Enhanced Analysis of Work Zone Safety through Integration of Statewide Crash Data with Lane Closure System Data

Yang Cheng, Ph.D.
Research Associate
Department of Civil and Environmental Engineering
University of Wisconsin – Madison
Cheng8@ wisc.edu

Steven T. Parker, Ph.D.
IT Program Manager
Traffic Operations and Safety (TOPS) Laboratory
Department of Civil and Environmental Engineering
University of Wisconsin – Madison
sparker@engr.wisc.edu

Bin Ran, Ph.D.
Professor
School of Transportation, Southeast University
No.2 Si Pai Lou, Nanjing 210096, China
and
Civil and Environmental Engineering
University of Wisconsin - Madison
Madison, WI 53706, USA
bran@wisc.edu

David A. Noyce, Ph.D., P.E.
Associate Professor
Traffic Operations and Safety (TOPS) Laboratory
Civil and Environmental Engineering
University of Wisconsin - Madison
Madison, WI 53706, USA
noyce@engr.wisc.edu

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Abstract

Effective work zone safety analysis requires 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. Fundamental to this analysis is the ability to match crashes to work zones. The traditional approach in Wisconsin, as in many states, has relied on a construction zone flag in the police crash report and targeted work zone studies. The crash report provides a macroscopic level of work zone crashes but does not provide details about the work zones themselves, except when noted in the 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 system-wide level. This paper investigates the ability to match hand-mapped highway crashes from the Wisconsin Department of Transportation (WisDOT) to WisLCS lane closure records. The underlying methodology is based on the WisDOT State Trunk Network (STN) linear referencing system, which provides a common GIS network for both data sets. A preliminary analysis of work zone safety based on WisLCS closure attributes is presented. 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.

INTRODUCTION

Effective work zone safety analysis requires consideration of a variety of data sources including frequency of crashes in and around a work zone, driver and environmental factors and work zone characteristics. Current research is focused mainly on using a variety of statistical methods to investigate the relationship between recorded work zone crashes and work zone attributes (*1-4*). Results from several crash characteristic studies demonstrate that a number of human errors, such as following too close, inattentive driving, and misjudging, could increase the risk of work zone crashes (*1*). Harb et al. (*2*) analyzed work zone crashes on Florida freeways using multiple and conditional logistic regression methods in an effort to identify risk factors in freeway work zones. The study indicated that factors including roadway geometry, weather condition, age, gender, lighting condition, residence code, and influence of alcohol/drugs could increase crash risk in freeway work zones. These methods rely on a comprehensive knowledge of the crashes and 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 relating to crashes (*3*).

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 a construction zone flag in the police crash report and targeted work zone studies. The crash report provides a macroscopic level of work zone crashes but does not provide details about the work zones themselves, except when noted in the 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 deployment of modern transportation information systems, many of which include geospatial capabilities, has improved the ability to manage and retrieve historical transportation data. However, these systems are often oriented towards specific application areas such as crash data or construction project planning information. The investigation of work zone safety needs work zone and crash details, as well as other information such as historical traffic volumes and roadway geometric features. It is necessary, therefore, to develop ways to integrate data across all systems, in particular with respect to time of day and geospatial attributes.

The Wisconsin Lane Closure System (WisLCS), which has provided a centralized management system for highway lane closures statewide since April 2008, provides a new opportunity to match crashes to specific work zones on a system-wide scale. This paper investigates the ability to match hand-mapped highway crashes from the Wisconsin Department of Transportation (WisDOT) MV4000 crash database to lane closure records in the WisLCS. The underlying methodology is based on the WisDOT State Trunk Network (STN) linear referencing system, which provides a common geospatial information system (GIS) network for both data sets. A preliminary analysis of 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 to properly correlate WisLCS work zone records to WisDOT MV4000 crashes.

Although both WisLCS closure records and MV4000 highway crash records are located to the STN, retrieving the correct work zone for a specific crash is not always straightforward. A variety of factors including data quality, work zone scheduling factors, and physical proximity of a crash to the work zone impact the overall matching algorithm.

2. Can the WisLCS provide useful details about work zone characteristics for crash analysis purposes?

   Work zone information in the crash report is currently limited to a construction zone checkbox 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 WisDOT Traffic Management Plan (TMP), if one exists. The WisLCS, on the other hand, 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 post-crash analysis.

3. Can the WisLCS provide a way to monitor work zone safety on a systematic level?

   Automating 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 where 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 Wisconsin Lane Closure System (WisLCS) (*4*) and Wisconsin MV4000 crash database (*5*), both of which are available through the WisTransPortal system (*6*) at the University of Wisconsin-Madison Traffic Operations and Safety (TOPS) Laboratory.

The 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 monitoring of work zone activities at the WisDOT Satewide Traffic Operation Center (STOC) and regional transportation offices, provides real-time lane closure information to the Wisconsin 511 traveler information system, and supports WisDOT Oversize / Overweight permitting activities. All construction, maintenance, utility, and other planned or unplanned closures on the Wisconsin highway system are recorded in

WisLCS in a detailed format. The WisLCS fully integrates the WisDOT State Trunk Network GIS linear referencing system to locate closures to 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.

Table 1 Some 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

Although most 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, are not covered in this analysis. The Duration attribute, which describes the hours of operation of a work zone, is described in further detail below.

As an acceptance system, all highway closures and restrictions must be entered into the WisLCS prior to the closure start-date. Updates to closure schedules and other details are also entered into the system in near real-time. Although full compliance is not always achieved, missing and erroneous data are often discovered through 511 and OSOW reporting. 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 Extract data from 1994 can be accessed via the WisTransPortal Crash Data Retrieval Facility (*5*, *7*). This database contains information on all police reported crashes in Wisconsin, including the location of each crash, vehicles involved, and general crash attributes. The TOPS Lab maintains this database for research purposes and as a service to the WisDOT. The WisTransPortal crash database is updated on a monthly basis from extracts provided by WisDOT Division of Motor Vehicles (DMV).

Highway related MV4000 crashes are manually geo-coded by WisDOT DMV 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 State Trunk Network (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.

The Location Fundamental: State Trunk Network

In order to describe the matching algorithm developed in this paper, it is worthwhile to first introduce the State Trunk Network. "The STN is a collection of State, Interstate, and National Highways that support the Roadway Infrastructure of … State of Wisconsin" (*8*). The STN is maintained by WisDOT as a linear referencing system in a collection of ESRI spatial data files and database tables (*9, 10*).

STN source data is organized into two categories: the Location Control Management (LCM) tables and the STN Inventory tables. The LCM tables contain the core STN spatial information consisting of links, chains, and routes that define the basic network structure. A roadway link is "a logical connection between two Reference Sites [nodes] representing a measured, real world distance along a liner feature (roadway)". A roadway link is also directional, "implied by the FROM and TO Reference Sites". A Reference Site is a physically identifiable position along a linear feature (roadway) which represents at-grade intersections or locations where a (traffic) path can merge or diverge" (STN LCM Entity Description). Whereas links are straight-line representations of the highway network, chains capture the cartographic representation of the system. Routes include the list of all US, interstate, and state highways in the STN.

The STN Inventory tables contain "business data," including 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. Maintenance of the STN inventory is distributed in WisDOT based on business area, and is tied back to the LCM through roadway link association. For example, the location of a bridge record in the Bridge table is defined with respect to a particular LCM link and link-offset. Given link and link-offset information, inventory data can be fully described with respect to roadway route, county, and/or proximity to other inventory data.

How Work Zones are located in WisLCS

As noted, location information is an essential, 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 which 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 begin- and end-locations along a highway segment, e.g., "US 63 SB from 80th Ave. to 55th Ave." Therefore, locating closures in the WisLCS comes down to assigning control points on the roadway.

In the WisLCS, control points are implemented by 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.) in order to provide end-users with a set of recognizable locations for entering closure extents. The set of landmarks are 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 starting and ending LCM link and offset values based on their associated start- and end-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 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 nearby 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, and direction and distance information (*7*). Highway crashes are subsequently hand mapped to STN links (offsets on links are also defined) by WisDOT DMV personnel. The crash mapping process is similar to how WisLCS lane closures are located: WisDOT maintains an internal set of Reference Points (RP) that model physical attributes along the highway system (generally access points and ramps). Each RP 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 an RP. This in turn resolves to specific LCM link and offset values for a given crash. Although there may be crashes which cannot be mapped, the proportion is quite low.

RETRIEVING THE CRASH RELATED WORK ZONES

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

Matching on Time Attributes

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. For example, if a daily/nightly work zone is from 10/1/2010 - 11/15/2010, 2:00 PM - 5:00 PM, the cones are dropped at 2pm each day and picked up 5pm each day;

- *Weekly*: the time of operation occurs on a weekly basis as specified by starting and ending day of week. For example, if a weekly work zone is from 10/1/2010 - 11/15/2010, MON 2:00 PM - FRI 5:00 PM, the cones are dropped at 2pm every Monday and picked up 5pm every Friday for each week within the start date and end date range;

- *Continuous*: indicates a 24 hour work zone lasting less than two weeks. For example, if a continuous work zone is from 10/1/2008 9:00 AM - 10/4/2008 2:00 PM, the cones are dropped at 9am October 1st and picked up on 2pm October 4th; and

- *Long Term*: indicates a 24 hour work zone lasting longer than two weeks. It is worth noting that 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 grey area for determining whether the crash occurred when the work zone is active.

The WisLCS also includes the ability to assign Schedule Override periods. A schedule override adds an exception to the Duration element by indicating specific times in which the work zone will not be in effect. For example, a Continuous work zone from July 1 – 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 on Location Attributes

A work zone is defined by a begin landmark and an end landmark; some work zones such as bridge maintenance, use only landmark. Here, the “landmarks” are predefined points in STN. The location of the crash relative to the work zone can be categorized as: (1) on the same highway; (2) one the intersecting highways; (3) on the ramp, as demonstrated in Figure 1.

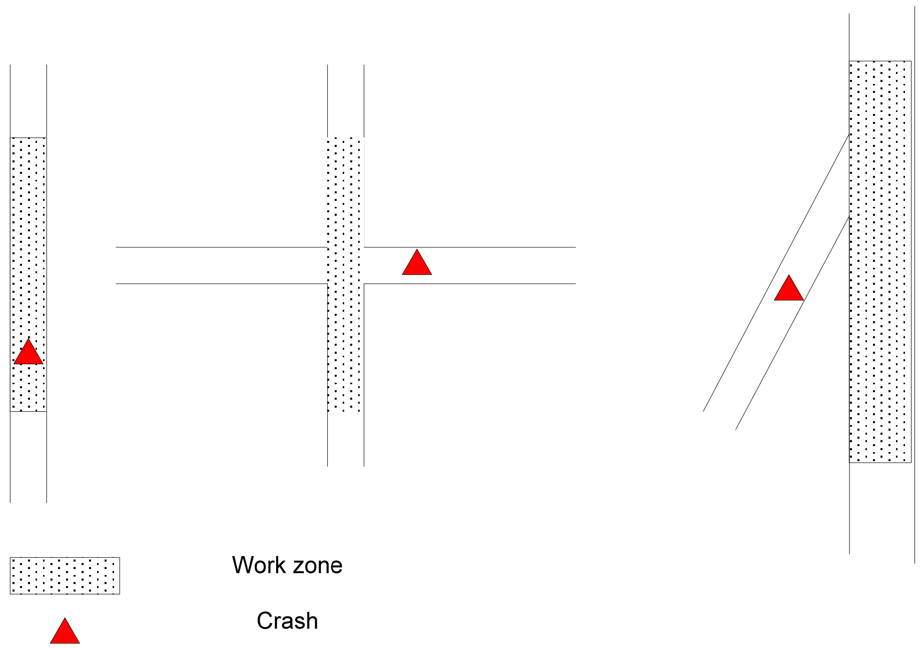

Figure 1 Locations of Work Zones and Crashes

A common scale is needed to compare the locations, for which we take the accumulative mileage of the landmarks (for work zones) and crash location on their associated highways. Another consideration is that the queue cumulated before a work zone is one of the contributing factors to work zone crashes; the method should include this distance. Because the STN is a linear referencing system, the calculation of cumulative mileage becomes possible:

$$M_p = M_L + L_{offset} \quad (1)$$

Where
M_p is the mileage of any point in STN, such as landmarks and crash location points,
M_L is the mileage of the begin point of the corresponding STN link, and
L_{offset} is the link offset, which is the distance from the begin of the link to the point.

As long as coded using STN, the STN link and link offset of a point is provided. The mileage of the begin point of an STN link is:

$$M_L = \sum_{\{i\}} L_i \quad (2)$$

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

Case 1: On the Same Highway
In this case it is straightforward. For a segment work zone, to be related with a specific crash, it needs to satisfy:

$$\begin{cases} M_{begin} - b_u <= M_{acc} \\ M_{end} + b_d >= M_{acc} \end{cases} \quad (3)$$

Where

$M_{begin}, M_{end}, M_{acc}$ are the mileages of the begin landmark, end landmark and the crash, respectively;

b_u, b_d are the distance buffer for upstream and downstream, respectively.

For a point work zone:

$$\begin{cases} M_w - l_u - b_u <= M_{acc} \\ M_w + l_d + b_d >= M_{acc} \end{cases} \quad (4)$$

Where

M_w is the mileage of the work zone location;

l_u, l_d are the estimated impact area of the work zone to upstream and downstream.

Because the point work zone is a short segment on the road although it is coded as a point in the system. In this study, $l_u = l_d = 0.25\,mile$

Case 2: On the Crossing Highway

These crashes occurred near an intersection. Similarly, for a segment work zone:

$$\begin{cases} M_{begin} <= M_{int} \\ M_{end} >= M_{int} \end{cases} \quad (5)$$

Where

M_{int} is the mileages of the intersection of the two highways.

Note that there is not buffer area used in this case.

For a point work zone:

$$\begin{cases} M_w - l_u <= M_{int} \\ M_w + l_d >= M_{int} \end{cases} \quad (6)$$

.

Case 3: On a Ramp

For a segment work zone:

$$\begin{cases} M_{begin} <= M_{ramp} \\ M_{end} >= M_{ramp} \end{cases} \quad (7)$$

Where

M_{ramp} is the mileages of the point where the ramp connects the highway.

Note that there is not buffer area used in this case too.

For a point work zone:

$$\begin{cases} M_w - l_u <= M_{ramp} \\ M_w + l_d >= M_{ramp} \end{cases} \quad (8)$$

RESULTS SUMMARY AND ANALYSIS

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

The Matching Results

There are 1517 work zone crashes recorded in the MV4000 database for 2009-2010, of which 1262 crashes can be associated with work zones in WisLCS through the matching algorithm. The overall matching rate is 83.2%. The categories of theses crashes are shown in Table 2.

Table 2 Summary of Geometry

Geometry with Work Zone	Crash Frequency
Upstream (1-2 mile)	42
Upstream (within 1 mile)	173
Within work zone	830
Downstream (within 1 mile)	40
Downstream (1 ~2 miles)	31
Crossing	116
Ramp	30
Total	1262

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

The severity of crashes is shown in Table 3. Severe crashes (defined as the combined group of K and A crashes) comprise less than 5% of the total, but are of particular interest for work zone safety analysis. As shown, the severity of work zone crashes (in terms of severe crashes) is generally higher than the general crashes. This table also demonstrates that the distribution of the matched crashes, which are the focus of the analysis, retains basically the same distribution as the construction zone crashes in the MV4000 database.

Table 3 Crash Severity

	All		Work Zone		Matched	
	Count	Percentage	Count	Percentage	Count	Percentage
K	447	0.6%	10	0.7%	8	0.6%
A	2482	3.1%	52	3.4%	46	3.7%
B	7335	9.0%	141	9.3%	107	8.5%
C	11540	14.2%	263	17.3%	207	16.4%
PD	59621	73.2%	1051	69.3%	894	70.8%
Total	81425	100.0%	1517	100.0%	1262	100.0%

Note

K: fatal; A: incapacitating; B:non-incapacitating; C: possible; PD: property damage.

By investigating the unmatched work zone crashes, the possible causes may include:

1. Crash mapping error: local road crashes that happened on a local road near a highway but were hand-mapped to an STN highway.
2. Local work zone: some crashes happened on the ramps and the police officers made their judgment that crashes are related with work zones.
3. Report coding error: MV4000 record doesn't match the original report.

Work Zone Safety Analysis

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

- Duration: describes the hours of operation of a work zone.
- Closure Type: describes the type of work zone or construction project.
- Lane Details: provide specific work zone configurations from an operational context.

Each of the work zone attributes are analyzed in two ways. In the first case, work zone attributes are compared with respect to crash severity. In the second case, work zone attributes are compared based on three proposed "rate" categories, where specific definitions for each of the rates are defined below.

Crash Severity Analysis for Work Zone Types

Table 4 Crash Severity by Work Zone Duration

	K	A	B	C	PD	Total	K+A
Continuous	1.2%	3.3%	8.2%	16.8%	70.5%	244	4.5%
Daily/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%	1262	4.3%

Table 4 shows crash severity by work zone Duration. All the four groups have similar proportions of K+A crashes, although Weekly work zones may associate with higher chances of crash occurrence.

Table 5 Crash Severity by Work Zone Types

	K	A	B	C	PD	Total	K+A
Construction	0.6%	3.7%	8.5%	16.1%	71.2%	1084	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%	1262	4.3%

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 zones is more dangerous. Possible explanations could be that Construction work zones are usually long term and the traffic would get familiar with the work zones, while Maintenance work zones are usually short and could be 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 more "dangerous". It is also interesting to note that Permit closure have the lowest percentage of property damage but makes up for that in terms of minor injury crashes.

Table 6 Crash Severity by Work Zone Lane Details

	K	A	B	C	PD	Total	K+A
Full Closure	0.3%	3.8%	6.8%	17.7%	71.5%	368	4.1%
2 Left Lanes Closed	0.0%	0.0%	7.9%	14.3%	77.8%	63	0.0%
2 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%	2012	3.7%

Note that because one crash may be matched to more than one work zones, the Combined number for the total crashes in Table 6 is more than the ones in Table 4 and Table 5. But the distinct crashes are the same 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 K and A categories.

Crash Occurrence Rate Analysis

In this section, the safety level of different types work zones is investigated. Since different types of work zones have different average time period and lengths, a simple crash occurrence for work zones may not be sufficient. 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 total duration (in year) of the work zones; Rate 3, the number of crashes divided by total duration (in year) and total length (in thousand miles) of the work zones. A higher rate indicates a more dangerous work zone category in terms of overall crash risk.

Table 7 Crash Rates by Work Zone Duration

	Total Work Zone		crash number		Rate 1	Rate 2	Rate 3
	Count	Percentage	Count	Percentage			
Continuous	1719	7.5%	244	19.3%	141.94	2.58	0.89
Daily/Nightly	19551	85.0%	250	19.8%	12.79	2.00	0.04
Long Term	1363	5.9%	709	56.2%	520.18	2.09	0.91
Weekly	380	1.7%	59	4.7%	155.26	3.08	1.83

In Table 7, Rate 1 shows that Long Term work zones have the highest rate. This leads to an implication that Long Term work zones are the most unsafe work zones, which is consistent to the finding by Table 4. However, since Long Term work zones have more traffic and exposure because of much longer operation time and longer segment length. Rate 2 and Rate 3 indicate that they are not as dangerous and they appear at the first inspection. Rate 1, Rate 2 and Rate 3 in Table 8 and Table 9 also show different aspects about how safe is a type of work zones.

Table 8 Crash Severity by Work Zone Type

	Total Work Zone		crash number		Rate 1	Rate 2	Rate 3
	Count	Percentage	Count	Percentage			
Construction	14293	62.1%	1084	85.9%	75.84	2.11	0.09
Emergency	347	1.5%	14	1.1%	40.35	1.50	2.63
Maintenance	7071	30.7%	138	10.9%	19.52	4.60	0.25
Permit	964	4.2%	26	2.1%	26.97	1.01	1.38

Table 8 shows the rates of crashes for different work zone types. Construction work zones are usually long term and on long segment of roads. Similar to Long Term in Table 7, Rate 1 of Construction is much higher than the rest, while Rate 2 indicates Construction work zone are not that dangerous and Rate 3 even implies they may be quite safe.

Table 9 Crash Severity by Work Zone Lane

	Total Work Zone		crash number		rate 1	rate 2	rate 3
	Count	Percentage	Count	Percentage			
FULL CLOSURE	5657	24.6%	368	29.2%	65.05	1.75	0.39
2 Left Lanes Closed	1019	4.4%	63	5.0%	61.83	20.07	12.61
2 Right Lanes Closed	757	3.3%	29	2.3%	38.31	12.77	12.74
3 Left Lanes Closed	6	0.03%	0	0.0%	0.00	0.00	0.00
3 Right Lanes Closed	20	0.09%	0	0.0%	0.00	0.00	0.00
Flagging Operation	1014	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	3487	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	1315	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	3825	16.6%	295	23.4%	77.12	7.61	1.20
Right Shoulder Closed	1493	6.5%	197	15.6%	131.95	4.61	1.28
Single Lane Closed	1971	8.6%	231	18.3%	117.20	3.43	0.55
Various Lanes Closed	1193	5.2%	62	4.9%	51.97	2.31	0.38

Median Turn Lane Closed, Off Roadway Left, and Off Roadway Right represent that closure configurations with 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 zone safety levels would require a very comprehensive knowledge about all the important attributes of the work zone. Thanks to the integration of the lane closure operation data and crash reports, more information is available in this study.

DISCUSSION

A number of other issues are worthy of mentioning:

1. 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 have been identified, stated in the foregoing section.

2. Potential Work Zone Related Crashes

Using the method presented for work zone crashes, the detailed information about the work zone can be retrieved to analyze the risk factors. On the other hand, applying this method to all the crashes, crashes without a construction flag may be found related to some work zones, which is verified by a preliminary pilot study by the authors.

Investigating these issues, as part of the future work, would lead to methods to provide an alternative to evaluate data quality in the MV4000 crash report database and WisLCS, and potentially enhance the ability to track work zone crashes on a systematic level.

CONCLUSION AND FUTURE WORK

Work zone safety planning has traditionally relied on an analysis of historical crash data at a given work zone location and/or through comparison of work zones with similar characteristics. Work zone safety monitoring, on the other hand, 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 UW-Madison TOPS Lab provides two useful tools, the MV4000 Crash Data Retrieval Facility and the Wisconsin Lane Closure System 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 monitoring 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 is provided by a proposed location matching algorithm which relates crashes and work zones from the MV4000 crash database and WisLCS respectively. A systematic work zone safety analysis was also provided for select WisLCS work zone attributes. From this study, it is concluded that WisLCS, as a sophisticated work zone management and query system, 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 which are based on geographic information system databases.

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

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