Injury Outcomes and Costs for Work Zone Crashes

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ABSTRACT

The main objective of this research was to quantify the injury outcomes and develop
reliable and comprehensive injury costs for work zone crashes based on crash type (rear-
end, head-on, etc.) and crash severity (KABCO scale). A three-step methodology was
used to quantify the comprehensive crash costs. All crashes in Wisconsin between 2001
and 2010 that were marked with a construction zone flag were identified and used in this
analysis. The Wisconsin Crash Outcome Data Evaluation System (CODES) database
provided comprehensive injury costs based on the injury types and severities suffered by
participants in study crashes. KABCO and Maximum Abbreviated Injury Score (MAIS)
ratings were similar for PDO and Possible Injuries. A vast majority of non-incapacitating
and incapacitating injuries sustained minor or moderate injuries only suggesting that use
of KABCO needs to be reconsidered. The calculated comprehensive costs for crash types
with sufficient sample sizes were found to be up to 105%, 35%, and 50% larger than the
default Federal Highway Administration values for incapacitating, nonincapacitating, and
possible injury crashes, respectively. Injury crash costs for different crash types varied
significantly, indicating that developing crash-specific costs could result in more accurate
benefit-cost analysis for the implementation of countermeasures.

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1 **INTRODUCTION**
2 Aging infrastructure, the need to increase capacity, and the desire to improve safety are
3 all reasons why work zones are necessary on our roads today. Work zones often violate
4 the expectancy of motorists by introducing new driving patterns (including merging lanes
5 or median weaves), which make drivers feel work zones are more hazardous than other
6 roads *(1)*. Between 2006 and 2010, the trend of crash fatalities per year has been
7 downward, as shown in TABLE 1 *(2)*. On the contrary, the percentage of work zone
8 fatalities compared to all roadway fatalities in Wisconsin has been slightly increasing per
9 year. To reverse this upward trend and improve work zone safety, the Strategic Highway
10 Safety Plan recommends implementing countermeasures such as reducing the duration of
11 work activities, improving traffic control devices, or enhancing driver education and
12 enforcement efforts *(3)*.

13 **TABLE 1 Work Zone Fatal Crash History, 2006-2010** *(2)*

Year	United States		Wisconsin	
	Total Fatalities	Work Zone Fatalities	Total Fatalities	Work Zone Fatalities
2006	42,708	1004 (2.4%)	724	14 (1.9%)
2007	41,259	831 (2.0%)	756	11 (1.5%)
2008	37,423	716 (1.9%)	605	8 (1.3%)
2009	33,883	680 (2.0%)	561	13 (2.3%)
2010	32,863	576 (1.8%)	571	14 (2.5%)

14

15   Benefit-cost analysis compares the benefits (expressed as a monetary value)
16 associated with a countermeasure with the cost of implementation, and allows engineers
17 to prioritize strategies to optimize the return on investment *(4)*. For any benefit-cost
18 analysis, crash costs are very important. The current practice of using the Federal
19 Highway Administration (FHWA) default values for a given crash severity for all crash
20 types does not truly capture the costs of crashes because:

21   1. Crash severity is based on the KABCO scale (K: Killed; A: Incapacitating
22   Injury; B: Non-incapacitating Injury; C: Possible Injury; and O: Property-
23   Damage-Only) as determined by the responding police officer on the
24   scene. The main role of the police officer is to clear the crash scene, not to
25   evaluate the injury severity of crash participants.
26   2. Past research has found that the KABCO scale does not effectively
27   analyze the threat to life and actual injury outcome as measured by the
28   Maximum Abbreviated Injury Score (MAIS) *(5, 6)*.
29   3. The costs of injuries of all participants are not considered. Rather, the
30   most severe injury outcome is used for assigning a cost.

31   In 1992, the National Highway Traffic Safety Administration (NHTSA) issued a
32 Request for Proposals to develop a system that links crash data to hospital data. The goal

1 was to better understand the costs associated with crashes. The Crash Outcomes Data
2 Evaluation System (CODES) was developed to evaluate the impact of factors such as
3 driver behavior, safety equipment, vehicle factors, and crash configuration, on health
4 outcomes *(7)*. Overall, CODES gives a complete picture of the crash cost by providing
5 injury outcome, maximum abbreviated injury score, and cost for each participant in the
6 crash *(8)*.

7   By utilizing CODES data in work zones, more realistic cost estimates can be
8 produced, which should allow better countermeasure benefit-cost analysis and improve
9 safety.

10 **WORK ZONE LITERATURE REVIEW**
11 There are many previous studies of work zones and the factors that ultimately lead to
12 crashes. While some results, such as predominant crash type in work zones, are mostly
13 consistent among past literature, others have only minimal research or contradictory
14 findings. Results of the literature review are summarized in Table 2.

15 **TABLE 2 Selected work zone study results regarding crash statistics, adapted from**
16 *(9)*

Subject	Findings	Comparison
Predominant Crash Type	Rear-end crash most predominant- *(10-20)*	Consistent Results
Collision during nighttime	Fixed Object Crashes most common - *(15)*	Consistent Results
	Fixed Object more likely to be hit at night - *(14)*	
	Single-vehicle crashes dominant - *(1, 15)*	
Light Conditions	Crashes during night more severe - *(13)*	Inconsistent Results
	Crashes during daylight more severe - *(14)*	
	Neither daytime nor nighttime crashes were more common - *(19)*	
Crash Location	Rural fatal crashes were more common - *(1, 21)*	Inconsistent Results
	Urban crashes were more common - *(22)*	
Roadway Type	Fatal crashes more common on Interstate Highways and State Highways than other roads - *(19)*	*Limited Study Information*

17

18 **What is a "defined" work zone?**
19 The definition of a crash in a work zone varies from state to state. For example,
20 Wisconsin considers a crash work zone related if the crash is "resulting from an activity,
21 behavior, or traffic control related to a construction zone but not necessarily within it"
22 *(23)*. A research report by the Michigan Department of Transportation suggests that
23 officers should identify a crash as a work zone crash "if the location of the accident is
24 within a designated or posted construction zone" *(24)*. Wang et al. recommend (and
25 agree with the Wisconsin methodology) to include all crashes related to work zones *(25)*.
26 However, some reporting confusion remains, as police officers may consider a crash as

1   work zone-related only if construction is happening at the time of the crash, or within the
2   designated work zone (versus pre-work zone queue), thus removing data from analysis.

3   **CRASH OUTCOME DATA EVALUATION SYSTEM (CODES)**
4   CODES is a national effort overseen by NHTSA to amass financial and medical outcome
5   data for motor vehicle crashes *(8)*. To enable better benefit-cost decision making for
6   highway safety, CODES provides data on crash injury type, severity, and other associated
7   costs.

8   To assemble each state's CODES database, crashes are probabilistically linked to
9   medical, driver, and other records to provide comprehensive cost data for each injured
10 and uninjured crash participant. Using the probabilistic linkage method instead of an
11 exact linkage method allows record linkage if a name was misspelled, the birthday was
12 incorrectly recorded, or even if the dataset did not have names *(7)*. The hospital charges
13 resulting from the probabilistic linkage do not capture all medical costs and are
14 consistently lower than medical costs. Charges also do not explain non-medical costs
15 associated with crashes, including property-damage and quality-of-life costs.

16   A study by Zaloshnja et al. compiled national injury costs, which are used in
17 CODES, based on the body part injured, the presence of a fracture, and the severity of the
18 injury on the MAIS scale *(26)*. The three types of injury costs in this report are:

19 • Medical Costs: ambulance, emergency medical, doctor, hospital, rehabilitation,
20   medication, and special treatment cost;
21 • Quality-of-Life Costs: based on quality-adjusted life years (QALYs), which
22   account for the loss of quality of life due to an injury and fatality with a 2000
23   monetary value of $91,752, which was determined by dividing the statistical
24   value of a life by a life span; and,
25 • Other Costs: emergency services, lost wages, household work, insurance
26   administration, legal costs, and property damage *(26)*.

27   Injury and cost data accumulated in the CODES database for each participating
28 state have been used in a wide variety of safety analyses. Examples include the
29 determination of the sensitivity of injury costs on identifying high crash locations in Iowa
30 *(27)*, and the estimation of comprehensive crash costs for roadway departure crashes in
31 Wisconsin *(28, 29)*, Massachusetts *(30)*, and Maine *(31)*.

32 **DATA COLLECTION**
33 Data used in this study was collected from two major sources: WisTransPortal (the
34 system that provides support for ITS data archiving, real-time traffic information services
35 and transportation research in the State of Wisconsin) *(32)* and CODES Data provided by

1   the Center for Health Systems Research and Analysis at the University of Wisconsin-
2   Madison *(33)*.

3   **Work-Zone Crash Data Collection**
4   WisTransPortal, which is maintained by the Traffic Operations and Safety Laboratory
5   (TOPS Lab) at the University of Wisconsin-Madison, includes a database of all police-
6   reported traffic crashes in the state of Wisconsin where someone was either killed,
7   injured, or the property damage exceeds a $1,000 threshold. WisTransPortal hosts local
8   copies of all crash reports in the state after 1994. The database was queried to return
9   crashes flagged as work zone-related (by field "CONSZONE"). To identify a large
10   enough scope for this project, crash data between the years 2001 and 2010 was analyzed.

11   **TABLE 3 Manner of Collision for Wisconsin Work Zone Crashes by Maximum**
12   **Injury Severity, 2001-2010**

Manner of Collision	Crash Severity					Grand Total
	Fatality K	Injury A	Injury B	Injury C	PDO	
Rear-End	17 – 0.3%	164 – 2.4%	499 – 7.4%	1967 – 29.0%	4128 – 61.0%	6775
Collision with Fixed Object	**48 – 1.0%**	**223 – 4.7%**	**650 – 13.8%**	566 – 12.0%	3234 – 68.5%	4721
Angle	22 – 0.7%	123 – 3.9%	371 – 11.9%	670 – 21.4%	1941 – 62.1%	3127
Sideswipe	6 – 0.3%	42 – 1.7%	112 – 4.4%	252 – 9.9%	2134 – 83.8%	2546
Head-On	6 – 2.5%	**29 – 11.9%**	**58 – 23.9%**	63 – 25.9%	87 – 35.8%	243
Other/ Unknown	2 – 1.2%	6 – 3.6%	8 – 4.8%	33 – 19.9%	117 – 70.5%	166

13

14   As seen in Table 3, the most common crash type in Wisconsin work zones
15   between 2001 and 2010 was rear-end collisions (38.5%), which correlates with
16   conclusions found in previous research. The next largest classifications include fixed
17   object (26.9%), angle (17.8%), sideswipe (14.5%), and head-on crashes (1.4%). The data
18   in Table 3 was organized by crash severity to highlight trends including:

19   • The large proportion of Injury A and Injury B head-on crashes when
20   compared to other head-on crash severities
21   • Collisions with fixed objects were the most frequent manner of collision for
22   crash severities Fatality, Injury A, and Injury B among all crash types

23   Further analysis discusses injury severity, which is different from the
24   aforementioned crash severity. Crash severity is the same for all participants in a crash,
25   and represents the most severe outcome of the participants. Injury severity is assigned to

1   each participant based on the injury that was sustained. Both crash severity and injury
2   severity use the KABCO scale.

CODES Data Collection
4   The Wisconsin CODES Database maintains complete injury, vehicle, and medical
5   information (for linked injuries) for each crash participant. CODES records are created
6   during a visit to an emergency room, but do not account for medical visits more than 30
7   days after a crash. With the Wisconsin CODES having limited ability to explain non-
8   medical costs (such as property damage), the FHWA default value ($10,956 in 2010
9   dollars) was assumed to be representative for PDO costs; further PDO analysis in this
10 paper has been excluded.

Data Linkage
12 Each record in the CODES database links to the WisTransPortal crash data by means of a
13 unique crash number identifier, which allows a one-to-many query that enables the two
14 databases to be linked at the participant level. When a valid diagnostic code was present,
15 the data was considered "linked". The proportion of injuries able to be linked by severity
16 is found in Table 4. Although the goal is to have every crash linked to hospital records,
17 that is not possible due to missing information, incorrect data fields, or if the crash was
18 PDO.

19 **TABLE 4 CODES Crash Injury Linkage Percentage, Work Zone Crash**
20 **Participants**

Injury Severity	Injured Crash Participants	Linked Crash Participants	Linkage Percentage
Killed (K)	116	29	25.0%
Incapacitating Injury (A)	754	522	69.2%
Non-incapacitating Injury (B)	2346	1142	48.7%
Possible Injury (C)	5512	1522	27.6%
Total Injuries	**8728**	**3215**	**36.8%**

21

22   The least likely injury linkage occurred with possible injuries ("C"). For
23 participants with minor injuries, the wounds are much less severe, are often not visually
24 apparent at the crash site, and generally do not require a trip to an emergency room. Some
25 examples of minor injuries include reporting a momentary loss of consciousness,
26 limping, or complaint of pain *(34)*.

MAIS & KABCO Injury Scales
28 The MAIS Score, assigned by a medical professional, assigns severity ratings similar to
29 the KABCO scale. However, there often are discrepancies between a police officer's
30 judgment of a participant's injury and a medical practitioner's assessment. Based on the
31 work zone crash data, police officers were rather precise in identifying minor injuries

1   labeled as "C" (90%), but variance increased as injury severity increased, as shown in
2   Table 5.

3   **TABLE 5 Cases (and Percent) of each KABCO participant falling into each MAIS**
4   **Class, Wisconsin Work Zone Crashes, 2001-2010**

MAIS Score	KABCO Scale					MAIS Injury Total
	O	C	B	A	K	
1 (Minor)	294 (93%)	1207 (90%)	801 (78%)	179 (37%)	0 (0%)	*2481 (78%)*
2 (Moderate)	18 (6%)	113 (8%)	163 (16%)	140 (29%)	0 (0%)	*434 (14%)*
3 (Serious)	2 (<1%)	14 (1%)	38 (4%)	93 (19%)	0 (0%)	*147 (5%)*
4 (Severe)	0 (0%)	6 (<1%)	20 (2%)	62 (13%)	0 (0%)	*88 (3%)*
5 (Critical)	0 (0%)	1 (<1%)	1 (<1%)	14 (3%)	0 (0%)	*16 (1%)*
6 or Killed	0 (0%)	0 (0%)	0 (0%)	0 (0%)	192 (100%)	-
Missing Score	*38922*	*3959*	*1256*	*243*	*0*	-
Total	314	1341	1023	488	192	-

5   *Note: Killed refers to coding of "fatal", no matter the value of MAIS.*

6   Over three-fourths (78%) of "B" crash participants actually sustained only minor
7   injuries (MAIS score of 1). About two-thirds (66%) of "A" crash participants sustained
8   only minor or moderate injuries (MAIS 1 and 2). Essentially, this presents a strong
9   argument against using the KABCO scale to assign comprehensive costs, as the presence
10   of numerous minor injuries in incapacitating crashes could bias calculated costs. Previous
11   research has both argued for *(35)* and against *(5)* the use of KABCO as a crash-severity
12   indicator, which suggests that additional research is needed regarding the use of the
13   KABCO scale and considering the use of a different scale such as MAIS.

14   With the current emphasis on reducing fatalities and severe injury (K+A) crashes
15   nationwide (not only in work zones), the data in TABLE 5 suggests that using KABCO
16   ratings for identifying locations for safety improvements may not be the best approach. .
17   The over-reporting of severe injuries caused by inaccurate judgment could prevent the
18   attainment of nationwide safety goals, such as the reduction of severe crashes in work
19   zones.

20   Other comparisons between KABCO and MAIS assignments can be found in
21   previous papers *(29, 35, 36)*. The results in those papers followed the same general trend
22   of the Wisconsin dataset – good concurrency between MAIS and KABCO for "O" and
23   "C" crashes, and scattered results for "A" injuries.

24   **METHODOLOGY**
25   This paper uses a methodology that was developed by Chitturi et al. *(29)* and Ooms *(36)*.
26   The methodology differs from guidelines in the Federal Highway Administration report
27   *"Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected*
28   *Crash Geometries"* that stipulate that a single, default cost be assigned for the differing
29   crash severities of fatal, injury, and property-damage-only, irrespective of the number of
30   participants in the crash *(37)*. Methodology consists of multiplying the average number of

1   participants by the average injury costs for each injury severity (i.e., five levels of
2   KABCO), followed by summing these costs to obtain an overall crash cost for the crash
3   severity, as shown in the following equation:

$$crash\ cost_{t,c} = \sum_{all\ i} (Average\ number\ of\ injuries)_{t,c,i} \times (Average\ injury\ cost)_{t,i}$$

4   Where:

5   •   t: analyzed crash type (i.e. all work-zone crashes, work-zone crashes on county
6   roads);
7   •   c: crash severity (*Fatal, Injury, Property-Damage-Only*); and,
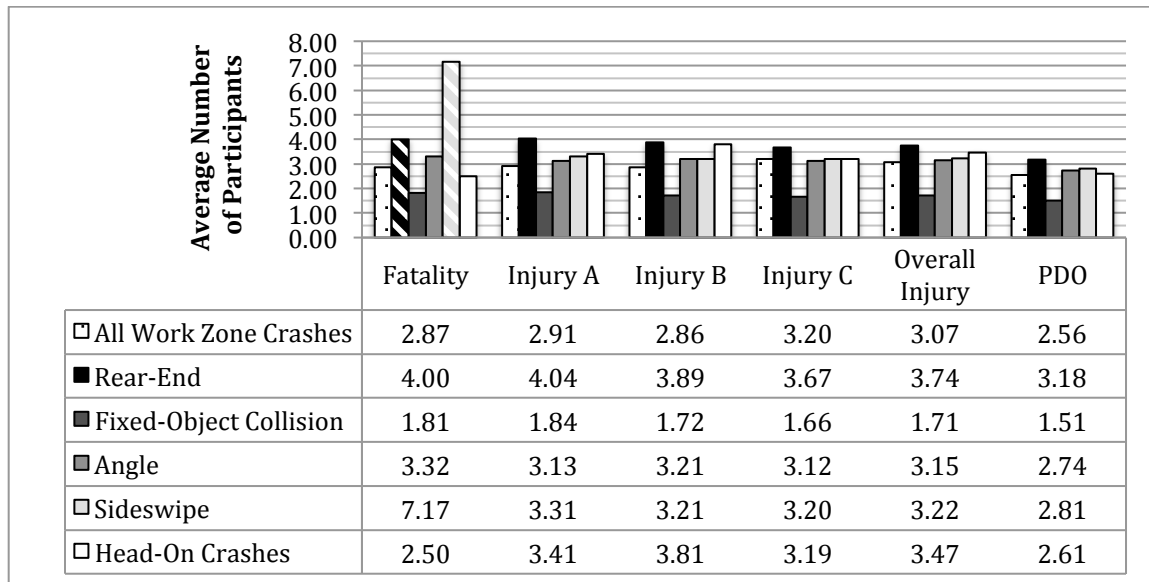8   •   i: injury severity (KABCO scale)

9   Therefore, three steps are needed to determine the overall crash cost for each
10 analyzed crash type and severity:

11   1. Average number of participants for each injury severity per crash
12   2. Average injury severity cost using CODES data
13   3. Average crash cost by crash severity

14   To provide more precise analysis, CODES costs were adjusted for inflation by
15 using data from the United States Department of Labor website. The inflation rates were
16 calibrated by location (Wisconsin) and item (medical costs), and adjusted to reflect 2010
17 values *(38)*. A more detailed explanation of the methodology can be found in previous
18 papers *(29, 36, 39)*.

19 **WORK-ZONE COST ANALYSIS**
20 As stated in the methodology, the first step is to find the average number of participants
21 for each injury severity per crash. For incapacitating crashes (INJ A) in the dataset, the
22 average number of participants would be the sum of the following averages: 0.00 fatal
23 participants (since there were no deaths), 1.22 INJ A participants, 0.28 INJ B participants,
24 0.23 INJ C participants, and 1.17 non-injured participants. Thus, the expected number of
25 persons, on average, involved in an incapacitating work zone crash is 2.91. The total
26 number of participants per crash is shown in Figure 1.

	Fatality	Injury A	Injury B	Injury C	Overall Injury	PDO
▢ All Work Zone Crashes	2.87	2.91	2.86	3.20	3.07	2.56
■ Rear-End	4.00	4.04	3.89	3.67	3.74	3.18
▣ Fixed-Object Collision	1.81	1.84	1.72	1.66	1.71	1.51
▨ Angle	3.32	3.13	3.21	3.12	3.15	2.74
▢ Sideswipe	7.17	3.31	3.21	3.20	3.22	2.81
▢ Head-On Crashes	2.50	3.41	3.81	3.19	3.47	2.61

1

2 **FIGURE 1 Average Number of Participants per Work Zone Crash by Manner of**
3 **Collision.**
4 *Note: Rear-End/Fatality and Sideswipe/Fatality values represent limited sample sizes (less than*
5 *20 data points); use with caution.*

6   The crash type that had the most participants per crash, on average, was rear-end
7 collisions. The high average number of participants could be explained by a large number
8 (1601 crashes) of rear-end collisions involving three or more vehicles. As fixed-object
9 collisions only include a single car, the average number of participants involved was very
10 low as compared to the other crash types.

11 **Average Injury Cost using CODES Data**
12 The second step involved finding the average injury cost. Analyzing incapacitating, non-
13 incapacitating, and possible injury crash participants with sufficient sample sizes gives
14 the following averages, minimums, and maximums of linked CODES injury costs, per
15 crash type are presented in Table 6. Due to smaller sample sizes, fatal crashes have been
16 excluded from further analysis.

1   **TABLE 6 Average Injury Cost per Crash Participant**

Crash Type	Incapacitating (INJ A)			Non-incapacitating (INJ B)			Possible Injury (INJ C)		
	Avg.	*Min.*	*Max.*	*Avg.*	*Min.*	*Max.*	*Avg.*	*Min.*	*Max.*
All Work-Zone	**$402K**	**$10.8K**	**$6.12M**	**$94.2K**	**$9.87K**	**$3.46M**	**$49.0K**	**$9.87K**	**$4.23M**
	522 Participants			*1142 Participants*			*1522 Participants*		
Rear-End	$252K	$10.9K	$4.47M	$81.4K	$10.8K	$1.69M	$35.7K	$9.87K	$3.27M
	135 Participants			*329 Participants*			*734 Participants*		
Fixed-Object Collision	$523K	$11.0K	$6.12M	$126K	$10.0K	$3.46M	$86.7K	$9.87K	$4.23M
	190 Participants			*388 Participants*			*221 Participants*		
Angle	$326K	$10.8K	$4.68M	$68.4K	$9.87K	$866K	$46.8K	$10.3K	$1.67M
	103 Participants			*284 Participants*			*381 Participants*		
Sideswipe	$541K	$10.9K	$4.47M	$81.6K	$10.9K	$866K	$36.0K	$10.8K	$403K
	40 Participants			*73 Participants*			*117 Participants*		
Head-On	$399K	$12.0K	$4.43M	$92.7K	$10.3K	$446K	$129K	$11.5K	$3.25M
	47 Participants			*62 Participants*			*15 Participants**		

2   *"M" represents $1,000,000, and "K" represents $1,000;*
3   **Note: Head-On/INJ C values represent limited sample sizes (less than 20 data points); use with*
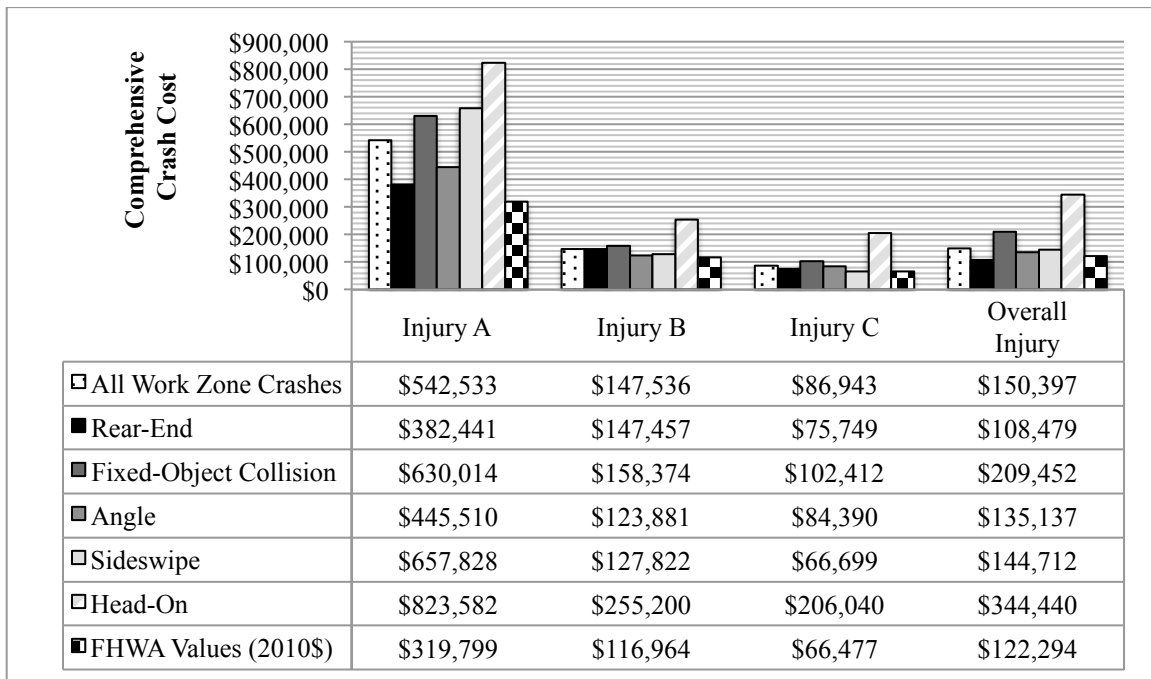4   *caution.*

5   The average injury costs per crash participant in TABLE 6 can be used to:

6   •   Find the comprehensive crash cost in conjunction with the results from Step 1;
7   •   Show the wide difference between incapacitating costs compared to non-
8   incapacitating and possible injury costs; and,
9   •   Illustrate the large ranges present for nearly each injury cost.

1   **Comprehensive Crash Cost Analysis**
2   To find the comprehensive crash costs, the average number of participants per crash is
3   multiplied by the average injury cost per crash participant and severity type to receive the
4   comprehensive crash cost. As mentioned previously, the default value of $10,956 will be
5   used for PDO crash costs computations. For example, the following equation details the
6   computation for incapacitating crashes in work zones.

$$(0.00)_K + (1.22 * \$402,000)_{INJ\,A} + (0.28 * \$94,200)_{INJ\,B} + (0.23 * \$49,000)_{INJ\,C}$$
$$+ (1.17 * \$10,956)_{PDO} \approx \$542,553$$

	Injury A	Injury B	Injury C	Overall Injury
☐ All Work Zone Crashes	$542,533	$147,536	$86,943	$150,397
■ Rear-End	$382,441	$147,457	$75,749	$108,479
▨ Fixed-Object Collision	$630,014	$158,374	$102,412	$209,452
▨ Angle	$445,510	$123,881	$84,390	$135,137
☐ Sideswipe	$657,828	$127,822	$66,699	$144,712
☐ Head-On	$823,582	$255,200	$206,040	$344,440
▤ FHWA Values (2010$)	$319,799	$116,964	$66,477	$122,294

7
8   **FIGURE 2 Comprehensive Crash Costs for Wisconsin Work Zone Crashes by**
9   **Injury Severity and Crash Type, 2001-2010**
10 *Note: Head-On crash values represent limited sample sizes (less than 20 data points); use with*
11 *caution.*

12   The most expensive crash type based on the dataset was head-on collisions.
13 However, due to a large per-injury cost for INJ C head-on collisions (based on a sample
14 size of only 15 data points), this data may be skewed, and should be used with caution.
15 The incapacitating injury crashes demonstrated a much higher standard deviation
16 ($176,571, not including "All Work Zone" crash and FHWA values) compared to non-
17 incapacitating and possible injury standard deviations ($53,960 and $56,446,
18 respectively).

19   Comprehensive crash costs for incapacitating crashes (with sufficient sample size)
20 were 20% to 105% greater than the default values, after adjusting for inflation. For
21 nonincapacitating crashes, calculated costs were between 6% and 35% larger than the

1   FHWA values, and possible injury crashes costs were 0.3% to 50% higher compared to
2   the default values.

3   Weighted overall injury cost for all work zone crashes is about 25% greater than
4   the FHWA cost. Interestingly, the weighted rear-end overall injury cost (based on the
5   number of crashes per severity) was 11% smaller than the inflation-adjusted FHWA cost,
6   due to the large number of minor rear-end collisions. FIGURE 2 also shows that the
7   overall injury costs vary significantly between different crash types. For instance head-on
8   crashes are over three times as expensive as a rear-end crash. Similarly, fixed object
9   crashes are about twice as expensive as a rear-end crash. The wide range of costs in
10   FIGURE 2 suggests that developing scenario-based cost estimates for each crash type
11   would improve future benefit-cost analysis for work zone countermeasure
12   implementation.

13   **CONCLUSION**
14   The main objective of this research was to quantify the injury outcomes and develop
15   reliable and comprehensive injury costs for work zone crashes in Wisconsin. All crashes
16   that were caused by the presence of a work zone between 2001 and 2010 were identified
17   and used for this analysis. The Wisconsin CODES database provided comprehensive
18   injury costs based on injury types and severities suffered by participants in study crashes.
19   A three-step methodology was used to quantify the crash costs for each severity and
20   manner of collision (rear-end, angle, etc.).

21   Injury severities of crash participants based on the KABCO scale (assigned by
22   law enforcement personnel) were compared to MAIS scores assigned by medical
23   practitioners. Participants in property-damage-only and possible injury crashes were
24   assigned very similar rankings between the two scales. However, for non-incapacitating
25   and incapacitating injuries the disparity between KABCO and MAIS ratings was very
26   significant. Vast majority of crash participants classified as injury A or B sustained only
27   minor or moderate injuries. Therefore, there is a need to reconsider the use of KABCO
28   scale.

29   Average comprehensive crash costs were found to be $542,533 for incapacitating
30   crashes in work zones, $147,536 for non-incapacitating crashes, and $86,943 for possible
31   injury crashes. Fatal crash costs were excluded due to small sample sizes, and property-
32   damage-only crashes were assigned the FHWA default PDO crash value of $10,956 (in
33   2010$). Incapacitating, nonincapacitating, and possible injury crashes (with sufficient
34   sample size) were 105%, 35%, and 50% larger than inflation-adjusted FHWA default
35   values, respectively.

1   Weighted overall injury cost for all work zone crashes is about 25% greater than
2 the FHWA cost. Head-on crashes and fixed object crashes were about three and two
3 times as expensive as rear-end crashes respectively.

4   The variance of comprehensive crash costs for each crash type suggests that a
5 "one-size-fits-all" FHWA value for crash cost cannot accurately represent every work
6 zone crash. By using more detailed and crash-specific costs, benefit-cost analyses for
7 implementing safety countermeasures that address particular crash types will be more
8 accurate.

9 **FUTURE RESEARCH**
10 For future CODES analysis, the investigation of other crash factors should be completed
11 to create even more specific comprehensive costs for work zone crashes. Some factors to
12 study include:

13 • Roadway type (interstate highway, state highway, county highway, local road)
14 • Light conditions (daylight, dark, lit overnight work zone, etc.)

15   Connecting CODES data to certain characteristics of work zones (such as lanes
16 closed, or type of work being done) can provide an additional wealth of information.
17 Current research is being performed to do that, and future iterations of CODES analysis
18 could include work zone type identified by the Wisconsin Lane Closure System *(40)*.

19   Finally, analyzing comprehensive crash costs in terms of the MAIS scale instead
20 of the KABCO scale will provide a different perspective, and possibly more reliable
21 values.

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