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The research reported herein was performed by the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center, within the Department of Mechanical and Aerospace Engineering at the University of California – Davis, for the Division of Research, Innovation and System Information (DRISI) at the California Department of Transportation. AHMCT and DRISI work collaboratively to complete valuable research for the California Department of Transportation.

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Advanced Highway Maintenance and Construction Technology Research Center

Department of Mechanical and Aerospace Engineering
University of California at Davis

SUPPORT FOR CHALLENGE AREA "WORK ZONE"

Patricia Fyhrie
&
Bahram Ravani, Principal Investigator

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This research study focused on the support of the "Work Zone Challenge Area" (WZCA) component of California's Strategic Highway Safety Plan (SHSP). The WZCA is charged with improving the safety of work zones and reducing the number of fatalities and serious injuries due to work zone related traffic collisions. The WZCA team has identified strategies to address this charge with subsequent "Action Items" to help implement these strategies. This research study led two action items. These action items are supporting the "Apply advanced technology to improve work zone safety" and the "Improve work zone data collection and analysis" as part of WZCA strategies. Focusing on "data driven" solutions to the WZCA challenge, a review of existing technologies, practices and applications was done to help identify any new technology or "in the field application" that may be of interest to the WZCA team. With respect to traffic related data, AHMCT made use of databases associated with Traffic Collision Reports (TCRs) such as Traffic Accidents Surveillance and Analysis System (TASAS) and Statewide Integrated Traffic Records System (SWITRS) to capture more collision content and associated attributes. Specifically, the research found what data is available for work zone traffic collisions, and the current study provides a detailed explanation of where the data is derived and what it contains to evaluate work zone safety. Data analysis from these sources are also provided to support the WZCA team's efforts. The description of data and how it can be used to better understand work zone collisions are aimed at the traffic safety community.

EXECUTIVE SUMMARY

This research study provided support for the California Strategic Highway Safety Plan (SHSP) Challenge Area Work Zone (WZCA) team in addressing the following two strategies:

- Applying advanced technology to enhance work zone safety area.
- Improve work zone data collection and analysis.

The California SHSP 2015-2019 is considered "the statewide, coordinated safety plan that provides a comprehensive framework for reducing highway fatalities and severe injuries on all public roads." The Work Zone Challenge Area team is charged with improving the safety of work zones and reducing the number of fatalities and serious injuries due to work zone related traffic collisions.

Research Objectives and Methodology

The objective of this research study was to provide data driven responses to questions as well as raw and filtered data related to advanced work zone safety technologies and data sources on work zone accidents as requested by the WZCA team. This research study contains a review of the existing literature and available technologies related to advanced work zone safety technologies. This review also included any experience or knowledge gained through "in the field application" that was of interest to the WZCA team. Furthermore, this research study identified data sources on work zone accidents. In relationship to data sources, this research study contains an evaluation of existing data collection systems, such as the SWITRS, TASAS, and Advanced Highway Maintenance and Construction Technology (AHMCT) Work Zone Injury Database. In addition, this research study discusses how these databases were used to capture more collision content and attributes and evaluate methods of improving such systems. The research team also supported the WZCA team by being active participants in activities, meetings, and brainstorming efforts. This was necessary to provide the right data in the right format to effectively support the SHSP "Data Driven" commitment.

Results and Recommendations

The literature review revealed that the use of Intelligent Transportation Systems (ITS) improves work zone safety while assisting in speed, traffic, and incident management, by providing methods such as queue warning systems, variable speed limits, and dynamic merging systems. The technology review indicated innovations in using autonomous driving and driver assistance technologies, advanced truck mounted attenuators, smart cones and barrels, automatic means for work zone notifications, and the use of wearable technology to alert roadway workers. In addition, the literature and technology review indicated the use of unique public communication methods such as audio warning messages with smart phones or use of active, as well as emotional, driver warning systems.

Data collection and analysis of work zone related accidents from 2010 to 2015 indicated an increasing trend in the percentage of work zone accidents as compared to the total number of collisions on California highways. Detailed results are summarized in the Table 1 below.

Table 1: Percentage of work zone accidents as compared to the total number of accidents on California Highways for 2010 to 2015.

Year	# Work Zone Collisions	Total # Collisions	% of Work Zone Collisions per Year
2010	3545	155768	2.28%
2011	4032	152267	2.65%
2012	5008	149288	3.35%
2013	5873	152426	3.85%
2014	6563	153994	4.26%
2015	7458	166604	4.48%

The researchers found that collisions near work zones were less severe and that there were more Property Damage Only (PDO) crashes in work zones as compared to all collisions. The fatalities were likely due to mostly night-time construction where alcohol is, probably, stronger factor affecting drivers. Furthermore, analysis of the data indicated that sideswipe and rear end accidents were much more common near work zones due to distractions and sudden changes in traffic speeds. Improper driving and unsafe speed were among the most causal factors in work zone accidents.

The following recommendations are made based on the results of this study:

- If the percentage of work zone collisions continues along the same trend as from 2010 to 2015, then it is recommended to have additional research and development efforts in areas that can impact work zone safety.

- Since Improper Driving and Unsafe speeds are two major factors in work zone collisions, additional research and development efforts aimed at influencing driver behaviors is recommended.

- In this study an example process was used to link traffic collisions data (i.e. TASAS) with Caltrans' Lane Closure System (LCS) data. More research and/or development work is recommended to link these two databases. By doing so, each collision identified with an active lane closure will have access to the LCS data. The ability to link lane closure data with traffic collisions on state highways can provide a new level of information on work zone collision analysis.

- In order to objectively evaluate work zone collision frequency, an objective measure of exposure to road work is needed. An objective measure of exposure can be developed by normalizing exposure based on length of time or total distance of closure. More research is recommended for developing such a measure of exposure.

- More research and analysis is recommended to identify collisions in work zone regions such as the advanced and transition regions. It will be useful to determine if serious injuries and fatalities occur in any one region type.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
AWM	Audio Warning Messages
Caltrans	California Department of Transportation
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
ITS	Intelligent Transportation Systems
LCS	Lane Closure System
PDO	Property Damage Only
SHSP	Strategic Highway Safety Plan
SWITRS	Statewide Integrated Traffic Records System
TASAS	Traffic Accident Surveillance and Analysis System
TxDOT	Texas DOT
TMA	Truck Mounted Attenuator
WZCA	Work Zone Challenge Area
*.PDF	Publishable data format file extension

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CHAPTER 1:
INTRODUCTION

Problem

According to the Statewide Integrated Traffic Records System (SWITRS), in 2015, the State of California had 7458 work zone collisions with 52 causing fatalities and 128 causing serious injury. The Strategic Highway Safety Plan (SHSP) Work Zone Challenge Area (WZCA) is charged with improving the safety of work zones and reducing the number of fatalities and serious injuries due to work zone related traffic collisions. The WZCA team has identified four strategies to meet its goals. These strategies are shown in Table and consist of not only identifying the best work zone practices but also looking into education, use of advanced technologies, and better data collection to improve safety.

Table 2: List of WZCA strategies.

Strategy #	Work Zone Challenge Area Strategy description
1	Evaluate and promote strategies for best work zone practices.
2	Enhance safe driving through work zones with education and enforcement.
3	Apply advanced technology to enhance work zone safety area.
4	Improve work zone data collection and analysis.

Objectives

This research study was intended to provide support for the actions and activities assigned to the WZCA team especially as it relates to Strategies 3 and 4 (Table). In the past, AHMCT has worked with the Challenge Area teams and has been identified by the WZCA team as potentially being the lead on some aspects of Strategies 3 and 4. Under this task, this research provides support through data derived answers to questions posed by the WZCA team as well providing raw and filtered data as requested by the WZCA team.

Scope

The scope of this research study was limited to support the WZCA team by providing dedicated work on Strategies 3 and 4 (Table). In relationship to Strategy 3 ("Apply advanced technology to enhance work zone safety area"), the researchers reviewed the existing literature and available technologies. This review also included any experience or knowledge gained through "in the field application" that may be of interest to the WZCA.

In relation to Strategy 4 ("Improve work zone data collection and analysis"), the researchers evaluated existing data collection systems such as SWITRS, TASAS, and AHMCT's Work Zone Injury Database. Furthermore, the researchers made use of databases associated with Traffic Collision Reports (TCRs), such as TASAS and SWITRS, to capture more collision content and attributes and evaluated methods of improving such systems. The research team also supported the WZCA team by being an active participant in activities, meetings, and brainstorming efforts. This was necessary to provide the right data in the right format to effectively support the SHSP "Data Driven" commitment.

Background

The California Strategic Highway Safety Plan (SHSP) 2015-2019 is "the statewide, coordinated safety plan that provides a comprehensive framework for reducing highway fatalities and severe injuries on all public roads." There are many stakeholders, including Caltrans, who are dedicated to meeting the objectives of the SHSP. A significant component of the SHSP is that "the plan must be data-driven." This indicates that quantifiable, safety-related metrics must be a key component in identifying areas of concern and then used to develop potential solutions.

Using Data to Improve Work Zone Safety

When a traffic collision occurs and a report is generated by a law enforcement officer; it can be noted on the report that "road work or construction" was present. The road work could have had some influence on the collision, and consequently is of interest to traffic safety professionals. Furthermore, road work usually indicates road workers and large moving equipment are likely to be present, creating a high-risk environment to both road workers and the traveling public.

When trying to evaluate the current status of work zone safety, it is difficult to find an objective way to analyze collisions. For example, a map displaying all work zone collision events for any given amount of time does not give an objective assessment of safety risk. Consider the situation where one particular highway has noticeably higher numbers of work zone collisions in a designated region than in other locations in the state. This could indicate that there was a great deal of road work being done on that freeway or there was an "issue" related to safety during a short interval of road work. Obviously, unless there is road work, reported collisions should not be tagged with this condition. Consequently a "no collision" section does not necessarily mean road work will be low risk. Some sort of objective comparison mechanism needs to be established.

In an effort to objectively quantify "exposure" of ongoing road work on California highways, the WZCA team indicated that amounts of road work be related to the prevalence of lane closures. Precise dates and times of active lane closures for Caltrans maintained highways are logged in the LCS. Also recorded in the LCS database are precise locations (highway number and post-mile marker ranges, side of highway, and number of closed lanes). To coincide with the lane closure information, it is necessary to determine which traffic collisions (provided by TASAS) occur at active lane closure sites (determined using LCS data). Since LCS data provides additional work zone data that is otherwise not provided in collision data, this information is considered to be very relevant towards understanding work zone collisions and implementing effective safety improvement measures.

Developing a method that identifies work zone collisions as those which occur concurrent with active lane closures is aligned with Strategy #4 (Improve work zone data collection and analysis). This method is more objective and robust than relying on a Traffic Collision Report marked as the road condition to be undergoing repair or construction which is the current method used today. This new method also has the advantage of providing the lane closure details which the current method does not. Knowing whether maintenance or construction activities are ongoing with each work zone collision can be very useful data. When the traffic collision data is linked to the lane closure data, an in-depth analysis may proceed. Although detailed analysis is an important aspect of Strategy #4, it is beyond the scope of this research. A "proof on concept" is developed for this report to illustrate the differences between the proposed method and the current method of identifying work zone collisions.

Research Methodology

The research methodology was based on previous experiences with work zone traffic collisions and Caltrans' TASAS database to provide support for the WZCA team. Specifically, the research team led the efforts in certain aspects of WZCA Strategies 3 and 4 which are: "applying advanced technology to enhance work zone safety area" and "improve work zone data collection and analysis." The research methodology consisted of the following five tasks:

1. Project management and final report preparation.
2. Review literature on methods to enhance work zone safety.
3. Evaluate work zone accident data for California highways from various databases.
4. Data Analysis.
5. Attendance of WZCA meetings.

Each of these tasks, with the exception of tasks 1 and 5 dealing with demonstration, presentation, and documentation, are described in the subsequent chapters of this report.

Overview of Research Results and Benefits

One result of this support was to investigate what technology, if any, might help improve the safety of highway work zone regions. This review of technologies and safety applications is covered in the Literature Review (Chapter 2). Chapters 3 and 4 address what data is available for work zone traffic collisions and provide a detailed explanation of where the data is derived from and what it contains to evaluate work zone safety. Data analysis from these sources are also provided to support the WZCA team's efforts. The description of data and how it can be used to better understand work zone collisions are aimed at the traffic safety community.

CHAPTER 2:
LITERATURE REVIEW

The literature review on work zone safety in this research study is divided into three sections: Practices, Technologies, and Research Articles. Different keywords were used in performing the search of the existing literature for each of these three sections and their corresponding sub-sections.

Practices

Keywords: ITS, Driverless Technology, Dynamic Merging, Queue Warning Systems, Variable Speed Limits

This review revealed that the use of Intelligent Transportation Systems (ITS) benefited both workers and drivers. ITS improve work zone safety while assisting in speed, traffic, and incident management. The report "Smart Work Zones" (2012) elaborates on the topic [1].

The article "How Work Zones are Becoming Smarter" also discusses the application of ITS and the many different practices such as queue warning systems, variable speed limits, and dynamic merging systems [2]. Additionally, the article highlights driverless work zone technology, specifically Truck Mounted Attenuator (TMA) trucks controlled by sensors and a leader/follower mechanism rather than a human driver. These driverless TMA trucks were tested by the Florida DOT. The article "Florida DOT to Test Autonomous Truck Mounted Attenuators in Work Zones Later this Year" (2015) elaborates on this [3].

Dynamic merging systems are discussed in detail in "Guidance for the Use of Dynamic Lane Merging Strategies" [4]. The article examines multiple merging strategies including the early, late, and static merging strategies. The article recommends dynamic merging in "two-to-one lane closures" for two lanes that travel in the same direction.

Keywords: Emotional practice, Rumble Strips , Changeable Message Signs

Since 2014, the State of Texas has started implementing many practices to help prevent work zone accidents. Several of these practices, highlighted below, were found in the article "Top 4 Things Texas is Doing Right When it Comes to Work Zone Safety" [5]. One recent practice in work zones conducted by the State of Texas relies on emotion. Texas DOT places cones with shoes on them to honor those who have died in work zone accidents. The aim of this act is to remember those lost in accidents while simultaneously striking an emotional chord in drivers in hopes that they slow down and drive more alert. Another practice was portable rumble strips. These devices helped alert drivers to upcoming work zones. Changeable message signs and new speed limit signs were among other new practices.

Keywords: Videos, Humor

The Ontario Road Builders' Association created and released a series of humorous videos to alert the motorists of the importance of alert and proper driving in work zones. These videos are available in the article "Videos Use Humor to Promote Work Zone Safety" (2016) [6].

Keywords: Smartphones, Audio Warning Message, AWM

The conference paper "Performance Measures of Smartphone Warning Messages in Work Zones and Intersections" discusses the positive effects of Audio Warning Messages (AWM) [7]. AWM is a technology that uses drivers' smartphones to alert them to approaching work zones and reminds them to drive safely. The message is in audio form so that drivers would not need to look at their phones. This paper argues that results show that AWM increases driver alertness and attention to work zones and associated signs.

A summary of the above identified practices used by some of the transportation agencies in improving work zone safety is provided in Table.

Technologies

Keywords: Remote Asset Management, Driveway Assistance Device, iCone, Smart Barrel

There are many modern technologies used in the industry today that help create safer work zones. The article "3 Innovative Technologies That Are Making the Work Zone Safer" discusses Remote Asset Management systems, Driveway Assistance Device, and the iCone [8]. The Asset Management System allows the user to track, collect, and analyze traffic conditions and data in a time efficient and cost effective way. Driveway Assistance Device (DAD) replaces the need for a human flagger to prompt drivers when and where to proceed. DAD uses flashing arrows to direct drivers in order to ultimately replace the need for construction workers to direct traffic. Lastly, the iCone is a device that looks like any simple, orange traffic drum but has a built in GPS and internet connection allowing for data collection. The iCone is simple to relocate, efficient in collecting data, and useful in monitoring traffic conditions.

More information about the smart cones and barrels can be found in the articles "Smart Barrel for an Adaptive Queue-Warning System" (2005) [9] and "Next Generation Smart Barrel System for Work zone Safety Enhancement" (2013) [10].

Keywords: Smart Vest, eVest

The eVest is one of the more modern technologies that seem promising for workers. This vest is loaded with a variety of sensors that associate with different human senses such as visual, auditory, and tactile. The aim of the eVest is to warn the worker wearing the vest of an incoming vehicle. If an oncoming vehicle were to be on a collision course with a worker wearing the smart vest, the vest would alert the worker through vibrations, loud noises, and flashing LED lights. Description of the eVest is expanded upon in the recent report "Researchers' Prototype Vest Offers a Warning System for Roadside Construction Workers, Rescue Personnel" (2015) [11].

Table 3: Summary of identified methods supporting the "Practices" section.

Keywords	URL(s)
ITS, Driverless Technology, Dynamic Merging, Queue Warning Systems, Variable Speed Limits	http://nationalruralitsconference.org/downloads/Presentations12/GRITS3_Murphy.pdf [1] http://www.royaltruckandequipment.com/blog/how-work-zones-are-becoming-smarter [8] https://www.workzonesafety.org/training-resources/fhwa_wz_grant/atssa_dynamic_lane_merging/ [4]
Emotional practice, Rumble Strips, Changeable Message Signs	http://www.royaltruckandequipment.com/blog/top-4-things-texas-is-doing-right-when-it-comes-to-work-zone-safety [5]
Videos, Humor	http://www.safetyandhealthmagazine.com/articles/14190-videos-use-humor-to-promote-work-zone-safety [6]
Smartphones, Audio Warning Message, AWM	https://www.researchgate.net/publication/303750794_Performance_Measures_of_Smartphone_Warning_Messages_in_Work_Zones_and_Intersections [7] https://www.vt.edu/spotlight/innovation/2015-08-31-beacon/safetyvests.html [11]

Table 4: A summary of identified technologies for "Technologies" section.

Keywords	URL(s)
Remote Asset Management, Driveway Assistance Device, iCone, Smart Barrel	http://www.royaltruckandequipment.com/blog/3-innovative-technologies-that-are-making-the-work-zone-safer [8] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.130.9491&rep=rep1&type=pdf [9] https://trid.trb.org/view.aspx?id=1237828 [10]
Smart Vest, eVest	https://www.vt.edu/spotlight/innovation/2015-08-31-beacon/safetyvests.html [11]
Remote Asset Management, Driveway Assistance Device, iCone, Smart Barrel	http://www.royaltruckandequipment.com/blog/3-innovative-technologies-that-are-making-the-work-zone-safer [8] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.130.9491&rep=rep1&type=pdf [9] https://trid.trb.org/view.aspx?id=1237828 [10]
Smart Vest, eVest	https://www.vt.edu/spotlight/innovation/2015-08-31-beacon/safetyvests.html [11]

Research Articles

A summary of research articles dealing with work zone safety methods is provided in Table.

Table 5: A summary of reference articles.

Name of Article	Reference	Description
Testing Effects of Warning Messages and Variable Speed Limits on Driver Behavior Using Driving Simulator	Lee, Chris, Abdel-Aty, Mohamed: "Testing Effects of Warning Messages and Variable Speed Limits on Driver Behavior Using Driving Simulator." Transportation research record. No. 2069, 55–64. (2008). [12]	This study examined the effects of various warning signs and speed limits on drivers' speeds. Research showed that when a combination of messages and speed were in place, drivers had a more uniform and reduced speed.
Radial Basis Function Neural Network for Work Zone Capacity and Queue Estimation	Karim, Asim, Adeli, Hojjat. "Radial Basis Function Neural Network for Work Zone Capacity and Queue Estimation." Journal of Transportation Engineering **Vol. 129**(5), 2003. [13]	This article reveals an adaptive computational model, overseeing the work zone capability, while looking further into aspects such as number of lanes, number of open lanes, work zone layout, darkness factor length, work intensity lane width, speed, proximity of ramps, and percentage trucks. This model calculates queue delays and their lengths in order to improve worker safety and efficiency within the work zone.
Traffic Flow Characteristics of the Late Merge Work Zone Control Strategy	G. Pesti, D. R. Jessen, P. S. Byrd, P. T. McCoy "Traffic Flow Characteristics of the Late Merge Work Zone Control Strategy." Transportation Research Record: Journal of the Transportation Research Board, Vol 1657, 1-9, 1999. [14]	Study discusses how usual work zone precautions work well except in a congestion occurrence. The article discusses the concept of "The Late Merge," aiding in less queue lengths and road rage. However, from the results, it was shown that motorists do not follow the set guidelines and the true potential will not be reached until all follow the needed rules.
Driver Performance Comparison of Fluorescent Orange to Standard Orange Work Zone Traffic Signs	Hummer, J., Scheffler, C. "Driver Performance Comparison of Fluorescent Orange to Standard Orange Work Zone Traffic Signs." Transportation Research Record: Journal of the Transportation Research Board, *1657*, 55-62, 1999. [15]	Using durable fluorescent orange sign sheeting on warning signs in work zones advances visibility compared to the standard nonfluorescent orange sheeting, though studies have not yet confirmed the results. After this study, it was proven that fluorescent orange signs were found to cause some changes, primarily positive, in driver behavior. This resulted in lower speeds, less collisions, and better driver awareness.

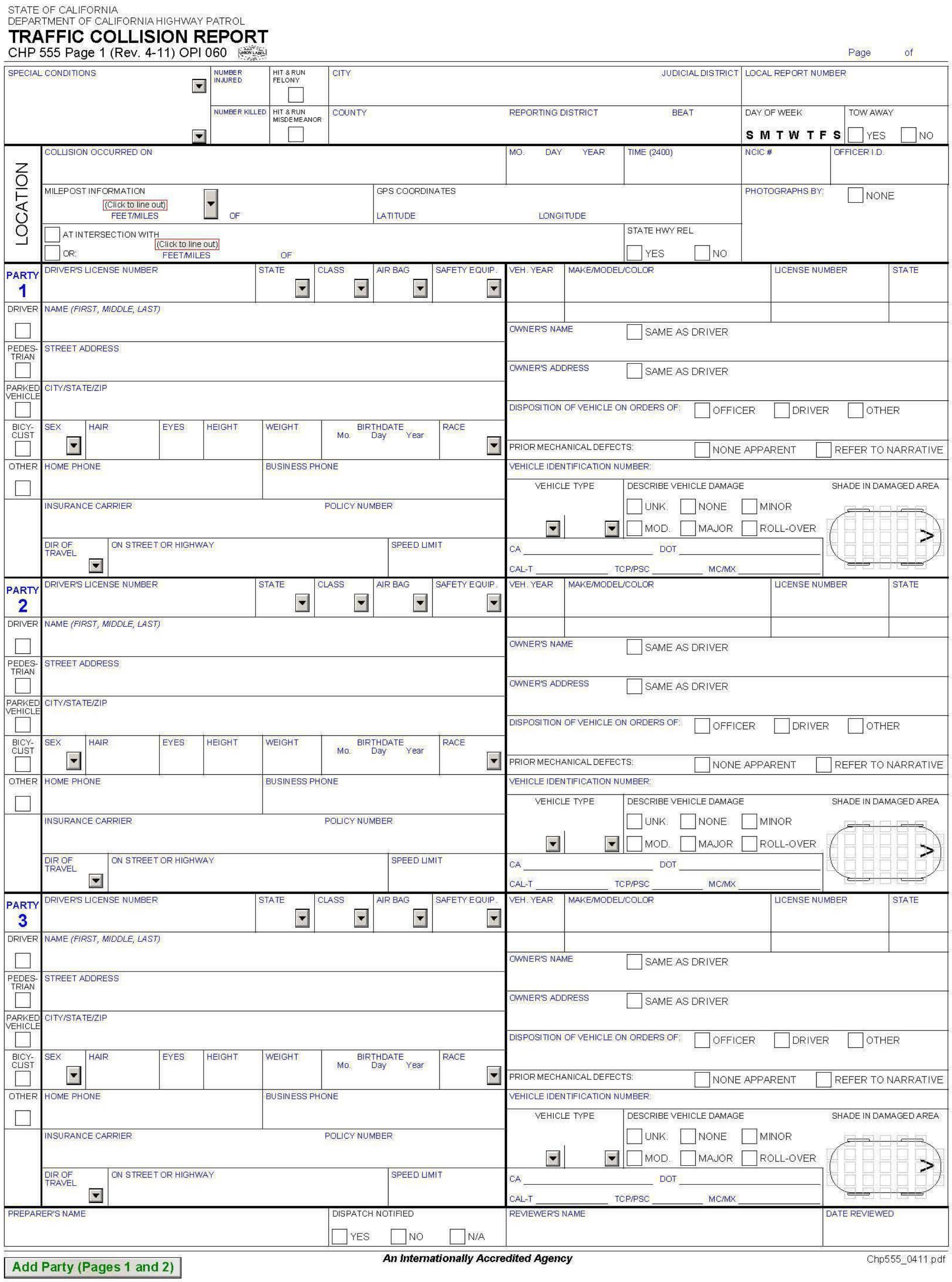
CHAPTER 3: WORK ZONE ACCIDENT DATA

There are several sources of information from which useful data on work zone collisions occurring on Caltrans' maintained highways can be extracted. This chapter evaluates the available data and its potential role towards improving work zone safety.

California Highway Patrol's Traffic Collision Report

California Highway Patrol (CHP)'s Traffic Collision Reports (TCRs) are the key component of work zone related collisions. All other traffic collisions and incidents not documented by CHP are assumed to not have occurred on California highways. Thus, the underlying element of all traffic collision data that may be used to evaluate work zone safety is based on CHP's TCRs. There is wide-spread information on these TCRs (also referred to as "Form 555" when all reports were generated manually on paper forms). The form, content, and procedures as to how to complete the forms have remained stable for the past decade. An example of a TCR can be seen in Figure 1a: P.

More information on the data obtained from TCRs can be found in Caltrans' *Traffic Manual* "Chapter 3: Accident and Roadway Records" (http://www.dot.ca.gov/trafficops/camutcd/traffic-manual.html) and CHP's iSWITRS website (http://iswitrs.chp.ca.gov/Reports/jsp/userLogin.jsp) where registered users can download the raw data template and field explanations.



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DEPARTMENT OF CALIFORNIA HIGHWAY PATROL
TRAFFIC COLLISION REPORT
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SPECIAL CONDITIONS | NUMBER INJURED | HIT & RUN FELONY | CITY | JUDICIAL DISTRICT | LOCAL REPORT NUMBER
NUMBER KILLED | HIT & RUN MISDEMEANOR | COUNTY | REPORTING DISTRICT | BEAT | DAY OF WEEK S M T W T F S | TOW AWAY YES NO

LOCATION
COLLISION OCCURRED ON | MO. DAY YEAR | TIME (2400) | NCIC # | OFFICER I.D.
MILEPOST INFORMATION (Click to line out) FEET/MILES OF | GPS COORDINATES LATITUDE LONGITUDE | PHOTOGRAPHS BY: NONE
AT INTERSECTION WITH | OR: (Click to line out) FEET/MILES OF | STATE HWY REL YES NO

PARTY 1
DRIVER'S LICENSE NUMBER | STATE | CLASS | AIR BAG | SAFETY EQUIP. | VEH. YEAR | MAKE/MODEL/COLOR | LICENSE NUMBER | STATE
DRIVER | NAME (FIRST, MIDDLE, LAST) | OWNER'S NAME SAME AS DRIVER
PEDESTRIAN | STREET ADDRESS | OWNER'S ADDRESS SAME AS DRIVER
PARKED VEHICLE | CITY/STATE/ZIP | DISPOSITION OF VEHICLE ON ORDERS OF: OFFICER DRIVER OTHER
BICYCLIST | SEX | HAIR | EYES | HEIGHT | WEIGHT | BIRTHDATE Mo. Day Year | RACE | PRIOR MECHANICAL DEFECTS: NONE APPARENT REFER TO NARRATIVE
OTHER | HOME PHONE | BUSINESS PHONE | VEHICLE IDENTIFICATION NUMBER:
INSURANCE CARRIER | POLICY NUMBER | VEHICLE TYPE | DESCRIBE VEHICLE DAMAGE UNK. NONE MINOR MOD. MAJOR ROLL-OVER | SHADE IN DAMAGED AREA
DIR OF TRAVEL | ON STREET OR HIGHWAY | SPEED LIMIT | CA | DOT | CAL-T | TCP/PSC | MC/MX

PARTY 2
DRIVER'S LICENSE NUMBER | STATE | CLASS | AIR BAG | SAFETY EQUIP. | VEH. YEAR | MAKE/MODEL/COLOR | LICENSE NUMBER | STATE
DRIVER | NAME (FIRST, MIDDLE, LAST) | OWNER'S NAME SAME AS DRIVER
PEDESTRIAN | STREET ADDRESS | OWNER'S ADDRESS SAME AS DRIVER
PARKED VEHICLE | CITY/STATE/ZIP | DISPOSITION OF VEHICLE ON ORDERS OF: OFFICER DRIVER OTHER
BICYCLIST | SEX | HAIR | EYES | HEIGHT | WEIGHT | BIRTHDATE Mo. Day Year | RACE | PRIOR MECHANICAL DEFECTS: NONE APPARENT REFER TO NARRATIVE
OTHER | HOME PHONE | BUSINESS PHONE | VEHICLE IDENTIFICATION NUMBER:
INSURANCE CARRIER | POLICY NUMBER | VEHICLE TYPE | DESCRIBE VEHICLE DAMAGE UNK. NONE MINOR MOD. MAJOR ROLL-OVER | SHADE IN DAMAGED AREA
DIR OF TRAVEL | ON STREET OR HIGHWAY | SPEED LIMIT | CA | DOT | CAL-T | TCP/PSC | MC/MX

PARTY 3
DRIVER'S LICENSE NUMBER | STATE | CLASS | AIR BAG | SAFETY EQUIP. | VEH. YEAR | MAKE/MODEL/COLOR | LICENSE NUMBER | STATE
DRIVER | NAME (FIRST, MIDDLE, LAST) | OWNER'S NAME SAME AS DRIVER
PEDESTRIAN | STREET ADDRESS | OWNER'S ADDRESS SAME AS DRIVER
PARKED VEHICLE | CITY/STATE/ZIP | DISPOSITION OF VEHICLE ON ORDERS OF: OFFICER DRIVER OTHER
BICYCLIST | SEX | HAIR | EYES | HEIGHT | WEIGHT | BIRTHDATE Mo. Day Year | RACE | PRIOR MECHANICAL DEFECTS: NONE APPARENT REFER TO NARRATIVE
OTHER | HOME PHONE | BUSINESS PHONE | VEHICLE IDENTIFICATION NUMBER:
INSURANCE CARRIER | POLICY NUMBER | VEHICLE TYPE | DESCRIBE VEHICLE DAMAGE UNK. NONE MINOR MOD. MAJOR ROLL-OVER | SHADE IN DAMAGED AREA
DIR OF TRAVEL | ON STREET OR HIGHWAY | SPEED LIMIT | CA | DOT | CAL-T | TCP/PSC | MC/MX

PREPARER'S NAME | DISPATCH NOTIFIED YES NO N/A | REVIEWER'S NAME | DATE REVIEWED

Add Party (Pages 1 and 2)
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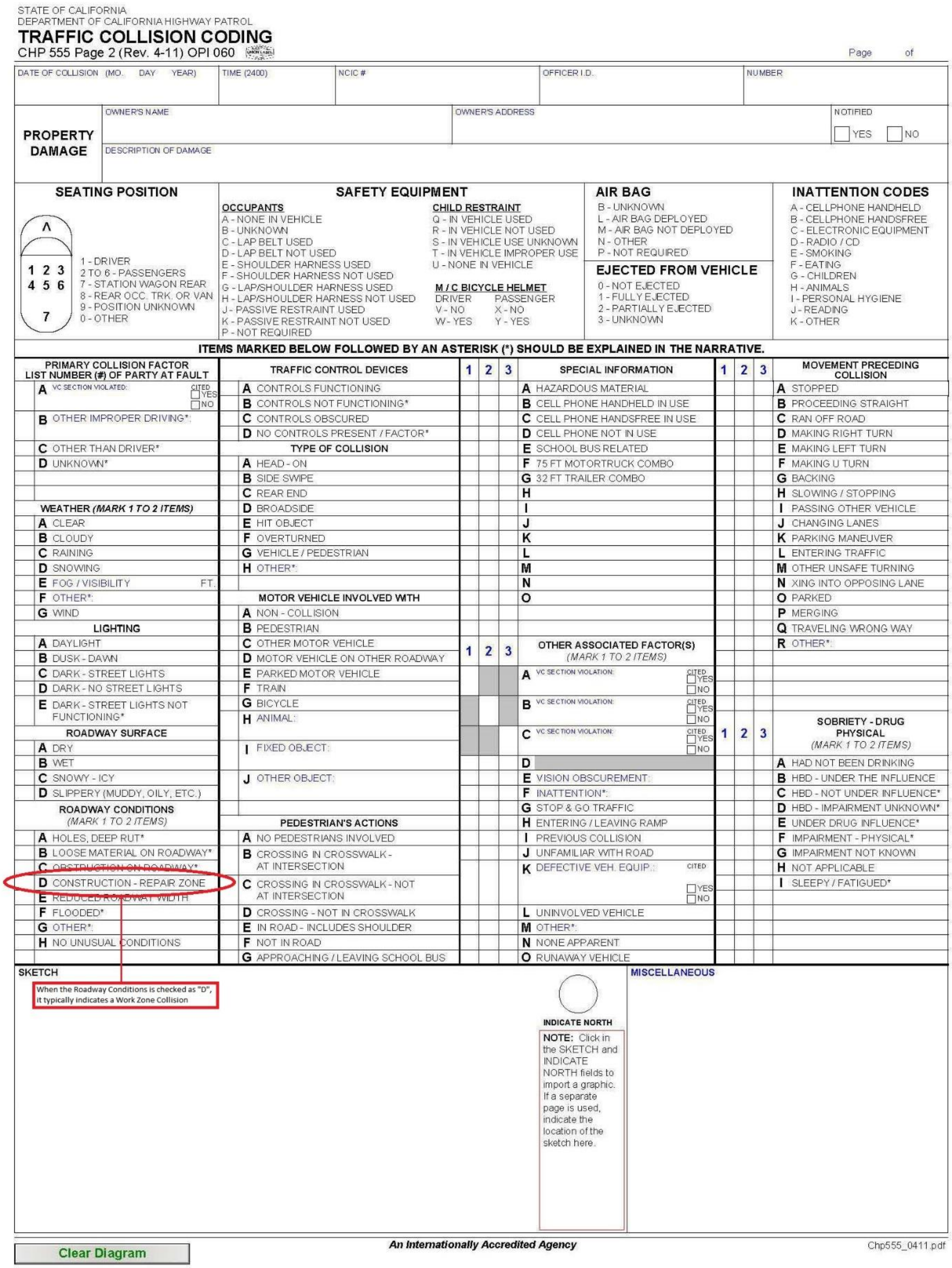
Figure 1a: Page 1 of CHP's Traffic Collision Report form.



STATE OF CALIFORNIA
DEPARTMENT OF CALIFORNIA HIGHWAY PATROL
TRAFFIC COLLISION CODING
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DATE OF COLLISION (MO. DAY YEAR)	TIME (2400)	NCIC #	OFFICER I.D.	NUMBER

PROPERTY DAMAGE

OWNER'S NAME	OWNER'S ADDRESS	NOTIFIED ☐ YES ☐ NO
DESCRIPTION OF DAMAGE		

SEATING POSITION

1 2 3
4 5 6
7

1 - DRIVER
2 TO 6 - PASSENGERS
7 - STATION WAGON REAR
8 - REAR OCC. TRK. OR VAN
9 - POSITION UNKNOWN
0 - OTHER

SAFETY EQUIPMENT

OCCUPANTS
A - NONE IN VEHICLE
B - UNKNOWN
C - LAP BELT USED
D - LAP BELT NOT USED
E - SHOULDER HARNESS USED
F - SHOULDER HARNESS NOT USED
G - LAP/SHOULDER HARNESS USED
H - LAP/SHOULDER HARNESS NOT USED
J - PASSIVE RESTRAINT USED
K - PASSIVE RESTRAINT NOT USED
P - NOT REQUIRED

CHILD RESTRAINT
Q - IN VEHICLE USED
R - IN VEHICLE NOT USED
S - IN VEHICLE USE UNKNOWN
T - IN VEHICLE IMPROPER USE
U - NONE IN VEHICLE

M / C BICYCLE HELMET
DRIVER PASSENGER
V - NO X - NO
W - YES Y - YES

AIR BAG
B - UNKNOWN
L - AIR BAG DEPLOYED
M - AIR BAG NOT DEPLOYED
N - OTHER
P - NOT REQUIRED

EJECTED FROM VEHICLE
0 - NOT EJECTED
1 - FULLY EJECTED
2 - PARTIALLY EJECTED
3 - UNKNOWN

INATTENTION CODES
A - CELLPHONE HANDHELD
B - CELLPHONE HANDSFREE
C - ELECTRONIC EQUIPMENT
D - RADIO / CD
E - SMOKING
F - EATING
G - CHILDREN
H - ANIMALS
I - PERSONAL HYGIENE
J - READING
K - OTHER

ITEMS MARKED BELOW FOLLOWED BY AN ASTERISK (*) SHOULD BE EXPLAINED IN THE NARRATIVE.

PRIMARY COLLISION FACTOR LIST NUMBER (#) OF PARTY AT FAULT
A VC SECTION VIOLATED: CITED ☐ YES ☐ NO
B OTHER IMPROPER DRIVING*:
C OTHER THAN DRIVER*
D UNKNOWN*

WEATHER (MARK 1 TO 2 ITEMS)
A CLEAR
B CLOUDY
C RAINING
D SNOWING
E FOG / VISIBILITY FT.
F OTHER*:
G WIND

LIGHTING
A DAYLIGHT
B DUSK - DAWN
C DARK - STREET LIGHTS
D DARK - NO STREET LIGHTS
E DARK - STREET LIGHTS NOT FUNCTIONING*

ROADWAY SURFACE
A DRY
B WET
C SNOWY - ICY
D SLIPPERY (MUDDY, OILY, ETC.)

ROADWAY CONDITIONS (MARK 1 TO 2 ITEMS)
A HOLES, DEEP RUT*
B LOOSE MATERIAL ON ROADWAY*
C OBSTRUCTION ON ROADWAY*
D CONSTRUCTION - REPAIR ZONE
E REDUCED ROADWAY WIDTH
F FLOODED*
G OTHER*:
H NO UNUSUAL CONDITIONS

TRAFFIC CONTROL DEVICES (1 2 3)
A CONTROLS FUNCTIONING
B CONTROLS NOT FUNCTIONING*
C CONTROLS OBSCURED
D NO CONTROLS PRESENT / FACTOR*

TYPE OF COLLISION
A HEAD - ON
B SIDE SWIPE
C REAR END
D BROADSIDE
E HIT OBJECT
F OVERTURNED
G VEHICLE / PEDESTRIAN
H OTHER*:

MOTOR VEHICLE INVOLVED WITH
A NON - COLLISION
B PEDESTRIAN
C OTHER MOTOR VEHICLE
D MOTOR VEHICLE ON OTHER ROADWAY
E PARKED MOTOR VEHICLE
F TRAIN
G BICYCLE
H ANIMAL:
I FIXED OBJECT:
J OTHER OBJECT:

PEDESTRIAN'S ACTIONS
A NO PEDESTRIANS INVOLVED
B CROSSING IN CROSSWALK - AT INTERSECTION
C CROSSING IN CROSSWALK - NOT AT INTERSECTION
D CROSSING - NOT IN CROSSWALK
E IN ROAD - INCLUDES SHOULDER
F NOT IN ROAD
G APPROACHING / LEAVING SCHOOL BUS

SPECIAL INFORMATION (1 2 3)
A HAZARDOUS MATERIAL
B CELL PHONE HANDHELD IN USE
C CELL PHONE HANDSFREE IN USE
D CELL PHONE NOT IN USE
E SCHOOL BUS RELATED
F 75 FT MOTORTRUCK COMBO
G 32 FT TRAILER COMBO
H
I
J
K
L
M
N
O

OTHER ASSOCIATED FACTOR(S) (MARK 1 TO 2 ITEMS) (1 2 3)
A VC SECTION VIOLATION: CITED ☐ YES ☐ NO
B VC SECTION VIOLATION: CITED ☐ YES ☐ NO
C VC SECTION VIOLATION: CITED ☐ YES ☐ NO
D
E VISION OBSCUREMENT:
F INATTENTION*:
G STOP & GO TRAFFIC
H ENTERING / LEAVING RAMP
I PREVIOUS COLLISION
J UNFAMILIAR WITH ROAD
K DEFECTIVE VEH. EQUIP.: CITED ☐ YES ☐ NO
L UNINVOLVED VEHICLE
M OTHER*:
N NONE APPARENT
O RUNAWAY VEHICLE

MOVEMENT PRECEDING COLLISION (1 2 3)
A STOPPED
B PROCEEDING STRAIGHT
C RAN OFF ROAD
D MAKING RIGHT TURN
E MAKING LEFT TURN
F MAKING U TURN
G BACKING
H SLOWING / STOPPING
I PASSING OTHER VEHICLE
J CHANGING LANES
K PARKING MANEUVER
L ENTERING TRAFFIC
M OTHER UNSAFE TURNING
N XING INTO OPPOSING LANE
O PARKED
P MERGING
Q TRAVELING WRONG WAY
R OTHER*:

SOBRIETY - DRUG PHYSICAL (MARK 1 TO 2 ITEMS) (1 2 3)
A HAD NOT BEEN DRINKING
B HBD - UNDER THE INFLUENCE
C HBD - NOT UNDER INFLUENCE*
D HBD - IMPAIRMENT UNKNOWN*
E UNDER DRUG INFLUENCE*
F IMPAIRMENT - PHYSICAL*
G IMPAIRMENT NOT KNOWN
H NOT APPLICABLE
I SLEEPY / FATIGUED*

SKETCH

When the Roadway Conditions is checked as "D", it typically indicates a Work Zone Collision

INDICATE NORTH

NOTE: Click in the SKETCH and INDICATE NORTH fields to import a graphic. If a separate page is used, indicate the location of the sketch here.

MISCELLANEOUS

Clear Diagram

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Figure 1b: Page 2 ("Coding") of CHP's Traffic Collision Report form.

STATE OF CALIFORNIA
DEPARTMENT OF CALIFORNIA HIGHWAY PATROL

INJURED / WITNESS / PASSENGERS

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DATE OF COLLISION (MO. DAY YEAR)	TIME (2400)	NCIC #	OFFICER I.D.	NUMBER

WITNESS ONLY	PASSENGER ONLY	AGE	SEX	EXTENT OF INJURY ("X" ONE)			
				FATAL INJURY	SEVERE INJURY	OTHER VISIBLE INJURY	COMPLAINT OF PAIN

INJURED WAS ("X" ONE)					PARTY NUMBER	SEAT POS.	AIR BAG	SAFETY EQUIP.	EJECTED
DRIVER	PASS.	PED.	BICYCLIST	OTHER					

#
NAME / D.O.B. / ADDRESS — TELEPHONE
(INJURED ONLY) TRANSPORTED BY: — TAKEN TO:
DESCRIBE INJURIES
VICTIM OF VIOLENT CRIME NOTIFIED

#
NAME / D.O.B. / ADDRESS — TELEPHONE
(INJURED ONLY) TRANSPORTED BY: — TAKEN TO:
DESCRIBE INJURIES
VICTIM OF VIOLENT CRIME NOTIFIED

#
NAME / D.O.B. / ADDRESS — TELEPHONE
(INJURED ONLY) TRANSPORTED BY: — TAKEN TO:
DESCRIBE INJURIES
VICTIM OF VIOLENT CRIME NOTIFIED

#
NAME / D.O.B. / ADDRESS — TELEPHONE
(INJURED ONLY) TRANSPORTED BY: — TAKEN TO:
DESCRIBE INJURIES
VICTIM OF VIOLENT CRIME NOTIFIED

#
NAME / D.O.B. / ADDRESS — TELEPHONE
(INJURED ONLY) TRANSPORTED BY: — TAKEN TO:
DESCRIBE INJURIES
VICTIM OF VIOLENT CRIME NOTIFIED

#
NAME / D.O.B. / ADDRESS — TELEPHONE
(INJURED ONLY) TRANSPORTED BY: — TAKEN TO:
DESCRIBE INJURIES
VICTIM OF VIOLENT CRIME NOTIFIED

PREPARER'S NAME	I.D. NUMBER	MO. DAY YEAR	REVIEWER'S NAME	MO. DAY YEAR

Add Inj/Wit/Pass (Page 3)

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Figure 1c: Page 3 ("Injured/Witness/Passengers") of CHP's Traffic Collision Report form.

Prior to 2016, all TCRs were paper documents. These were processed by CHP and Caltrans by using a combination of paper documents and scanned image files in *.pdf format. Starting in 2016, approximately 90% of TCRs were developed and processed digitally. The remaining 10% of CHP reports are processed as scanned image files and typically originate from "Allied" CHP stations located in low population density regions of California. The processing and usage of electronic TCRs are still in the early stages, and the data generated by the format are the same at this point in time. For the purposes of this research, there is no discernable difference in the origin of the TCR and the data extracted from it.

Data Extractions into Existing Databases from Traffic Collision Reports

The extraction of data from all the TCRs and into a database format follows these basic steps:

1. Reports are generated by CHP and sent to Caltrans. For work zone safety analysis purposes, there are fields in both the SWITRS and TASAS databases describing the "Roadway Condition" where the reporting office checks off a box designating it as "Construction – Repair Zone." There are no other fields that refer to any kind of work zone activity. This road condition can refer to the road surface or close proximity to the work zone site.

2. Dedicated Caltrans personnel calculate the precise location of the collision in terms of the highway number and post-mile marker value, side of the highway, and whether it was at an intersection or freeway ramp.

3. Once the location has been coded, the report is sent back to CHP for further processing and the data is then stored in CHP's Statewide Integrated Traffic Records System (SWITRS) database. Note that all collisions reported by CHP are stored in SWITRS, including those that occur on non-state roads.

4. Caltrans has its own database for storing TCR data where only collisions that occur on state highways are stored. This is referred to as the Traffic Accident Surveillance and Analysis System (TASAS).

5. The main differences between SWITRS and TASAS is that TASAS only contains data dedicated to California highways (i.e., state highways) and only the collision severity value is stored with no victim level injury data. TASAS also does not store CHP related data such as "Beat Type," etc.

6. It should be noted that SWITRS data can indicate only collisions that sustained injuries and/or fatalities. The SWITRS data is used in this study, however, contains all collision severity levels, including PDO. This data was downloaded from the "iSWITRS" website (http://iswitrs.chp.ca.gov/Reports/jsp/userLogin.jsp), where the raw data was requested. To see detailed information on injury only SWITRS data, please see the Transportation Injury Mapping System (TIMS) which can be found on https://tims.berkeley.edu/login.php?next=/tools/query/.

7. Neither SWITRS nor TASAS contain personal data such as names and addresses, although it does exist in the original *.pdf format of the TCR.

The data contained in the SWITRS database is listed in Appendix A. Although there is a great deal of information contained in the SWITRS database, there is no access to any of the narrative or diagrams contained in the TCR reports. SWITRS is predominantly used to document injury and fatality data. The only method to determine whether a collision occurred within close proximity of a work zone is if the reporting office checks a box indicating the "Road Condition" as undergoing some sort of construction or maintenance procedure. Unless one has access to the entire report to evaluate diagrams and the narratives, there is no way to determine if the collision occurred at an active work site, in the advanced zone, or up-road from the advanced zone due to sudden braking due to the ongoing work.

As can be seen in Appendix A, SWITRS captures all the information relayed in the Collision Data (TCR page 1), Party Information (TCR page 2), and Victim Information (TCR page 3). Please note that the SWITRS data also documents collisions that occur on non-state highway roads. Thus for work zone related studies, it is critical to only use data where the "State Highway" field is "Yes" and "Road Condition" is marked as "Ongoing Road Work."

For Caltrans' purposes, a streamlined database (TASAS) is employed and contains only those collisions that occur on a state highway and eliminate some of the SWITRS fields. It also includes sequence of events data that describes which vehicle hit which and whether any other objects were struck.

A guideline as to how to obtain both SWITRS and TASAS data can be found in Appendix B.

AHMCT's Work Zone Injury Database

A more thorough type of data on work zone collisions is AHMCT's Work Zone Injury Database [17]. This database is a comprehensive data set containing a great deal of information from all TCRs that have the "Roadway Condition" marked as "Construction – Repair Zone." The shortcoming of this database however, is that it contains only data from the years 2006 to 2010. This database is particularly useful for it contains work zone specific data derived from the entire TCR. The extra data includes:

- Where the collision occurred with respect to the work zone area (i.e. advanced, transition, active, or downstream regions).
- Was there intrusion into the work zone area?
- Financial impact of the injuries sustained.
- Traveling speeds of the parties when reported.
- Diagrams and narrative text.

This dataset was not included in this research project since the data was considered outdated (2006-2010).

Lane Closure System Data

The Lane Closure System (LCS), an Oracle database that tracks all information related to planned lane closures from Caltrans maintenance, construction, and encroachment permits field activities on the State Highway System. Thus, this database is a mechanism indicating the presence of a work zone on a state highway. The Caltrans Division of Traffic Operations was extremely helpful and provided downloads from the years 2010-2015 when asked for access to the data. More recent data was also available, but since traffic collision data was not available after 2015 at the time of this research, it was decided to limit the LCS data to this same timeframe (2010-2015). The fields contained in the LCS data are shown in Table.

Table 6: Field names and corresponding description for data in the LCS.

LCS Field Name	*Description or possible answers*
District	1 to 12
Submitted by Branch	Encroachment permit, Maintenance, Construction
Project No	Provided by Caltrans
Start	Planned (date and time)Start of field activity
End	Planned (date and time)End of field activity
Duration	"Standard" or other
Closure Id	Assigned attribute
Log No	Relates to number of entries for each closure
Request Status	"Approved" (otherwise there would be no lane closure)
Current Status 1097	Y if the lane closure started
Current Status 1097 Date	Corresponding date to above
Current Status 1098	Y if the lane closure ended
Current Status 1098 Date	Corresponding date to above
Current Status 1022	Closure cancelled "in the field"
Current Status 1022 Date	Date if 1022 Status= "Y"
Route No	Same system as TASAS
Direction	Same system as TASAS
Begin Post Mile	Same system as TASAS
End Post Mile	Same system as TASAS
Facility	Supplied by Caltrans
Total Existing Lanes	Same system as TASAS
Types Of Closure	Road work details
Closure Details	Road work details
Type Of Work	Road work details

Table shows that there are a number of data fields that seem to be very similar to those found in the other databases. It is helpful to know that the LCS is a dynamic tool where all Caltrans related lane closures are managed. Thus advanced planning information is present along with project management activities and daily operations which encounter a multitude of challenges. The codes include the following:

- 1022 is when a closure is cancelled in the field
- 1097 is when the crew places the 1st cone on the traffic lane (begin time)
- 1098 is when crew removes all of the cones from the traffic lane (end time)

To identify which records in the LCS refer to actual lane closures (as opposed to planned but not statused), the following is a guide as to which rows should be designated as "active/actual" and the others as planned but not executed:

- If a scheduled closure is not canceled and there is a start time but not an end time, you assume the closure did happen. .
- The start and end fields indicate the planned closure start time and may not indicate the actual start of the closure. The start date and end date are only the range when a closure is allowed for that work. The actual start time and end time should be within that range.
- The first two digits of the construction contract number identifies the district where the project is located
- Start and end Post Miles are where the actual closure starts, not where there are advanced warning signs.
- Construction project numbers have a Begin County name and End County name as well as a route.
- For maintenance projects, each "project number" is actually associated with a crew in that district.

Application of the LCS data will be further explained in Chapter 4.

CHAPTER 4:
DATA ANALYSIS

The data sets described in Chapter 3 were processed and analyzed. This chapter provides an example data analysis.

TASAS/SWITRS Data

To develop an understanding of the work zone collision attributes, all collisions from 2010-2015 were downloaded from the CHP's SWITRS web service. This service provides traffic collision data on all road types (not just highways) and all collision severity levels (property damage only, injuries and fatalities). For this study, all non-state highway collisions were filtered out and deleted. Further filtering occurs when identifying "work zone collisions". The current standard practice assumes there is ongoing road work or construction activity when the "Roadway Conditions" field in Page 2 of the Traffic Collision Report (Figure 1b) is checked as "D". This scenario is also referred to as "Road_Cond=D". This condition does not identify inactive work zone collisions which are also of interest.

Within the set of work zone collisions, crash severity types were retained. In Table, the number of collisions occurring on California highways for the years 2010-2015 can be found. Please note that at the time of this report, 2015 was the most recent data set. Also, the number of work zone collisions and the corresponding percentage for that year is listed. It can be seen that the percentage of work zone collisions has steadily increased from 2010 (2.28%) to 2015 (4.26%) by 2%. Although the percentage has increased throughout the years, it could be a reflection on amount of money spent on construction and maintenance.

Table 7: Number of collisions on California highways for the years 2010-2015. Shown are the number of work zone collisions, the total number of collisions and the percentage of work zone collisions for each respective year. Note the work zone collision is defined as Road_Cond=D.

Year	# Work Zone Collisions	Total # Collisions	% of Work Zone Collisions per Year
2010	3545	155768	2.28%
2011	4032	152267	2.65%
2012	5008	149288	3.35%
2013	5873	152426	3.85%
2014	6563	153994	4.26%
2015	7458	166604	4.48%

The work zone collision frequency from each Caltrans district is shown in Figure 2. Districts 1, 3, 11, and 12 seem to show a general reduction in these collisions from 2010 to 2013. District 8 more than doubled the work zone collisions between 2012 (832) and 2015 (1926). It can also be seen in

Figure 2 that "District 0" had the most collisions in 2015. This anomaly is due to SWITRS keeping the District field in the SWITRS database blank until the data record has been finalized. Once finalized however, it is expected that all 12 Districts will have more collisions in 2015 than seen in Figure 2 as those "district unknown" records get assigned to their appropriate Districts.

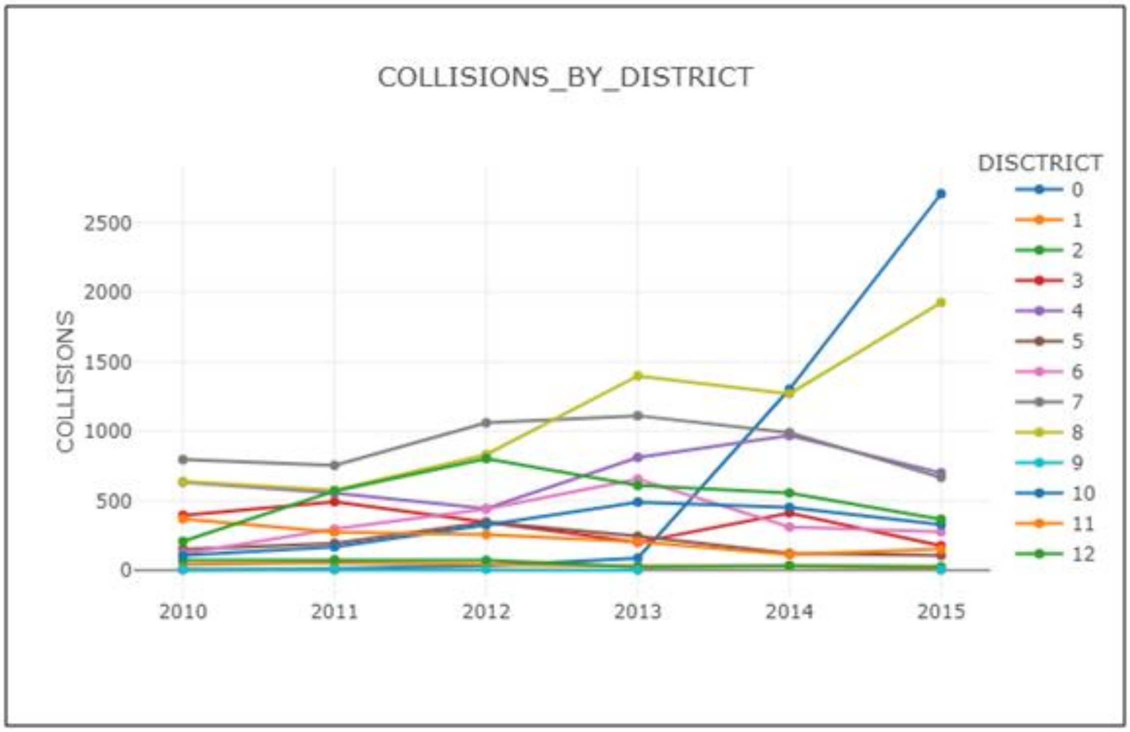

Figure 2: Distribution of Work Zone collision frequency by Caltrans district and shown for the years 2010-2015.

The following tables contain the "codes" that are used in the SWITRS and TASAS databases. When looking at the data in these databases, the fields contain only the coded data. These tables are needed to decipher the meaning of the data. For example, in Table 7, when a fatality occurs, the "Crash Severity" field is designated as "1". More than one person can be killed in the identified collision and so there is another field designated the "Number Killed" field (not shown).

Table 8: Collision Severity Category description.

Collision Severity	Description
0	Property Damage Only (PDO)
1	Fatality
2	Serious Injury
3	Other visible injury
4	Complaint of pain

In Table 9, it can be seen that there are a variety of codes that define the "Primary Causal Factor" (PCF). Column 3 in Table 9 provides the entire list of PCF possibilities. When looking at the traffic collision distribution of all 25 PCF values, it is difficult to see the trends in the data. Consequently, categories (Column 1 in Table 9) were defined. Each original PCF code was lumped into a particular category and the result is shown in Column 2 of Table 9. These categories are used when analyzing collision data in this report.

Table 9: Primary Cause Category definitions: TASAS/SWITRS PCF field entries correlation.

<table>
<tr><th>Primary Cause Category Name</th><th>Corresponding SWITRS entries</th><th>Original PCF Categories used in TASAS</th></tr>
<tr><td>Unsafe Speed</td><td>03, 3, 04, 4</td><td rowspan="6">01 - Driving or Bicycling Under the Influence of Alcohol or Drug
02 - Impeding Traffic
03 - Unsafe Speed
04 - Following Too Closely
05 - Wrong Side of Road
06 - Improper Passing
07 - Unsafe Lane Change
08 - Improper Turning
09 - Automobile Right of Way
10 - Pedestrian Right of Way
11 - Pedestrian Violation
12 - Traffic Signals and Signs
13 - Hazardous Parking
14 - Lights
15 - Brakes
16 - Other Equipment
17 - Other Hazardous Violation
18 - Other Than Driver (or Pedestrian)
21 - Unsafe Starting or Backing
22 - Other Improper Driving
23 - Pedestrian or "Other" Under the Influence of Alcohol or Drug
24 - Fell Asleep
00 - Unknown
- - Not Stated</td></tr>
<tr><td>Improper Driving</td><td>07, 08, 7, 13, 17, 21, 22, 5, 6</td></tr>
<tr><td>Alcohol, Drugs</td><td>1, 01</td></tr>
<tr><td>Other than Driver</td><td>18</td></tr>
<tr><td>Miscellaneous</td><td>All other code numbers not covered in the above categories</td></tr>
<tr><td></td><td></td></tr>
</table>

In a similar manner to categorizing "Primary Causal Factors", the "Type of Collision" SWITRS data field has also been categorized. These results are shown in Table 10. The "Other" category collects all of the infrequently occurring collision types.

Table 10: Type of Collision Category definitions: TASAS/SWITRS TOC field entries correlation.

<table>
<tr><th>Type of Collision Category</th><th>SWITRS entries</th><th>Original TOC Categories used in TASAS</th></tr>
<tr><td>HEAD-ON</td><td>A</td><td rowspan="6">A - Head-On
B - Sideswipe
C - Rear End
D - Broadside
E - Hit Object
F - Overturned
G - Vehicle/Pedestrian
H - Other
- - Not Stated</td></tr>
<tr><td>SIDESWIPE</td><td>B</td></tr>
<tr><td>REAR -END</td><td>C</td></tr>
<tr><td>BROADSIDE</td><td>D</td></tr>
<tr><td>Other</td><td>E, F, G, H</td></tr>
<tr><td></td><td></td></tr>
</table>

In Table 11, it can be seen there are a variety of codes that define the "Type of Vehicle" category. Column 3 in Table 11 provides the entire list of categorized vehicle types defined in SWITRS. Vehicle type categories for analysis purposes were also defined and are shown in Column 1 in Table 11. The corresponding entries from the SWITRS Vehicle Type field are listed in the second column of Table 11.

Table 11: Type of Collision Category definitions: TASAS/SWITRS TOC field entries correlation.

<table>
<tr><th>Vehicle Type Category</th><th>Database Entries</th><th>SWITRS Vehicle Type</th></tr>
<tr><td>Passenger Car</td><td>A,B</td><td rowspan="6">A - Passenger Car/Station Wagon
B - Passenger Car with Trailer
C - Motorcycle/Scooter
D - Pickup or Panel Truck
E - Pickup or Panel Truck with Trailer
F - Truck or Truck Tractor
G - Truck or Truck Tractor with Trailer
H – School bus
I - Other Bus
J - Emergency Vehicle
K - Highway Construction Equipment
L - Bicycle
M - Other Vehicle
N - Pedestrian
O - Moped
- or blank - Not St</td></tr>
<tr><td>Motorcycle</td><td>C</td></tr>
<tr><td>Pickup or Panel Truck</td><td>D, E</td></tr>
<tr><td>Tractor/ Trailer</td><td>F,G</td></tr>
<tr><td>Other</td><td>All other code numbers not covered in the above categories.</td></tr>
<tr><td></td><td></td></tr>
</table>

When referring to Figures 3 through 7, the data presented refers to these categories. In Figure 3, the Collision Type versus Crash Severity is shown for "work zone" collisions only. In all categories, the majority of work zone crashes are "Property Damage Only" with no injuries or fatalities. Rear End, Side-Swipe and Other types of collisions are the predominant categories for non-injury and Complaint of Pain crash severity levels. Sideswipe and rear end accidents are much more common near work zones due to distractions and sudden changes in traffic speeds. This data is plotted in the bar charts of Figure 5: Comparison of work zone collisions to all collisions. Distribution of vehicle types for work zone collisions versus all collisions. and Figure 4.

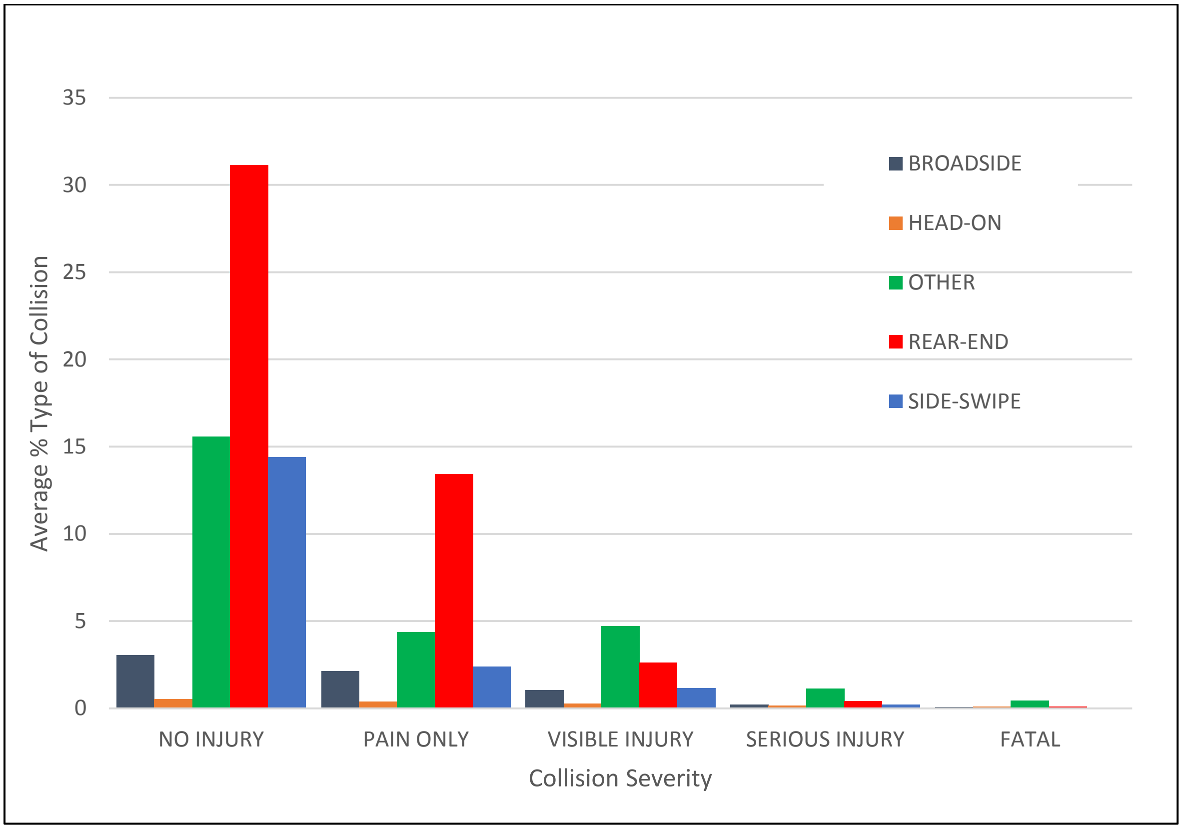

Figure 3: Distribution of collision type versus collision severity (Road_Cond=D) for the years 2010-2015.

In Figure 4, the Primary Causal Factor is graphed against crash severity. For non-injury and minor injury crashes, driving too fast or too close to the vehicle in front along with driving improperly, are the 2 predominant factors.

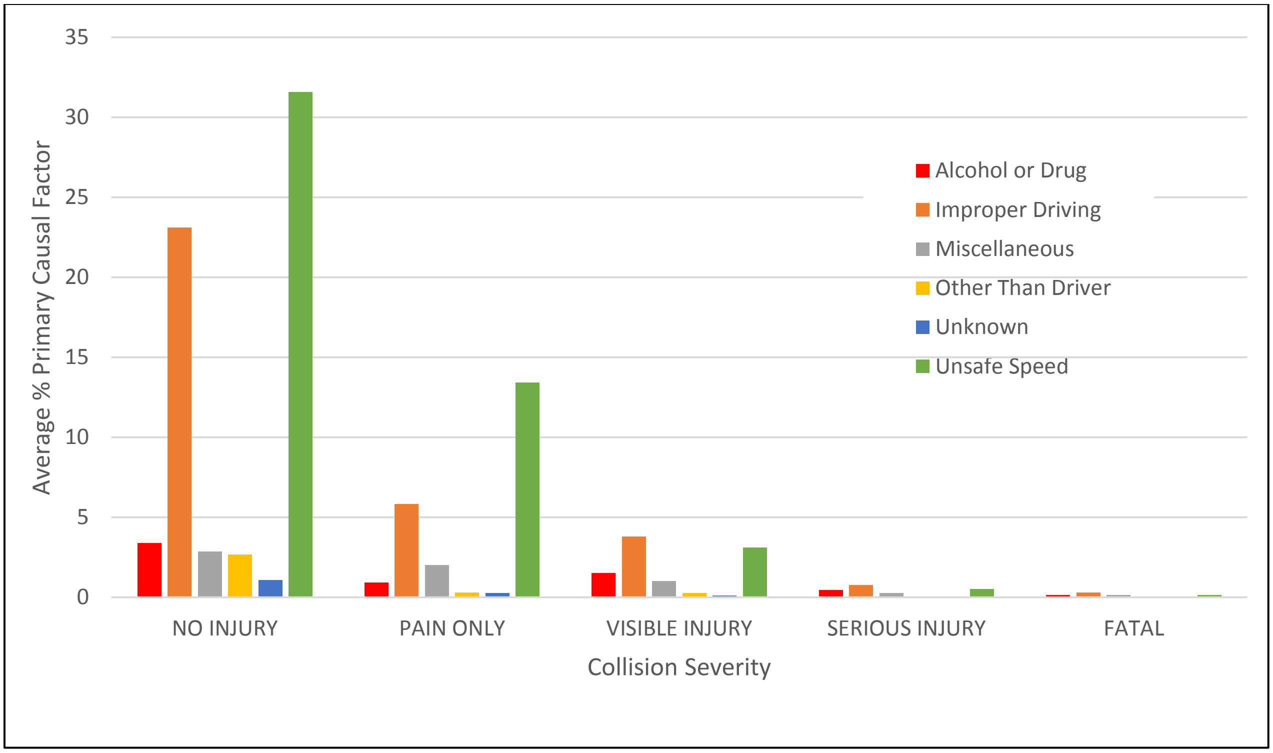

Figure 4: Distribution of Primary Causes (average percentage from years 2010-2015) versus collision severity (Road_Cond=D) for the years 2010-2015.

Collisions were also analyzed by vehicle type. Figure 5 shows the distribution of collisions by vehicle type for "work zone collisions". The data shown here is for all collision severity types, including property damage only. For "Large Trucks", there are more than twice as many collisions involving large trucks in work zones as opposed to those not in work zones. All other vehicle type categories indicate similar percentage distribution.

Looking at work zone only collisions in California during 2015, there were 52 fatalities with 15 of them involving large trucks. This indicates that large truck fatalities corresponded to 29% of fatalities in California. At the national level there were 173 fatal collisions involving large trucks out of a total of 700 fatal collisions [16]. This indicates that large truck fatalities correspond to 25% of fatalities in highway collisions at the national level. Consequently, these data indicate that in 2015 California had a higher percentage of fatalities involving large trucks than the national average.

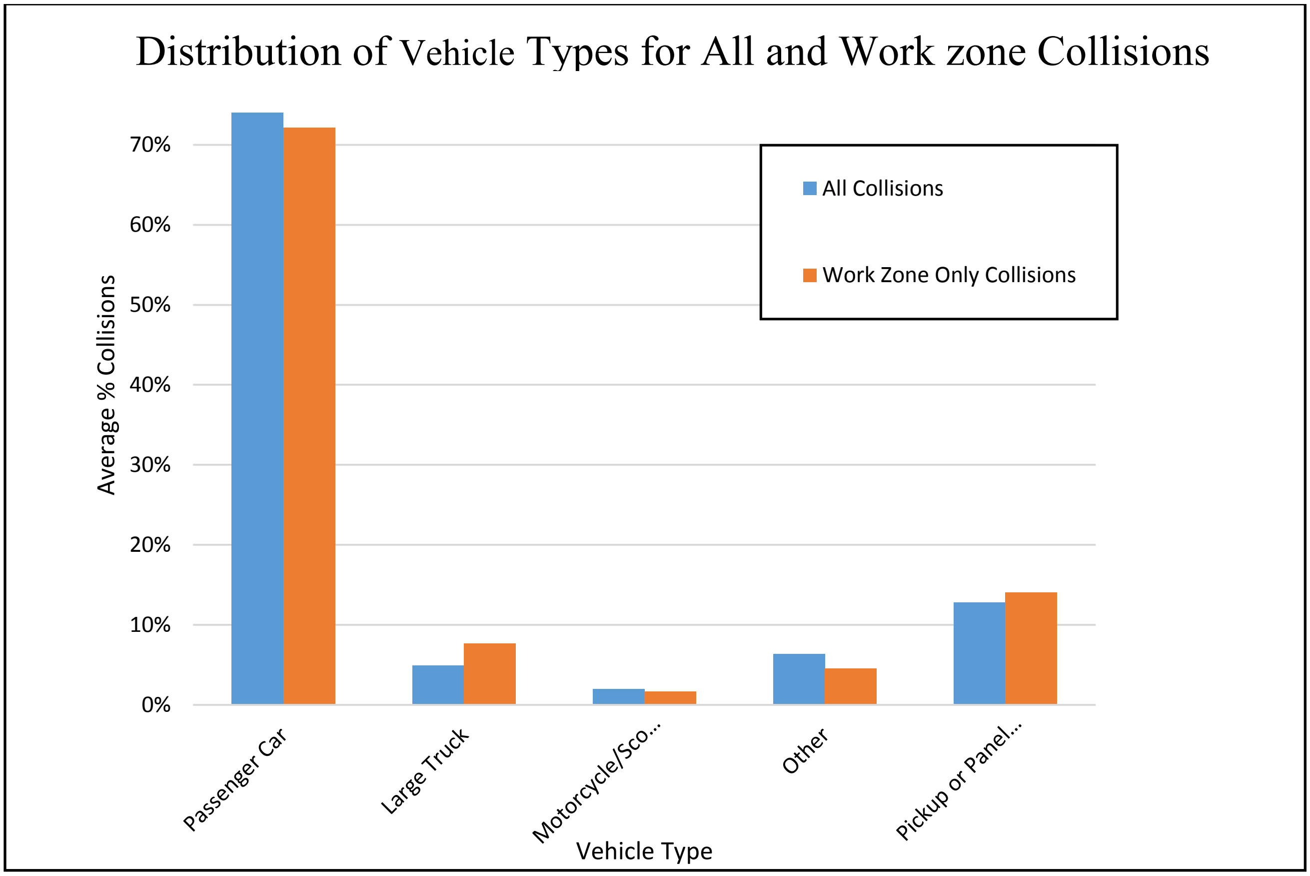

Figure 5: Comparison of work zone collisions to all collisions. Distribution of vehicle types for work zone collisions versus all collisions.

Lane Closure Related Collisions

As indicated in the previous chapter, the current method of identifying which traffic collisions occur at a work zone site is solely dependent on how the reporting police officer designates it in the TCR. Once this designation is indicated, there is no way to determine from the TASAS or SWITRS databases the location or nature of the work site. Assuming that a work site is where there is an encroachment on the highway due to lane closures, a robust method of identifying traffic collisions at a work site is to use the existence of a lane closure. Since Caltrans maintains a log of all Lane Closures (maintenance, construction or permit driven), this research study attempted to evaluate whether or not it would be possible to link the LCS database with the SWITRS database.

To evaluate the feasibility of such a capability, a test case was performed with District 10 data from 2013 only. All Lane Closure data for this District and year was collected by the Traffic Operations group.

Processing the data and comparing the results using Lane Closure data and TASAS data for District 10 for 2013 indicated the following:

- In 2013 District 10 contained 6060 records for actual lane closures.

- The number of traffic collisions in District 10 was 5024.

- The number of collisions as indicated in the CHP traffic reports marked as "Road_Cond"=D were 415.

- There were a total of 352 lane closures that had at least one collision associated with it. Out of these 352, there were only 255 unique collisions. The difference may be due to the presence of multiple concurrent lane closures.

- Comparing the two sets of collision data (255 from lane closures and 415 with Road_Cond=D) only 61 collisions were found to be common in both data sets.

Again using District 10 in 2013, the process was repeated but with each lane closure expanded to include a 2 mile advance zone to identify any collisions that were caused by a queuing of traffic. The corresponding results are:

- A total of 5024 traffic collisions with 415 of these with Road_Cond=D as before. The same number of lane closure records remained at 6060 but the length of each lane closure was extended 2 miles in the advanced area.

- 767 lane closure records had collision(s) concurrent, but only 437 had unique collision IDs.

- Out of these 437 collisions, only 102 also had the attribute Road_Cond=D.

From the above information, it appears that roughly 25% of work zone traffic collisions identified were common in both the TASAS and LCS databases. In other words, there is a large discrepancy in how a "work zone collision" can be identified.

Using District 10 in 2013 as an example, maps depicting collision distributions identify three different collision distributions (Figure6). In Figure 6a, "Road_Cond=D" collisions from TASAS show a common type of collision with "ongoing roadwork." Figure 6b shows only collisions that have some associated active lane closures, no matter the road condition. Figure 6c shows those collisions which have both an associated lane closure and also have the "Road_Cond=D" attribute designated on the collision report.

Again using Figure 6 to illustrate the results between the differing methods of defining a "Work Zone Collision", a portion of Stockton is shown. Figure 6a shows 31 "Road_Cond=D" collisions with yellow and green circles showing the number of collisions in that cluster. Note: clusters with 10 or more collisions are coded yellow and less than 10 are coded green. Figure 6b shows the more than 200 unique collisions associated with a lane closure with Figure 6c showing only the 30 collisions that have both "Road_Cond=D" and an active lane closure.

Figure 4: Distribution of Primary Causes (average percentage from years 2010-2015) versus collision severity (Road_Cond=D) for the years 2010-2015. depicts a portion of Stockton with a high frequency of traffic collisions in 2013. The clusters with numbers (yellow and green)

represent the number of collisions in the respective cluster. Figure 6a shows the distribution and frequency of collisions that were identified on the CHP collision report as "Construction – Repair Zone". Figure 6b shows those collisions that have a lane closure ongoing at the same time and location. For this example, the results from the 2 mile lane extension is applied. Figure 6c shows the overlap of the two sets (i.e. those collisions concurrent with an active lane closure and with the CHP report marked as a construction or repair zone. On examination of Figures 6a and 6b, it can be seen there are noticeable discrepancies between the two methods. Figure 6c illustrates that a minor subset of collisions had fulfilled both methods protocol.

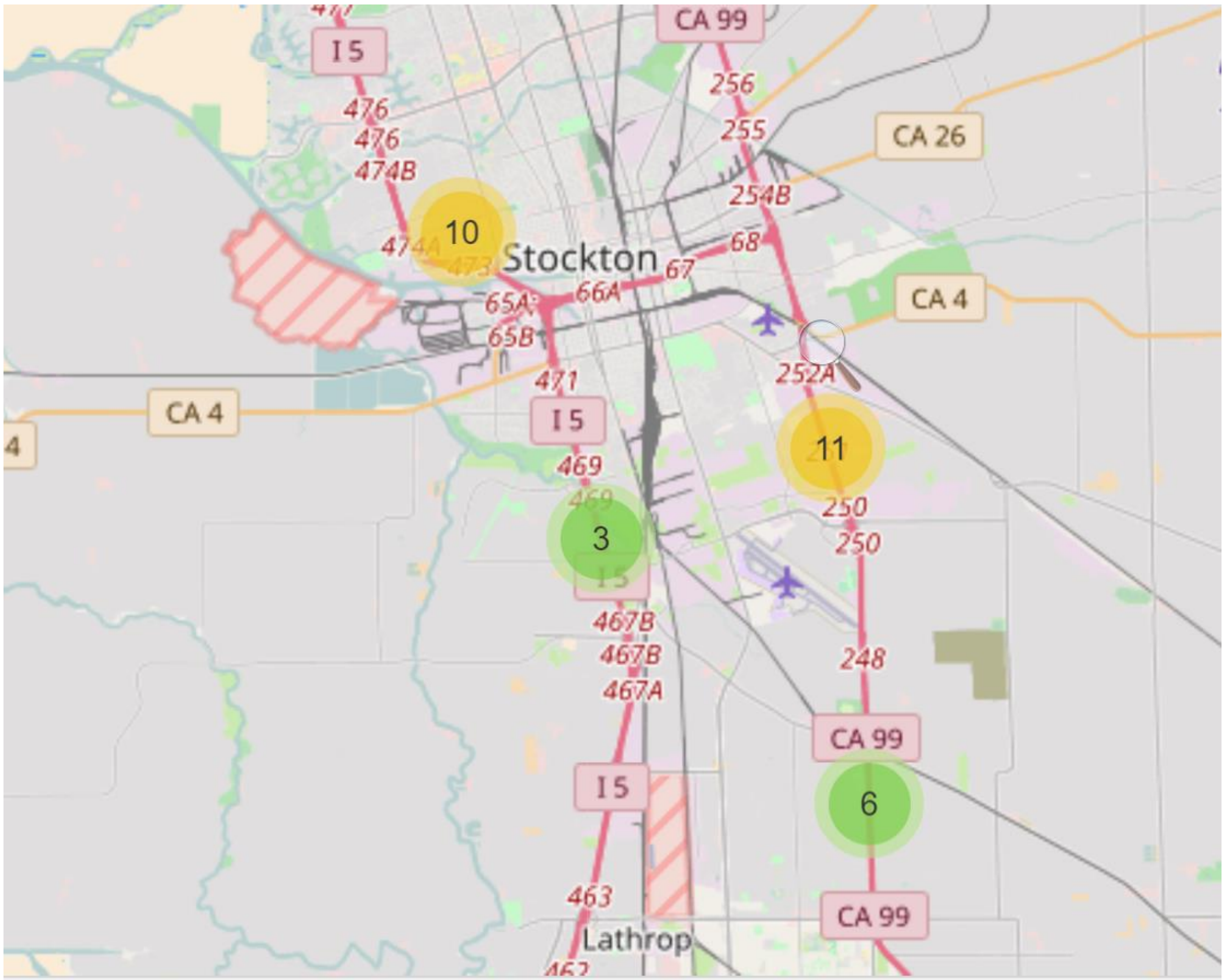

Figure 6a: Map of Stockton showing the distribution and frequency of collisions in 2013 that were identified on the CHP collision report as "Construction – Repair Zone". Map shows frequency of collisions in clusters of green and yellow.

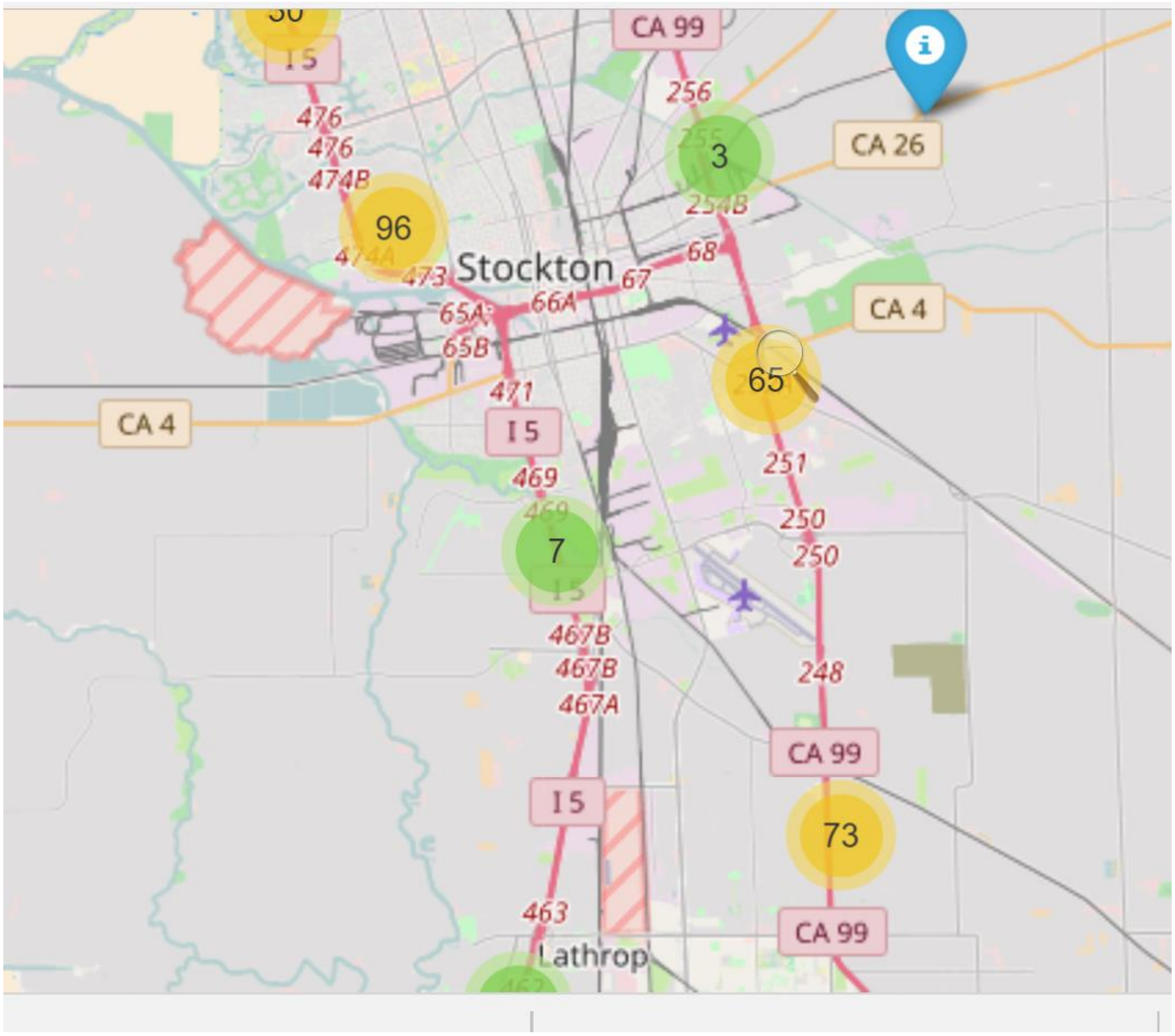

Figure 6b: Map of Stockton showing the distribution and frequency of collisions in 2013 that occurred adjacent to an active lane closure or within a 2 mile advanced zone of an active lane closure. Map shows frequency of these collisions in clusters of green and yellow.

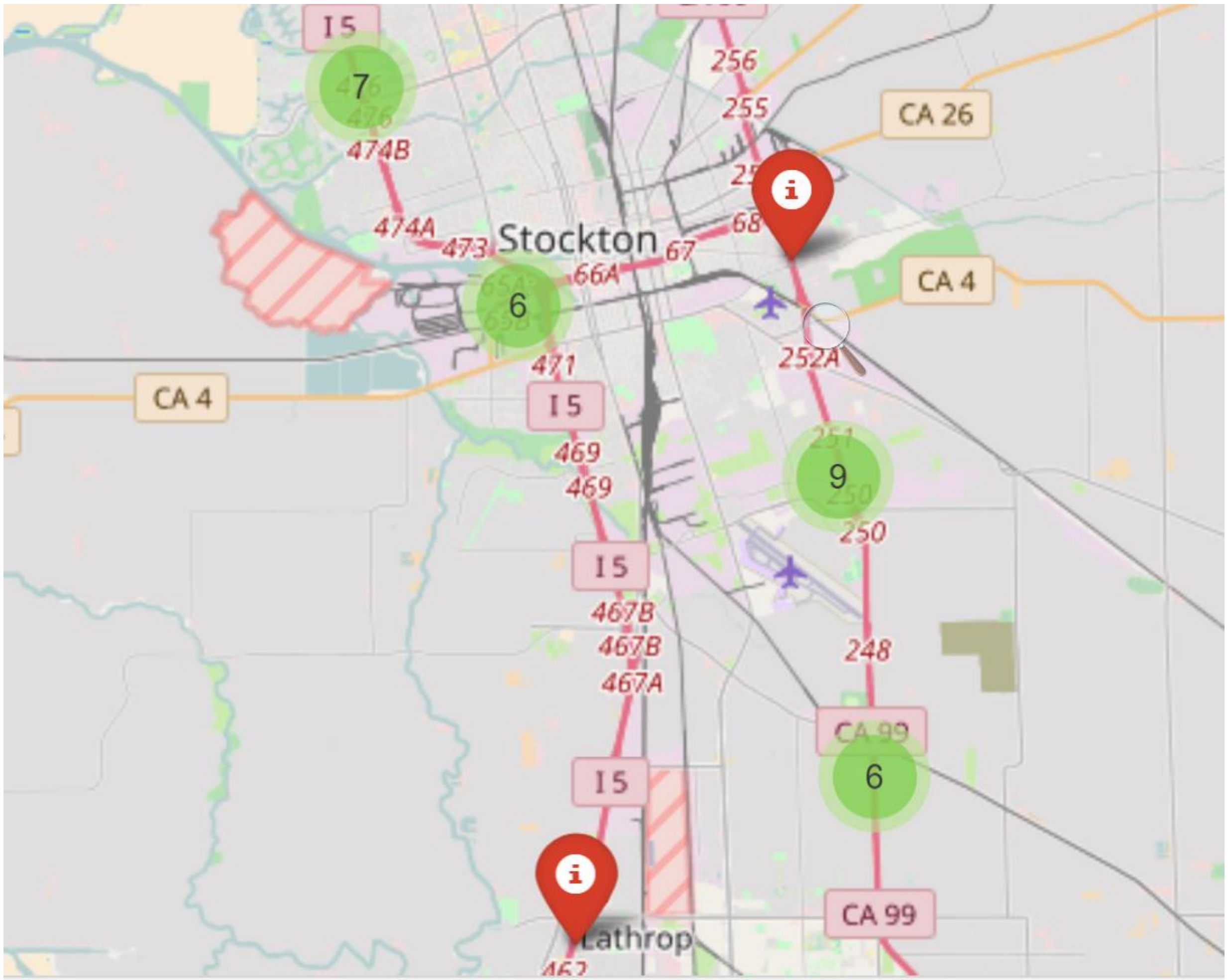

Figure 6c: Map of Stockton showing the overlap of collisions occurring in 2013 that had *both* the CHP report indicating a work zone area and also having an active lane closure adjacent or downstream by 2 miles. Map shows frequency of these collisions in clusters of green and yellow for more than 1 collision with "red" indicating a single collision at a particular location.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Focusing on the work zone collision data obtained from the SWITRS and TASAS databases from 2010-2015, the following conclusions are made:

1. The percentage of work zone collisions relative to total collisions on state highways increased from 2.27% in 2010 to 4.48% in 2015 (see Table). In other words, there were nearly twice as many work zone collisions in 2015 than 2010. Although the number of road work projects in the later years may be significantly more than in the earlier years (in this period), it should be noted that prior to 2010, and using a general "rule of thumb", the number of work zone collisions were in the lower range (between 2% and 2.5%). This noticeable increase in recent years could be due to several factors that need to be further studied.

2. During the 2010-2015 period, the work zone collision frequency for all Caltrans districts, except District 8, remained approximately constant or decreased (Figure 2). District 8 had a noticeable increase in road work collisions from 832 collisions in 2012 to 1926 collisions in 2015. Districts 4, 7, and 12 show a reduction in collisions from previous years.

3. Collisions with no injuries (Severity=0) or with "Complaint of Pain" injuries (Severity=4) were predominantly associated with rear end collisions. Sideswipe collisions typically result in no or minor injuries as well. These trends can be seen in Figure 3.

4. In Figure 4 it can be seen that driver behavior may be a key factor in the majority of work zone collisions. It can be seen that the majority of collisions in a work zone are due to "Improper Driving" and "Unsafe Speed".

Including the Lane Closure System data to identify collisions that occur concurrently with an active lane closure as a "work zone collision", the following conclusions are made:

5. Figure 6 shows that current methods of identifying work zone collisions may not reflect the influence of lane closures. In the same area during the same time span, 31 crashes were identified in work zones using the current methodology of relying on CHP reports (Figure 6a), while 244 collisions were found to occur adjacent to an active lane closure (Figure 6b). The collisions that are flagged by CHP and also occur adjacent to a lane closure are shown in Figure 6c (indicating the overlap between collisions marked in 6a and those in 6b). This shows the feasibility of combining the two sizeable datasets relied on by Caltrans, and the differences between work zone collisions indicated by them. Furthermore, identifying collisions concurrent with active lane closures using LCS also provides detailed data such as the type, responsible party, and nature of the work being performed. This additional data allows for more accurate and in depth analysis of the work zone collisions.

6. Possible sources of discrepancies between the 2 methods of identifying a work zone collision as shown in Figure 6, may lead to further insights on the causes and outcomes of work zone collisions:

a. There is an existing work zone not visible to the reporting officer.

b. CHP officers may be using the road condition description section inconsistently.

c. In general, CHP officers doing the collision write-up do not provide additional detail in the narrative to indicate whether a work zone was active or not.

7. Using only the Traffic Collision Report's "Road Condition" value, there is no direct way to determine any type of road work information when evaluating work zone collision attributes and injuries/fatalities. The ability to link lane closure data, such as that from LCS, with any traffic collision on state highways could provide a new level of information on work zone collisions.

8. The literature and technology reviews performed indicate lack of significant recent and up-to-date research studies on work zone safety as well as technologies being developed for work zone safety.

Recommendations

1. There seems to be a lack of significant, recent, and up-to-date research on work zone safety or new technologies being developed for work zone safety. If the percentage of work zone collisions continues with the same trend as from 2010 to 2015, then it is recommended to perform additional research and development efforts in areas that can impact work zone safety.

2. Since Improper Driving and Unsafe Speeds are two of the major factors in work zone collisions, additional research and development efforts aimed at influencing driver behavior might be in order.

3. In this study, an example process was used to link traffic collisions with Caltrans' LCS. More research and/or development work is recommended to link these two datasets. At the present time, there is no way to determine any type of road work information when evaluating work zone collision attributes. The ability to link lane closure data with traffic collisions on state highways could provide a new level of information on work zone collision attributes. Linking the LCS and TASAS will provide the distinction between collisions associated with maintenance operations and those associated with construction projects. In the past, there has not been a method to distinguish between the collisions in these two operations.

4. In order to objectively evaluate work zone collision frequency, an objective measure of the influence of road work on crash rates is needed. Applying the use of Lane Closure data from Caltrans' LCS, it is conceivable that an objective measure of influence could be developed by normalizing influence based on length of time or total distance of a closure. Influence of road work on crash rates could be expanded to not only include lane closure times and distances but also include other traffic attributes such as volume, number of

lanes, and road topography. More research is recommended toward developing such measures of influence.

5. Lane Closure data may be used to identify work zone regions, such as the advanced and transition regions. This data is needed to distinguish collision attributes that occur in these different regions, and such information can be used to see if the serious injury and fatalities occur in any one region more than the others. More research and analysis is recommended to address such issues.

6. Since there are significant differences in determining a work zone collision using data from LCS and TASAS, further studies are recommended to investigate the reasons for this discrepancy. Once this is understood, then more in depth studies are recommended using multiple years of more current data for all 12 districts.

REFERENCES

[1] Murphy, R., and Grate, D., 2012, "Smart Work Zones :
The use of Intelligent Transportation Systems (ITS) for Work Zone traffic management. ," http://nationalruralitsconference.org/downloads/Presentations12/GRITS3_Murphy.pdf.
[2] Busch, T., 2016, "How Work Zones are Becoming Smarter," http://www.royaltruckandequipment.com/blog/how-work-zones-are-becoming-smarter.
[3] Hill, C., 2015, "Florida DOT to test autonomous truck mounted attenuators in work zones later this year," http://www.equipmentworld.com/florida-dot-to-test-autonomous-truck-mounted-attenuators-in-work-zones-later-this-year/.
[4] 2012, "Guidance for the Use of Dynamic Lane Merging Strategies," https://www.workzonesafety.org/training-resources/fhwa_wz_grant/atssa_dynamic_lane_merging/.
[5] Tardif, L., 2016, "Top 4 Things Texas is Doing Right When it Comes to Work Zone Safety," http://www.royaltruckandequipment.com/blog/top-4-things-texas-is-doing-right-when-it-comes-to-work-zone-safety.
[6] Safety+Health, 2016, "Videos use humor to promote work zone safety," http://www.safetyandhealthmagazine.com/articles/14190-videos-use-humor-to-promote-work-zone-safety.
[7] Qing Li, F. Q., Yu Lei, 2016, "Performance Measures of Smartphone Warning Messages in Work Zones and Intersections," https://www.researchgate.net/publication/303750794_Performance_Measures_of_Smartphone_Warning_Messages_in_Work_Zones_and_Intersections.
[8] Tardif, L., 2016, "3 Innovative Technologies That Are Making the Work Zone Safer," https://royaltruckandequipment.com/?s=technologies+work+zone.
[9] Sullivan, J. M., Winkler, C. B., and Hagan, M. R., 2005, "Smart Barrel for an Adaptive Queue-Warning System ", http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.130.9491&rep=rep1&type=pdf.
[10] Zhang, Y., Suarez, H., and Perera, S., 2013, "Next Generation Smart Barrel System for Workzone Safety Enhancement," https://trid.trb.org/view.aspx?id=1237828.
[11] Hines, K., Lages, W., Somasundaram, N., and Martin, T., 2016, "Protecting Workers with Smart E-Vests," https://vt.edu/spotlight/innovation/2015-08-31-beacon/safetyvests.html.
[12] Lee, C., and Abdel-Aty, M., 2008, "Testing Effects of Warning Messages and Variable Speed Limits on Driver Behavior Using Driving Simulator," Transportation research record, 2069, pp. 55-64.
[13] Karim, A., and Adeli, H., 2003, "Radial Basis Function Neural Network for Work Zone Capacity and Queue Estimation," Journal of Transportation Engineering, 129(5).
[14] Pesti, G., Jessen, D. R., Byrd, P. S., and McCoy, P. T., 1999, "Traffic Flow Characteristics of the Late Merge Work Zone Control Strategy," Transportation Research Record: Journal of the Transportation Research Board, 1657, pp. 1-9.
[15] Hummer, J., and Scheffler, C., 1999, "Driver Performance Comparison of Fluorescent Orange to Standard Orange Work Zone Traffic Signs," Transportation Research Record: Journal of the Transportation Research Board, 1657, pp. 55-62.
[16] WORK ZONES AND CMVs-Communications and Outreach Plan, A Virtual Roundtable, US Dept. of Transportation, Federal Highway Administration, August 2, 2017.

[17] Ravani, B., Fyhrie, P., Wehage, K., Gobal, A., Hong, H.Y., 2015, "Work Zone Injury Data Collection and Analysis," Report #UCD-ARR-15-06-30-01.