have been identified, as stated earlier in the paper.

Potential Work Zone–Related Crashes

The application of the method presented for work zone crashes allows detailed information about the work zone to be retrieved and the risk factors analyzed. However, when this method is applied to all crashes, crashes may be found that are related to work zones but do not have a construction flag; this circumstance was verified in a preliminary pilot study conducted by the authors.

The investigation of these issues, as part of the future work, could lead to methods that provide an alternative for the evaluation of data quality in the MV4000 crash report database and the WisLCS and could enhance the ability to track work zone crashes on a systematic level.

TABLE 9 Crash Rates by Work Zone Lane Details

	Total Work Zone		Crash Number		Crash Rate		
Lane Condition	Count	Percentage	Count	Percentage	1	2	3
Full closure	5,657	24.6	368	29.2	65.05	1.75	0.39
Two left lanes closed	1,019	4.4	63	5.0	61.83	20.07	12.61
Two right lanes closed	757	3.3	29	2.3	38.31	12.77	12.74
Three left lanes closed	6	0.03	0	0.0	0.00	0.00	0.00
Three right lanes closed	20	0.09	0	0.0	0.00	0.00	0.00
Flagging operation	1,014	4.4	24	1.9	23.67	0.65	0.19
Lane restriction	282	1.2	235	18.6	833.33	4.63	15.98
Left lane closed	3,487	15.2	235	18.6	67.39	6.48	1.07
Left shoulder closed	759	3.3	220	17.4	289.86	8.35	4.35
Median turn lane closed	36	0.2	3	0.2	83.33	2.05	93.21
Moving full closure	70	0.3	0	0.0	0.00	0.00	0.00
Moving lane closure	1,315	5.7	22	1.7	16.73	0.81	0.08
Off roadway (left)	26	0.1	14	1.1	538.46	4.31	146.39
Off roadway (right)	44	0.2	14	1.1	318.18	3.75	36.04
Passing lane closed	39	0.2	0	0.0	0.00	0.00	0.00
Right lane closed	3,825	16.6	295	23.4	77.12	7.61	1.20
Right shoulder closed	1,493	6.5	197	15.6	131.95	4.61	1.28
Single lane closed	1,971	8.6	231	18.3	117.20	3.43	0.55
Various lanes closed	1,193	5.2	62	4.9	51.97	2.31	0.38

CONCLUSION AND FUTURE WORK

The development of a better understanding of work zone crash history and the nature of high-risk work zones is essential to incorporate meaningful and effective safety considerations into work zone planning and operations. Work zone safety research and planning have traditionally relied on an analysis of historical crash data at a given work zone location or a comparison of work zones with similar characteristics. Work zone safety monitoring, however, has generally relied on enforcement activities and, more recently, on the placement of traffic cameras and other sensor devices at the site. The WisTransPortal system at the University of Wisconsin–Madison Traffic Operations and Safety Laboratory provides two useful tools, the MV4000 crash data retrieval facility and the WisLCS, that enable the analysis of work zone–related crashes. Based on the time and location matching algorithm, crashes and work zones can be correlated. Therefore, three types of applications are possible:

1. An alternative way to identify work zone–related crashes that does not rely solely on the police crash report,
2. The ability to monitor work zone safety on a systematic level and within the lane closure approval process, and
3. The ability to bring more detailed information about specific work zones to the analysis.

In this paper, the verification of such applications was provided by a proposed location-matching algorithm that related crashes and work zones from the MV4000 crash database and the WisLCS, respectively. A systematic work zone safety analysis was also provided for selected WisLCS work zone attributes. From this study, it is concluded that a comprehensive work zone database, such as the WisLCS, can serve as a valuable data source to facilitate work zone safety research. Although the methodology introduced is specific to these two databases, the general ideas can be applied to any similar sets of crash and work zone systems.

Future work can be foreseen as follows. First, an investigation into whether the WisLCS can provide an alternative way to identify highway work zone–related crashes. Work zone crashes are currently identified by the listing of a construction zone flag in the crash report. This identification relies on the police officer's judgment at the crash scene. The WisLCS can provide validation of the police report in this sense. Second, it has been found that the traffic flow rate and the weather conditions have a significant impact on work zone crashes. Such data are also accessible from the WisTransPortal; the integration of these data sources would provide even more comprehensive knowledge about the risk factors affecting work zone crashes.

ACKNOWLEDGMENT

The Wisconsin Lane Closure System and the WisTransPortal MV4000 crash database were developed through the sponsorship of and the collaboration with the Wisconsin DOT Bureau of Traffic Operations.

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The Statewide Transportation Data and Information Systems Committee peer-reviewed this paper.