Characteristics and Contributing Factors of On-Duty Struck-by Crashes

Lang Yu [(1)]
Graduate Research Assistant, Traffic Operations and Safety (TOPS) Laboratory
Department of Civil and Environmental Engineering, University of Wisconsin-Madison
1241 Engineering Hall, 1415 Engineering Drive, Madison, WI, 53706
Phone number: (608) 556-5800,
E-mail: lyu8@wisc.edu

Andrea R. Bill
Traffic Safety Engineering Program Manager, Traffic Operations and Safety (TOPS) Laboratory
Department of Civil and Environmental Engineering, University of Wisconsin-Madison
B243 Engineering Hall, 1415 Engineering Drive, Madison, WI 53706
Phone number: (608) 890-3524, Fax: (608)262-5199,
E-mail: bill@wisc.edu

Madhav V. Chitturi, Ph.D.
Assistant Researcher, Traffic Operations and Safety (TOPS) Laboratory
Department of Civil and Environmental Engineering, University of Wisconsin-Madison
B243 Engineering Hall, 1415 Engineering Drive, Madison, WI 53706
Phone number: (608) 890-2439, Fax: (608)262-5199,
E-mail: mchitturi@wisc.edu

David A. Noyce, Ph.D., P.E.
Professor, Director, Traffic Operations and Safety (TOPS) Laboratory
Department of Civil and Environmental Engineering, University of Wisconsin-Madison
1204 Engineering Hall, 1415 Engineering Drive Madison, WI 53706
Phone number: (608) 265-1882, Fax: (608)262-5199,
E-mail: noyce@engr.wisc.edu

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[(1)] Corresponding Author

ABSTRACT

Emergency responders and roadway workers are on-duty to assist incidents and perform roadway maintenance and construction, which benefits all road users. However, the location of their work implies that they are exposed to being struck by surrounding traffic. On-duty struck-by crashes are defined as a traffic incident that involves police officers, roadway workers, firefighters and EMT/First Responders, who are hit by a motorist while on duty assisting an incident or at a work zone. The objective of this research is to summarize and analyze struck-by crashes.

Initial crash data were extracted from the WisTransPortal on Wisconsin's State Trunk Network (STN). Data were selected from 2000-2010 and included several filtering steps and manual identification for data reduction. Two hundred sixty-five crashes were identified as struck-by crashes and the characteristics and contributing factors are analyzed. Responder and worker struck-by crashes are separately analyzed with different characteristics shown, all STN crashes from 2000-2010 are used as a comparison group. Characteristics are classified into crash, highway, environment, and on-duty person characteristics. Driver contributing factors are also presented.

Results show that for responders crashes, police officers are the predominant type of on-duty person. A large proportion of responder crashes occurred on rural interstate highways. Speeding or "too fast for conditions" is the key driver factor that leads to struck-by crashes at incidents and adverse roadway/weather conditions are the most significant environmental factor. Most emergency responder struck-by crashes occur when responders are assisting traffic incidents. On the other hand, for roadway workers, flagmen hit by surrounding traffic account for around half of all worker struck-by crashes, worker crashes are likely uncorrelated with adverse weather, roadway or lighting conditions. Inattentive driving of civilian drivers is the most significant contributing factor. These results could provide a basis for countermeasures to protect emergency responders and roadway workers.

INTRODUCTION

Emergency responders are called daily to assist people in need and to mitigate dangerous situations on highways (*1*). They are present when a traffic incident occurs, assist the people involved and investigate crash causations. Roadway maintenance and construction personnel help maintain and improve roadway conditions to facilitate all roadway users. However, the location of the work performed is mostly in-roadway or roadside, which implies that they are exposed to the danger of being hit by surrounding traffic. The Occupational Safety and Health Administration stated in a report that "workers such as emergency responders, clean-up, utility, demolition, construction, and others in areas where there are moving vehicles and traffic are exposed to being struck-by moving vehicles" (*2*). In 2002, approximately 50 percent of all police, emergency medical services personnel and firefighter fatalities occurred as a result of transportation incidents (*3*). Therefore, the safety of emergency responders and maintenance personnel is at risk whenever they are on a street or highway near traffic.

In this research, on-duty struck-by crashes are defined as a traffic incident that involves firefighters, police officers, emergency medical techinician/first responders and roadway maintenance and construction workers that are hit by a motorist while the person is on duty assisting an incident or work zone.

Crash data are often the primary source of knowledge concerning the traffic safety environment, human behavior, and vehicle performance (*4*). Although records are currently maintained in regard to the number of work zone crashes, the number of struck-by incidents involving first responders in a traffic management area is not being tracked in Wisconsin (*5*). Furthermore, the Wisconsin Crash Reporting Form (MV4000) does not provide an option to identify struck-by crashes nor can one determine a struck-by crash by only using options filled in by police officers. A report from Glatfelter Insurance Group stated that "no one agency tracks or governs highway safety activities has led to limited dissemination of information and under-reporting of emergency service injuries and fatalities associated with highway incidents (*6*)." Therefore, tracking struck-by crashes has proven to be difficult due to the large number of agencies that respond to incidents on the state highway system and inconsistencies within reporting procedures. A need to track, summarize and analyze struck-by crashes thus emerges, and is the main objective of this research.

BACKGROUND LITERATURE

The analysis of struck-by crashes needs to be based on past literature involving a variety of fields. However, little comprehensive research exists in terms of analysis of struck-by crashes, especially those analyzing characteristics of and contributing factors to this type of crash. Most of the related research is qualitative, lacking sufficient details.

Emergency Responder Safety

Statistics on police officer fatalities in the United States (U.S.) during the last decade are shown in Figure 1. Several governmental agencies and non-governmental organizations are involved with the archiving, study and promotion of emergency responder safety. Those organizations include, but are not limited to: "

- Emergency Responder Safety Institute;
- Firefighter Fatality Investigation, National Institute of Occupational Safety and Health;

- First Responder Roadside Vehicle Safety, National Highway Traffic Safety Administration;
- National Law Enforcement Officers Memorial Fund;
- Move Over, America, National Safety Commission;
- National Traffic Incident Management Coalition (NTIMC).

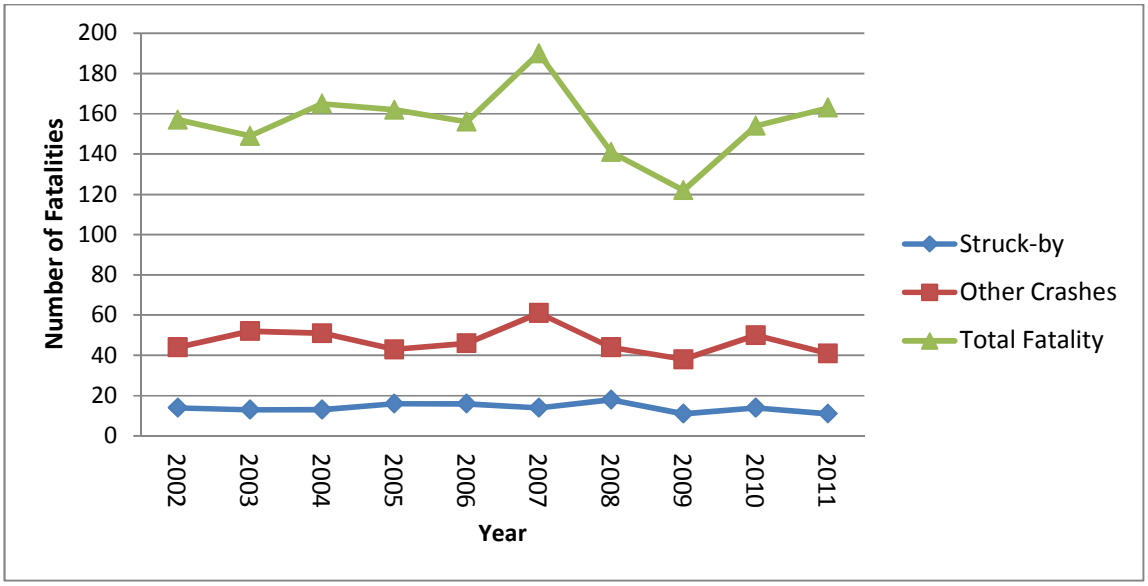


FIGURE 1 Law Enforcement Officer Fatality by Causation (*7*)

Few research papers or reports include a systematic study or justification of potential contributing factors to struck-by crashes. A report from NTIMC provided some example factors that include weather, time of day, scene lighting (including area lighting and optical warning devices, traffic speed and volume) and road configuration (including hills, curves and other obstructions that limit visibility) (*8*). The Participant's Manual of an emergency responder safety program conducted by Glatfelter Insurance Group listed the following contributing factors to struck-by crashes (*6*):

- Ineffective notice, warning to civilian driver. Advance warning is crucial since civilian drivers need to perceive and react to incident zone especially on higher speed roadways.
- Weather and roadway conditions. Adverse weather conditions significantly increase stopping sight distance and reduce visibility.
- Scene visibility and lighting. Too much or inappropriate lighting negatively impact the vision of approaching civilian drivers.
- Emergency worker physical movement. The Manual stated several measures to minimize risk by always acting as if the traffic is trying to hit them.
- Private vehicle. The Manual stated that personnel in private owned vehicles should never respond to limited-access highway incidents.
- Protection of the scene. Protecting the scene is to protect the emergency workers.

Work Zone Worker Safety

Protecting workers in a work zone is a key objective in ensuring work zone safety. Highway workers in work zones are in close proximity to traveling vehicles, exposing them to

injury risks when vehicles intrude into the work zone (9). Each year, more than 100 workers are killed and over 20,000 are injured in the highway construction industry (*10*), a significant amount due to traffic accidents. The following figure shows the number of work zone worker fatalities due to traffic accidents from 2003 to 2010. Data used in the figure are from The National Work Zone Safety Information Clearinghouse (*11*).

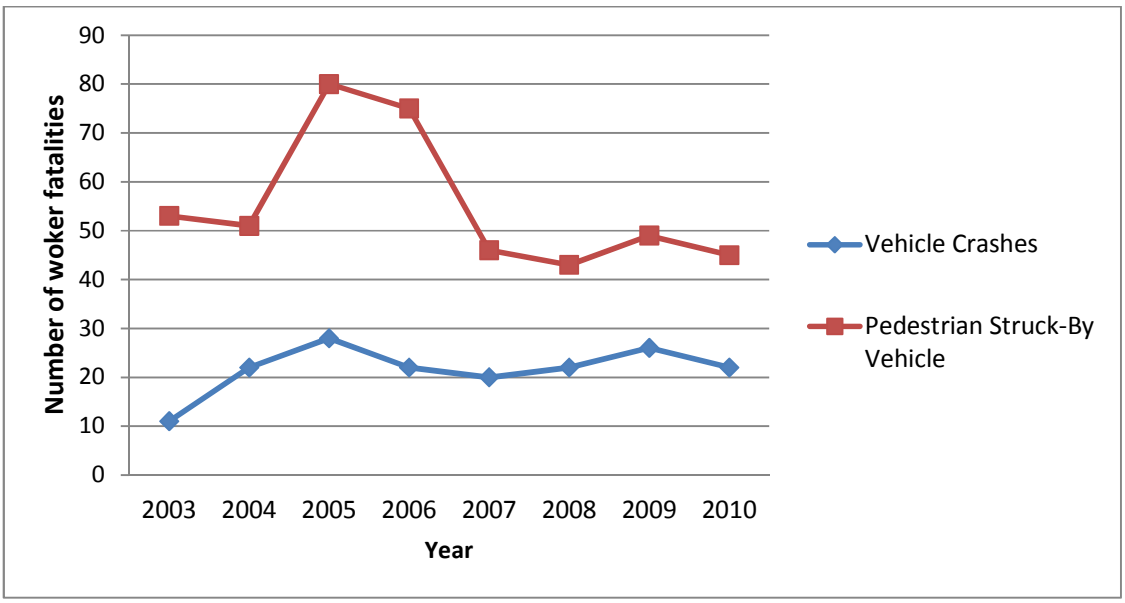


FIGURE 2 Worker Zone Worker Fatality Caused by Traffic Accidents (*11*)

Factors that significantly affect the occurrence of work zone crashes have been identified through multiple research. A report completed by the American Traffic Safety Services Association indicated several factors that could contribute to erratic motorist behavior and maneuvers in work zones. These factors include "hills, curves, obstructions, color contrast, bad weather, visibility issues, poor pavement markings, eradicated lane lines that look like lane markings in wet weather, poor signing, driveways, turning movements, construction vehicles entering/exiting, temporary roadway geometrics (lane widths, taper lengths, device placement) (*12*)." Akepati and Dissanayake investigated driver contributing factors in work zones. Significant factors include inattentive driving, following too close for conditions, failure to yield right of way, driving too fast for conditions, and exceeding posted speed limits within work zones (*13*). Wong et al. studied factors that influence injury severity on work zone crashes. It was found that work zone locations, work zone duration, time of day and type of activity performed by workers have the most significant impact (*9*).

Legislation

Move-Over Law is a major legislation effort undertaken to protect emergency responders. In general, according to NTIMC "Move Over / Slow Down laws "require motorists to change lanes to provide an empty travel lane between their vehicle and emergency vehicles along the roadside, or to slow down while approaching—and passing—a traffic incident, if moving to another lane is not possible (*1*). As of today, 49 states have already passed the "Move-over" law. Only the state of Hawaii and the District of Columbia do not have a "Move-Over" law. The State of Wisconsin passed the "Move-Over" law in 2001.

Two other types of legislation regarding the protection of emergency responders also exist, namely Driver Removal laws and Authority Removal laws. Driver removal laws require motorists involved in minor crashes, without apparent or serious injuries and where vehicles are still drivable, to move their vehicles out of travel lanes to safer locations, such as the road shoulder, before exchanging information or waiting for law enforcement or towing response (*14*). About 50 percent of the states have some form of driver removal law, which may also be called "move-it" or "steer it, clear it" laws, but the laws vary widely in wording, coverage, and sanctions. The Authority removal laws provide authorization for pre-designated public agencies to remove disabled or wrecked vehicles, as well as spilled cargo and other property that interferes with the normal flow of traffic (*14*).

Traffic Incident Management

According to the Traffic Incident Management Handbook a traffic incident is "… any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand. Such events include traffic crashes, disabled vehicles, spilled cargo, highway maintenance and reconstruction projects, and special non-emergency events (*3*)." Traffic incidents significantly affect traffic operations and cause safey hazards.

Due to the problems that traffic incidents are causing, it is crucial to implement effective management practices at the incident scene to reduce operational and safety problems. The Freeway Management Operations Handbook describes traffic incident management as: "…the systematic, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of traffic incidents, and improve the safety of motorists, crash victims, and traffic incident responders (*15*)." If these resources are effectively used, roadways can improve in terms of operating efficiency, safety, and mobility. This results from reducing the time to detect and verify a traffic incident occurrence; implementing the appropriate response; safely clearing the incident; and managing the affected flow until full capacity is restored.

An NTIMC report suggested following standardized responder safety operational procedures at incident scenes, which include the following approaches (*8*):

- Traffic control at traffic incident scenes, including 24/7 staffing for traffic control functions; vehicle positioning upon arrival to protect responders; and safe procedures for reopening highways.
- High-visibility reflective apparel as standard safety equipment for all responders operating in or near moving traffic.
- Incident Command System operations as they relate to traffic control duties.
- The use of adjunct warning lights or audible devices while responding to, or operating at, emergency scenes.

Corbin et al. stated in a Public Roads article that "a critical step toward improving responder safety is adopting and enforcing Driver Removal, Move-Over, and Authority Removal laws." Another key to improving responder safety is the development of recommended practices that are acceptable to all responding disciplines at the incident scenes. Driver training and awareness also are essential to improving responder safety *(14*).

METHODOLOGY

A systematic process was used in this research to comprehensively understand the problem and perform analysis accordingly. First, research goals and objectives needed to be

identified. Relevant literature was reviewed to better understand the problem and previous research completed. One important objective was to filter out all possible struck-by crashes within the time and location frame, and identify the selected methods, based on deliberate justification. Within all struck-by crashes identified, common characteristics and significant contributing factors were analyzed. Potential countermeasures to prevent struck-by crashes and protect emergency responders and roadway maintenance and construction workers were proposed. Finally, conclusions were reached and potential future work and research in this field were summarized.

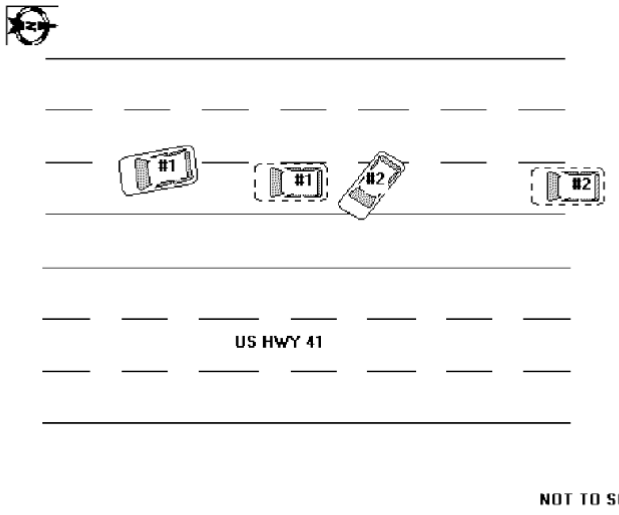
Data Collection

The identification of struck-by crashes was completed for the last 11 years (2000-2010). Due to the expected relatively small amount of struck-by crashes that occurred each year, a longer study time frame was used to gain a larger amount of crashes. A larger sample size will lead to more reliable and persuasive analysis results. In terms of location selection, all crashes on Wisconsin's State Trunk Network (STN) were considered to identify struck-by crashes. The State Trunk Network includes interstate highways, U.S. highways and state highways; they constitute the state's most traveled roadways. Crashes on other roadways were not analyzed in this research due to their lower highway functional class.

Preliminary crash data was queried from the WisTransPortal. The WisTransPortal contains a complete database of Wisconsin MV4000 Traffic Accident Extract data from 1994 through the current year. The database contains information on all reported crashes in Wisconsin, including the location of each crash, vehicles involved, and general crash attributes (*16*). According to its definition, struck-by crashes contain at least one of the following two types of characteristics in the crash reports:

- A reported crash where "ONDUTY" field has one of the following variables: police, EMT/First responder, firefighter, or winter highway maintenance, identifying crashes involving emergency responders.
- A reported crash where Pedestrian and Construction Zone flags are marked, identifying crashes involving work zone workers.

However, meeting one of the aforementioned criterion does not necessarily indicate a struck-by crash. Most crashes needed to be manually reviewed to determine whether to be considered struck-by or not. Note that police vehicles, ambulances, fire vehicles and other emergency response vehicles hit while on the way to incident scene or not responding to incidents are not considered struck-by crashes. In order to minimize manual review work, researchers were able to further filter crash data. These filtering steps include eliminating non-STN crashes, animal-related crashes, and single unit crashes. This yielded 2727 crashes to be manually reviewed through reading police officer narratives and diagrams, an example of which is shown in Figure 3.



UNIT #1 WAS AN ON DUTY DEPUTY SHERIFF LEGALLY PARKED WITH RED AND BLUE EMERGENCY LIGHTS OPERATING INVESTIGATING A MULTIPLE VEHICLE CRASH. UNIT #2 WAS TRAVELING S/B. THE DRIVER OF UNIT #2 CAME AROUND A CURVE AND REMEMBERS SEEING FLASHING LIGHTS AND HIS CAR TURNING SIDEWAYS.
THE DRIVER OF UNIT #2 DOES NOT REMEMBER HIS VEHICLE STRIKING ANYTHING. THE ON DUTY DEPUTY WAS NOT IN HIS VEHICLE E AND DID NOT OBSERVE THE CRASH.
BASED ON THE DAMAGE SUSTAINED TO BOTH VEHICLES AND THEIR PLACEMENT ON THE ROADWAY, IT IS LIKELY UNIT #2 LOST CONTROL AND BEGAN TO SLIDE SIDEWAYS STRIKING THE REAR OF UNIT #1 WITH IT'S PASSENGER SIDE.

ROAD CONDITIONS WERE POOR AS THEY WERE COVERED IN ICE. THERE WERE MULTIPLE CRASHES IN FRONT OF UNIT #1.

FIGURE 3 Example Of Police Officer's Narrative And Diagram In Crash Report

With the aforementioned filtering and reviewing process, 265 crashes were identified as struck-by crashes. Among them, 236 are related to emergency responders, and 29 are worker related. Lack of exposure-related factors in the data sets, such as the number of vehicles passing through the work zones during daytime and nighttime, the number of incidents that occurred on a roadway, length and duration of work zone, number of traffic stops, etc. limited the research in terms of analyzing the work zone crashes more precisely.

RESULTS AND ANALYSIS

The following subsections present the characteristics, contributing factors and classification of struck-by crashes. For contrast purposes, all crashes that occurred on Wisconsin STN (State Trunk Network) roadways from 2000-2010 were selected as the control group. This include 555,832 crashes in total. Their characteristics were used to compare with struck-by crashes to identify the unique characteristics of struck-by crashes.

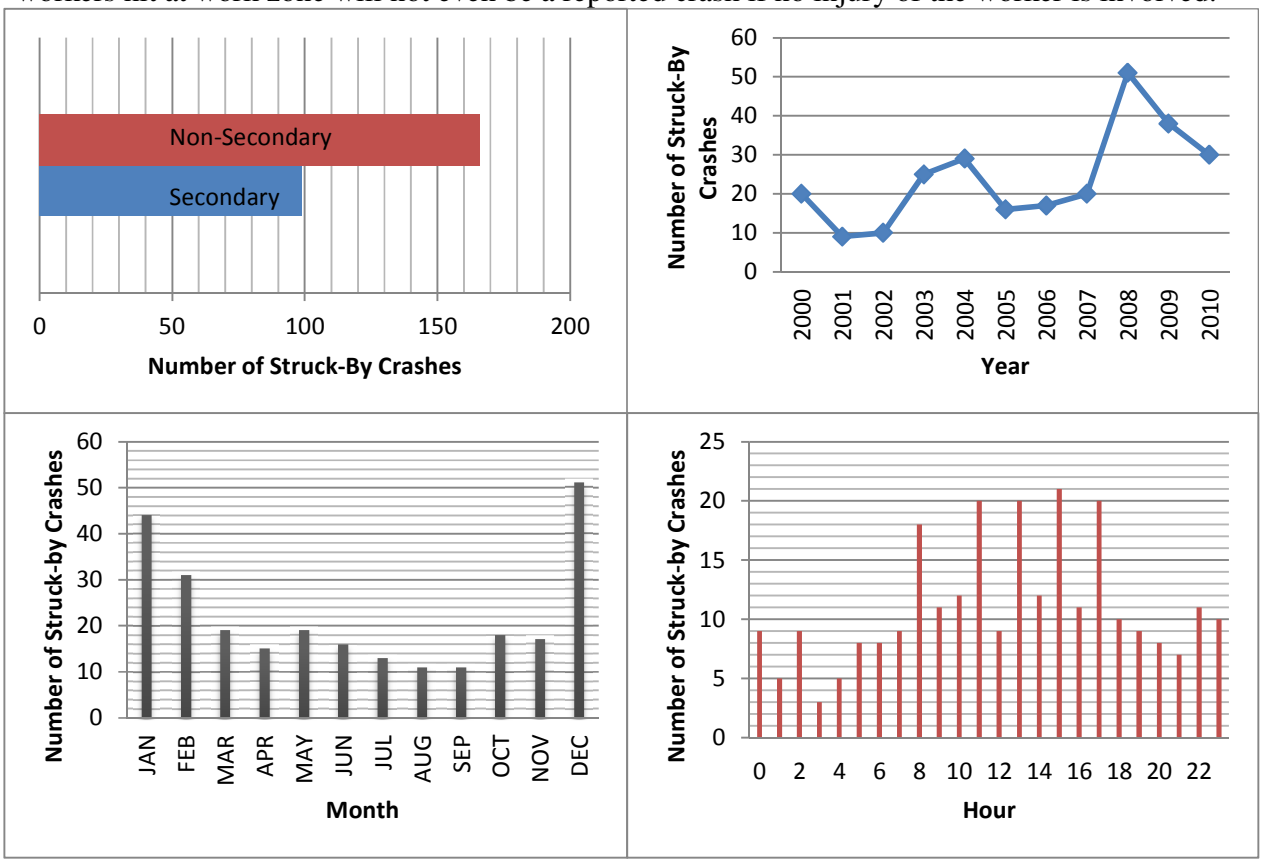
Crash Characteristics

Crash-related struck-by characteristics are shown in Figure 4, which summarizes temporal characteristics, injury severity and whether or not occurred as secondary incidents. The State of Wisconsin implemented the “Move-Over” Law in 2001, which is one of the most important legislature efforts to protect emergency responders. However, crash statistics showed that the number of struck-by crashes is increasing, with the peak number of crashes occurred in 2008.

Monthly distribution showed that winter months have significantly more struck-by crashes, which can be mainly attributed to adverse weather and roadway conditions. Hourly

distribution indicated that around 60 percent of struck-by crashes occurred during daytime from 8AM to 5PM. Figure 4 also shows that secondary crashes are a significant component of struck-by crashes. Secondary crashes are defined as reported crashes both spatially and temporally near a primary reported crash. Around 38 percent of struck-by crashes are considered secondary crashes. Note that since the MV4000 does not include an option for specifying whether a crash is secondary or not, researchers manually added this option and selected mainly based on the police officer narrative. Therefore subjective judgment in classification might exist.

Injury severities are separately presented for emergency responders and maintenance and road construction workers, with significant contrast between the two groups. Half of all struck-by crashes that involve emergency responders are property damage only, while all roadway workers related crashes involve injury of the worker. Fatal/incapacitating (K & A), non-incapacitating (B) and minor injuries (C) each account for approximately a third of all worker crashes. The reason may be due to a difference in criteria with crash reporting. Responders sitting in squad vehicle while being at incident hit will likely cause only property damage, while workers hit at work zone will not even be a reported crash if no injury of the worker is involved.



KABCO Scale	Emergency Responders Crashes	Maintenance & Construction Workers Crashes	All STN Crashes
K	0.42%	6.90%	0.62%
A	5.51%	27.59%	3.38%
B	23.73%	31.03%	9.31%
C	25.42%	34.48%	16.34%
PDO	44.92%	0.00%	70.35%

FIGURE 4 Crash Characteristics of Struck-by Crashes

Highway Characteristics

Highway related struck-by characteristics are shown in Table 1. Characterstics for responder and worker crashes are separately classified, "all STN crashes" column is used as a comparison purpose. Intersections involve major traffic flow conflicts and are usually a major crash location. However, only a small percentage of all struck-by crashes occurred at intersections, which implies that struck-by crashes may not influenced by intersection attributes. From the distribution of roadway functional class, rural interstate highway are much more prevalent for both responder and worker crashes compared with all STN crashes. Note that lower functional class roadways are not included in this research. Traffic way refers to the classification of motor vehicle operations area. It can be observed that the distribution of traffic way types for worker crashes and all STN crashes closely matches, while responder crashes occur more often on divided roadways (70 percent) compared with all STN crashes.

TABLE 1 Highway Related Characteristics of Struck-by Crashes

Description	STN Struck-by Crashes		All STN Crashes
	Workers	Responders	
Crash Location			
Intersection	20.7%	11.4%	32.0%
Non-Intersection	79.3%	88.6%	68.0%
Functional Class			
Rural US/State Highway	51.7%	32.6%	49.2%
Urban US/State Highway	27.6%	28.8%	33.5%
Rural Interstate Highway	17.2%	22.0%	8.4%
Urban Interstate Highway	3.4%	16.5%	8.9%
Traffic Way			
Divided W/O Barrier	37.9%	40.7%	32.3%
Divided W/ Barrier	13.8%	29.7%	19.4%
Not Divided	48.3%	25.0%	44.3%
One Way	0%	4.7%	4.1%
Roadway Geometry			
Curve	3.4%	19.1%	10.7%
Hill	27.6%	19.1%	12.9%
Curve and/or Hill	27.6%	32.6%	20.1%
No Special Roadway Geometry	72.4%	67.4%	80.0%
Speed Limit (mph)			
25	10.3%	5.9%	10.9%
30	6.9%	3.8%	7.0%
35	10.3%	7.6%	8.9%
40	0%	3.4%	4.1%
45	13.8%	4.2%	9.4%
50	6.9%	5.1%	3.6%
55	37.9%	28.8%	37.2%
65	13.8%	41.1%	18.9%

Special roadway geometry such as horizontal and vertical alignments, are common crash locations since they need more vehicle maneuvers and have visibility issues. For worker struck-by crashes, hills are much more prevalent in contrast to all STN crashes, while horizontal curve are much less present. For responder struck-by crashes, about 32 percent of crashes occurred at a curve or hill or both, which is also a larger proportion compared with all STN crashes. From the distribution of speed limit, similar patterns with special roadway geometry can be observed. Worker crashes match closely with all STN crashes, while for responder crashes, it can be seen that more than 40 percent of crashes occurred on 65 mph speed limit interstate highways.

Environment Characteristics

Crashes occurring under different environmental conditions such as lighting conditions, weather conditions, and road surface conditions were analyzed to identify characteristics of struck-by crashes and are shown in Table 2. Visibility is an important factor that influences a driver's safe driving. Crash data showed that almost 90 percent of worker crashes occurred during daytime, while only 50 percent of responder crashes occurred in daylight, with 73 percent of all STN crashes have as a comparison. This implies that responders crashes are attributed to lighting condition to some extent, with more crashes occurred in dark-unlighted conditions. Worker crashes, on the contrary, seems to be unrelated with lighting conditions, since most work zone work will not happen under dark-unlighted conditions.

TABLE 2 Environment Related Characteristics of Struck-by Crashes

Description		STN Struck-by Crashes				All STN Crashes	
		Workers		Responders			
Lighting Conditions							
Daylight		89.7%		50.8%		73.2%	
Dark-Unlighted		6.9%		26.3%		12.7%	
Dark-Lighted		0%		18.6%		10.7%	
Dawn		3.4%		2.1%		1.6%	
Dusk		0.0%		2.1%		1.9%	
Roadway Conditions							
Dry		93.1%		39.4%		71.8%	
Snow	Adverse Roadway Conditions	0%	6.9%	29.7%	60.6%	10.2%	28.9%
Ice		0%		19.1%		5.1%	
Wet		6.9%		11.9%		12.6%	
Weather Conditions							
Clear		79.3%		36.9%		55.5%	
Cloudy		17.2%		19.5%		24.8%	
Snow	Adverse Weather Conditions	0%	3.4%	26.7%	43.6%	9.9%	19.4%
Rain		0%		6.4%		7.1%	
Sleet		0%		6.4%		1.2%	
Wind		0%		3.9%		0.6%	
Fog		3.4%		0.4%		0.6%	

In terms of roadway and weather conditions, similar patterns can be observed. Adverse roadway conditions, including snowy, icy, or wet pavement were present for more than 60

percent of responder crashes, which is a likely significant factor, with contrast to only seven percent for worker crashes and 28 percent for all STN crashes. Weather condition analysis showed that adverse weather conditions, which include snow, rain, sleet, fog and strong winds, account for around more than 40 percent of responder crashes, compared with only three percent of worker crashes and 19 percent of all STN crashes. Again, most construction works does not occur under adverse weather conditions, which implies that adverse conditions does not affect the risk of worker crashes. However, emergency responder crashes are much more correlated with weather and pavement conditions. Among adverse weather, snow is the predominant type of weather, and is the key factor that leads to snowy and icy roadway surfaces.

Driver Contributing Factors

The driver plays a critical role in crashes, thus the need to identify driver contribution to crashes is highly important for suggesting possible countermeasures. In struck-by crashes, two types of persons are involved. On one hand, the on-duty person is the victim of the crash, hit while performing work or assistance activities. Their detailed activities and position on the roadway need to be carefully analyzed, which is discussed in the next sub-section. On the other hand, struck-by crashes involve the driver of the vehicle at-fault that hit the on-duty person around a traffic incident or maintenance work zone. Those contributing factors are identified and the results are shown in Table 3. Note that the sum of factors are greater than 100 percent since multiple factors may be involved in a crash.

TABLE 3 Driver Contributing Factors To Struck-By Crashes

Driver Factors	STN Struck-by Crashes	
	Responders	Workers
Too Fast for Conditions/Speeding	50.4%	17.2%
Failure to Have Control	37.3%	17.2%
Inattentive Driving	19.9%	48.3%
Alcohol and Drug (Impaired Driving)	12.7%	6.9%
Other	11.9%	17.2%
Disregard Traffic Control	7.6%	10.3%
Following Too Close	5.1%	6.9%
Failure to Yield	4.7%	0%
Unsafe Backing	3.8%	0%
Improper Turn	0.8%	3.4%
Improper Overtaking	0.8%	0%

For responder crashes, the dominant driver contributing factor is speed-related. In almost half of the responder struck-by crashes, drivers were either exceeding the speed limit or failed to slow down for conditions such as traffic incidents or work zones. The second highest contributing factor is drivers failing to keep their vehicle under control, (37 percent) which is closely related to the speed issue. This occurred when drivers would suddenly brake and lose control of their vehicle. Inattentive driving is another major cause of an on-duty person being hit. Circumstances included drivers not looking at the road ahead, looking at cellphones, using in-car devices, or staring at the primary incident. For worker crashes, inattentive driving of civilian drivers were present in almost half of worker crashes. Speed and failure to have control also account for a significant percentage of driver factors.

On-Duty Person Characteristics

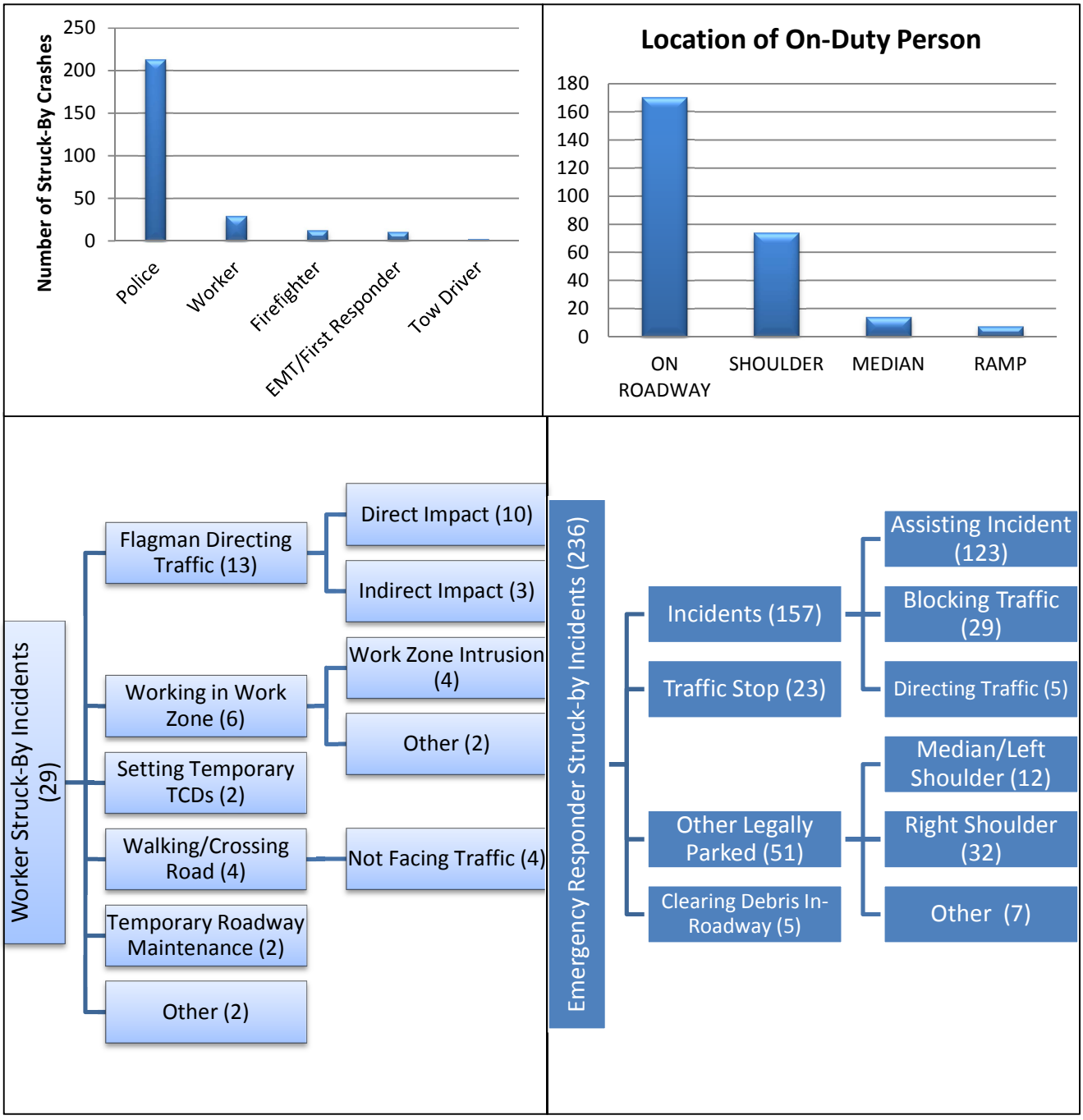


FIGURE 5 On-Duty Person Characteristics of Struck-by Crashes

One important component of struck-by crashes is the on-duty person. Understanding the actions and work performed by on-duty persons and their location is crucial to enhancing the safety of emergency responders and roadway workers. The characteristics of on-duty persons are shown in Figure 5. From the figure, it can be observed that around 80 percent of struck-by

crashes involve a police officer or squad car being hit while on duty, followed by roadway workers as a significantly smaller sample. Eleven and 10 firefighters and Emergency Medical Technician (EMT) are hit respectively. Note that tow-truck drivers are also considered emergency responders for this research. However, no options are provided in crash reports to identify the involvement of tow truck drivers. Therefore, data concerning tow truck drivers are likely incomplete. The majority of on-duty persons are positioned in roadway travel lanes at the time of crash (64 percent), followed by the shoulder, which accounts for 28 percent.

Actions performed by emergency responders and roadway workers are separately summarized and classified in Figure 5. Due to the small amount of crashes, all categories are marked with their respective number of cases rather than percentages. A significant amount of worker struck-by crashes are flagmen hit while directing traffic in a construction zone. Indirect impacts in this category are defined as circumstances where the car that hit the worker was hit by another car that pushed the first car into the worker. It can also be observed that four cases were work zone intrusion crashes, and two were workers setting up temporary traffic control devices. Four crashes were walking/crossing road crashes, all cases occurred when the worker was not facing traffic. Among the 236 emergency responder struck-by crashes, more than half occurred when emergency responders were assisting at the incident scene. Other crashes occurred when emergency responders were blocking traffic using their squad, or directing traffic. Police officers hit while conducting traffic stop (i.e. pull over a car) also represent about ten percent of all emergency responder crashes.

DISCUSSIONS AND CONCLUSIONS

Based on the above analysis, characteristics and contributing factors are identified and analyzed. Several key points and findings are summarized below.

For emergency responder struck-by crashes:

- Police officers are the predominant type of on-duty person.
- A large proportion of responder crashes occurred on rural interstate highways.
- Speeding or “too fast for conditions” is the key driver factor that leads to struck-by crashes at incidents.
- Adverse roadway/weather conditions (icy, slippery or snowy roadways) are the most significant environmental factor, and explain why winter months have much more struck-by crashes than others.
- Most emergency responder struck-by crashes occur when responders are assisting traffic incidents.

For roadway worker struck-by crashes:

- Flagmen hit by surrounding traffic account for around half of all worker struck-by crashes.
- Worker crashes are likely uncorrelated with adverse weather, roadway or lighting conditions.
- Inattentive driving of civilian drivers is the most significant contributing factor, speed issue comes second.

In order to reduce the number of these crashes, based on the conclusions above, several possible countermeasures are provided. Since speed is a key issue contributing to struck-by crashes, controlling vehicle speed near incident scene or work zone is crucial. Enhancing speed control can be done in several ways, including more strict enforcement of the Move Over Law. Speed and inattentiveness can both be caused by ineffective warning to drivers. Therefore, enhancing warning mechanisms through temporary traffic control devices can be a useful approach. The Manual on Uniform Traffic Control Devices (MUTCD) indicates that

"Construction, maintenance, utility, and incident zones can all benefit from Temporary Traffic Control (TTC) to compensate for the unexpected or unusual situations faced by road users (*17*)." It is suggested that temporary traffic control devices be used at all incidents, including crashes, work zones, disabled vehicle assistance, etc. Portable flashing beacons are also suggested to increase warning effects to drivers. Furthermore, more protection needs to be focused on flagmen directing traffic, including retroflective vests and advance warning to drivers. Finally, apart from engineering and enforcement solutions, emergency responders and roadside workers need to increase their safety awareness by trying to face traffic and watch out for any unexpected situations.

A significant amount of research energy and time are spent to identify struck-by crashes. Since the current Wisconsin MV4000 Crash Reporting Forms do not directly identify struck-by crashes, the authors tried to filter out as many irrelevant crashes as possible. At the end, the authors still needed to manually review more than two thousand crash reports. In order to better track struck-by incidents in the future, it is suggested that additional options be added in the crash report forms. The ON-DUTY block currently includes police, EMT, firefighters and winter highway maintenance. An additional two options (roadway workers, and tow-truck drivers) could be added to that block. Options on work performed by the on-duty person could also be added to facilitate the identification of struck-by crashes. Data accuracy and consistency should also be enhanced through training of police officers. Another problem is the lack of exposure data and incident or work zone data. Without this information, more incident or work zone related factors could not be analyzed and crash rates could not be computed. Furthermore, a statistical model could not be built due to the lack of data and the relatively small data size, which limited the analysis of struck-by crashes.

Based on problems mentioned above, it is suggested that future research in this field can be completed to explore struck-by crashes on lower functional class roadways, such as county roads and urban streets and roadways. Exposure and incident or work zone data could be incorporated to build a statistical model. Larger data sets will provide more reliable and statistically significant results. If data from other states are available, more research could be conducted on a national basis to compare differences on struck-by crashes and traffic incident management and work zone procedures.

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