Final Report

INTEGRATED WORK ZONE SAFETY MANAGEMENT SYSTEM AND ANALYSIS TOOLS

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By

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16. Abstract

In Florida, despite recent efforts to improve work zone safety, the number of crashes and fatalities at work zones has increased continuously over several past years. For addressing the existing safety problems, it is necessary to develop an integrated work zone safety analysis tool for assisting traffic engineers to obtain a clear understanding of the characteristics of work zone crashes. This understanding is beneficial to the selection of proper measures for improving work zone safety. In addition, Dynamic Lane Merge system, a novel work zone traffic control system mitigates the traffic disturbance due to discontinued lanes at upstream of work zones, can improve work zone safety and operational performance. However, the effectiveness of the new merge control in Florida has not been evaluated yet.

An analysis of work zone fatal crashes in Florida was presented in the study to address a clear understanding of the characteristics of work zone fatal crashes in Florida. Descriptive statistics method was used to find major factors and predominant causes of work zone fatal crashes from different aspects. And a set of binary logit models were developed to explain the impacts of various factors on the occurrence of work zone fatal crashes. Based on the analysis, a web-based application, Florida Work Zone Crash Database, was also developed to provide functions for storing, updating, and analyzing work zone fatal crashes. This analysis function of the system can help traffic engineers address the major safety problems of work zones in Florida. In addition, a CORSIM-based preliminary evaluation of the Dynamic Lane Merge (DLM) system at freeway work zones was produced to demonstrate if DLM has positive impacts on traffic operations or safety under certain traffic conditions. The information of various work zone safety devices, including warning devices, guiding devices, and protective devices, was summarized by searching the internet web sites and literature reviewing. Simultaneously, a work zone safety survey was carried out to obtain the primary impression of work zone safety concerns, contributing factors to work zone accidents, and general measures or devices to work zone safety.

The research result can be used for proposing new measures to improve work zone safety, or be taken as the reference for feature researches.

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INTEGRATED WORK ZONE SAFETY MANAGEMENT SYSTEM AND ANALYSIS TOOLS

BACKGROUND

,. For addressing the existing safety problems, it is necessary to develop an integrated work zone safety analysis tool for obtaining a clear understanding of the characteristics of work zone crashes. It will assist engineers to find work zone safety problems and to select proper measures for improving work zone safety.

In addition, new technologies in communication and computer science, and the new generation of traffic control methods, have created an opportunity to enhance traffic management at work zones to improve traffic safety and operational performance. Dynamic Lane Merge system, a novel work zone traffic control system, mitigates the traffic disturbance due to discontinued lanes at upstream of work zones. However, the effectiveness of the implementation of the new merge control in Florida is not yet evaluated.

OBJECTIVES

- To investigate the characteristics of work zone fatal crashes in Florida;
- To develop a web-based work zone safety analysis application for assisting traffic engineers to understand characteristics of work zone crashes;
- To evaluate safety and operational performances of the Dynamic Lane Merge system (DLM) preliminarily using micro-simulation technology; and
- To collect comprehensive knowledge of effectiveness of work zone safety devices.

FINDINGS AND CONCLUSIONS

Some conclusions were obtained from this study as follows:

- Angle, pedestrian, and rear-end are the principal crash types of work zone fatal crashes in Florida, while careless driving is the most predominant contributing factors for work zone fatal crashes and followed by failed to yield right of way.

- High speed limit, influence of intersection/bridge/ramp/road access, surface roads, bad weather, and failed to yield right of way are more likely increase the probability of angle crashes. The pedestrian crashes are easy to occur when work zones are located in urban area, vehicle moves straightly, or daylight is absent. For rear-end crashes, several factors like high speed limit, urban area, straight movement, absence of daylight, other pavement types (not blacktop), and drivers' careless driving tend to raise the opportunity of crash occurrence.

- Work zone fatal crashes for young drivers are easy to occur when they are driving in narrow roadways or at night. The probability of work zone fatal crashes for middle age drivers is likely to increase when alcohol is involved or when they drive heavy vehicle. . For elderly drivers, the influence of intersection, bridge, ramp, and road access are the significant factors that increase the probability of work zone fatal crashes.

- With only one lane is open at work zones (one direction), the Dynamic Lane Merge (DLM) significantly reduces the lane change behaviors. DLM has almost no positive effectiveness on reducing average travel time.

- Due to the limitation of the preliminary evaluation of DLM using CORSIM software, a field test should be performed in next stage of research to obtain more accurate evaluation on the safety and operational effectiveness of DLM in Florida.

BENEFITS

The analysis of the characteristics of work zone fatal crashes is helpful to to select proper measures for improving the work zone safety in Florida. The web-base work zone safety analysis application developed in this study can be used to assist traffic safety analysts to collect work zone crash data and to process the work zone characteristic analysis.

The result of the preliminary evaluation on the safety and operational performance of DLM may be used as a reference and guidance for the field test in feature. In addition, a comprehensive collection of knowledge of traditional work zone safety devices is also of benefit to traffic engineers to understand the effectiveness of these equipments.

This research project was conducted by Jian John Lu, Ph.D., P.E., Professor, of the University of South Florida. For more information, contact Sastry Putcha, Ph.D., P.E., Project Manager, at (850)412-8021, sastry.putcha@dot.state.fl.us.

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1. INTRODUCTION

1.1 Problem Statement

A work zone refers to a road section where a construction or maintenance project is presented. Manual on Uniform Traffic Control Devices (MUTCD) divides a work zone into four areas: the advance warning area, the transition area, the activity area, and the termination area. Road users traveling through a work zone are warned of the upcoming hazardous area in the advanced warning section and then are directed out of their normal path in the transition area. The transition area frequently forms a bottleneck which could dramatically reduce the traffic throughput. The termination area is the section following activity area where road users return to their normal path.

Hazardous conditions for drivers and construction workers are easy to occur at work zones since construction activities produce disturbances on normal traffic flows. The disturbances may introduce severe traffic congestions and increase the risk of traffic crash at work zones. In Florida, for addressing the safety problems, an integrated work zone safety analysis tool is needed to be developed for obtaining a clear understanding of the characteristics of work zone crashes. The knowledge of work zone crashes is of benefit to engineers to select proper measures that can minimize the negative impacts of work zones on traffic safety.

A variety of traffic safety devices have been implemented at work zones. These devices have different principles, functions, and performances. Limited tests for these devices in Florida have been conducted in accordance with the guidelines set forth in National Cooperative Highway Research Program (NCHRP) Report No. 350. Thus, comprehensive knowledge of work zone safety devices is important to deploy appropriate work zone safety devices by transportation agency.

New technologies in communication and computer science, and the new generation of traffic control methods, have created an opportunity to enhance traffic management at work zones to improve safety and operational performance. Dynamic Lane Merge system, a novel work zone traffic control system, mitigates the traffic disturbance due to discontinued lanes at upstream of work zones. The effectiveness of the Dynamic Lane Merge system in Florida has not been evaluated yet.

1.2 Research Objectives

The primary objectives of this research are shown as follows:

- To investigate the characteristics of work zone fatal crashes in Florida;
- To develop a web-based work zone safety analysis tool for assisting traffic safety analysts to understand distributions and contributing factors of work zone fatal crashes;
- To evaluate safety and operational performance of Dynamic Lane Merge system at work zones preliminarily using micro-simulation; and
- To collect comprehensive knowledge of the effectiveness of various work zone safety devices.

1.3 Research Approach

First, a broad literature review was conducted to collect comprehensive information of traditional work zone safety devices. The information included device type, function description, and implementation experience in other states. Second, survey forms were distributed to state DOTs, transportation agencies, and universities/research centers for obtaining the primary impression of work zone safety concerns, contributing factors to work zone crashes, and general safety measures or devices at work zones. Third, an analysis of characteristics of work zone fatal crashes was performed based on history crash data in Florida. In this study, the predominant factors and contributing causes for different variables were determined. In addition, binary logistical models were developed to address the significant factors which influence the occurrence of work zone fatal crashes. And then, a web-based integrated work zone safety analysis application was developed to provide a powerful computer aid tool for addressing the safety problems at work zones. Four major functions were provided in this system: update, conditional query, analysis, and user management. Finally, a simulation-based preliminary evaluation of Dynamic Lane Merge system was conducted to give a demonstration of the performance of the new technology. A FRESIM model was developed to simulate the system operations under various traffic scenarios. Average travel time and lane changes were selected as the measures for evaluating operational and safety effectiveness of the system respectively.

1.4 Outline of the Report

This report consists of six chapters. Chapter 1 provides a brief introduction of the research. Chapter 2 describes the results of a comprehensive literature review. Chapter 3 expresses the conclusions of work zone fatal crash data analysis. The description of the integrated work zone safety analysis system is provided in Chapter 4. And the preliminary test of the Dynamic Lane Merge system is presented in Chapter 5. Finally, Chapter 6 gives the summary, conclusions and recommendations of this research. In addition, Appendix A explains the collection of traditional work zone safety devices. And Appendix B illustrates the results of the survey. Furthermore, the user manual of Florida Work Zone Crash Database is provided in Appendix F.

2. LITERATURE REVIEW

2.1 Introduction

This section describes a comprehensive literature review performed for this study. The findings have been grouped into the following three categories.

- Previous analysis on work zone crashes to investigate the characteristics of work zone crashes,
- Previous researches that introduced and/or evaluated various work zone safety devices or strategies implemented at work zones,
- Previous studies on the evaluation of Dynamic Lane Merge system (DLM).

In this chapter, previous analysis on work zone crashes and DLM are described. Review of work zone safety devices was presented in Appendix A.

2.2 Previous Researches on Work Zone Crashes

Many studies have been conducted to analysis on highway work zone crashes over past several years in several states. These studies focused on examining the characteristics of work zone crashes, and evaluated the effectiveness of traffic control measures on traffic safety at work zones.

Bai and Li (2004) conducted a study to investigate the characteristics of work zone fatal crashes in Kansas and dominant contributing factors to these crashes in the work zones so that effective safety measures could be developed and implemented in the near future. A total 157 crashes during 1992 and 2004 were examined using descriptive analysis and regression analysis. They found that (1) male drivers cause about 75% of the fatal work zone crashes in Kansas; drivers between 35 and 44 years old, and older than 65, are the high-risk driver groups in work zones; (2) The daytime non-peak hours (10:00 a.m. – 4:00 p.m.) are the most hazardous time period in work zones; (3) Work zones on rural roads with speed limit from 51 mph to 70mph or located on complex geometric alignments are high risk locations; (4) Most fatal crashes are multi-vehicle crashes. Head-on, angle-side impact, and rear-end are the three most frequent collision types for the multi-vehicle crashes; (5) Inefficient traffic controls and human errors contributed to most fatal work zone crashes. Inattentive driving and misjudgment/disregarding traffic control are the top contributing factors for work zone fatal crashes.

In Taxes, Hill et al. (2003) analyzed the characteristics of work zone fatalities and then evaluated the effectiveness of existing work zone traffic safety measures based on 376 work zone fatal crashes in Texas from January 1, 1997 to December 31, 1999. In this study, three comparisons were conducted between daytime versus nighttime, male drivers versus female drivers, and commercial-truck-involved versus non-commercial-truck-involved. Then logistic regression was implemented to examine the effectiveness of traffic counter measures such as using an officer/flagman and using a stop/go signal. Results of this study indicated that there was a significant difference in crash type and driver error between daytime crashes and nighttime crashes. This difference also existed between driver genders. In addition, commercial truck related crashes were more likely to involve multiple vehicles. According to the logistic regression results, the use of an officer/flagman or a stop/go signal would reduce the chance of having a crash by 68% or 64% respectively.

Ullman et al. (2006) conducted a study on the safety effects of night work activity upon crashes at two types of construction projects in Texas. The first project type involved both day and night work (hybrid project), whereas the other project type performed only at night. Researchers determined the change in crash likelihood during periods of active night work, active day work (if applicable), and during times of work inactivity day and night. Some conclusions were derived from this study: (1) crashes increased significantly during periods of work activity than during periods of work inactivity; (2) large crash increases at night was expected because the night work more likely involved lane closure than the day work; (3) for the hybrid project, crashes increased at night more than at day.

Garber and Zhao (2002) studied the distribution of work zone crashes in Virginia in terms of severity, crash type, and road type over four different locations within the work zone referred to as the advance warning area, transition area (taper), longitudinal buffer area, activity area, and termination area. In total, 1484 work zone related crashes during 1993 and

1999 were analyzed. The results indicate that the activity area is the predominant location for work zone crashes for all crash types, and the rear-end crashes are the predominant type of crashes except for the terminate area, where the proportion of angle crashes is significantly higher than other types.

A study on the typical characteristics of multistate work zone crashes was conducted by Chambless et al. (2002) to perform a set of comprehensive comparisons of computerized work zone and non-work zone crash data in Alabama, Michigan, and Tennessee. The Information Mining for Producing Accident Countermeasure Technology (IMPACT) module of Critical Analysis Reporting Environment (CARE) software developed by University of Alabama was used in this study to process the statistical analysis to obtain the conclusions: (1) 63% of work zone crashes take place on interstate, US, and state roads, as compared to 37% of non-work zone crashes. (2) 48% of work zone crashes occur on 45- and 55-mph speed zones, as opposed to 34% of non-work zone crashes. (3) "Misjudging stopping distance/following too close" accounted for 27% of the "prime contributing crash circumstances" for work zone crashes as opposed to 15 percent for non-work zone crashes.

In the study conducted by Mohan and Gautam (2002), the various injury types and their cost estimates were analyzed. As the results, researchers found that (1) the average direct cost of a motorist's injury is estimated at $3,687; (2) an overturned vehicle has the largest average cost of $12,627, followed by a rear-end collision averaging $5,541; and (3) rear-end collisions are the most common (31%) vehicle crashes, followed by "hit-small-object" collisions at 11% of the total motor vehicle crashes.

Ha and Nemeth (1995) conducted a study in an effort to identify the major cause-and effect relationships between work zone crashes and traffic controls in order to make the first step towards development of effective work zone traffic control strategies. They analyze the crash data during 1982 and 1986 at nine sites in Ohio, and focused on the impacts of factors such as inadequate or confusing traffic control, edge drop or soft shoulder, traffic slowdowns, lane changing or merging, guardrails, and alcohol impairment on work zone crashes. Results of the study indicates that (1) the predominant type of crash was rear-end; (2) improper traffic control was one of the safety problems in construction zones; (3) involvement of trucks in crashes at crossovers was significant; (4) work zone crashes were slightly less severe than other types of crashes; (5) although work zone crashes increased at nights, they actually decreased in proportion to all crashes.

Pigman and Agent (1990) studied the traffic data and traffic control devices of 20 highway work zones for 3 years (1983-1986) in Kentucky, and found that (1) most work zone crashes occur on interstate roads; (2) work zone crashes are more server than other crashes, especially in night or truck involved; (3) the dominant crash type is rear-end and same-direction-sideswipe; and (4) the dominant contributing factor is following to close.

Hall and Lorenz (1989) investigated the crashes at work zones in New Mexico from 1983 to 1985 by comparing the difference of crashes before- and during- construction at same road sections. They concluded that the proportion of crashes caused by following too close was much higher in during-work zone periods than in before-work zone periods. Another conclusion was that improper traffic control was the prevalent problem causing high crash rates in work zones.

2.3 Previous Researches on Dynamic Lane Merge

2.3.1 Conventional Merge Control

The Temporary Traffic Control (TTC) plan, described in the *Manual on Uniform Traffic Control Devices* (MUTCD), illustrates the conventional merge control which informs drivers to move out of closed lane well in advance of the work zone closure taper. Typical distance for placement of advanced lane closed signs on freeways should be on both sides of the roadway as far as 0.5 mile or more ahead of the taper.

This merge control, which widely used in all states, works well as long as congestion does not develop. However, when the traffic demand exceeds the capacity of the work zone, queues may extend back passed the advanced warning signs, often surprising the approaching traffic and increasing the accident potential.

2.3.2 Dynamic Lane Merge

In 1980's, the static early merge control was proposed to improve work zone safety and operational performance. This control strategy extends the placement of additional lane closed signs in advance of the lane closure area at several intervals (approximate 1 mile to several miles).

Based on simulations conducted by Nemeth and Rouphail (1982), the static early merge control could reduce the rate of forced merges, even at higher traffic volumes. On the other hand, simulations by Mousa et al (1990) found that early merge control strategies increased the travel times through the work zone, because vehicles are more likely to be delayed over greater distances by slower vehicles ahead of them in the open lane. This may in turn increase the likelihood of drivers in the open lane attempting to use the closed lane to pass slower vehicles, which would increase the potential of lane-change accidents. Some states use lane drop arrows, rumble strips, and/or no-passing zones for distances of up to 1 mile or more in advance of the lane closure to discourage drivers from using the closed lane to pass.

The Indiana Lane Merge System (ILMS), a typical dynamic early merge control developed by the Indiana Department of Transportation, changes the no-passing zone in real-time by using sonic detectors to determine the presence of a queue in the open lane. The detectors are mounted on DO NOT PASS signs with two flashing strobes and WHEN FLASHING supplementary plates. The signs are installed adjacent to the closed lane at ¼- to ½-mile intervals for up to 2.5 miles or more in advance of the lane closure. When stopped vehicles are detected in the open lane next to a sign, a signal is transmitted to turn on the flashing strobes on the next sign upstream. When vehicles are moving again, the strobes are shut off. In this way, the length of the no-passing zone is tailored to the length of congestion present.

In 1997, the system was tested on operational and safety performance in field by the Indiana Department of Transportation (Tarko, Kainpakapatman, and Wasson, 1998). This evaluation displayed that the ILMS could smooth the merging operations in advance of the lane closure. Drivers merged when they were supposed to merge and flow in the open lane was uniform with very few rear-end accidents. Preliminary benefit-cost estimates by the Indiana

Department of Transportation indicate that implementation of the system is justified at lane closures where the capacity of the single lane will be exceeded at least 15 to 20 times per week.

The University of Nebraska-Lincoln (UNL) (McCoy and Pesti, 2001) conducted field studies to compare the *Indiana Lane Merge* and the *conventional merge*. The study sites were right lane closures. The lane distributions within 3000 feet of the lane closures observed in the field studies indicated that vehicles moved into the open lane sooner with the *Indiana Lane Merge* than they did with the *conventional merge*. Also, the merging operations with the *Indiana Lane Merge* occurred more uniformly over a much longer distance than they did with the *conventional merge*, which were concentrated over a 500-foot section approximately 1200 feet in advance of the lane closure. Spreading the merging over a longer distance produced smoother merging operations. Only seven traffic conflicts were observed in 16 hours of data collection during moderate to high traffic volumes at the *Indiana Lane Merge* study site; whereas forced merges were observed at the rate of 20 or more per hour under comparable levels of traffic volume at the *conventional merge* study site.

3. STUDY ON WORK ZONE FATAL CRASHES

With the increase of maintenance and rehabilitation of the highway system in Florida over past years, number of work zones have increased and will continue to increase. Thus more efforts to maintain traffic safety at work zones are required. A clear understanding of the characteristics of work zone fatal crashes will be useful to select and implement effective measures to improve work zone safety.

This chapter presents the results of a study on work zone fatal crashes in Florida. The primary objective of this study is to investigate the characteristics of fatal crashes at work zones in Florida and to address the influence of various factors.

3.1 Methodology

3.1.1 Data Collection

This study focused on a data set of work zone fatal crashes in Florida for a 4 year period (from 2002 to 2005). A total of 421 work zone fatal crashes with 20 data variables were extracted from the Florida Crash Analysis Reporting (CAR) system, which provides a completed crash database of Florida motor vehicle accidents, and that of the involved vehicles and persons. All of these data were categorical data or ordinal data, and were assigned with integer values for easy treatment in SAS software. The data variables and corresponding codes are given in Appendix D.

3.1.2 Analysis Procedure

A two-stage analysis procedure was applied in this study. In first stage, a descriptive statistical method was used to examine the distributions of work zone fatal crashes over various variables. The predominant factors for each variable, defined as the factors which are responsible for a high proportion, were determined. Especially, principal crash types and corresponding predominant contributing factors were identified to explore major causes for the specific crash types.

In second stage, analysis emphasized on what factors influence the occurrence of a certain work zone crash type. For this purpose, predictive models were developed to describe the relationship between the probability of the occurrence of fatal crashes and explanatory variables. Since the occurrence of a specific type of traffic crashes is a binary value (1-occurrence, 0-nonoccurence), the binary logistic regression was adopted to develop the models which predict the probability of the occurrence of fatal crashes at work zones by crash types, by age groups, or by predominant contributing factors.

3.1.3 Binary Logistic Regression

Binary logistic regression is used to predict a dichotomous variable from a set of explanatory variables. For a binary logistic regression, the predicted dependent variable is a function of the probability that a particular subject will be of occurrence, and the explanatory variables could be nominal data, continuous data, or a mix of them. An important advantage of binary logistic regression is that there is no assumption on the distribution of explanatory variables. Binary logistic regression is used widely in traffic crash analysis since it is more flexible and accurate.

Let Y denote an event ($Y = 1$ and $Y = 0$ denote the occurrence and nonoccurrence respectively) and let a vector X be a set of predictors $\{X_1, X_2, \cdots, X_k\}$, then the probability (P) of the occurrence of Y given X could be expressed as:

$$P(Y = 1|X) = \frac{e^{X\beta}}{1 + e^{X\beta}} \tag{3-1}$$

where β is the regression parameter vector , and $X\beta = \beta_0 + \beta_1 X_1 + \cdots + \beta_k X_k$. This equation can be expressed in a logit form:

$$\text{logit}(Y = 1|X) = \log(odds) = \log(\frac{P}{1 - P}) = \beta_0 + \beta_1 X_1 + \cdots \beta_k X_k \tag{3-2}$$

where odds is defined as the ratio of the probability of the occurrence over the probability of the nonoccurrence. Its log value has a linear relationship with predictors. For equation 3-2, Maximum Likelihood Estimate (MLE) can be used to estimate the parameters combination that maximizes the likelihood of the observed outcomes. Finally, we have a set of estimated parameters $\hat{\beta}_1, \hat{\beta}_2, \cdots \hat{\beta}_k$, and then the estimated value $\hat{P}$ of the probability that the event occurs can be computed based on Equation 3-1.

After obtaining the estimated values of coefficients, it is necessary to produce an examination on how well the model fits the observations (Goodness-of-fit). The Pearson Chi-square, Likelihood-Ratio (deviance), and Hosmer-Lemeshow tests are three widely used statistics indicies for measuring the Goodness-of-fit of logistic regression models. Since some restrictions for Pearson Chi-square and deviance exist when the model has many variables and variable levels, Hosmer-Lemeshow test was adopted in this study to test the Goodness-of-fit. This test divides subjects into several groups (no more than 10) based on predicted probabilities, then computes a chi-square from observed and expected frequencies. It tests the null hypothesis that there is no difference between the observed and predicted values of the response variable. Therefore, when the test is not significant at a significance level (0.05), the null hypothesis cannot be rejected, that means the model fits the data well. The values of Pearson Chi-square and Deviance are also provided as a reference in results of model estimation.

The Likelihood-Ratio test, Wald test and Score test are used to examine the significance of parameters of the overall model (global test). The null hypothesis is that all coefficients of predictors are equal to zero $(\beta_1 = \beta_2 = \cdots \beta_k = 0)$. If these tests are significant at a 0.1 level, the null hypothesis will be rejected, that means the predictors have influence on the prediction result. Wald test also has been applied to test the significance of individual model parameters.

The regression parameters were estimated by maximum likelihood estimate (MLE) method with LOGISTIC procedure in SAS. Backward elimination method was used through the regression process to remove statistically insignificant predictor variables. The significance level was 0.1, which reflects a moderately restrictive approach in the selection of explanatory variables during modeling. It has been taken into account that more restrictive significant level would generally include fewer explanatory variables in the model and would reduce the overall predictive ability of the model.

3.2 Results of Descriptive Statistics Analysis

3.2.1 The Trend of Work Zone Fatal Crashes

The trend of work zone fatal crashes and work zone fatalities were ascending continuously from 2002 to 2005 in Florida (see Figure 3-1). The average annual increase rate of work zone fatal crashes was 17%, and the number of fatal crashes in 2005 was 62% more than one in 2002. This trend indicated that the work zone safety in Florida remained a serious concern.

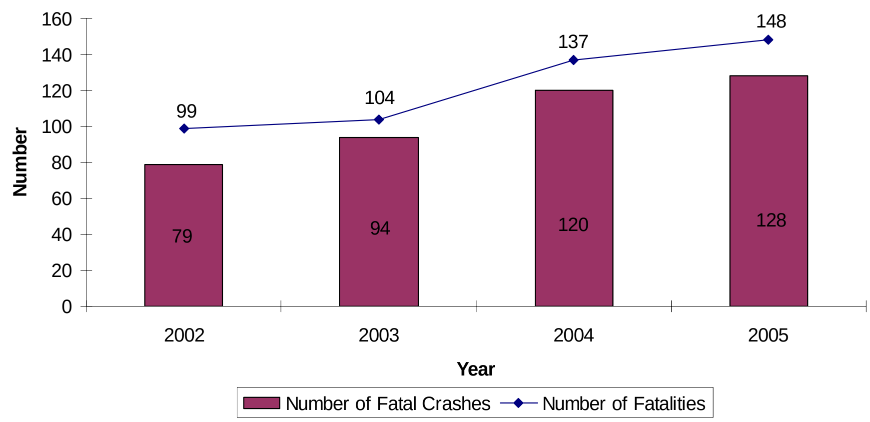


Figure 3-1 Florida Work Zone Fatal Crashes Trend

3.2.2 Distribution of Fatal Crashes by Drivers' Ages

Figure 3-2 illustrates the age distribution of the responsible drivers for work zone fatal crashes. The drivers at fault were divided into three age groups: Young Age (less than 24), Middle Age (25 – 64), and Elderly Age (greater than 65). On average, the middle age drivers caused the highest proportion (64%) of the fatal crashes, while the elderly age drivers were only responsible for 13% of the crashes. The driver group having the second highest fatal work zone crash rate (23%) was the young age drivers.

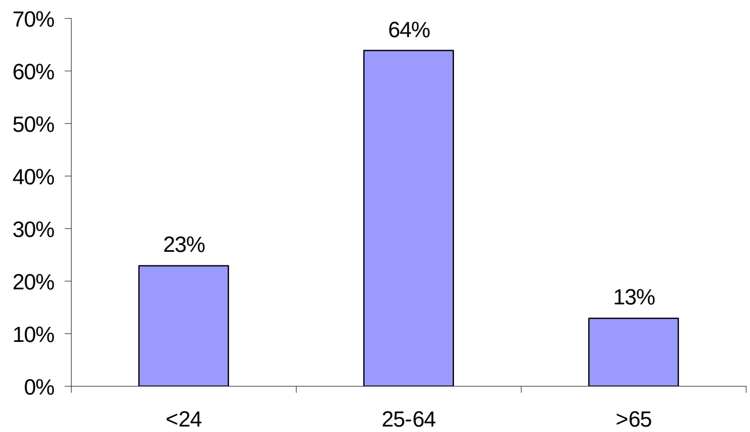


Figure 3-2 Distribution of the Responsible Drivers' Age

3.2.3 Distribution of Fatal Crashes by Time

The distribution of work zone fatal crashes by time is shown in Figure 3-3, which indicates that most of crashes occurred during the non-peak hours (20:00-6:00 and 10:00-16:00). And the nighttime period (20:00-6:00) had the highest crash rate (48%) among the four periods.

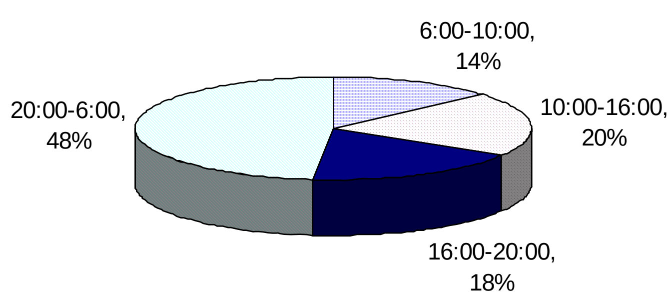


Figure 3-3 Distribution of Fatal Crashes by Time

3.2.4 Distribution of Fatal Crashes by Climatic Environmental Conditions

Climatic environmental conditions include light conditions, weather conditions, and road surface conditions. Figure 3-4 summarizes the distribution of the crashes by light conditions. 41% of the crashes occurred when the light condition was good. Among the dark conditions, dark without streetlight had a higher crash rate significantly than dark with street light. That means that street light could reduce the probability of fatal crashes.

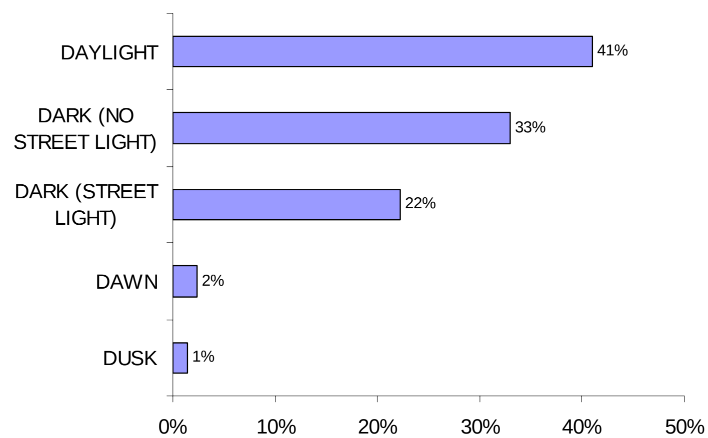


Figure 3-4 Distribution of Fatal Crashes by Light Conditions

The results of analysis of the distribution of fatal crashes by weather and road surface conditions are shown in Figures 3-5 and 3-6 respectively. The results indicate that only a small proportion of fatal work zone crashes occurred in bad weather and road surface conditions. In contrast to the common sense, the adverse weather and road conditions did not have significant influence on the work zone fatal crashes.

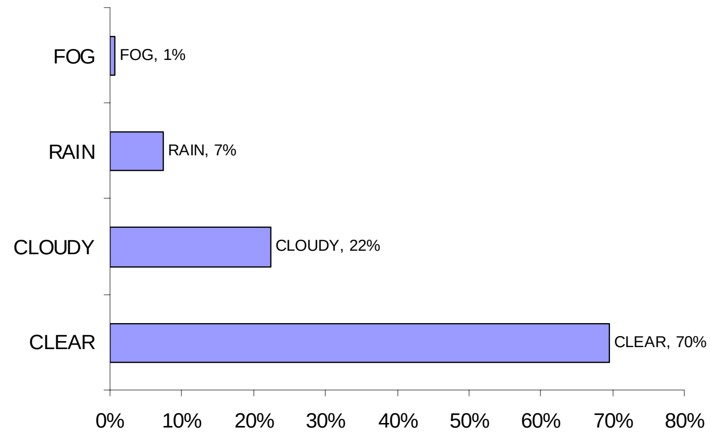


Figure 3-5 Distribution of Fatal Crashes by Weather Conditions

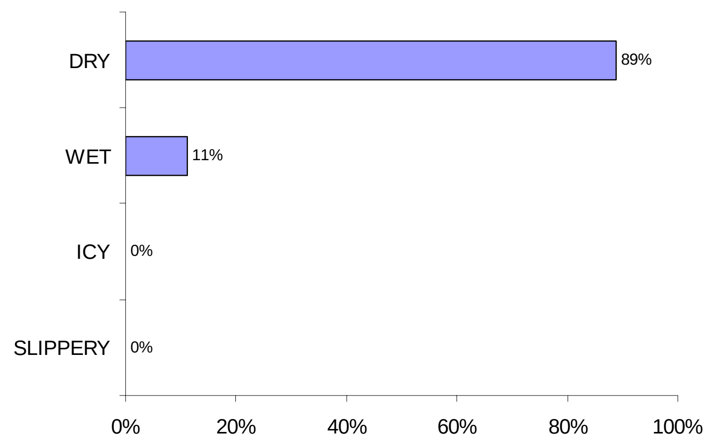


Figure 3-6 Distribution of Fatal Crashes by Road Surface Conditions

3.2.5 Distribution of Fatal Crashes by Crash Types

As shown in Figure 3-7, angles was the most frequent work zone crash type (14%), followed by pedestrian (13%), and rear-end (12%). Each of the these three crash types had over 10% of work zone fatal crashes, and are defined as the principal crash types in this study.

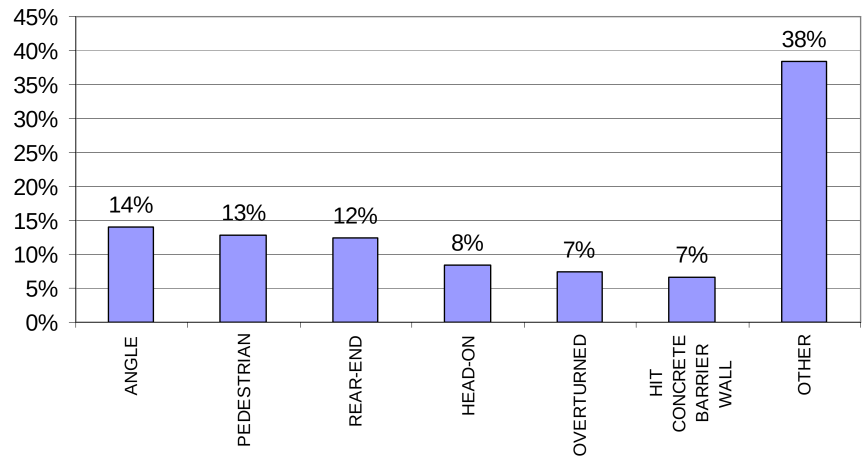


Figure 3-7 Distribution of Fatal Crashes by Crash Types

3.2.6 Distribution of Fatal Crashes by Contributing Factors

The distribution of contributing factors for total work zone fatal crashes is shown in Figure 3-8. Among the factors, careless driving, the most predominant contributing factor, was responsible for 39% of total crashes. Another predominant contributing factor was failed to yield right of way (10%) followed by no improper driving action (8%), alcohol-under influence (6%), and drove left of center (5%) respectively.

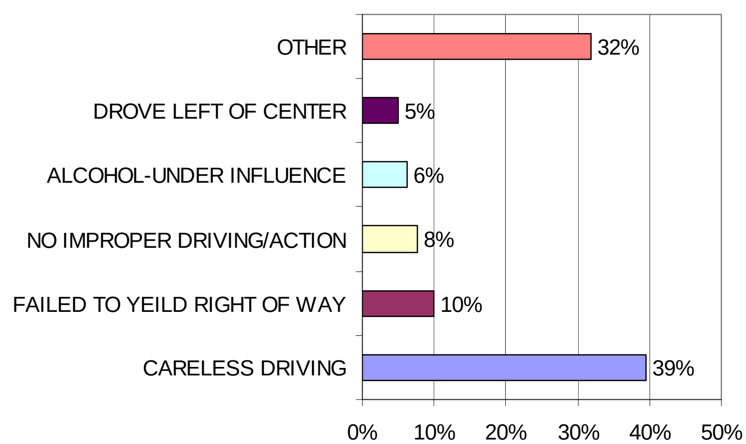


Figure 3-8 Work Zone Fatal Crashes Distribution by Contributing Factors

Figure 3-9 represents the distribution of predominant contribution factors over the principal crash types. The most predominant contributing factor for angle crashes was failure to yield right of way (29%). For pedestrian crashes, the most predominant contributing factor was improper driving/action (22%). Careless driving was the most frequent contributing factor for rear-end crashes, which was responsible for 79% of rear-end crashes.

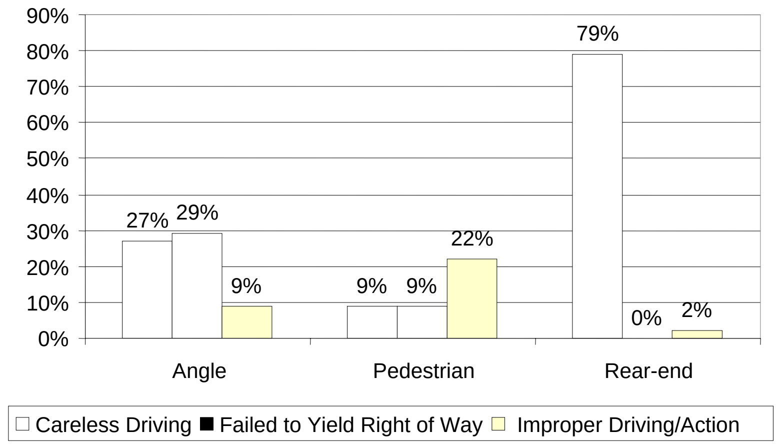


Figure 3-9 Predominant Contributing Factors by Principal Crash Types

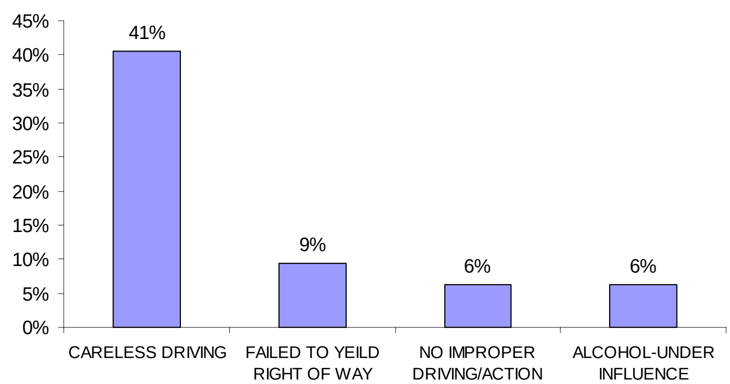


Figure 3-10 Predominant Contributing Factors for Young Age Drivers

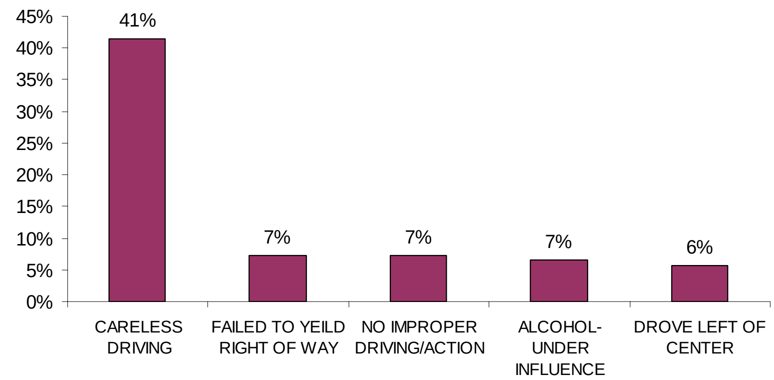


Figure 3-11 Predominant Contributing Factors for Middle Age Drivers

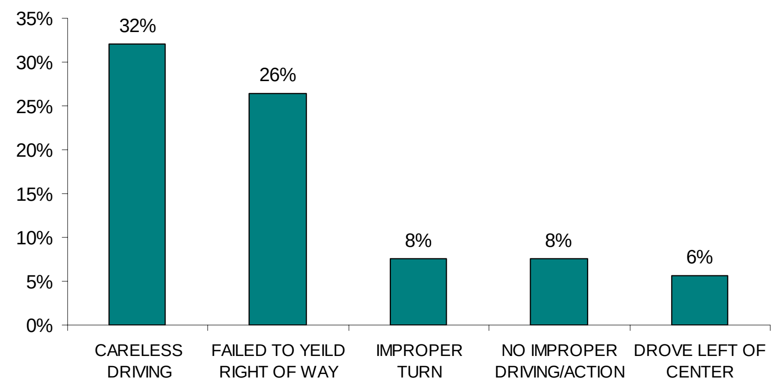


Figure 3-12 Predominant Contributing Factors for Elderly Age Drivers

Figures 3-9 to 3-12 express the distribution of contributing factors by age groups. Careless driving was the most predominant contributing factor followed by failure to yield right of way for all age groups. For elderly age group, the percentage of failure to yield right of way (26%) was significantly greater than that for young age group (9%) and middle age group (7%). Another difference between elderly age group and the other two age groups was that alcohol under influence was not a predominant contributing factor for older age drivers but it was for young age drivers (6%) and middle age drivers (7%). Improper turn was also a specific predominant contributing factor for elderly age group (8%).

3.2.7 Predominant Factors for Other Variables

The most predominant factors for other variables are given in Table 3-1. About 42% of the crashes involved alcohol or drug, and 28% involved heavy vehicles, which are defined as large truck, truck tractor, recreation vehicle, and bus. For road geometric conditions, straight with level was the most frequent factor (70%) followed by straight with grade (15%), and curve with level (10%). Most of crashes occurred on the pavement of blacktop; in addition, 68% of the crashes took place at normal locations (without influence of intersections, bridges, railway cross, etc.), while 20% of them occurred at intersections. The predominant factors of vehicle movement before crash and vision obscured conditions were straight ahead and no obscurity respectively. The percentage of crashes where the road access was full is 42%, and 46% of the crashes occurred under the influence of speed controls. Another predominant factor was that 65% of the crashes happened at a high speed zone (≥50 mph).

Table 3-1 Predominant Factors for Other Variables

Variable	Predominant Factors
Heavy Vehicle Involved	No (72%), Yes (28%)
Road Geometric Condition	Straight & Level (70%), Straight & Grade (15%), Curve & Level (10%)
Pavement Type	Blacktop (92%)
Special Location	Not at Intersection/Railway cross/Bridge (68%), Intersection (20%)
Road Function Class	Principle Arterial (39%), Interstate (30%), Minor Arterial (13%), Local (10%)
Vehicle Maneuvers before accident	Straight Ahead (72%), Make Left Turn (7.8%), Lane Change (6.9%)
Vision Obscured	No (94%)
Alcohol Involved	No (58%), Yes (42%)
Road Access Condition	None (47%), Full (37%)
Traffic Control	Speed Control Sign (29%), No Control (29%), Special Speed Zone (17%)
Speed Limit	50mph ~ 60mph (34%), >60mph (31%)

3.3 Modeling Analysis

3.3.1 Modeling Variables

Form the analysis results in the first stage, it can be concluded that angle, pedestrian, and rear-end are the principal crash types of work zone fatal crashes in Florida. In addition, careless driving and failure to yield right of way are the predominant contributing factors. The occurrence of a certain type of fatal crashes would be affected by various factors; thus binary logistic models developed to address the related variables and explained the impacts of the predictor variables on the occurrence. The response variables and explanatory variables are shown in Table 3-2.

Table 3-2 Definitions of Variables in Models

Variable	Description	Level	Value
Angle	Fatal crash type is angle	No	0
		Yes (occurrence)	1
Pedestrian	Fatal crash type is pedestrian	No	0
		Yes (occurrence)	1
RearEnd	Fatal crash type is rear-end	No	0
		Yes (occurrence)	1
SpeedLimit	≥60mph	No	0
		Yes	1
SiteType	Under the influence of intersection, bridge, railroad crossing, or road access	No	0
		Yes	1
RoadClass	Freeway/Expressway	No	0
		Yes	1
Urban	Urban area	No	0
		Yes	1
GoStraight	The movement before crash is running straightly	No	0
		Yes	1
			1
SurfaceType	The road surface is blacktop	No	0
		Yes	1
GeoStraight	The road geometric design is straight not curve	No	0
		Yes	1
GeoLevel	The road geometric design is level not grade	No	0
		Yes	1
Weather	Clear	No	0
		Yes	1
Daylight	Daylight	No	0
		Yes	1
HVInv	Heavy Vehicle involved	No	0
		Yes	1
		Yes	1
		Yes	1
AADT	The AADT of the section of work zones	<15,000	1
		15000 ~ 30000	2
		>30000	3
RoadWidth	Road width	>=20	0
		<20	1
DriverErr1	Fatal crashes due to Careless Driving	No	0
		Yes (occurrence)	1
DriverErr2	Fatal crashes due to Failed to yield Right of Way	No	0
		Yes (occurrence)	1

3.3.2 Models for Crash Types

Table 3-3 presents the results of the model estimation for angle crashes. The response variable is Angle, where "1" value indicates the occurrence of angle crashes, "0" value denotes the nonoccurrence. This model predicts the probability of the occurrence of angle crashes (Angle=1) with 5 predictor variables. The coefficients of three variables, including SpeedLimit, SiteType, and DriverErr2, are positive; that means when values of these variables are equal to "1", the probability of the occurrence of angle crashes will be increased. In other words, these variables have "positive" impacts on the occurrence of angle crashes. For instance, when the posted speed limit at work zones is greater than 60mph (SpeedLimit=1), the probability of the occurrence of angle crashes will be bigger than that when the posted speed limit is less than 60mph. There are two factors increasing the probability of angle crashes. One is that there are intersections, bridges, or railroad crossings within or near work zone area; another is that drivers fail to yield the right of way.

Another method used to interpret the coefficients is the odds ratio which indicates the ratio of the probability of the occurrence of angle crashes to the probability of the nonoccurrence of angle crashes when the corresponding variable adopts 1. For example, the odds ratio of the speed limit is 2.498. It can be explained as that the probability of the occurrence of angle crashes is 2.498 times greater than the probability of the nonoccurrence of angle crashes if the posted speed limit is over 60mph (SpeedLimit=1).

By contrast to the "positive" variables, Weather and RoadClass have "negative" impacts on the occurrence of angle crashes since their coefficients are smaller than zero. The probability of the occurrence of angle crashes will be reduced when the weather is clear (Weather=1), or the work zone location is located in a freeway section (RoadClass=1). The odds ratios of the two variables are 0.338 and 0.340 respectively.

Table 3-4 and Table 3-5 illustrate the models for pedestrian crashes and rear-end crashes respectively. For pedestrian crashes, the probability of the occurrence will be decreased when speed limit is high (over 60mph), road section is under the influence of specific road features, or daylight is present. If the vehicle is running straight, it will reduce the probability of the occurrence of pedestrian crashes. From this model, it can also be found that the probability of the occurrence of pedestrian crashes in urban area is higher than that in rural area. This happens because more pedestrians are present on road in urban area.

At high speeds, the probability of the occurrence of rear-end crashes increases. Obviously, the probability of rear-end crashes increases when the vehicle at fault is running straight, or the road geometric design property is not curved.

The probability of rear-end crashes is more likely to increase if vehicles are going straight or the geometric design is no curved. It is understandable that rear-end crashes are more likely to occur when vehicles are going straight than when vesicles are making lane change, turn, and other non-straight activities, which more likely conduct to angle crashes or other crashes except for rear-end type.

The possible explanation of geometric design is that in a curved road section, there is always an angle between the successive vehicles, so the crash type is more likely to be angle or other types rather than rear-end.

Careless driving is an important factor which increases the probability of the occurrence of rear-end crashes. When a crash happened in urban area, the probability of the occurrence is lower than that in rural area. The possible explanation is that in urban area, there is more interrupted traffic than in rural area. That means there may be more conflicts from side in urban area than in rural area. So the probability of rear-end crashes in urban area is lower than that in rural area while the probability of angle or other crash types except for rear-end in urban area is higher than that in rural area.

The presence of daylight tends to prevent the occurrence of rear-end crashes, and another “negative” factor is the influence of specific road features (such as the influence of intersection, bridge, railroad crossing or road access within or close to workzone area). The variable is “SiteType” which is defined in Table 3-2.

Table 3-3 Estimated Parameters of the Model for Angle Crashes

Estimated Parameters

Variable	*DF*	*Coefficient Estimate* $\hat{\beta}$	*Standard Error*	*Wald* χ^2	*Pr>* χ^2
Intercept	1	-1.7511	0.3194	30.0501	< .0001
SpeedLimit	1	0.9155	0.4017	5.1950	0.0227
SiteType	1	0.9389	0.3324	7.9807	0.0047
DriverErr2	1	1.3503	0.4143	10.6250	0.0011
Weather	1	-1.3503	0.3134	11.9750	0.0005
RoadClass	1	-1.0790	0.4363	6.1152	0.0134

Model Summary

Number of Observations	421

Goodness-of-fit Statistics

Criterion	*DF*	*Value*	*Pr>* χ^2
Deviance	17	23.6417	0.1295
Pearson Chi-Square	17	19.2097	0.3166
Hosmer and Lemeshow Test	8	6.4357	0.5985

Odds Ratio Estimates

Effect	*Point Estimate*	*95% Wald Estimate Confidence Limits*	
Speed Limit	2.498	1.137	5.489
SiteType[1]	2.557	1.333	8.691
DriverErr2[2]	3.859	1.713	8.691
Weather	0.338	0.183	0.625
RoadClass	0.340	0.145	0.799

Table 3-4 Estimated Parameters of the Model for Pedestrian Crashes

Estimated Parameters

Variable	*DF*	*Coefficient Estimate* $\hat{\beta}$	*Standard Error*	*Wald* χ^2	*Pr>* χ^2
Intercept	1	-0.7556	0.3968	3.6259	0.0569
SpeedLimit	1	-1.0203	0.3769	7.3274	0.0068
SiteType	1	-0.7064	0.3592	3.8675	0.0492
Urban	1	0.6912	0.3545	3.8013	0.0512
DayLight	1	-1.2217	0.3815	10.2542	0.0014
GoStraight	1	-1.1835	0.3155	14.0738	0.0002

Model Summary

Number of Observations	421

Goodness-of-fit Statistics

Criterion	*DF*	*Value*	*Pr>* χ^2
Deviance	25	31.9332	0.1591
Pearson Chi-Square	25	33.1344	0.1277
Hosmer and Lemeshow Test	7	6.9928	0.4296

Odds Ratio Estimates

Effect	*Point Estimate*	*95% Wald Estimate Confidence Limits*	
SpeedLimit	0.360	0.172	0.755
SiteType	0.493	0.244	0.998
Urban	1.996	0.996	3.999
DayLight	0.295	0.140	0.623
GoStraight	0.306	0.165	0.568

Table 3-5 Estimated Parameters of the Model for Rear-End Crashes

Estimated Parameters

Variable	*DF*	*Coefficient Estimate* $\hat{\beta}$	*Standard Error*	*Wald* χ^2	*Pr>* χ^2
Intercept	1	-6.2403	1.3609	21.0264	<.0001
SpeedLimit	1	0.9034	0.3495	6.6802	0.0097
SurfaceType	1	-1.5064	0.5740	6.8863	0.0087
Urban	1	-0.6820	0.3569	3.6507	0.0560
DayLight	1	-0.6752	0.3617	3.4847	0.0619
GoStraight	1	2.1472	0.7514	8.1648	0.0043
GeoDesign	1	3.1510	1.0573	8.8816	0.0029
DriverErr1	1	1.8611	0.3906	22.7089	<.0001

Model Summary

Number of Observations	421

Goodness-of-fit Statistics

Criterion	*DF*	*Value*	*Pr>* χ^2
Deviance	62	37.4722	0.9942
Pearson Chi-Square	62	36.8815	0.9953
Hosmer and Lemeshow Test	8	6.9631	0.5406

Odds Ratio Estimates

Effect	*Point Estimate*	*95% Wald Estimate Confidence Limits*	
SpeedLimit	2.468	1.244	4.896
SurfaceType	0.222	0.072	0.683
Urban	0.506	0.251	1.018
DayLight	0.509	0.251	1.034
GoStraight	8.560	1.963	37.336
GeoDesign	23.359	2.941	185.533
DriverErr1	6.431	2.991	13.827

3.3.3 Models for Contributing Factors

Careless driving and failure to yield right of way are two predominant contributing factors for work zone fatal crashes. In this section, two binary logistic models were developed to investigate the impacts of predictor variables on the occurrence of work zone fatal crashes due to the two contributing factors. The result of the model for careless driving crashes is shown in Table 3-6. The response variable of this model is DriverErr1, and predictor variables are AADT, RoadClass, HVInv, and GoStraight. With missing value removed, the number of observations is 356 .From the results, it is known that the probability of the occurrence of work zone fatal crashes due to careless driving under a low traffic volume (AADT=1) is higher than that under a high traffic volume (AADT=2 or 3). A possible explanation of this phenomenon is that drivers are easy to lose their attention from driving when traffic volume is low. The probability is also increased when work zones are located in freeway, or vehicles are running straight before accident. The presence of heavy vehicles is another factor leading to an increase in the probability.

For fatal crashes due to failure to yield right of way (see Table3-7), the response variable is DriverErr2. Among the predictor variables, SiteType has a positive coefficient. That means the presence of the road specific features will increase the probability of the occurrence of the fatal crashes due to failure to yield right of way. It also can be concluded that the probability of fatal crashes is increased when work zones are located on a surface road (road that assumes the interrupted traffic; in other words, the surface road means there are road access points or intersections along the road).

An upgrade/downgrade road geometric design and the absence of daylight have “negative” impacts on the occurrence of the fatal crashes. Based on the statistical analysis, the probability of the fatal crashes (failed to yield right of way) with a level grade geometric design is greater than that with an upgrade/downgrade geometric design. There is a conflict between this conclusion and our common sense. It is a wired phenomenon, but the conclusion is derived from the crash data. A possible explanation is that drivers are more cautious to drive in a road section with upgrade/downgrade geometric design so that the failure to yield right of way is less likely to occur in an upgrade/downgrade road section than in a level road section.

Table 3-6 Estimated Parameters of the Model for DriverErr1 Crashes

Estimated Parameters

Variable	*DF*	*Coefficient Estimate* $\hat{\beta}$	*Standard Error*	*Wald* χ^2	*Pr>* χ^2
Intercept	1	-1.5491	0.3497	19.6213	<.0001
AADT (=2)	1	-1.0926	0.4344	6.3250	0.0119
AADT (=3)	1	-0.6340	0.3552	3.1867	0.0742
RoadClass	1	1.4343	0.2997	22.9109	<.0001
GoStraight	1	1.3962	0.2914	22.9576	<.0001
HVInv	1	0.6771	0.4081	2.7521	0.0971

Model Summary

Number of Observations	356

Goodness-of-fit Statistics

Criterion	*DF*	*Value*	*Pr>* χ^2
Deviance	12	13.5164	0.3327
Pearson Chi-Square	12	11.7369	0.4670
Hosmer and Lemeshow Test	5	6.0904	0.2975

Odds Ratio Estimates

Effect	*Point Estimate*	*95% Wald Estimate Confidence Limits*	
AADT (2 vs 1)	0.335	0.143	0.786
AADT (3 vs 1)	0.530	0.264	1.064
RoadClass	4.197	2.333	7.551
GoStraight	4.040	2.282	7.151
HVInv	1.968	0.884	4.380

Table 3-7 Estimated Parameters of the Model for DriverErr2 Crashes

Estimated Parameters

Variable	***DF***	***Coefficient Estimate*** $\hat{\beta}$	***Standard Error***	***Wald*** χ^2	***Pr>*** χ^2
Intercept	1	-3.5389	0.8204	18.6080	<.0001
RoadClass	1	-2.8892	1.0450	7.6438	0.0057
SiteType	1	2.1170	0.4426	22.8767	<.0001
GeoLevel	1	1.3030	0.7043	3.4233	0.064
GoStraight	1	-1.7616	0.3985	19.5404	<.0001
Daylight	1	0.8088	0.3978	4.1340	0.0420

Model Summary

Number of Observations	421

Goodness-of-fit Statistics

Criterion	***DF***	***Value***	***Pr>*** χ^2
Deviance	23	19.2788	0.6849
Pearson Chi-Square	23	19.6702	0.6617
Hosmer and Lemeshow Test	8	7.8229	0.4510

Odds Ratio Estimates

Effect	***Point Estimate***	***95% Wald Estimate Confidence Limits***	
Freeway	0.056	0.007	0.431
SiteType	8.306	3.488	19.776
Level	3.680	0.926	14.634
GoStraight	0.172	0.079	0.375
Daylight	2.245	1.030	4.897

3.3.4 Models for Age Groups

Three binary logit models were developed in this section to address the factors which have significant impacts on the occurrence of work zone fatal crashes for three age groups (young age, middle age, and elderly age) respectively. The estimation results are given in Tables 3-8 to 3-10. For young age group, three variables were included in the model. Coefficients of DayLight and HVinv are negative, and that of RoadWidth is positive. It can be concluded that the probability of work zone fatal crashes for young drivers is likely to increase when light condition is not good, or road width is less than 20 feet. Heavy vehicle involvement does not increase the probability.

For middle age drivers, the probability of the work zone fatal crash occurrence is likely to increase when heavy vehicle and alcohol are involved. But the probability is not increased due to intersections, bridges, or railroad crossings within or near work zone area; or road width is less than 20 feet.

For elderly age drivers, the probability of the occurrence of fatal crashes increases when there are intersections, bridges, or railroad crossings within or near work zone areas. Alcohol involvement is not a factor that increases the probability.

Table 3-8 Estimated Parameters of the Model for Young Age Group

Estimated Parameters

Variable	***DF***	***Coefficient Estimate*** $\hat{\beta}$	***Standard Error***	***Wald*** χ^2	***Pr>*** χ^2
Intercept	1	-0.8805	0.1683	27.3842	<.0001
DayLight	1	-0.6574	0.2871	5.2443	0.0220
HVInv	1	-0.8582	0.3873	4.9092	0.026
RoadWidth	1	0.9977	0.5371	3.4500	0.063

Model Summary

Number of Observations	342

Goodness-of-fit Statistics

Criterion	***DF***	***Value***	***Pr>*** χ^2
Deviance	308	325.8981	0.2314
Pearson Chi-Square	308	318.6215	0.3264
Hosmer and Lemeshow Test	3	0.9007	0.825

Odds Ratio Estimates

Effect	***Point Estimate***	***95% Wald Estimate Confidence Limits***	
DayLight	0.335	0.295	0.910
HVInv	0.530	0.198	0.906
RoadWidth	4.197	0.946	7.772

Table 3-9 Estimated Parameters of the Model for Middle Age Group

Estimated Parameters

Variable	***DF***	***Coefficient Estimate*** $\hat{\beta}$	***Standard Error***	***Wald*** χ^2	***Pr>*** χ^2
Intercept	1	0.4078	0.1809	5.0819	0.0242
SiteType	1	-0.4685	0.2487	3.5487	0.0596
HVInv	1	0.9546	0.3105	9.4511	0.0021
RoadWidth	1	-1.3545	0.5588	5.8759	0.0153
Alcinv	1	0.5124	0.2424	4.4701	0.0345

Model Summary

Number of Observations	342

Goodness-of-fit Statistics

Criterion	***DF***	***Value***	***Pr>*** χ^2
Deviance	307	386.3211	0.0014
Pearson Chi-Square	307	315.6048	0.3554
Hosmer and Lemeshow Test	6	3.3010	0.7702

Odds Ratio Estimates

Effect	***Point Estimate***	***95% Wald Estimate Confidence Limits***	
SiteType	0.626	0.384	1.019
HVInv	2.598	1.038	2.684
RoadWidth	0.258	1.413	4.774
Alcinv	1.669	0.086	0.772

Table 3-10 Estimated Parameters of the Model for Elderly Age Group

Estimated Parameters

Variable	*DF*	*Coefficient Estimate* $\hat{\beta}$	*Standard Error*	*Wald* χ^2	*Pr>* χ^2
Intercept	1	-2.0694	0.2498	68.6287	<.0001
SiteType	1	1.2051	0.3356	12.8960	0.0003
Alcinv	1	-0.9832	0.3760	6.8380	0.0089

Model Summary

Number of Observations	342

Goodness-of-fit Statistics

Criterion	*DF*	*Value*	*Pr>* χ^2
Deviance	307	386.3211	0.0014
Pearson Chi-Square	307	315.6048	0.3554
Hosmer and Lemeshow Test	6	3.3010	0.7702

Odds Ratio Estimates

Effect	*Point Estimate*	*95% Wald Estimate Confidence Limits*	
SiteType	3.337	1.729	6.442
Alcinv	0.374	0.179	0.782

3.3.5 Impacts of Factors

For summarizing the impacts of predictor variables on the probability of the occurrence of work zone fatal crashes, a list of the factor impacts is shown in Table 3-11. In this table, columns indicate different models, while rows denote explanatory variables. When a factor has a significant impact on the occurrence of work zone fatal crashes, the corresponding cell is denoted as "P" (positive) if the impact is likely to increase the probability of the occurrence, or denoted as "N" (negative) if the impact is likely to decrease the probability.

Table 3-11 Impacts of Factors*

	Crash Type			Contributing Factor		Age Group		
Factor	**Angle**	**Pedestrian**	**Rear-End**	**DriverErr1**	**DriverErr2**	**Young**	**Middle**	**Elderly**
Posted Speed Limit ≥ 60mph	P	N	P	-	-	-	-	-
Under influence of Intersection, Bridge, and Access	P	N	-	-	P	-	N	P
Freeway	N	-	-	P	P	-	-	-
Urban Area	-	P	P	-	-	-	-	-
Vehicle move straightly	-	P	P	P	N	-	-	-
The pavement is not blacktop	-	-	P	-	-	-	-	-
Straight geometric design	-	-	P	-	-	-	-	-
Upgrade/Downgrade	-	-	-	-	N	-	-	-
Weather is clear	N	-	-	-	-	-	-	-
The presence of daylight		N	N	-	P	N	-	-
Heavy Vehicle Involved	-	-	-	P	-	N	P	-
Alcohol Involved	-	-	-	-	-	-	P	N
A low AADT (<15,000)	-	-	-	P	-	-	-	-
Road Width (<20feet)	-	-	-	-	-	P	N	-
Careless Driving	-	-	P	N/A	N/A	-	-	-
Failed to yield right of way	P	-	-	N/A	N/A	-	-	-

*P ~ a significant positive impact;
N ~ a significant negative impact;
- ~ no significant impact.

4. DEVELOPMENT OF FLORIDA CRASH DATABASE

4.1 Introduction

In this research, an integrated work zone safety analysis tool, Florida Work Zone Crash Database, was developed. All work zone fatal crash related data from several data sources were integrated in this database. Analysis functions were also provided with this database system to address traffic safety problems at work zones and identify the contributing factors for these problems.

The main objectives of developing Florida Work Zone Crash Database are:

- To integrate all work zone crash data from various data sources;
- To provide safety analysis functions to address traffic safety problems at work zones and to identify the contributing factors; and
- To provide system management function to protect the security of the database.

4.2 System Description

4.2.1 System Structure

This system is a typical web-based database application. Main functions are running on the application server, while all crash data are stored on the database server. Results of analysis and query are published to clients through the web server. Client computers just take in charge of displaying the results and interacting with users. An advantage of the web-based structure is that users can access the service anywhere if they have a TCP/IP network connecting to the servers. Another merit of the web-based application is that no special hardware or software is required at client-end computers except for a web browser, which is the most common software for all kinds of computer systems. The system structure is shown in Figure 4-1.

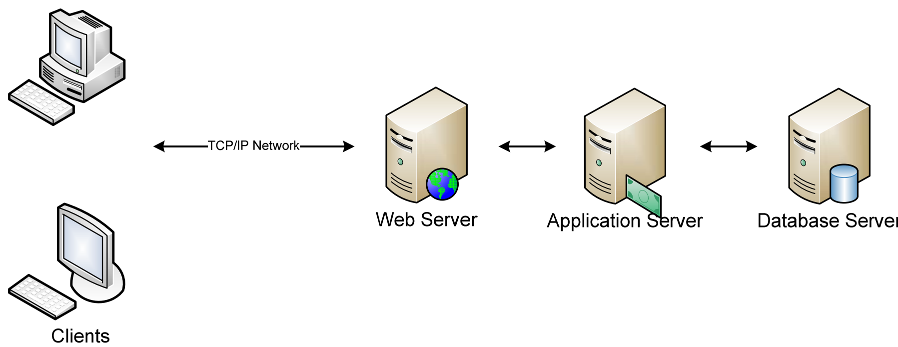


Figure 4-1 System Structure of the Florida Work Zone Crash Database

The three servers could be installed in one physical computer although they are separated in logic.

4.2.2 System Functions

The system has the following functions:

- To obtain completed work zone fatal crash data from various data sources;
- To establish the relationship among these data;
- To find the predominant problems based on the data;
- To address the contributing factors for the problems;
- To query the work zone fatal crash data according to certain conditions;
- To display the results of analysis and query;
- To provide a mechanism to restrict user’s access.

These functions could be categories into four function groups: Update, Analysis, Query, and Management.

4.3 Database Development

4.3.1 Database Structure

The work zone fatal crash data has three different data sources:

- Florida Work Zone Fatal Crash Summary Report,
- FDOT's Crash Analysis Reporting system (CAR),
- And Engineer's Maintenance of Traffic Evaluation forms (MOTs).

The Florida Work Zone Fatal Crash Summary Report, produced by FDOT Safety Office, covers all fatal crashes at work zones in Florida with crash identification information (crash ID, Date/Time and Location), and some work zone impacts evaluation information. More detailed information of the work zone fatal crash are provided in the CAR system, which is an electronic database storing all crash data occurred in Florida state roads from 2001. These records could be categorized into three levels: CRASH, PERSON, and VEHICLE. Except for the above information, the MOT evaluation information is offered in MOT forms.

Corresponding to the three data sources, three data tables, SUMMARY, CRASH and MOT, were created in the Florida Work Zone Crash Database. And each table contains several data fields. The description of the data fields are given in Appendix E (Tables E-1 to E-3).

The three tables are matched by Crash ID, which is the identification data field with a unique value for each crash record. The relationship among the tables is described in Figure 4-2.

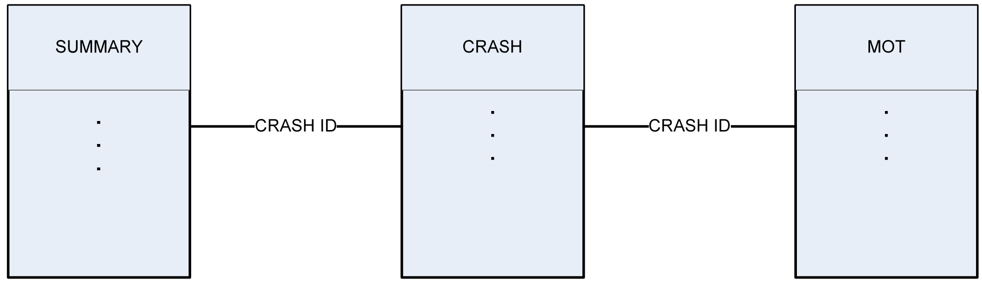


Figure 4-2 Relationship among Data Tables

4.3.2 Data Match

The work zone fatal crash data are stored separately in three tables, and combined by Crash ID. However, sometimes Crash ID is not available for some records in SUMMARY or MOT tables. Thus, an algorithm was developed in this study to match the data in different tables based on other identification information when Crash ID is unavailable. The identification information except for Crash ID could be divided into two categories: Date/Time and Location. The description of the identification information used in this algorithm is given in Table 4-1.

Table 4-1 Identification Information

Category	Name	Description	Tables*
DATA/TIME	CRASHDTE	DATE OF CRASH	S, C, M
	TIMEOFAC	TIME OF CRASH	S, C, M
LOCATION	CONTYDOT	DEPT. OF TRANS. COUNTY	S, C, M
	SRNUM	STATE ROAD FULL ID NUMBER	S, C, M
	LOCMP	CRSH LOC FINAL MP ON ROADWAY	C, M

*S-SUMMARY TABLE, C-CRASH TABLE, M-MOT TABLE

For matching data between CRASH table and SUMMARY table or between CRASH table and MOT table, a series of comparisons between the paired tables (CRASH versus SUMMARY or CRASH versus MOT) are carried out based on the crash fields in Table 4-1 one by one. If all data fields of the corresponding records in the paired tables are matched, these records are considered as a same crash. For some data fields (CRASHDTE, CONTYDOT, and SRNUM), if their values in the paired tables are identical, they are believed to be matched.

But for other fields (SRNUM and LOCMP), the match criteria is measured by the difference of the field values between the paired tables less than a threshold value. Furthermore, if a data field is empty, the comparison of this data field is ignored. This strategy tries to avoid rejecting two matched records which have some empty data fields. The flow chart of the algorithm is described in Figure 4-3.

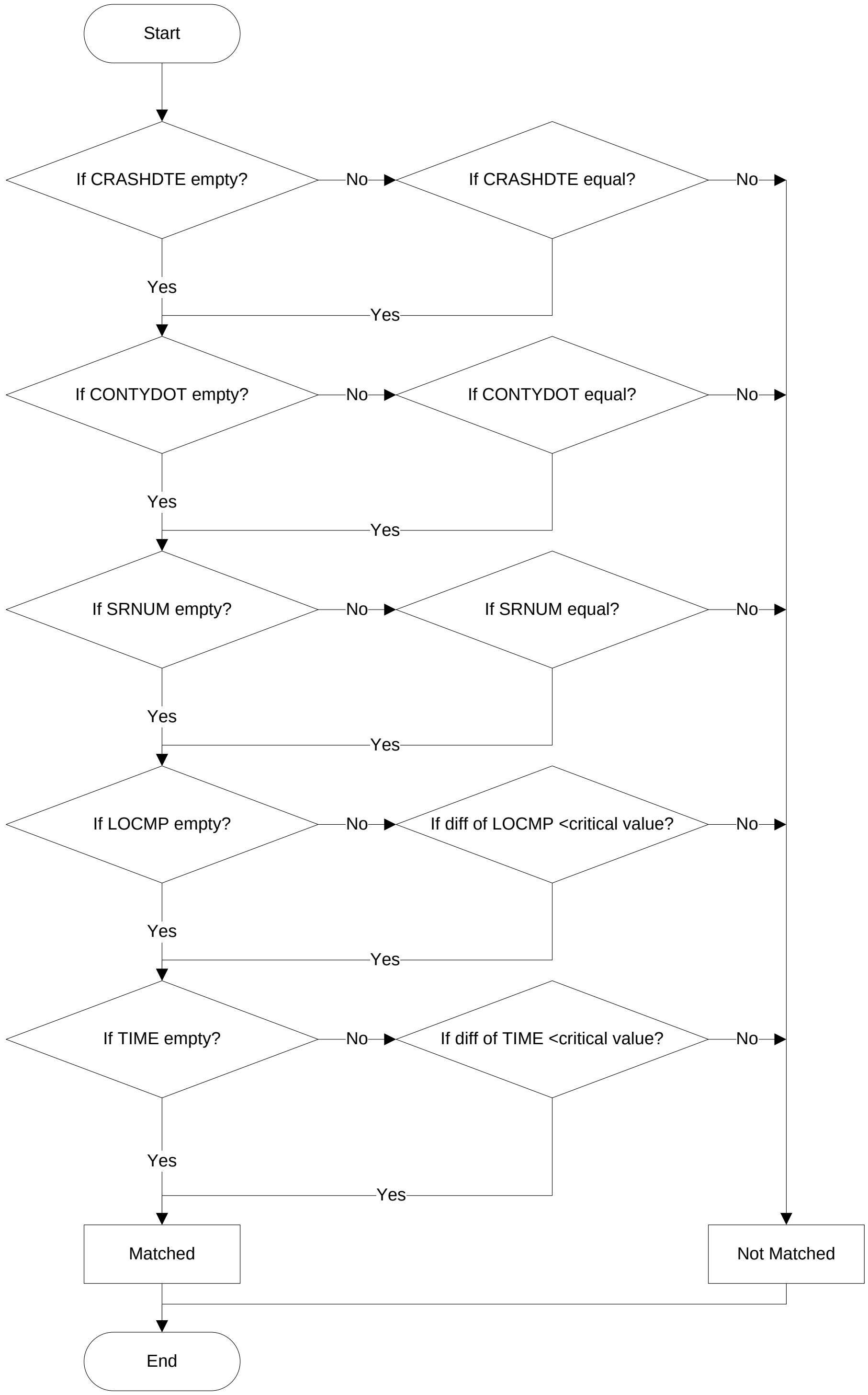


Figure 4-3 Matching Algorithm

4.4 Analysis Functions Development

For investigating the characteristics of fatal crashes, three categories of analysis functions are provided in this system: Fatal Crashes Trend Analysis, Comparison Analysis (Work Zone with Non-Work Zone), and Contributing Causes Analysis.

4.4.1 Fatal Crashes Trend Analysis

This function describes the trend of fatal crashes and fatalities at work zones over different variables. From the analysis results, users can understand the temporal distribution of the number of fatal crashes and fatalities at work zones by years.

4.4.2 Comparison Analysis

By comparing the proportion of fatal crashes by a certain variable between work zones and non-work zones during a given period, the difference of characteristics of fatal crashes between the two zones is addressed. And a contributing factors analysis is provided to address the dominant contributing factors accounting for the difference. The proportion of fatal crashes is defined as:

$$P_{zv} = \frac{F_{zv}}{N_z} \times 100\%$$

where
P_{zv} – the proportion of fatal crashes in z zones by the variable v;
F_{zv} – the number of fatal crashes in in z zones by the variable v;
N_z – the total number of fatal crashes in z zones;
z – type of zone : work zone or non - work zone; and
v – variable.

In Figure 4-4, an example is given to demonstrate the comparison of the variable “Harmful Event at Fault” between work zone and non-work zone. This variable indicates the type of work zone fatal crashes.

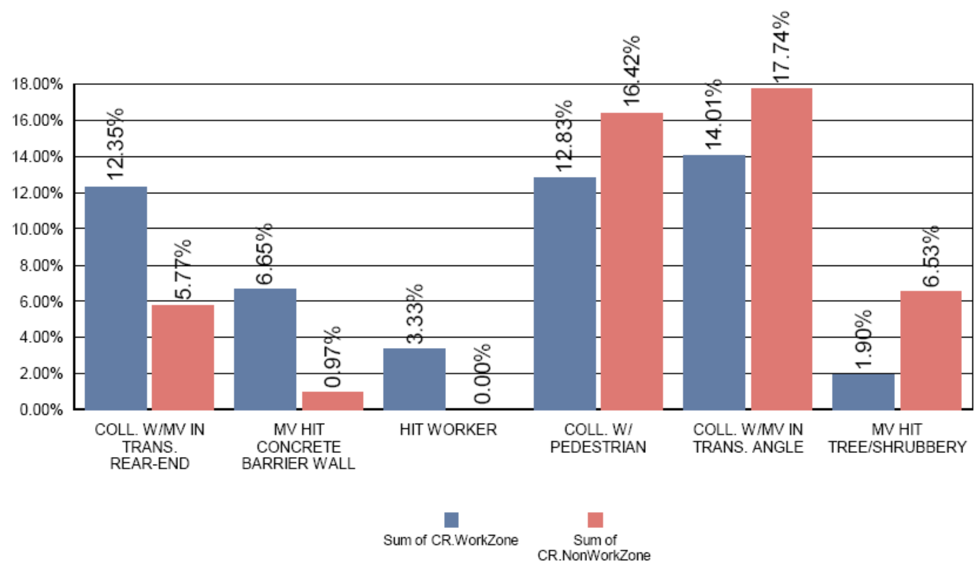


Figure 4-4 Comparison of Harmful Event at Fault

Based on the result shown in Figure 4-4, it can be concluded that the proportion of rear-end crashes at work zones is higher than at non-work zones; and the difference is the biggest one (12.35%-5.77%=6.58%). The dominant contributing factors, careless driving and failed to slow/stop due to slowed traffic, for explaining this difference are shown in Figure 4-5.

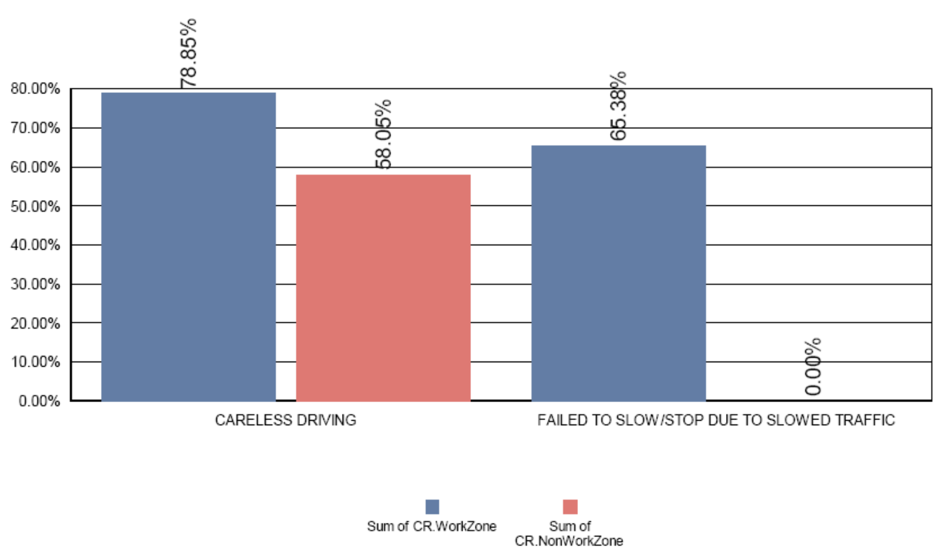


Figure 4-5 Domination Contributing Factors

4.4.1 Contributing Causes Analysis

In the Contributing Causes Analysis, two steps are performed. First, a set of factors of a certain variable are ranked based on their corresponding proportions of fatal crashes, P_{fv}, where v is a certain variable and f indicates a factor of this variable. This step addresses the distribution of work zone fatal crashes by the variable. In second step, for each of the factors, predominant contributing causes will be listed to explain what causes lead to the factor.

In Figure 4-6, an example displayed the distribution of factors of the variable Harmful Event at Fault. From this figure, we know that the most frequent harmful event (crash type) was ANGLE. To interpret this phenomenon, the distribution of contributing causes for Harm Event ANGLE was provided in Figure 4-7. From this figure, it can be concluded that the top important causes were FAILED TO YEILD RIGHT OF WAY (29%) and CARELESS DRIVING (27%).

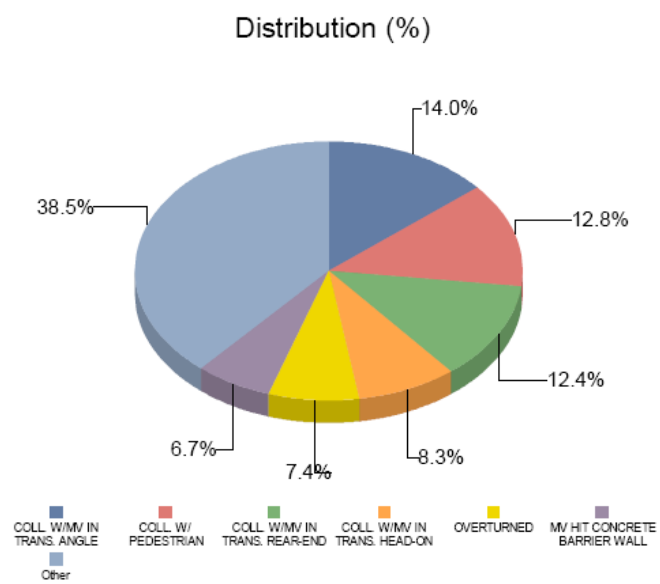


Figure 4-6 Distribution of Factors of Harmful Event at Fault

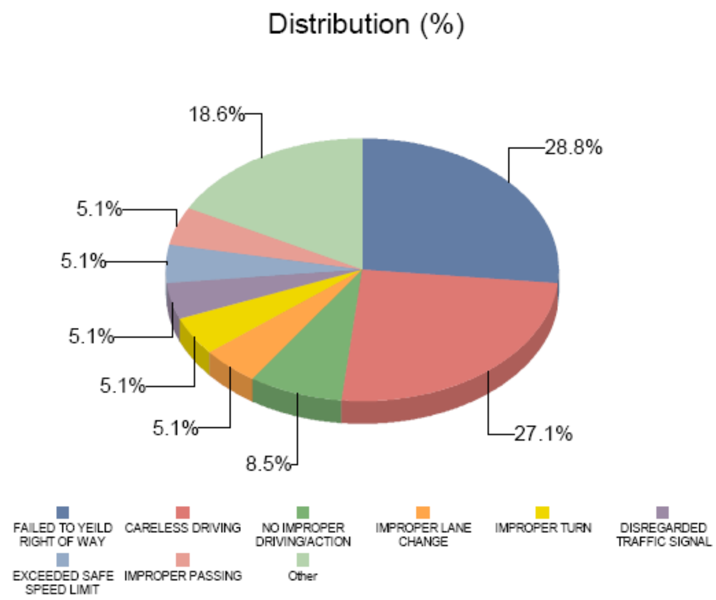


Figure 4-7 Distribution of Contributing Causes for Harmful Event ANGLE

5. PRELIMINARY EVALUATION OF DYNAMIC LANE MERGE SYSTEM

5.1 Introduction

When drivers access the work zone area, some of them try to use closed lanes to avoid congestion in open lanes up to the last merge point where lane change behavior is difficult and risky. This aggressive driving maneuver introduces a disturbance on the volume in open lanes, so that negative effects on traffic safety and operational performance are conducted. Especially, the shock wave in open lanes associated with the forced lane change behavior under heavy traffic congestions increases the potential of rear-end accidents. Drivers who are in open lanes and without aggressive behavior, when passed by drivers in the closed lane become upset with road rage. The range of these negative effects will be felt not only at the merge point within the work zone, but also at points far from the aggressive lane where the lane changes take place. .

For resolving this problem, Dynamic Lane Merge system (DLM) was designed to encourage drivers to merge into the open lanes sooner than they would with the conventional merge. DLM provides advance notice over a variable distance ahead of the lane closure based on traffic conditions in work zones. This scheme creates a variable no-passing zone to encourage drivers to merge into open lanes before arriving at the end of queue caused by congestion, and to prohibit them from using the closed lane to pass vehicles in the queue and merge into the open lane ahead of them. Several variable signs, which display “DO NOT PASS WHEN FLASHING” mounted with two flashing strobes, are installed adjacent to closed lane at 500 to 1200 feet intervals for up to 2.5 miles in advance of the lane closure as shown in Figure 5-1. When strobes of a sign are turned on, the section of the closed lane from this sign to work zone taper will be closed as a no-passing zone. The number of flashing signs, controlling the length of no-passing zone, could be changed by the occurrence of traffic congestion.

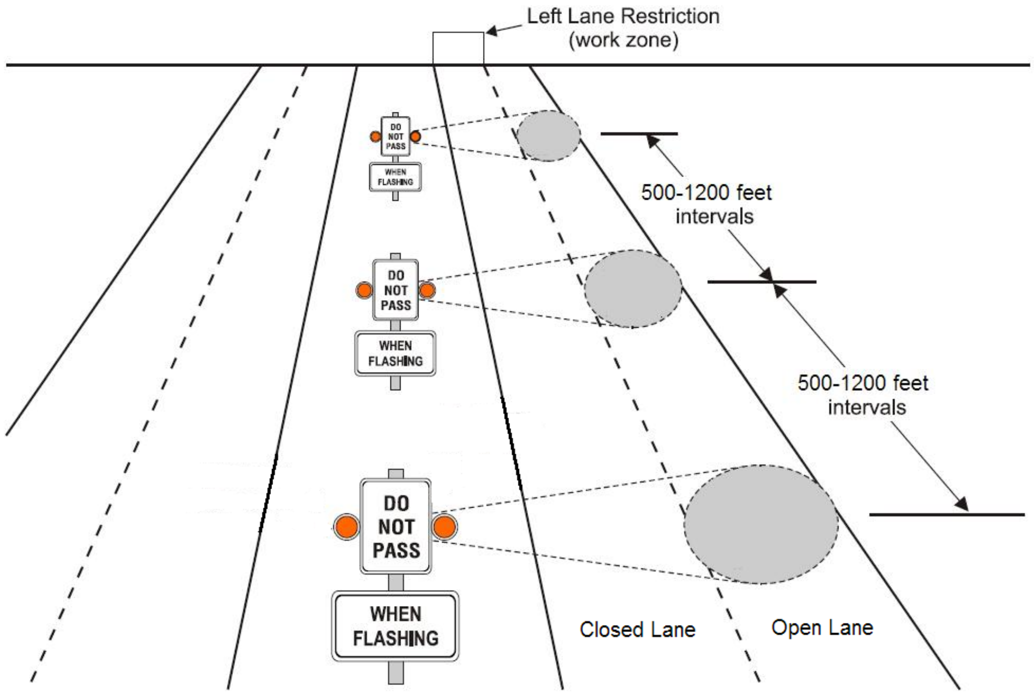


Figure 5-1 Dynamic Lane Merge System

This chapter represents the result of a CORSIM-based preliminary evaluation of Dynamic Lane Merge system at freeway work zones intending to determine the range of traffic situations where DLM has significant positive operations and safety performance. The result can be used as a primary guideline for a comprehensive field test of DLM.

5.2 Methodology

For evaluating the performance of DLM control strategy, a CORSIM simulation model was developed to simulate the real freeway work zone and operations of DLM. The development of simulation model included simulation model design, model calibration, and composing traffic scenarios. Data collection was performed by running CORSIM model on computer and reading Measure of Effectiveness (MOEs) from the simulation output files. Finally, data analysis was conducted to determine the range of traffic conditions where DLM has positive effectiveness on traffic operations and safety.

5.2.1 Simulation Model

A 30000 feet freeway section (as shown in Figure 5-2), covered with vehicle detectors at 100 feet interval, was setup in CORSIM with FRESIM model for simulating a real work zone section. The closed lanes during this section could be divided into 3 parts: advanced warning zone, variable closure zone, and work zone.

Work zone (Section A-B) is the area where maintenance and construction activities take place. Vehicles are forbidden to run into this section. Variable closure zone (Section B-G) is located in the upstream of the work zone section, and provides a changeable no-passing area to force drivers merge into open lanes before arriving at the start point of work zone. The length of the no-passing area could be changed at 5 levels, from 0 feet to 2500 feet with 500 feet interval. When the length is 0 feet, that means the whole area is opened for passing through, the merge strategy is conventional merge control. When the section B-C is closed for passing through, the merge strategy turns into the early merge control with 500 feet no-passing zone. With the extension of the closed section (B-D, B-E, B-F, or B-G), the length of no-passing zone will increase to 1000 feet, 1500 feet, 2000 feet, and 2500 feet respectively.

Advanced warning zone is the area to present warning information of lane closure to drivers before them entering no-passing zone. In this area, drivers are encouraged to merge into open lanes by a warning sign installed at Point H, but not forced.

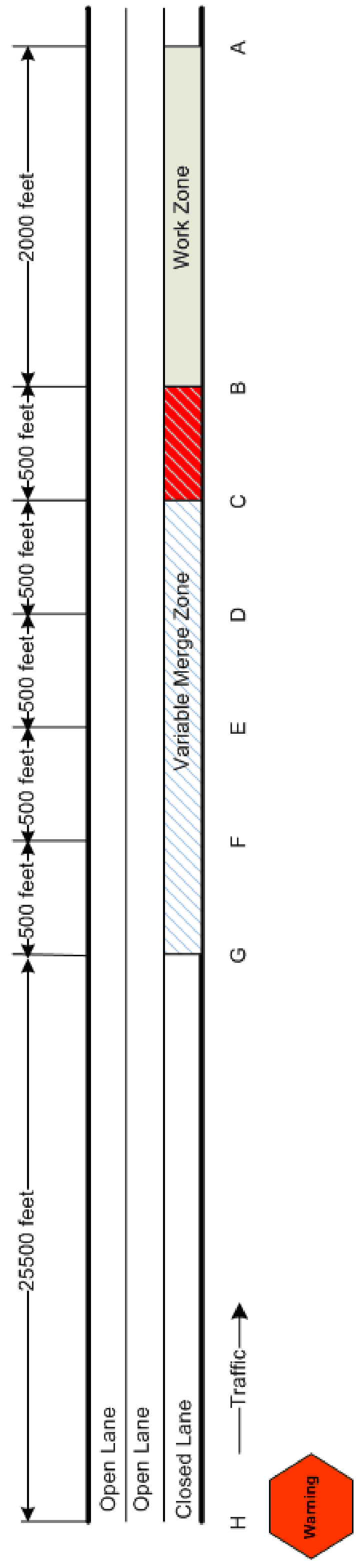


Figure 5- 2 Simulation Model Layout Design

5.2.2 Model Calibration

Model calibration is used to make the CORSIM model can simulate the real world more accurately. In general, the internal factors of the model are calibrated according to a set of small size field observations. Because this preliminary evaluation did not aim at representing any real freeway segment or project, the calibration in the study adopted parameter configures from a previous research.

Park and Qi (2004) developed a systematic procedure for microscopic simulation model calibration and validation, which was successfully applied to freeway work zone case studies. In the procedure, a genetic algorithm optimization program is implemented to find an optimal calibration parameter set from the feasible parameter ranges. The optimal calibration parameter set for freeway work zones is shown in Table 5-1, which was adopted in the preliminary evaluation of DLM.

Table 5-1 Calibration Parameters

Parameter	Default Value	Altered Value
Entry Vehicles Headway Distribution	Uniform	Enlarge
Car following sensitivity Index	1	1
Pitt car following constant (ft)	10	3
Lag acceleration (sec)	0.3	1.2
Lag deceleration (sec)	0.3	0.5
Time to complete a lane-change maneuver (sec)	2.0	1.0
Gap acceptance parameter	3	4
Percent of drivers desiring to yield to merging vehicles (%)	20	20
Multiplier for desire to make a discretionary lane change	0.5	0.4
Advantage threshold for discretionary lane change	0.4	0.8
Minimum separation for generation of vehicles (sec)	1.6	1.3
Distribution of free flow speed by driver type Index	1	2

5.2.3 Traffic Scenarios

Through the review of past research, the factors listed in Table 5-2 are selected to form various traffic scenarios for freeway work zones. In the study, three typical work zone configurations were selected: two-lane freeway with one lane closed, three-lane freeway with one lane closed, and three-lane freeway with two lanes closed. These work zone configurations are noted as [2-1], [3-1], and [3-2].

Free flow speed (FFS) is defined in HCM 2000 as the mean speed of passenger cars that could be accommodated under low to moderate flow rates on a uniform freeway segment under prevailing roadway and traffic conditions. In this study, 70mph, 65mph, and 60mph are selected as values of FFS.

From past researches, it can be concluded that vehicle speeds at work zones under non-congested conditions remain stable, while they dropped 10 mph to 20 mph from the normal work zone speeds during congestion. In this study, based on the FFS in normal freeway sections, the reduction of FFS in work zone is fixed 10mph.

It seems reasonable that work zone grade would affect the capacity and speed because of the presence of grades would exacerbate any flow constriction that would otherwise exist, particularly in the presence of heavy vehicles. 3 levels of work zone grade are selected: -5, 0, +5.

Heavy vehicle occupy more space on the roadway than passenger cars. Moreover, heavy vehicles accelerate slowly and their presence makes other drivers more apprehensive, and they need more operation time to shift lane in freeway. These factors reduce the overall capacity of the work zone. In this study, percentage of heavy vehicle is categorized into four levels: 0%, 5%, 10%, and 15%.

The entry volume for different scenarios should cover a wide range to evaluate the variable early merge comprehensively. But too small entry volume has no sense because in that situation, all vehicles are running at free flow speed and the disturbance between vehicles is very small. The upper limit of entry volume is decided by the value which will result in the length of queue ahead of work zone exceeding the whole section (Point H). The entry volume levels were selected as shown in Table 5-2.

Table 5-2 Traffic Scenarios

Factor	Level
Work Zone Configuration	[2-1], [3-1], [3-2]
FFS	70mph, 65mph, 60mph
Work Zone FFS Reduction	10mph
Work Zone Grade	-5,0,+5
Percentage of Heavy Vehicle	0,5%,10%,15%
Entry Volume (one direction)	2-1: 2200vph~2900vph Interval: 100vph 3-1: 2500vph~3700vph Interval: 200vph 3-2: 2200vph~2900vph Interval: 100vph

5.2.4 Simulation of DLM Operation

It is difficult to realize the feedback mechanism of DLM, which is used to control "NO-PASSING" signs according to the current traffic situations in real time, with CORSIM software. So a substituted method was developed to simulate the operations of DLM.

The length of the variable closure zone was changed from 0 feet to 2500 feet at 6 levels for each traffic scenario (shown in Table 5-3). When the length is 0 feet, the simulation model is running as the conventional merge control. And when the length adopts other values, the simulation model can be considered working as DLM. Each traffic scenario was simulated for 6 times with different levels of the merge zone.

Table 5-3 Length of the Closure Zone

Factor	Level
Length of Closure Zone	0 feet, 500 feet, 1000 feet, 1500 feet, 2000 feet, 2500 feet

5.2.5 Data Collection

Because the CORSIM simulation is stochastic, the results from different simulations with a same input files is not identical. To reduce the stochastic errors and get a stable result, it is necessary to run simulation for many times instead of only once. But too many runs will result in increase in the simulation time and the amount of output data.

So the default value of 10 run times is adopted in this study, because it will satisfy the precision of results and does not increase the simulation time greatly.

The Measures of Effectiveness (MOE) is the output of CORSIM simulations. In this study, two types of MOEs were adopted to evaluate the operational and safety performances.

The average travel time (sec/veh), defined as the travel time on the link (A-H, Figure 5- 2) for each vehicle, is calculated by taking the total travel time and dividing it by the number of vehicle trips. This MOE was used to evaluate the operational performance of DLM.

Because the traffic conflicts or crashes cannot be observed directly from CORSIM simulations, the total lane changes, defined as the number of lane changes occurred on the link (A-H, Figure 2) since the beginning of the simulation, was used to evaluate the safety performance of DLM. In fact, more lane change behaviors leads more opportunities of occurrences of the traffic conflicts, in other words, the traffic system becomes more dangerous. Thus, this MOE is reasonable to evaluate the safety effectiveness.

5.2.6 Data Analysis

For evaluating effectiveness of DLM, a series of comparisons of the two MOEs for each traffic scenario among different closure lengths were conducted to find the difference between DLM without (the closure length=0) and with the control (the closure length>0). The procedure of the comparison is shown as following:

- Apply one way Analysis of Variance (ANOVA) to test whether six datasets are significantly different from each other. The six datasets represent the observations of a certain MOE (average travel time or lane changes) which are collected from the simulation experiment with 6 different closure length levels (0, 500, 1000, 1500, 2000, and 2500 feet) respectively.

- If there is no significant difference between in these data sets, it can be concluded that DLM has no positive effectiveness.

- If there is a significant difference among these data sets, a Student's *t* Test is performed to test whether the datasets representing DLM control (the closure length>0) is difference to the dataset representing no DLM control (the closure length=0) in statistics.

- If at least one dataset representing DLM control is different to the dataset representing no DLM control, and the mean of the dataset representing DLM control is less than the mean of the dataset representing no DLM control, it can be concluded that DLM has a positive effectiveness on traffic operations if the MOE is average travel time, or traffic safety if the MOE is lane changes.

- Otherwise, it can be concluded that DLM has no positive effectiveness.

ANOVA

A one-way analysis of variance (ANOVA) measures whether one or more components of a multiple level independent variable predict the value of a dependent variable. The analysis of variance splits the variance of all the elements into variance between samples and variance within samples. These are calculated as the sum of the squares of deviations divided by the corresponding degrees of freedom, and compared by the *F*-test.

The hypothesis in the ANOVA is

$$H_0 : \mu_M = \mu_N$$
$$H_1 : \mu_M \neq \mu_N$$

For all $M \neq N$, $M, N = 0,500,1000,1500,2000,2500$

If the calculated F value is greater than the critical F value, then the null hypothesis is rejected and the difference would be significant.

One- tail t Test

The Student's *t* test could be used to compare mean values of two samples which are independent from each other. The hypothesis in this test is

$$H_0 : \mu_L = \mu_0$$
$$H_1 : \mu_L \neq \mu_0$$

μ_0 is the mean of data set without DLM;

μ_L is the mean of data set with DLM;

$L = 500,1000,1500,2000,2500$

The t value can be calculated as:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{\sum\left(x_1 - \overline{x_1}\right)^2 + \sum\left(x_2 - \overline{x_2}\right)^2}{(n_1 - 1) + (n_2 - 1)} \times \left(\frac{n_1 + n_2}{n_1 \times n_2}\right)}}$$

where,

$x_1, x_2 =$ observations from two data sets

$n_1 = n_2 = 10$, the number of observations in two data sets

$\overline{x_1}, \overline{x_2} =$ mean values of the observations from two data sets

If the calculated t value is greater or less than critical values which indicates the region of rejection area at the given confidence interval (0.05), the null hypothesis is rejected and it could be concluded that μ_L is different to μ_0 significantly.

5.3 Preliminary Results

Effectiveness tables described traffic scenarios that DLM has a positive effectiveness. Each cell in the table was the result of the analysis procedure described in the previous section. If DLM had a positive performance, the cell is filled with "Yes", otherwise filled with "No".

Results for two-lane freeway with one-lane closed are shown in Tables 5-4 to 5-9; results for three-lane freeway with one-lane closed are given in Tables 5-10 to 5-15; and results for three-lane freeway with two-lane closed are presented in Tables 5-16 to 5-21.

5.3.1 Two-lane Freeway with One-lane Closed

Table 5-4 Effectiveness (Lane Changes) FFS: 60mph for [2-1]

Volume	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
2200	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2300	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2400	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2500	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2600	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2700	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2800	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2900	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 5-5 Effectiveness (Lane Changes) FFS: 65mph for [2-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2300	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2400	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2500	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2600	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2700	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2800	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2900	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NO	Yes

Table 5-6 Effectiveness (Lane Changes) FFS: 70mph for [2-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2300	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2400	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2500	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2600	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2700	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2800	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2900	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

Table 5-7 Effectiveness (Average Travel Time) FFS: 60mph for [2-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2300	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2400	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2600	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2800	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2900	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 5-8 Effectiveness (Average Travel Time) FFS: 65mph for [2-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2300	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2400	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2600	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2800	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2900	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 5-9 Effectiveness (Average Travel Time) FFS: 70mph for [2-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2300	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2400	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2600	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2800	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2900	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

5.3.2 Three-lane Freeway with One-lane Closed

Table 5-10 Effectiveness (Lane Changes) FFS: 60mph for [3-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2900	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
3100	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
3300	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	YES
3500	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO

Table 5-11 Effectiveness (Lane Changes) FFS: 65mph for [3-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2900	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
3100	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
3300	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 5-12 Effectiveness (Lane Changes) FFS: 70mph for [3-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
2900	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
3100	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	YES
3300	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
3500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 5-13 Effectiveness (Average Travel Time) FFS: 60mph for [3-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2900	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3100	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3300	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
3500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 5-14 Effectiveness (Average Travel Time) FFS: 65mph for [3-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2900	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3100	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3300	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 5-15 Effectiveness (Average Travel Time) FFS: 70mph for [3-1]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2900	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3100	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3300	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES

5.3.3 Three-lane Freeway with Two-lane Closed

Table 5-16 Effectiveness (Lane Changes) FFS: 60mph for [3-2]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2300	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES
2400	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2500	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES
2600	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES
2700	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2800	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2900	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES

Table 5-17 Effectiveness (Lane Changes) FFS: 65mph for [3-2]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2300	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES
2400	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2500	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES
2600	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES
2700	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2800	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2900	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES

Table 5-18 Effectiveness (Lane Changes) FFS: 70mph for [3-2]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	YES	YES	NO	NO	YES	NO	NO	YES	YES	YES
2300	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES
2400	NO	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES
2500	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES
2600	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2700	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2800	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES
2900	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES

Table 5-19 Effectiveness (Average Travel Time) FFS: 60mph for [3-2]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2300	NO	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO
2400	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	YES	NO
2500	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2600	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2800	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2900	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO

Table 5-20 Effectiveness (Average Travel Time) FFS: 65mph for [3-2]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	YES	NO	NO	YES	NO	NO	NO	NO	NO
2300	NO	YES	YES	NO	NO	NO	YES	NO	NO	NO	NO	YES
2400	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2500	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO
2600	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
2800	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
2900	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO

Table 5-21 Effectiveness (Average Travel Time) FFS: 70mph for [3-2]

	Grade: -5				Grade: 0				Grade: 5			
	HV 0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Volume 2200	NO	NO	NO	YES	NO	NO	NO	NO	YES	NO	YES	NO
2300	NO	YES	NO	YES	YES	NO	NO	NO	NO	NO	NO	NO
2400	YES	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO
2500	YES	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO
2600	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2700	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2800	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2900	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

5.4 Summary

Based on the results of the preliminary evaluation, the following conclusions can be obtained:

- DLM always has a positive effect on the reduction of lane changes for two-lane with one-lane closed or three-lane with two-lane closed. In other words, when only one lane is open, the merge control will significantly reduce the lane change behaviors in order to decrease the potential of traffic crashes.

- For three-lane with one-lane closed, the reduction of lane changes is not significant after the implementation of DLM. The reason may be that two open lanes provide more capacity for through traffic so that lane change actions are not severe.

- DLM has almost no positive effectiveness on reducing average travel time. The reason is that the extended lane closure length will reduce the capacity of work zones.

However, there are some limitations in the preliminary evaluation of DLM:

- Results of the simulation may not give us a full understanding of the safety performance of DLM because traffic conflicts and crashes cannot be collected from simulation.

- Simulation calibration is based on previous researches; a more accurate evaluation need more field data experiments in Florida for model calibration.

- There is no feedback mechanism in CORSIM package; therefore the dynamic process of extending the closure length could not be realized in the study. This limitation will increase the error of results.

Due to the limitations listed above, the simulation results can be used as an initial reference, but not an accurate evaluation. Therefore a comprehensive evaluation based on field data collection should be carried out to obtain accurate assessments on the safety and operational effectiveness of DLM.

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Hazardous conditions for drivers and construction workers are easy to occur at work zones since construction activities produce disturbances on normal traffic flows and some drivers' aggressive lane change behaviors. The disturbances aggravate the existing traffic conditions including increasing the risk of traffic crash and causing a server traffic congestion. In Florida, despite recent efforts to improve work zone safety, the number of fatalities and injuries at work zones has increased continually over the past years. In addition, a number of new technologies to improve safety at construction zones are currently being tested in Florida. However the relative effectiveness of each of these technologies under given conditions is not yet to be determined.

This study was to generate a comprehensive research on work zone safety factors including work zone safety devices, the characteristics of work zone fatal crashes, the primary impression of work zone safety concerns, and the effectiveness of a novel lane merge controls system. As the final result, a web-based integrated work zone safety analysis tool, the Florida Work Zone Crash Database, was developed to provide a high efficient analysis application for addressing the safety problems at work zones.

The information of various work zone safety devices, including warning devices, guiding devices, and protective devices, was summarized by searching the internet web sites and literature reviewing. The information, covering the concept, configuration, effectiveness, and implementation of traditional work zone safety devices, can be used as a reference for deployment of work zone safety devices in Florida.

A work zone safety survey was carried out to obtain the primary impression of work zone safety concerns, contributing factors to work zone accident, and generic measures or devices to work zone safety. Nine survey forms were designed to cover these information and distributed to a wide range of participators. The statistic analyses, ANOVA, are applied to analysis the answers of the questions in survey forms to find out the severity of safety concern, or the effectiveness of a countermeasure.

An analysis of work zone fatal crashes in Florida was presented in the study to provide a clear understanding of the characteristics and major causal factors of work zone fatal crashes. The result can help traffic engineers to implement proper measures for minimizing the probability of work zone fatal crashes. A descriptive statistic analysis method was conducted to address the characteristics and major contributing factors; and binary logistic models were developed to examine the influence of various factors on the occurrence of specific work zone fatal crashes.

A work zone safety analysis tool, the Florida Work Zone Crash Database, was developed to provide functions of storing, updating, querying, and analyzing work zone fatal crashes. A match process was designed to gather and merge work zone fatal crash data from various data sources; and the analysis function is used to offer a flexible automatic utility to address traffic safety problems at work zones and identify the main contributing factors.

A novel traffic control strategy, Dynamic Lane Merge (DLM) system, is designed to improve the work zone safety by encouraging drivers to merge into the open lanes sooner than they would with the conventional merge in order to reduce the risk at merge point. A CORSIM-based preliminary evaluation of the system at freeway work zones was performed to determine the range of traffic situations where DLM has significant positive operations and safety performance on operations and safety. A simulation model was created to build various traffic scenarios and the operation of DLM was simulated approximately by changing the lane closure length in the model. Average travel time and lane changes were selected as the criteria to evaluate operational and safety effectiveness respectively.

Based on the studies above, some conclusions and recommendations can be summarized as follows:

- Based on the results in the first stage of work zone fatal crash analysis, angle, pedestrian, and rear-end are the principal crash types of work zone fatal crashes in Florida, while careless driving is the most predominant contributing factors for work zone fatal crashes with almost 40% proportion of total crashes, and followed by failed to yield right of way. For angle crashes, failed to yield right of way is the most frequent contribution factor; and for rear-end crashes, the major contributing factor is careless driving.

- Regarding the factor impact analysis of the predict models, it can be concluded that some factors, including a high speed limit, the influence of specific road features, surface roads, bad weather, and driver failed to yield right of way, are more likely to increase the probability of angle crashes. The pedestrian crashes easily occur when the speed limit is low, work zone is in urban area, vehicle moves straightly, or daylight is absent. For rear-end crashes, several factors like a high speed limit, urban area, straight movement of vehicles, the absence of daylight, other pavement types (not blacktop), and drivers' careless driving tend to raise the opportunity of crash occurrence.

- Crashes due to careless driving easily occur in freeway work zones; and the straight movement of vehicles, the presence of heavy vehicles, and a low AADT also result in an increase in the probability of the occurrence of this kind of crashes. The probability of crashes due to being field to yield to right of way is increasing as the existence of the specific road features, freeway work zones, and making turn/lane change.

- Work zone fatal crashes for young drivers (<25) easily occur when they are running at a narrow road (road width <20 feet) or at night. The probability of work zone fatal crashes for middle drivers (25-64) increases when heavy vehicle and alcohol are involved. For elderly drivers, the influence of intersection, bridge, ramp, and road access is a significant factor that increases the probability of work zone fatal crashes.

- The results of the preliminary evaluation on DLM system indicate that DLM has significant effects on reducing the number of lane changes at merge area when only one lane is open. Traffic operational performance may not be improved after the implementation of DLM system because of the work zone capacity reduction at work zones.

- For overcoming the limitations in simulation, a comprehensive evaluation based on field data collection should be performed to obtain an accurate evaluation on safety and operational effectiveness of DLM in Florida.

REFERENCES

Agresti, A. Categorical Data Analysis. John Wiley & Sons, New York, 1990.

Bai, Y. and Li, Y. Determining Major Causes of Highway Work Zone Accidents in Kansas. Publication K-TRAN: KU-05-1. Kansas Department of Transportation, 2004.

Ben-Akiva, M. and Lerman, S.R.. Discrete Choice Analysis: Theory and Application to Travel Demand. MIT Press, Cambridge, Mass, 1985

Benekohal, R. F., Elzohairy, Y. M. and Saak, J. E., A Comparison of Delay from HCS, Synchro, PASSER II, PASSER IV and CORSIM for an Urban Arterial, Transportation Research Board, National Research Council, Washington, D.C., 2002.

Benekohal, R. F., Kaja-Mohideen, A., and Chitturi, M., A Methodology for Estimating Operating Speed and Capacity in Work Zones, Transportation Research Board, National Research Council, Washington, D.C., 2004.

Bloomberg, L.., Swenson, M., and Haldors, B., Comparison of Simulation Models and the HCM, Transportation Research Board, National Research Council, Washington, D.C., 2003.

Chambless, J., Chadiali, A. M., Lindly, J. K, and McFadden, J. Multistate Work zone Crash Characteristics. ITE Journal, Vol. 72, 2002, pp46 – 50.

Chien, Steven and Chowdhury, M. S., Simulation-Based Estimates of Delays at Freeway Work Zones, Transportation Research Board, National Research Council, Washington, D.C., 2002.

Choa, F., Milam, R., and Stanek, D., CORSIM, PARAMICS and VISSIM-What the Manuals Never Told You, 2002.

Cohen, S. L. An Approach to Calibration and Validation of Traffic Simulation Models, Transportation Research Board, National Research Council, Washington, D.C., 2004.

Crowther, B. C., A Comparison of CORSIM and INTEGRATION for the Modeling of Stationary Bottlenecks. Master Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 2001.

Dixon, K. K., Hummer, J. E., and Rouphail, N. M., Comparison of Rural Freeway Work Zone Queue Length Estimation Techniques: A Case Study, Transportation Research Board, Washington, D. C, 1998.

FHWA. Manual on Uniform Traffic Control Devices for Streets and Highways. 2003Edition, Federal Highway Administration. U.S. Department of Transportation, 2003.

Garber, N. J. and Zhao, M. Crash Characteristics at Work Zones. Publication VTRC 02-R12, Virginia Transportation Research Council, Charlottesville, Virginia, 2002.

Greene, W.H. Econometric Analysis. Fifth Edition, Prentice Hall, New Jersey. 2003.

Ha, T. and Nemeth, Z. A. Detailed Study of Accident Experience in Construction and Maintenance Zones. Transportation Research Record, No. 1590, TRB, National Research Council, Washington, D.C., 1995, pp38 – 45.

Hall, J. W. and Lorenz, V. M. Characteristics of Construction Zone Crashes. Transportation Research Record No. 1230, TRB, National Research Council, Washington, D.C., 1989, pp20 – 27.

Hill, R. W. Statistical Analysis of Fatal Traffic Accident Data. Master's Thesis, Texas Tech University. 2003.

Hosmer, D. W. and Lemeshow, S. Applied Logistic Regression, Second Edition, John Wiley and Sons, New York, 1998.

McCoy, P. T., and Pesti, G., Dynamic Late Merge Control Concept for Work Zones on Rural Freeways. Transportation Research Board, National Research Council, Washington, D.C., 2001

Mohan, S. B. and Gautam, P. (2002). Cost of Highway Work Zone Injuries. Practical Periodical on Structural Design and Construction. Vol. 7, No.2, 2002, pp68 – 73.

Mousa, R.M., Rouphail, N.M. and Azadivar, F. Integrating Microscopic Simulation and Optimization: Application to Freeway Work Zone Traffic Control. *Transportation Research Record* 1254, 1990

Nemeth, Z.A and Rouphail, N.M. Lane Clousres at freeway Work Zones: Simulation Study. *Transportation Research Record* 869. 1982

Park, B. Brian and Qi, Hongtu. Development and Evaluation of a Calibration and Validation Procedure for Microscopic Simulation Models. Final Contract Report, Virginia Transportation Research Council, 2004

Pigman, J. G. and Agent, K. R. Highway Crashes in Construction and Maintenance Work Zones. Transportation Research Record, No. 1270, TRB, National Research Council, Washington, D.C., 1990, pp12 – 21.

Spainhour, L. K. and Wootton, I. A. Modeling Fault in Fatal Pedestrian Crashes Using Various Data Sources. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.

Suresh, R., Analysis of Freeway Weaving Areas Using Corridor Simulator and Highway Capacity Manual, Master's Thesis, Master Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1997.

Tarko, A., Kainpakapatman, S., and Wasson, J. Modeling and Optimization of the Indiana Lane Merge Control System on Approaches to Freeway Work Zones. Final Report, FHWA/IN/JTRP-97/12. Purdue University, West Lafayette, Iniana. 1998

Thomas, G.B. Optimal Detector Location on Arterial Streets for Advanced Traveler Information Systems. Doctoral Dissertation, Arizona State University, Tempe, Arizona, Dec. 1998.

Thomas, G.B., The Relationship between Detector Location and Travel Characteristics. ITE Journal, October 1999.

Tian, Z., Urbanik, T., Engelbrecht, R.J., and Balke, K.N., Variations in Capacity and Delay Estimates from Microscopic Traffic Simulations Models. Transportation Research Board, National Research Council, Washington, D.C., 2002.

Transportation Research Board, Highway Capacity Manual, 4th edition, National Research Council, Washington, D.C. 2000.

Transportation Research Board, National Cooperative Highway Research Program (NCHRP) Report No. 350, Transportation Research Board National Research Council, 1993.

Ullman, G. L., Finley, M. D., and Ullman, B. R. Analysis of Crash at Active Night Work Zone in Texas. Presented at 85th Annual Meeting of the Transportation Research Board, Washington, D.C., 2006.

APPENDICES

APPENDIX A WORK ZONE SAFETY DEVICES

As a part of the literature reviews, this chapter presents various work zone safety devices and their implementation. The devices include warning devices, guiding devices, and protective devices, etc. The methodology applied in this study was to search the internet web sites by using the key words “work zone”, “safety”, “devices”, etc,. After literature review of current work zone devices, the typical work zone safety devices which have been used or tested in some states were compiled and grouped. As such, Florida Department of Transportation (FDOT) is not responsible for the content.

A.1 Warning Devices

Warning devices are used to warn crews by siren or flashing light when vehicles or motorists may intrude working zones.

A.1.1 Intrusion Alarms

Intrusion alarms are devices that sound an alarm when a vehicle enters a work area. Four types of alarms are available: microwave alarms, infrared intrusion alarms, pneumatic tube, and SonoBlaster. Microwave and infrared models are mounted on drums or cones, and use microwave signals or beams of infrared light to connect units. When a vehicle crosses into a work zone and interrupts the signal or beams, a high-pitched alarm is sounded near the workers. The pneumatic tube model is placed on the ground, with the tubes being laid perpendicular to traffic. When a vehicle drives into the area and over the tubes, the alarm sounds.

Microwave Intrusion Alarms

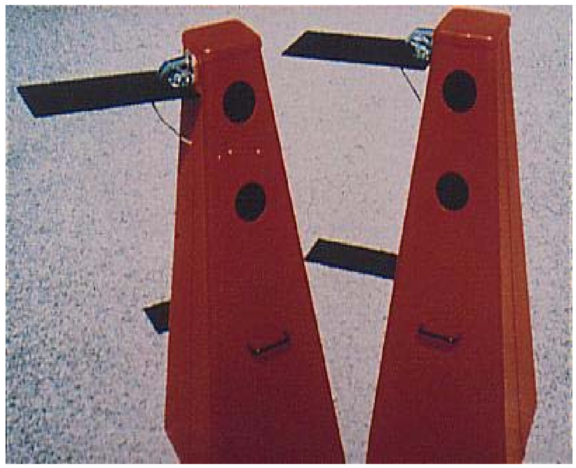
A typical microwave intrusion alarm features a transmitter mounted on one drum and a receiver and siren mounted on another drum up to 1000 ft away. Strobe lights can also be included in the system to alert workers under noisy conditions. Some units also feature a drone radar unit that activates radar detectors within 2296 ft. The drone radar can be used to detect vehicle speeds and activate the siren when a vehicle is found to be traveling over a preset threshold speed. Batteries for the microwave intrusion alarms can be recharged using solar cells.

Some states have had difficulty in using the microwave intrusion alarms. Reports have indicated that setup time is lengthy, strobe lights were not bright enough, sirens were not loud enough, and initial alignment of the unit was very difficult. A number of states also noted that false alarms were created by rain, dust, or drum movement.

The Iowa DOT rejected use of microwave intrusion alarms due to their lengthy setup time. Iowa tries to minimize the amount of time that crews are exposed to traffic, and the setup of the intrusion alarms would serve to extend the amount of time that a crew would need to do their job.

The Colorado DOT did not approve the use of the intrusion alarms because it felt that the sirens were not loud enough, the lights were not bright enough, and alignment of the units was too difficult. Alabama DOT also had difficulty keeping test units aligned. Its test devices then failed mechanically and had to be shipped backed to the manufacturer. Pennsylvania DOT noted that false alarms were so frequent that workers ignored the alarms. Washington DOT could not get its test unit to operate and noted that there was no troubleshooting guide to help workers determine what was malfunctioning.

Infrared Intrusion Alarms



Infrared intrusion alarms are mounted on two cones. A transmitter cone is placed on the shoulder at the beginning of the taper, and a receiver/siren cone is placed diagonally at the opposite end of the detection zone. The alarm’s 120 decibel siren is supposed to provide 4-7 seconds of warning to workers. The infrared intrusion alarms met NCHRP crash-worthiness standards regarding fragmentation, vehicle damage, and work zone hazards. Strobe lights and solar rechargers are also available.

States testing the infrared intrusion alarm experienced a number of problems. Several states indicated that this unit was too sensitive, creating numerous false alarms. Due to the difficulty in aligning the beams, the infrared intrusion alarms can be used only for stationary operations.

Also, it was noted that on hot days traffic cones become more flexible, causing the infrared beam to misalign, thereby triggering false alarms.

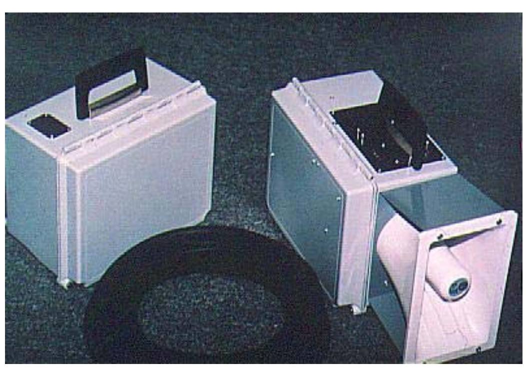
The Colorado DOT tested an infrared intrusion alarm but found that the CB frequency used by the alarm had too much interference, creating many false alarms. New

York DOT recommended that the use of the infrared alarms be limited to sites where workers do not enter and exit the zone while the alarm is operational in order to reduce the number of false alarms.

Missouri rejected the system because it was too sensitive, and Iowa did not approve it due to alignment problems. Pennsylvania DOT tested the system, but chose not to use it since the agency could not get consistent results from the system. Washington DOT could not align its test units and noted the device did not perform as designed.

The Vermont DOT began testing two models of infrared intrusion alarms shortly after two state highway agency employees were injured by an inattentive driver in a work zone. The alarm's first application was in early 1995 on a survey of a bridge deck. The workers reported that when vehicles tripped the alarm, the siren was "more than loud enough" to be heard over the noise of the generator and other equipment in the work zone. The intrusion alarm has since been used at nearly a half-dozen work zones. The research team concluded that the alarm might be best suited for projects that are a day long or shorter. However, even regular users reported having trouble installing it at job sites that lack shoulders wide enough for the placement of the alarm's components.

Pneumatic Tube Alarms



The pneumatic road tube intrusion alarm system involves placing road tubes on the roadway perpendicular to the flow of traffic at the beginning of the work zone. The tubes are connected to a transmitter that activates a siren and a strobe light when a vehicle drives over them. They can protect a distance of anywhere from 98 ft to 590 ft.

States that have tested the pneumatic tube system have also encountered problems. Several states reported that the system does not give enough warning time for workers to respond, and that the setup time is long. There were also questions about the durability of the system and its dependability. Pneumatic tubes are also easily punctured by heavy equipment and may require boosters after several hundred feet to ensure that air pressure is sufficient to activate a switch.

SonoBlaster

The SonoBlaster was recognized as a Top New Product in 2002 by Better Roads and is accepted by the FHWA. The SonoBlaster Work Zone Intrusion Alarm is impact activated to warn both roadway workers and errant vehicle drivers at the same time to prevent crashes and injuries in work zones. The SonoBlaster mounts on standard work zone barricades, such as traffic cones, drums, A-frames, delineators and other types of barricades.

Upon impact by an errant vehicle, the SonoBlaster's CO_2 powered horn blasts at approximately 125 dB to signal workers that their protective zone has been violated allowing them critical reaction time to move out of harm's way. The SonoBlaster's loud alarm can also alert distracted or drowsing drivers and allow them to steer out of the work zone or brake prior to reaching workers. Dozing drivers are a major cause of roadway and work zone crashes.

- No electrical power, recharging or regular maintenance;
- Critical unit alignment not required;
- No receiver unit required – each unit operates independently;
- As easy to deploy and retrieve as setting a standard traffic cone;
- Economical, light weight, long life units;
- Powered by safe, reliable CO2 cartridges;
- Resistant to normal roadway harmonics and vibration;

To sum up, the problems with warning devices are evident and numerous. First, most work zones are very noisy, besides traffic noise and wind, heavy construction machinery, such as jack hummer, shot blaster, and concrete cutters which create a tremendous amount of noise. Because the OSHA (U.S. Occupational Safety and Health Administration) standards require operators of such machinery to wear hearing protection, the operator are unable to hear audible warning over the noise of the equipment they are operating through their hearing protection.

Secondly, some warning devices use a single detector position upstream from the work zone and about 90^0 to the approaching vehicles; it is possible for vehicles to enter the work zone without active the detector. Further more, the heat and audible noise produced by work zone equipment and vehicles passing by would interfere with such infrared and ultrasonic detectors, thereby causing false detections.

Moreover, the distance between the detector and the siren necessitated a wireless data link. Modern work zones are flooded with electromagnetic noise within the popular communication frequencies. The frequent use of walkie-talkies by work zone personal, portable and cellular telephones by work zone personnel and passing traffic, sometime short wave radio by air traffic would trigger the siren causing a significant problem with false alarms.

A.1.2 Radar Drones

Radar drones are small, lightweight, weatherproof devices that are equipped with sensors that activate radar detectors in vehicles. These devices are used to make drivers with radar detectors think there is a police presence in the area, potentially causing drivers to slow down. They can be mounted on guardrails, signs, or maintenance vehicles. Batteries can last several days without recharging, and vehicle-mounted units can be plugged into cigarette lighters. Radar signals are sent on the K band, which is the band most often used by police.

Studies have shown that vehicles with radar detectors tend to travel faster than those without detectors. Since excessive speed is a contributing factor in many work zone crashes, radar drones have been used to influence drivers to slow down by making them think that there is a police officer nearby. Radar drone manufacturers claim that their products result in significant decreases in mean speeds and the number of high-speed vehicles. Manufacturers also report a decrease in crashes and speed variance when drone radar is used.

Previous studies have shown that while radar drones do not create large reductions in the mean speed of the traffic stream, they can be effective in reducing the number of vehicles traveling 10 mph or more over the speed limit. Benekohal et al. tested radar drones at two sites in Illinois. They found that mean speeds were reduced 8 mph at their first site, but speeds were not reduced significantly at the second site.

Freedman et al. examined radar drones at a long-term construction site, a short-term work zone, a rural high-crash location, and an urban high-crash location. They found that the maximum reductions in passenger car mean speeds were 3.4 mph in work zones and 1.8 mph at high-crash locations. The maximum reductions in tractor trailer mean speeds were 3.6 mph at work zones and 2 mph at high-crash locations. A study by Ullman found that radar drones reduced work zone speeds 2 to 3 mph, but had the greatest impact on trucks and vehicles traveling over 65 mph, possibly due to the higher incidence of radar detectors in these vehicles.

All of these studies noted that commuters and truck drivers who drove the road repeatedly became suspicious if there was no obvious enforcement presence. Occasional police enforcement would seem to be important to maintain the effectiveness of radar drone.

Speed Measurement Laboratories (SML) performed a study from 1995 to 1998 on rural interstates in New Mexico and Texas. In recent years, radar detectors can translate signals into specific warnings. The radar drones SML studied had the ability to send out three programmable messages: Road Hazard Ahead, Emergency Vehicle, and Train Approaching, and the detectors received these messages. The study on I-40 in New

Mexico and I-10/I-40 in Texas showed a consistent decrease in traffic speeds. The drones were placed on arrow boards, construction barrels, and department of transportation vehicles. Trucks slowed down an average of 3 to 4 mph while cars reduced their speeds an average of 2.5 mph. Monitoring of CB transmissions revealed that truck drivers communicated the radar detections to each other.

The South Dakota Highway Safety Department has used radar drones for over three years, and they have 500 units operating on moving maintenance vehicles. South Dakota found that the number of cars traveling more than 75 mph and the number of crashes involving maintenance vehicles has decreased. An increase in the number of severe braking incidents and amount of erratic vehicle behavior near the maintenance vehicles was observed when the drone radar was in use. Since most of this behavior occurred as vehicles passed a maintenance caravan, South Dakota now instructs its maintenance personnel to turn off the radar unit as vehicles pass. The Kentucky Department of Highways also uses drone radar with their moving maintenance operations and has been impressed with its effectiveness.

The Massachusetts DOT has used radar drones in work zones for almost two years. Their operation involves the attachment of the radar drone to arrow panels or sign posts. The general observation is that the work areas have become safer with the reduction in vehicle speeds.

The 12th district of the Ohio DOT, in the Cleveland area, has used radar drones for approximately three years. The units have been placed on portable changeable message signs for freeway construction projects. These signs are placed in advance of the work zone to serve as a warning device. The main motivation for this project was to alert long haul commercial motor vehicles not familiar with the area. The results of this project are that vehicle speeds have been reduced, especially at night.

In 1996, the Virginia DOT purchased 36 radar drone units to use in construction work zones on their interstate system. A study in 1997 found that the devices were reducing the overall speeds in the work zones by 3 to 4 mph. In addition, the variance of the speeds was also reduced.

These three transportation departmental applications concluded that the devices could be used in all urban and rural freeways within their states. The Connecticut DOT has used radar drones for over three years but does not feel that it has been particularly effective. They stated that truck drivers quickly became aware of the widespread use of drone radar in the state and began to ignore it. The Missouri DOT does not se radar drones due to concerns about limited effectiveness.

Some drivers installed radar detector in their vehicles to avoid tickets of speeding. This device can detect the frequency of a police car, and slow down their speed to the posted speed. Radar drones are intended to trigger radar detectors, causing those drivers to reduce their speed. Assuming that drivers using radar detectors tend to travel faster than the mean, this would reduce not only the mean speed but also the variation in speeds. It has the following features:

But according to a research funded by FHWA, The data they collected at field suggests that drones may cause a small decrease in the 85th percentile speed near the unit, but that speeds increase farther downstream. The use of a radar drone does not seem to be an effective device for reducing speeds in highway work zones.

A.1.3 Speed Display Trailer

Speed display trailer combines radar units with a dynamic message interface. The speed display trailer typically shows either the vehicle's current speed or some other type of warning message to alert drivers of their speed. Speed display trailer should be more effective than radar drones since vehicles without radar detectors will also be impacted, and a visual component is added to the system.

McCoy et al. tested a speed display at a work zone in South Dakota. The unit tested was manufactured by the South Dakota DOT and utilized a 28 in. by 20 in. display with 9 in. tall digits. The speed display was solar powered and was mounted on a portable trailer. A "Work Zone" advisory sign as well as an advisory "45 mph" were mounted on the radar trailer. The unit was tested at a bridge replacement project on I-90 near Sioux Falls, South Dakota. A 55 mph speed limit was in place, and the road carried 9000 vpd. The right lane was closed prior to a median crossover. Two speed monitors were installed 310 ft. in advance of the lane closure taper.

Speed data were collected before the units were set up and after they had been in place for one week. This study found an average speed reduction of 4 mph for vehicles with two axles, and a 5 mph average reduction for vehicles with more than two axles. The speed display also significantly lowered the percentage of vehicles traveling more than 10 mph over the speed limit. The number of two-axle vehicles traveling more than 10 mph over the speed limit was reduced between 20 and 25 percent, while the number of vehicles with more than two axles traveling more than 10 mph over the speed limit was reduced by 40 percent.

The Minnesota DOT tested a radar-controlled speed display that constantly displayed the speeds of passing traffic. The sign was tested in a work zone posted at 40 mph. Before the radar speed display was installed, the 85th percentile speed was 58 mph, and 14 percent of all traffic was exceeding 60 mph. After the speed sign was put in place, the 85th percentile speed was 53 mph, and only 1 percent of all traffic was exceeding 60 mph.

Garber and Patel tested a radar-activated changeable message sign (CMS) to determine its impact on speeding vehicles driving through interstate work zones. The

CMS displayed one of five warning messages when a vehicle was detected traveling more than 3 mph over the posted speed limit. The sign face remained blank if a vehicle had not triggered the message.

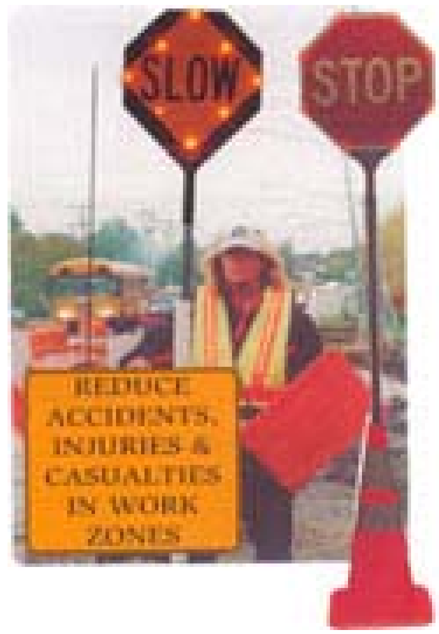
After testing the messages at seven different interstate sites in Virginia, they determined that the message "YOU ARE SPEEDING -- SLOW DOWN" was the most effective in reducing speeds at the beginning, middle, and end of the work zone. Vehicles that triggered this warning message reduced their speeds by an average of 15.3 mph. The mean speed of the entire traffic stream was reduced by about 4 mph, and the 85th percentile speed of the overall traffic stream was reduced by 6 mph. The percent of vehicles speeding by any amount was reduced from 41.5 percent to 12.2 percent once the CMS with radar was set up, and the percent of vehicles speeding by 5 mph or more was reduced from 14.5 percent to 3.1 percent after the CMS was installed. The percent of vehicles traveling more than 10 mph over the speed limit dropped from 3.8 percent to 1.2 percent. The researchers found all of these reductions to be statistically significant at $\alpha=0.05$, except for the percent reduction in vehicles speeding by 10 mph or more.

Garber and Srinivasan conducted a follow-up study to determine whether the impact of the CMS with radar decreases as the duration of exposure and length of work zone increases. Speed reductions for vehicles that triggered the warning message averaged about 9 mph, which is about 6 mph less than the results from the first phase of the study. Speed reductions were still found to be statistically significant after the sign had been in place for seven weeks, although no specific relationship was found between the duration of exposure and the amount of speed reduction generated. Analysis also revealed that as the length of the work zone increases, the speeds at the end of the work zone tend to increase.

A.1.4 Panic Button-Type Safety Clothing

Panic button-type safety clothing is a kind of safety device designed for worker safety within a work zone area; it should be worn by all workers to warn each other of out-of control vehicles that may encroach upon the activity area.

A.1.5 Flashing Stop/Slow Paddle



The flashing stop/slow paddle is available in 18 in. and 24 in. faces, with "STOP" on one side and "SLOW" on the other. One type (T-series) has two flashing lights that can be seen from either side. Another (J-series) has two lights that can only be seen from the STOP side of the paddle. The signs are attached to an 8 in. long PVC handle, where the batteries are kept. The handle comes with two PVC attachments that can keep the sign 72 in. above grade. Two standard "D" size batteries provide over 24 hours of continuous steady flashing. The paddle face is made with reflective sheeting.

The flashing stop/slow paddle is one of the most widely used work zone safety products developed under the Strategic Highway Research Program (SHRP). But like any new product, it had some growing pains. Some highway agencies that tried the first models of the device thought the idea was a good one, but the device wasn't durable enough or it otherwise failed to meet their rigorous requirements.

The flashing paddle is much like conventional stop/slow paddles used by flaggers at work zones, but it is equipped with high-intensity flashing lights that are visible even during the day. When a driver fails to heed the flagger's instructions, the flagger can activate the flashing lights to get the driver's attention. Alerted to the flagger's message, the driver is less likely to cause an accident in the work zone.

During the spring of 1995, the Pennsylvania DOT distributed flashing stop/slow paddles to its district work crews. The paddles were used at more than 300 work zones on two-lane, two-way highways where speeds at the work zone sites ranged from 35 mph to 55 mph. Flaggers reported that the flashing paddles caused drivers to slow down, although no speed data was collected to substantiate this. Based on these results, Pennsylvania DOT has approved the continued use of the paddles. Alabama DOT distributed the flashing stop/slow paddles to their eight divisions. The flaggers that utilize the paddles found that they were easy to handle and drivers responded well to them.

Some deficiencies of the flashing paddles have been noted. The Alabama and Nevada DOTs found that the paddles sometimes create radio interference. Arkansas and Alabama DOTs also had difficulty keeping the batteries charged for the duration of the project. Arkansas also felt that the less expensive flashing paddles were not durable enough. Tennessee and West Virginia DOTs both thought that the flashing paddles improved visibility of the flagger greatly at night, but did not improve visibility very much during the day. They recommended against using the flashing mode during the day in order to conserve battery power.

A.1.6 Portable Traffic Signs

By definition, traffic signs are devices placed along, beside, or above a highway or other route to guide, warn, and regulate the flow of traffic including motor vehicles, bicycles, pedestrians, equestrians, and other travelers.

In 1987 TTI researchers studied the use of portable traffic signals to replace flaggers. Although portable traffic responsive systems are currently available, this study only examined a fixed time portable signal system. This signal was studied at three work zones with annual average daily traffic (AADT) between 600 and 10,000 vpd and lengths between 600 and 2600 ft. The cost for the fixed time signals was $8000 per pair. At the time of the study, TX DOT had limited the use of portable signals to lane closures on restricted width bridges where construction would take more than three months.

The study found that overall delay increased by using the fixed time portable signals instead of flaggers. This was primarily attributable to the fact that flaggers can allow isolated arrivals to drive through the work zone without stopping, and fixed time signals cannot. This had the greatest impact on delay when hourly volumes were low.

When the hourly volume was 50 vph, the fixed time signal increased the average delay by 24 s/vehicle over flagging. When the hourly volume was 750 vph, use of the fixed time signal only resulted in a delay increase of 2 s/vehicle over flagging.

The researchers also looked at driver compliance with the portable signals. The rate of noncompliance with the red indication was as high as five vehicles running the red light per 1000 entering vehicles. Some drivers drove straight through the red light without stopping, while others came to a halt and then proceeded through the signal. Red light noncompliance could create a severe hazard in actual construction zones. Additional reinforcement at the signal such as a temporary stop bar or a "STOP HERE ON RED" sign (R10-6) may be necessary to ensure compliance with portable signals.

A.1.7 Portable Rumble Strips

A typical portable rumble strip is made of durable neoprene rubber, with dimensions of 20 in. by 120 in. by 0.75 in. It weighs 75 lb. and is laid across the approaching lane, usually about 328 ft. ahead of the flagger. It can be deployed from a pickup by two workers. When driven over, a moderate jolt is delivered to the vehicle to get the driver's attention, and the low rumble is also audible. It is best suited for low-speed roads that carry few heavy trucks. Portable rumble strips meet the specifications in section 6F-8D of the Texas MUTCD.

The consensus among the states that have tested the portable rumble strip has been unfavorable. It has been noted that the rumble strips do not work well when high speeds or large truck volumes are present since these cause the strip to shift out of position.

In 1995 SHRP reported that most states that had tried the portable rumble strip had difficulty in keeping it in place. Some also had problems handling and deploying the strips, indicating that it took a considerable amount of time to install and remove the strips.

The Indiana DOT tested the rumble strips at several locations and found that the strip cracked easily and moved when trucks passed over it. It also noted that some drivers swerved around the strip to avoid it since it looked like a flat tire in the roadway. The Maryland, Utah, and Arkansas DOTs also noted this phenomenon. New Mexico DOT found that the strip wore out quickly, which created a hazard since this exposed the devices used to hold the rumble strip in place. None of the DOT that studied the portable rumble strip recommended its use.

A.2 Protective Devices

The protective devices are used to protect the working crews in a work zone. Truck mounted attenuator and remote driven vehicle are typical devices used in work zone.

A.2.1 Truck Mounted Attenuator

A truck mounted attenuator (TMA) is a portable impact attenuator attached to the rear of a large truck. The TMA is used as a shield to prevent errant vehicles from entering the work zone. They are most frequently used in short-term or mobile work zones.

It was approved by the FHWA at NCHRP 350.

A.2.2 Remote Driven Vehicle

Crash rates for slow-moving maintenance operations are about three times as high as those for other types of maintenance activity. A shadow vehicle, sometimes equipped with a truck mounted attenuator, is frequently used to protect maintenance vehicles from being struck in the rear. While this protects the maintenance caravan, it puts the driver of the shadow vehicle at risk.

SHRP contracted with ENSCO, Inc. to develop a remotely driven shadow vehicle in order to reduce the risk to the operator of the vehicle. The prototype was a 1991 Ford L8000 dump truck, which was loaned to SHRP by the MnDOT. The prototype vehicle still retained its ability to perform normal maintenance functions, such as snow plowing.

The remote control unit can command all of the important vehicle functions. It allows the operator to start the vehicle, adjust the throttle, brake, and steer, as well as shift gears, use turn signals, and turn on the headlights. The remote control has a dead-man switch that turns off the remote vehicle if the operator removes his hand from a bar. The remote control weighs 4 lb. and has a range of 1200 ft. It is powered by an internal battery, which has a one week life.

The RDV has several built-in safety features. Panic buttons are positioned on either side of the truck, allowing workers to immediately shut down the vehicle if necessary. The RDV also has collision sensors that detect obstacles on all sides of the vehicle and stop the truck automatically if anything is detected.

The RDV has not gained wide acceptance, primarily due to the cost associated with converting an existing vehicle into an RDV. Indiana hosted a test of the device but elected to wait until the cost came down before pursuing it further. Maryland also postponed pursuing the device due to its high cost.

A.2.3 Water Filled Barrier

Water-filled barriers have been marketed by manufacturers as a device to improve work zone safety. The illustration shows an example of a water-filled barrier. The manufacturer states that the barrier will not be penetrated by an 1800 lb. vehicle striking the barrier at a 20 degree angle at 45 mph. The barrier will also not be penetrated by a 4500 lb. vehicle impacting at a 25 degree angle at 45 mph. However, the barriers are not rigid, and deflections of up to 22.6 feet have been observed during testing. The manufacturer says that the water-filled barrier will bring vehicles to a controlled stop without allowing penetration. This is in contrast to concrete barriers, which deflect vehicles back into the traffic stream, and delineating devices, which do not effectively restrict vehicles from the work area.

The size of a water-filled barrier is similar to that of a concrete barrier. Three heights are available: 28 in., 42 in. (standard), and 54 in. All barriers are 24 in. wide at base and taper to a 10 in. width at the mid-height. It has a length of 78 in., of which 6 in. are used in the interlocking extension that is used to attach several barriers into a row. It comes in white and orange, and weighs 170 lb. empty. When filled with 185 gallons of water, the weight increases to 1700 lb.

Water is drained by a small outlet near the bottom of one of the sides. In addition to work zone protection, they can also be used in traffic channeling and control, lane delineation, and building security.

The barriers can be installed by two workers with no special tools. Contractors have been timed installing the barriers at a rate of 600 ft. per hour. Forklift holes are provided in case the barrier must be moved once it has been filled with water.

Water-filled barriers have been used in several other states with some amount of success. Other agencies have noted that the barriers are easy to install and remove, but caution that they should not be used as a replacement for concrete barriers due to the large lateral displacements that occur when the water-filled barriers are struck. Other states have noted that the water-filled barriers are used in situations where they would have previously used only plastic barrels.

The Alabama DOT has used the water-filled barriers in 45 mph work zones and highly recommends them. The barriers performed well during actual incidents. However, some states have noted that the barriers have not always been repairable after collisions.

There are still a number of questions about the use of these barriers that need to be resolved. New Hampshire expressed some concerns about the potential hazards that could be created by releasing water onto the roadway after a crash. Also, no crash tests were performed when the water in the barriers was frozen. The manufacturer recommends adding antifreeze during cold months, but this creates a disposal issue since water cannot be released using the built-in valves.

A.2.4 Balsi Beam

Balsi Beam is a truck mounted, expandable beam that will provide work zone protection comparable to a concrete barrier. It is specifically intended to enhance worker safety when carrying out shoulder repair in work zones adjacent to guardrails, bridge rails, and sound walls. Usually the shadow vehicle or the truck mounted attenuator provides protection from rear end collisions; the new device would provide protection from adjacent lane traffic.

Each side of the trailer consists of high-strength steel box section beams that are capable of extending an additional 4.6 m (15 ft). Using hydraulic power, each beam can rotate to either side (left or right), depending on which side of the road a protective barrier is needed. The trailer then extends to provide a 9.1-m (30-ft) secure work zone. The trailer beams act as a rigid obstacle to deflect traffic away from maintenance workers.

The device is being used in Caltrans' District 4, which serves the San Francisco Bay area. Caltrans plans to deploy it for more testing elsewhere in the State. The prototype device cost approximately $217,000 to build, but it is expected that cost would drop significantly when other models are produced. A patent for the Balsi Beam system is pending.

A.2.5 Portable Crash Cushion

Barrels are used at work sites to protect highway workers and cushion the impact of a crash. Setting up crash barrels is a time consuming process and its infeasible for mobile work zone operations and also exposes workers to considerable danger.

By making the process easier and faster, the risk to workers is lessened because the barrels are likely to be used more often. This would be a boon to the safety of workers and motorists alike. It is being tested in five states; Alabama, California, Iowa, Minnesota, and New York

The portable crash cushion trailer is a tilt-bed trailer equipped with a pallet of hinged steel plates. Sand-filled barrels are secured to the pallet, and a winch is provided to assist in installation and removal of the barrels. Rollers on the trailer bed allow the pallet to easily slide on and off the trailer.

Another type of crushable cushion manufactured by Energy Absorption Systems is made of energy-absorbing cartridges surrounded by a framework of steel beam panels. Its compact and modular design (3 to 9 bays) accommodates speeds from 70 km/h (43 mph) to 115 km/h (71 mph). The monorail base eliminates the need for anchoring chains and tension cable, therefore easy installation. The equipment is relatively lightweight and the entire system can be moved as a single unit using lifting brackets on diaphragms.

A.2.6 Alternative Worker Vest

Alternative worker vest, in another word, its high visible worker vest or clothing, the 1993 revision to the MUTCD was the first time that the MUTCD made reference to safety clothing on personnel other than flaggers. The 1993 revision states that "Workers exposed to traffic should be attired in bright, highly visible clothing similar to that of flaggers." The MUTCD further states that "the flaggers vest, shirt, or jacket shall be orange, yellow, strong yellow-green, or fluorescent versions of these colors".

A study by the University of Illinois in 1997 indicated that motorists do not see flaggers very well in construction zones. It stated that flaggers tended to blend in with the orange traffic control devices and equipment present in a typical work zone. A special provision was written into Illinois' Standard Specifications article that stated that the use of yellow-green vests will be used to distinguish the flagger from all of the prevalent orange in the area. The vest was to contain fluorescent orange stripes. The use of fluorescent orange vests will be limited to emergencies only.

Turner et al. examined a variety of vest colors in order to determine which colors had the highest conspicuity. They tested the following vest colors: fluorescent green, fluorescent yellow-green, fluorescent yellow, semi-fluorescent yellow, ordinary yellow, fluorescent yellow/orange, fluorescent red-orange, fluorescent red-orange combined with fluorescent yellow-green, fluorescent red mesh, ordinary orange, and fluorescent pink. Vests were placed on mannequins dressed in typical worker attire (white t-shirt with denim pants).

The mannequins were setup in a mock work zone with typical orange traffic control devices. Test subjects were driven through the mock work zones at a rate of 20 mph. Every 100 ft. a shutter would open for 300 milliseconds, after which the subject would be asked if they saw any safety clothing. This study found that fluorescent red-orange had the best mean detection distance at 984 ft., followed by fluorescent red mesh at 892 ft., and fluorescent yellow-green at 853 ft. These results seem to validate the requirements of the MUTCD.

In 1997, the Iowa Department of Transportation started using vests that were yellow green with orange markings and reflective stripes. If a hard hat was not worn, a yellow green cap with a reflective stripe was substituted. Pants of similar color were also added for nighttime use. In1995, the Iowa DOT had experimented with yellow-green open mesh vests due to concerns that plain orange vests were hard to see because they tended to blend in with equipment. They ran into problems with the new yellow-green vests also since the yellow-green blended in with the cornfields.

A.2.7 Cone Shooter

The AHMCT (Advanced Highway Maintenance and Construction Technology) Center has developed a machine that can automatically place and retrieve traffic cones. This new device can safely and quickly open and close busy lanes. Typical lane configuration uses 80 traffic cones for each 1.5 miles of lane closure. Usually cones come to size of 36 inches Caltrans uses a 28-inch cone weighing 10 pounds.

Manually only three cones can only be carried by a worker at a time. Also it is difficult for place cones during mobile operations. It is slow and dangerous in busy roads. The cone shooter is meant to reduce injury and cost.

It has the following Features:

- The Cone Shooter handles generic 28 inch highway cone. It can be readily modified to handle other sizes of cones.
- The Cone Shooter is controlled using simple switches by the driver.
- The automated equipment occupies minimal space on standard trucks. A standard vehicle envelope is maintained when not handling cones.
- By default, 80 cones can be stored in stacks lying on side. The carrying capacity can be readily modified.
- Cones can be placed in the forward direction, on either the left or right side.
- In the default configuration, you can automatically space cones every 25, 50 or 100 feet and while traveling at a speed of 10 MPH. Spacing choices are readily modified.
- Easy retrieval of upright or knocked-over cones on either the left or right side while traveling either in a forward or reverse direction.

A.2.8 Robotic Highway Safety Marker

All work zone maintenance operation uses traffic control devices such as cones, signs, safety barrels and barricades. Proper traffic control is critical in highway work zone safety. Deployment of these devices in work zone involves labor, consumes time, and poses hazards to workers. Also for mobile work operations, placement of the devices could be impossible. In order to efficiently use the devices for work zones, the department of Mechanical engineering in University of Nebraska Lincoln has developed a mobile safety barrel robot. The robotic safety barrels can self-deploy and self-retrieve, removing workers from this dangerous task. The robots move independently so they can be deployed in parallel and can quickly reconfigure as the work zone changes.

These devices would be of great advantage in mobile work zones, where the cones or barrels could move along with the working crew, saving time and increasing safety to workers.

A.2.9 Pavement Sealer

One of the frequent maintenance operations involves crack sealing of the pavements. Sealing of cracks along the pavement is done by mobile operation. Crack sealing is performed for longitudinal cracks or sealing of joints between concrete lanes and also random cracks along the pavement. Hand sealing of longitudinal as well as random cracks consume more time, involve workers, safety concerns and also lanes closure.

AHMCT has developed a couple of automated pavement crack sealers, which could perform the same operation with greater efficiency and less time. A typical sealing operation involves a large crew sealing 1.5 to 3 km per day, while the crew is exposed to moving traffic in adjacent lanes.

The two devices developed by AHMCT are:

- Longitudinal Crack Sealer
- Random Crack Sealer.

Machine (LCSM) was developed to automate the sealing of relatively continuous longitudinal cracks, such as those that occur between a concrete lane and asphalt shoulders.

The LCSM enables a highway worker to seal longitudinal pavement cracks and joints with hot applied sealant from inside the relative safety of the truck cab. The workers no longer are exposed to direct traffic in longitudinal sealing operations as in the traditional manual application procedure. The driver controls the entire sealing process from within the truck cab while a support worker is typically utilized to load the sealant blocks into the kettle. Use of the LCSM also dramatically increases seal production rate, primarily by eliminating the strenuous nature of the operation.

A.2.10 Vehicle Visibility Improvement

A recent survey of innovative traffic control techniques in Europe found that many European countries utilize various retro-reflective treatments to improve the visibility of maintenance and incident response vehicles. These vehicles have retro-reflective material applied to the rear of the vehicle in order to improve the conspicuity within the work zone. The material was typically two-color alternating diagonal stripes that were placed along the perimeter of the rear of a truck or van. Color combinations observed included yellow and orange, red and white, fluorescent yellow-green and blue, and fluorescent yellow-green and black.

A.2.11 Temporary Stop Bar

Temporary stop bars are something painted on the road in order to designate a stopping point for vehicles when flaggers are present. These temporary stop bars are typically only used when there is going to be long-term construction work since it is not feasible to install temporary markings and then remove them if the project lasts only a short time.

Booker et al. tested a removable stop bar that would be appropriate for these short duration projects.

The stop bar tested consisted of six 40 in. long, 6 in. wide, and 0.4 in. thick white rubber interlocking strips. These strips were placed three long by two wide to create a 10 ft. long by 12 in. wide stop bar. This stop bar was evaluated on a two-lane rural highway near Port Arthur, Texas, with an AADT of 7000 vehicles per day. The eastbound lane of this road was closed in order to install a shoulder.

The temporary stop bar reduced the average stopping distance between the vehicle and the flagger from 57 ft. to 47 ft. in the closed lane, and from 67 ft. to 43 ft. in the open lane.

It also reduced the standard deviation of the distance from 32 to 21 ft. in the closed lane and from 99 to 38 ft. in the open lane. The stop bar was observed to have had a very positive impact on designating a stopping point for vehicles. Only 5.5 percent of the vehicles encroached on the bar, and none were observed stopping beyond the bar. The stop bar did not have an impact on speeds.

A.3 Guiding Devices

Guiding devices are applied to guide or tell the motorists the present of work zone and/or the traffic direction of work zone, devices that express the detour information and other suggestions will be included in this part.

A.3.1 Fluorescent Orange Roll-up Sign

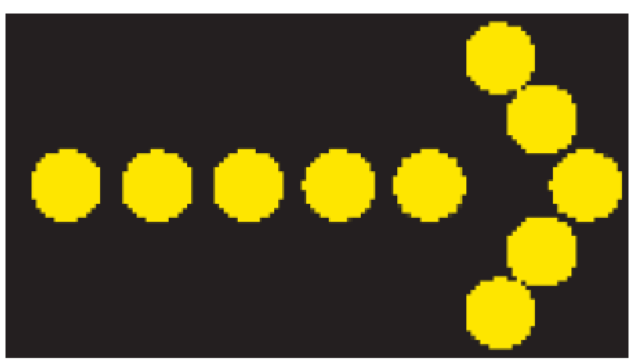
Work zone safety devices are usually burdens for workers to handle, because most of these devices are very heavy and take a long time to deploy. Fluorescent orange roll-up sign are light weight and don’t need too much space.

Michael D. Fontaine of Texas Transportation Institute tested the effectiveness of fluorescent orange roll-up sign with some other four devices for short-term maintenance work zone.

He concluded that the fluorescent orange signs did not have any measurable impact on the speed of traffic in the work zone. Workers felt that the signs offered improved visibility over conventional roll-up signs, and also did not think that the signs would increase the amount of time required to install or remove traffic control at the site.

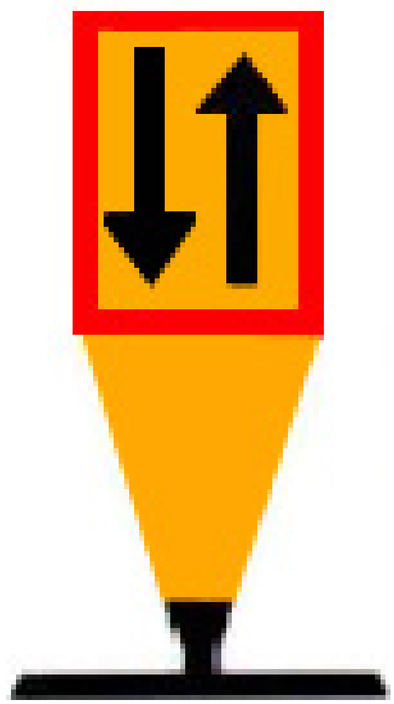
Whereas the driver comments about the signs were positive, and many drivers commented that the signs appeared brighter than usual.

A.3.2 Arrow Panel



An arrow panel is a sign with a matrix of elements. The matrix, capable of either flashing or sequential displays, is intended to provide additional warning and directional information to assist in merging and controlling traffic through or around a temporary traffic control zone. An arrow panel should be used in combination with appropriate signs, barricades or other traffic control devices. Only the chevron mode is permissible for lane closures.

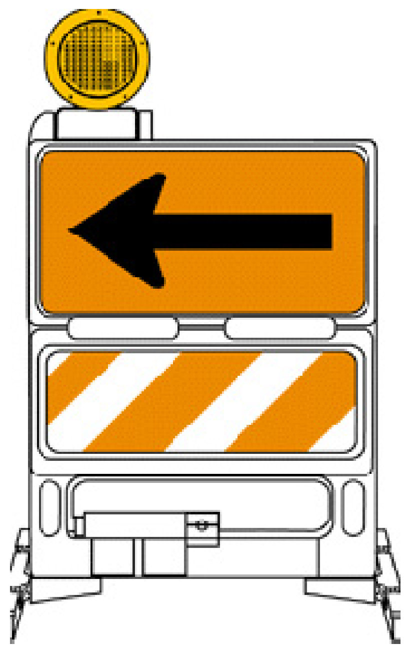
A.3.3 Opposing Traffic Lane Divider



The OTLD is a centerline delineator for maintenance work zones that conveys necessary travel path changes to motorists. An example application is when four-lane traffic is reduced to two lane two-way traffic. It is a two-way sign mounted on a 900mm tall tubular channel. The sign itself consists of a two-way arrow, in black against a high intensity orange sheeting and located 300mm off the ground. The heavy 200mm base of the channelizer is attached to the pavement with bitumen adhesive tape and provides additional stability for the sign during impact.

While the prototype had helical springs as the joint between the plastic sign and its base, modifications had to be made. It was found that OTLD can improve drivers' understanding of certain types of two-lane, two-way work zones. In open highway tests, they appeared to shift drivers away from the centerline which could reduce head-on collisions. Two alternatives to the OTLD evaluated during SHRP have become commercially available.

A.3.4 Directional Indicator Barricade



The direction indicator barricade (DIB) provides positive directional guidance to motorists at the taper to a work zone. The DIB consists of a single plastic panel hinged to a pair of horizontal feet. An arrow sign is at the top of the DIB, and an orange and white diagonal stripe panel is at the bottom of the DIB. If desired, a steady-burn or flashing light can be mounted on the top of the DIB.

The manufacturer claims that the unit is designed to fall flat if hit. The cost is $60-100 depending on the grade of sheeting used and whether a light is attached or not. DIBs have been used by Arkansas, Georgia, Alabama, and Illinois. All four of these states have been pleased with the DIBs. After one year of using the DIB, the Russellville District of the Arkansas DOT reported that the device was very useful. The maintenance crew particularly liked the ease in handling and setting up the device when compared to that of the traditional sawhorse barricade. They also stated that they felt safer with the device in place, and the observed traffic flow in the work zones had improved.

Georgia DOT (GDOT) began evaluating the DIBs in the spring of 1994 in the Atlanta metropolitan area, with a majority of the projects on the Interstate system. The maintenance work crews reported that the DIBs performed well in all applications and seemed to be respected by drivers. GDOT also noted that the barriers were quick to install and easy to store, and far superior to barrels. The compact size of the DIBs enabled workers to set them up very quickly, minimizing the amount of time the workers are exposed to traffic.

Alabama DOT (ALDOT) tested the DIBs for nearly two months on two-lane and undivided four-lane rural highways that carried a range of speeds and between 150 and 15,000 vehicles per day. The ALDOT reported that the devices were reliable, easy to install and move, and accepted by maintenance workers. Motorists encountering the device appeared to recognize and interpret the device faster than with standard traffic cones. Based on the limited effects by the weather and other factors on the devices, the DIBs proved to be sturdy and durable. ALDOT has approved of the immediate use of the DIBs, but suggests further testing on the device's effectiveness at night and its long-term safety record.

Illinois DOT decided to use the DIB in the summer of 1994 on a bridge reconstruction project on I-55 near Springfield. DOT personnel believed that the device was more effective in telling motorists what was expected of them. The arrows provided more positive guidance, and the DOT stated that the devices were perfect for use in the taper end of a closed lane. Illinois received requests from field crews to use more DIBs and has started replacing drums with DIB.

A.3.5 Portable Changeable Message Sign

Portable Changeable Message Signs are used primarily to provide real time, dynamic information about current road conditions. Specifically, changeable message signs have been used to supply detour information, warn of lane drops, provide additional reinforcement of speed limits, and warn of the periodic use of flaggers. Changeable message signs generally cause little or no disruption to traffic flow, and are effective at night or during inclement weather.

Changeable message signs should only be used for short periods. If they are used for long term applications, they tend to lose some effectiveness. Users should always make sure that messages are up-to-date and reliable; otherwise drivers will lose confidence in the messages on the CMS.

Messages must also be designed so that they are short enough to be read by drivers as they pass by the sign.

Several studies have been conducted to determine the impact of changeable message signs on work zone traffic conditions. Richards et al. found that a CMS showing a speed limit message reduced vehicle speeds by an average of 3 mph. Another study by Hanscom found that a CMS that provided warning of an upcoming lane closure increased preparatory lane change activity and reduced speeds by up to 7 mph. This resulted in significantly fewer late exits from the closed lane.

Benekohal and Shu found that a CMS displaying a speed advisory message ("SPEED LIMIT 45 MPH - WORKERS AHEAD") resulted in speed reductions near the CMS.

This message reduced passenger car speeds by 2.8 mph and truck speeds by 1.4 mph. This study also found that the number of cars exceeding the speed limit was reduced by 20 percent. Vehicles were also observed to increase their speed as they traveled further away from the sign.

Garber and Patel tested a radar-activated changeable message sign (CMS) to determine its impact on speeding vehicles driving through interstate work zones. The CMS displayed one of five warning messages when a vehicle was detected traveling more than 3 mph over the posted speed limit. The sign face remained blank if a vehicle had not triggered the message.

After testing the messages at seven different interstate sites in Virginia, they determined that the message "YOU ARE SPEEDING -- SLOW DOWN" was the most effective in reducing speeds at the beginning, middle, and end of the work zone. Vehicles that triggered this warning message reduced their speeds by an average of 15.3 mph. The mean speed of the entire traffic stream was reduced by about 4 mph, and the 85th percentile speed of the overall traffic stream was reduced by 6 mph. The percent of vehicles speeding by any amount was reduced from 41.5 percent to 12.2 percent once the CMS with radar was set up, and the percent of vehicles speeding by 5 mph or more was reduced from 14.5 percent to 3.1 percent after the CMS was installed. The percent of vehicles traveling more than 10 mph over the speed limit dropped from 3.8 percent to 1.2 percent.

The researchers found all of these reductions to be statistically significant at α=0.05, except for the percent reduction in vehicles speeding by 10 mph or more.

Garber and Srinivasanb conducted a follow-up study to determine whether the impact of the CMS with radar decreases as the duration of exposure and length of work zone increases. Speed reductions for vehicles that triggered the warning message averaged about 9 mph, which is about 6 mph less than the results from the first phase of the study.

Speed reductions were still found to be statistically significant after the sign had been in place for seven weeks, although no specific relationship was found between the duration of exposure and the amount of speed reduction generated. Analysis also revealed that as the length of the work zone increases, the speeds at the end of the work zone tend to increase.

The FHWA published a report in 1992 that covered general guidelines for the use and operation of changeable message signs. This report included the following guidelines:

- It is better to display little or no information if the operator is unsure of current traffic conditions.
- Tell drivers information that they deem trivial or already know results in a loss of sign credibility.
- Run-on messages are not suitable when traffic is moving at freeway speeds.
- Messages must be legible from a distance that allows drivers to read and comprehend the message. The minimum exposure time is one second per short work or two second per unit of information, whichever is larger.
- Character height should be at least 18 in. for freeway applications.

A.3.6 Queue length detector

Work crews often are unaware of traffic conditions upstream of the work zone. The Queue Length Detector is designed to detect the presence of a traffic queue so that workers can take action. It consists of an ultrasonic detector placed 200m in advance of the work zone, a work zone receiver and a buzzer with flashing light.

The ultrasonic ranging system is readily available commercially.

When a vehicle passes in front of the sensor, the interface board creates an electronic signal. If the vehicle stays in front of the unit for 15 seconds or more, an electronic signal is passed through the interpretation circuit to the tone encoder. The tone encoder then generates a warning tone of 1 kilohertz (kHz) which is sent out by the transmitter set at CB channel 30. The signal is received by the work supervisor via a walkie-talkie. With this warning, the work crew can respond and attempt to move traffic through the zone.

The QLD interface monitors the timer output but it uses the output to operate a re-settable and adjustable counter circuit. This interface circuit consists of a stable oscillator and a three-stage counter circuit with overflow outputs.

The output from the timer circuit operates a relay that toggles between the reset and run modes. If no vehicle is present, the counters are held in the reset state. If a vehicle is present, the counter circuit is in run mode and it counts as long as the vehicle is present.

After a certain time, the circuit overflows, providing an alert signal. The time elapsed before overflow is determined by the frequency of the oscillator and can be varied: Higher frequencies mean shorter times, lower frequencies mean longer times. The QLD is commercially available in essentially the same configuration as tested by SHRP.

A.3.7 All Terrain Sign

During highway maintenance or repair, the signs are setup on the shoulder or slope at the side of the road, warning motorists of the work zone ahead. Major highways generally have wide, flat shoulders with plenty of room for signs, but many roads have narrow shoulders or no shoulders at all especially in mountainous states. So it is not easy to setup the signs along the shoulder on these roads.

This problem is overcome by the use of the portable all-terrain sign and stand. The device features adjustable legs that can be placed on any slope. Stakes driven through the legs secure the sign to the ground. It can be used on roads with a narrow shoulder or where ditches, embankments, or other features leave no space for a conventional sign.

The all-terrain sign stand is also useful in areas with high winds or on roads that carry a great deal of truck traffic, as it remains stable in gusty, windy situations. This device is being widely used by the Tennessee Department of Transportation (DOT).

The all-terrain sign are useful for the following.

Place warning signs on the side of any road, whether the site is windy, has little or no shoulder, or abuts a steep slope. Drivers are warned of work zones ahead even in roads where there is no room on the shoulder for a traditional sign.

A.3.8 Pavement Marking and Reflector

Delineation of proper driving path to drivers is of significant importance in work zones, especially at nighttime or during inclement weather. With significant highway reconstruction under progress across the US and emphasis on getting the work done quickly, work zones with overnight lane closures are becoming common. Pavement marking usually involved Raised pavement markings coated with reflector material and painted delineation. Raised pavement markings coated with reflector material offer increased visibility during nighttime and inclement weather, thereby potentially improving work zone safety. The use of pavement marking and/or coated with reflector in work zones appears to vary among state transportation agencies in work zones.

APPENDIX B WORK ZONE SAFETY SURVEY

The purpose of the work zone safety survey was to obtain the primary impression of work zone safety concerns, contributing factors to work zone accidents, and generic measures or devices to work zone safety. In survey forms, the work zone type (long-term work zone, short-term work zone, or work zone at night) was not pointed out, though different work zone types have dissimilar safety concern, causes of crashes and related measures.

B.1 Survey Forms

Nine forms were designed for the work zone safety survey, and grouped into three parts: Part I (Forms 1 and 2) dealt with the safety concerns of working crew inside work zone and motorists passing by or through work zones; Part II (Forms 3, 4, and 5) attempted to find out the different weight of contributing factors to work zone safety. The contributing factors in Form 3 were work zone related factors; Form 4 contained all factors related to passing motorists, whereas Form 5 compiled all the other contributing factors; Part III covered the possible measures to improve work zone safety. Forms 6, 7, 8, and 9 were designed to get the most effective measures from general solutions, warning devices, protective devices, and guiding devices for work zone respectively. All forms are shown in Appendix C.

The participators scored each question from number naught to five by checking the corresponding box at the right side according to their judgments. Naught stands for the lowest concern (no concern); five means the most concern; 1, 2, 3, and 4 are sorted by the comparative importance upwards. All the scores were summarized; and the statistic characteristics of the scores, such as P-value, mean rates, number of responses, and the average deviation of each question, were calculated thereafter. At the bottom of each survey form, the participators could make their complementarities about the safety concern, the contributing factors and the measures to work zone safety.

B.1.1 Part I

There are two kinds of people who are easily involved into work zone crashes or injures, one is the working crew inside work zones, and the other is the motorists passing by or through the zone areas. Due to the sparsity of pedestrians in most cities, the safety concerns for them are ignored. Form 1 represents four questions concerning the safety of crew; and Form 2 put forward questions concerning the safety of motorists passing by work zones.

B.1.2 Part II

Many factors can influence the safety of work zones, such as the work zone configuration, access management design at the upstream of work zones, and the characteristics of drivers passing by as well as the enforcement standard of work zones. This part divides the contributing factors related to work zone safety into three forms: Form 3 contains eight contributing factors related to work zone; Form 4 includes five contributing factors which are thought to have relations with the passing motorists; all the other contributing factors are attributed to Form 5.

B.1.3 Part III

To improve the safety of work zones, a lot of measures can be taken into consideration to enhance the various aspects of work zones. Generally, the planning and geometry design of work zones are the primarily factors to work zone safety, whereas a strict traffic control and conspicuous enforcement can reduce the traffic crashes in the work zone area dramatically.

A large number of work zone safety devices have been applied in many states of U.S. The traditional work zone device, such as cones and drums even can be found in every state, while some states are adopting more advanced and complicated work zone safety solutions such as Dynamic Work Zone System or Smart Work Zone. The prevailing safety devices are still the main choice of the other states.

Basically, the work zone devices can be classified into three groups: warning devices, protective devices, and guiding devices. However, some devices are multi-functional devices which are hard to be attributed into one catalog only. For example, portable traffic sign can be treated as warning device and guiding device both. In survey forms, to simplify the research results, all sorts of safety devices were classified by their main purpose according to analyst's judgment.

Ten questions present the general measures to improve work zone safety in survey Form 6. Form 7, including twelve questions, attempts to compare the effectiveness of warning devices currently applied in most urban and rural areas in U.S. Form 8 covers the protective devices, which are mainly for the safety of working crew, project managers, contractors, or pedestrians happened in work zones. The guiding devices are used to guide the motorists passing by or through work zones; it gives information to drivers such as the present of work zone ahead, the direction change of through lane, etc. All the questions related to the guiding devices in work zone are complied in Form 9.

B.2 Survey Process

From different viewpoints of work zone designers, planners, contractors, managers, work crew, or motorists, the safety concerns of work zones are unlike from each other. According to the literature review, some work zone devices seemed attractive to work crew are not welcomed by motorists. In order to get the most unbiased results from the survey, participators were selected from a wide range including faculties, engineers, managers of state DOTs, senior statisticians of state department of safety, and coordinators of Governor's Highway Safety Program, etc. Some associate training specialists, IT production specialist, and research analysts were also included in the survey list.

The internet search engine www.google.com was used to get all the participators email address. A work zone safety contact database including 650 contact persons from state departments of transportation, the Federal Highway Administration, LTAP Technology Transfer Centers, and various agencies and associations was available in http://wzsafety.tamu.edu/. These contacts were for the following work zone safety related subjects: accident data, current practices, equipment, laws, outreach activities, research, standards & specifications, and training.

In total, 625 survey forms were distributed to the selected persons at 03/03/2006, with a cover letter explaining the purpose of the survey. Feedbacks returned from 03/04/2006 to 04/10/2006. Finally, 55 survey forms, 8.8% of total survey forms, filled by participators.

Not all the questions in the survey form were filled by attendees. The reason for this issue was that the repliers were not very familiar with all the parts of the survey forms; they just filled the survey forms in which they were best interested and left the other forms or questions blank.

ANOVA, a statistic method, was applied to each question in this chapter. F-test at $\alpha=0.05$ and P-value were given for each survey form. The number of responses, mean rates (MR) and average deviation (AD) were shown in the corresponding tables. Basically, F-test indicates whether the difference between mean rates is statistically significant or not at a given significant level. P-value is the probability that the test statistic will take on a value that is at least as extreme as the observed value of the statistic when the null hypothesis H_0 is true. Here, the null hypothesis H_0 is that all the mean rates of a survey are equal. The number of responses can be used to check how popular a kind of safety concern or countermeasure is, because the participator tried avoiding those which are not in their field. The mean rates express the severity of safety concern, or the effectiveness of a countermeasure as well as a device. Average deviation tells us the warp between different responses.

B.3 Results

B.3.1 Part I

Tables B-1 and B-2 illustrate the result of Form 1.

Table B-1 Results of Work Zone Survey Form 1

Questions	Mean Rates	Ave. Deviation	No. of responses
Q1	4.21	0.82	52
Q2	3.08	1.09	52
Q3	3.33	0.99	52
Q4	3.25	1.03	52

Table B-2 Statistic Results of Work Zone Safety Survey Form 1

F_0	9.377
F critical	2.649
P value	7.8E-06

The possibility of working crew hit by intruding vehicle is thought to be the most concern with the highest mean rate 4.21 and lowest average deviation 0.82. To test if difference of the mean rates among different questions about the safety concerns of crew is statistically significant, a null hypothesis, the mean rates of questions within this form are equal, was made. The F_0 is bigger than F critical, which means the null hypothesis should be rejected and the conclusion that the safety concerns of working crew are significant statistically should be drawn. P-value is very small, which means the test is very powerful.

A participator indicated that the answer to the first question depends on the real situation, if the temporary lane closure uses drums and cones without a positive protection such as temp barrier curb, it will get 5 score, otherwise, it will be assigned 2.

A participator pointed out in the comment area that current OSHA (Occupational Safety & Health Administration) studies indicated the percentage of workers hit by intruding vehicles has been reduced greatly; most workers are hit by their own construction equipments. Another factor from survey answers is that the buffer zone is very important to the safety of work zone crew since it provides response time for workers in case of errant vehicles in the work area.

Tables B-3 and B-4 show the result of Form 2.

Table B-3 Results of Work Zone Safety Survey Form 2

Questions	Mean Rates	Ave. Deviation	No. of responses
Q1	3.58	1.00	52
Q2	2.83	1.18	52
Q3	2.88	1.09	52
Q4	3.87	0.91	46

Table B-4 Statistic Results of Work Zone Safety Survey Form 2

F_0	8.363
F critical	2.650
P value	2.9E-05

Question 4 of Form 2, about the motorist impacts on persons in work zone areas, got the highest score 3.87 and the lowest average deviation 0.91 both; it can be concluded that vehicles passing by a work zone are very easy to impact on persons who may be workers inside work zones or pedestrians happened to present at work zones.

The question about motorist passing by or through work zones being hit by other vehicles got the second highest score 3.58 and second lowest average deviation 1.00 both; some participators believe the collisions and fatalities of multi-vehicle have been considerably more frequent in/around work zone areas. A return email indicated that the biggest concern about Question 2 was dump trucks or other slow moving vehicles entering/leaving roadway.

B.3.2 Part II

Question 5 about advance warning information got the highest score 4.7 and lowest average deviation 0.44 at the same time. It can be concluded that there are little divarications about the importance of advanced warning information for vehicles to the safety of work zones.

The first question concerning the configuration of work zone got the second highest score 4.5 and second lowest deviation 0.56, which made it quite clear that careful configuration before the implementation of work zone is very vital for work zone safety. The number of responses also supports the same conclusion.

Table B-5 Results of Work Zone Safety Survey Form 3

Questions	Mean Rates	Ave. Deviation	No. of responses
Q1	4.50	0.56	50
Q2	4.26	0.71	50
Q3	4.40	0.67	50
Q4	3.82	0.94	50
Q5	4.70	0.44	50
Q6	3.72	1.05	50
Q7	3.92	0.92	50
Q8	4.08	0.73	48

Table B-6 Statistic Results of Work Zone Safety Survey Form 3

F_0	6.551
F critical	2.033
P value	2.5E-07

Concerning MOT's regulation of speed, a participator indicated in his/her comments that significant reduction in speed at work zone will improve safety for workers but can result in a less safe environment for motorists (e.g. increase in rear end collisions when queuing occurs.)

With regarding to question fifth about advance warning information, a significant number of motorists do not notice or heed advance signing, radio communications, etc.; therefore advance warning information is limited to its effectiveness when it is present.

Table B-7 Results of Work Zone Safety Survey Form 4

Questions	Mean Rates	Ave. Deviation	No. of responses
Q1	4.10	0.74	51
Q2	4.63	0.53	51
Q3	4.72	0.43	50
Q4	3.82	0.82	51
Q5	3.52	0.98	50

Table B-8 Statistic Results of Work Zone Safety Survey Form 4

F_0	16.647
F critical	2.408
P value	4.2E-12

Tables B-7 and B-8 give the consequence of Form 4. Question 3 about intoxicant in Form 4 received the highest mean rates 4.72 and the lowest average deviation 0.43. Under the control of intoxicants is totally unacceptable by even all the participators, question concerning careless driver following the question of intoxicant got the mean rates 4.63 and average deviation 0.53.

For the first question, a participator pointed out that if there is a positive protection available at work zones, the speed will not be as much of a factor. However, some attendee deemed that driving too fast and inattention driving are main reasons cited in work zone crashes. As a matter of fact, elderly drivers and teenage wheelers are involved in a lot of incidents provided by a participator.

Table B-9 Results of Work Zone Safety Survey Form 5

Questions	Mean Rates	Ave. Deviation	No. of responses
Q1	2.98	1.03	50
Q2	4.40	0.60	50
Q3	3.70	0.77	50
Q4	3.16	0.91	49
Q5	2.84	1.01	49
Q6	3.54	1.12	50

Table B-10 Statistic Results of Work Zone Safety Survey Form 5

F_0	12.848
F critical	2.245
P value	2.7E-11

The second question about insufficient sight distance received the leading mean rates 4.4 and lowest average deviation 0.6 simultaneously. Question 5 about signal progression gained the lowest mean rates 2.84, which means that traffic signal progression is not an important factor to work zone safety figured by participators.

B.3.3 Part III

Work zone plan, the groundwork of work zone safety, has been justified by participators with the topmost mean rates 4.56 and the minimum deviation 0.54. The seventh question about automated equipment got the lowest mean rate. It is against common sense since automated equipment will replace the human power in order to reduce the exposure of workers at work zone areas.

Table B-11 Results of Work Zone Safety Survey Form 6

Questions	Mean Rates	Ave. Deviation	No. of responses
Q1	4.56	0.54	50
Q2	4.24	0.61	50
Q3	3.86	0.72	49
Q4	4.21	0.63	48
Q5	4.08	0.59	50
Q6	4.14	0.65	50
Q7	3.08	0.85	48
Q8	4.26	0.68	50
Q9	3.32	0.87	50
Q10	4.33	0.69	48

Table B-12 Statistic Results of Work Zone Safety Survey Form 6

F_0	14.254
F critical	1.899
P value	1.7E-20

The result of Form 7 is illustrated in Tables B-13 and B-14. Clearly, the twelfth question about the well designed MOT is of the most importance to work zone safety, with the highest mean rate 4.56 and the minimum average deviation 0.56. Question 1 got the poorest creditability with the mean rate 2.65; many participators complained that they had experimented with series of intrusion alarms, and were given too much false warnings.

Table B-13 Results of Work Zone Safety Survey Form 7

Questions	Mean Rates	Ave. Deviation	No. of responses
Q1	2.65	0.86	23
Q2	2.73	0.76	22
Q3	2.70	0.82	20
Q4	2.69	0.93	16
Q5	3.23	1.05	30
Q6	3.51	0.70	49
Q7	3.18	0.69	27
Q8	2.88	0.77	17
Q9	3.33	0.82	30
Q10	3.80	0.59	41

Q11	3.38	0.83	34
Q12	4.56	0.56	41

Table B-14 Statistic Results of Work Zone Safety Survey Form 7

F_0	10.166
F critical	1.817
P value	4.7E-16

The number of responses is an interesting phenomenon in Form 7, with the highest 49 and lowest 16; Question 6 about the speed display trailer received the highest responses while SonoBlaster accounted for the minimum one. It seemed that many states applied speed display trailer while the new commercial product SonoBlaster had been tested only in a few states. The attendees did not give too much attention to the panic button or safety clothing neither.

Table B-15 Results of Work Zone Safety Survey Form 8

Questions	Mean Rates	Ave. Deviation	No. of responses
Q1	4.43	0.61	46
Q2	2.47	1.35	19
Q3	3.32	1.02	37
Q4	2.94	1.02	17
Q5	3.90	0.60	31
Q6	3.78	0.66	28
Q7	3.33	1.05	21
Q8	2.55	1.10	20
Q9	2.12	1.02	16
Q10	2.25	1.12	16
Q11	4.05	0.62	40
Q12	3.26	0.95	27

Table B-16 Statistic Results of Work Zone Safety Survey Form 8

F_0	11.542
F critical	1.820
P value	5.2E-18

Consequences of Form 8 are revealed in Tables B-15 and B-16. The question about truck mounted attenuator, a protective device, received the highest mean rates 4.43 and lowest deviation 0.61 at the same time; it also got the top number of responses.

Robotic highway safety marker mentioned in Question 9 gained the lowest mean rate and number of responses both.

Table B-17 Results of Work Zone Safety Survey Form 9

Questions	Mean Rates	Ave. Deviation	No. of responses
Q1	3.97	0.70	39
Q2	3.80	0.78	44
Q3	4.41	0.59	44
Q4	4.05	0.62	40
Q5	3.67	0.81	33
Q6	4.08	0.66	47
Q7	3.77	0.84	26
Q8	3.17	1.12	23
Q9	4.52	0.62	46

Table B-18 Statistic Results of Work Zone Safety Survey Form 9

F_0	6.225
F critical	1.966
P value	1.7E-07

Tables B-17 and B-18 display the outcomes of Form 9. The pavement marking and the reflector got the top mean rate and the number of responses. And the guiding device arrow panel has the minimum average deviation. The mean rate of opposing traffic lane divider is comparatively high in the list of guiding devices, but one participator pointed out that they had used them in a number of work zones in the past but had to suspend the practice (around 1995) due to the number of crossover crashes. The problem is maybe caused by the opposing traffic lane divider itself or owing to the lack of enforcement.

APPENDIX C WORK ZONE SAFETY SURVEY FORMS

Form 1	Safety Concerns for Working Crew Inside Work Zone (Please Check or Type "x" in the Boxes on the Right Side)	Not Concerned					Most Concerned
		0	1	2	3	4	5
1	How concerned are you about the working crew being hit by intruding vehicle?						
2	How concerned are you about the working crew being hit by construction vehicle?						
3	How concerned are you about the working crew being injured by construction equipment?						
4	How concerned are you about the crew working in an unsafe working conditions, such as live power lines, steep inclines, slip & fall hazards, etc.?						
Others/ Comments							

Form 2	Safety Concerns for Traveling Motorists Passing Work Zone (Please Check or Type "x" in the Boxes on the Right Side)	Not Concerned					Most Concerned
		0	1	2	3	4	5
1	How concerned are you about motorist passing by or through work zone being hit by other vehicle?						
2	How concerned are you about motorist passing by or through work zone being hit by construction vehicles?						
3	How concerned are you about motorist passing by or through work zone being impacted by equipment?						
4	How concerned are you about motorist passing by or through work zone impacts person?						
Others/ Comments							

Form 3	Contributing Factors to Work Zone Safety (Work Zone Related) (Please Check or Type “x” in the Boxes on the Right Side)	Not Significant			Most Significant		
		0	1	2	3	4	5
1	If the work zone has inadequate configuration, how significant is that to safety?						
2	If the separation between work zone and passing vehicles is insufficient, how significant is that to safety?						
3	If MOT* fails to convey needed information, how significant is that to safety?						
4	If MOT fails to alter traffic speed as desired, how significant is that to safety?						
5	If no advance warning information for vehicles, how significant is that to safety?						
6	If no physical barriers between crews and construction vehicles, how significant is that to safety?						
7	If no protective devices such as helmet and reflective vest for workers, how significant is that to safety?						
8	If no escape area available when a vehicle intrudes, how significant is that to safety?						
Others/ Comments							

Form 4	Contributing Factors to Work Zone Safety (by Passing Motorists) (Please Check or Type "x" in the Boxes on the Right Side)	Not Significant					Most Significant
		0	1	2	3	4	5
1	What significance does speeding by passing motorist have on work zone safety?						
2	What significance does careless driving by passing motorist have on work zone safety?						
3	What significance does motorist under influence of intoxicants have on work zone safety?						
4	What significance does inexperienced driver have on work zone safety?						
5	What significance does over confidence in driving have on work zone safety?						
Others/ Comments							

Form 5	Contributing Factors to Work Zone Safety (by Others) (Please Check or Type "x" in the Boxes on the Right Side)	Not Significant			Most Significant		
		0	1	2	3	4	5
1	How significant is inconspicuous presence of law enforcement to work zone safety?						
2	How significant is insufficient sight distance to work zone safety?						
3	How significant is inclement weather conditions such as snow, ice, or rain to work zone safety?						
4	How significant is dust and noise to work zone safety?						
5	How significant is traffic signal progression to work zone safety?						
6	How significant is congestion to work zone safety?						
Others/ Comments							

Form 6	Measures to Improve Work Zone Safety (General) (Please Check or Type “x” in the Boxes on the Right Side)	Not Effective					Most Effective
		0	1	2	3	4	5
1	How effective is careful work zone planning before deployment to work zone safety?						
2	How effective is sound work zone geometry design to work zone safety?						
3	How effective is access management near work zone area to work zone safety?						
4	How effective is strictly work zone traffic control to work zone safety?						
5	How effective is flagger to work zone safety?						
6	How effective is barriers to work zone safety?						
7	How effective is automated equipment which is applied to replace human power to work zone safety?						
8	How effective is police car with flashing light on and radar active to work zone safety?						
9	How effective is broadcasting work zone information to public to work zone safety?						
10	How effective is plentiful and strict enforcement to work zone safety?						
Others/ Comments							

Form 7	Measures (Warning Devices) (Please Check or Type “x” in the Boxes on the Right Side)	Unknown	Not Effective Most Effective						Applied in Your State	
			0	1	2	3	4	5	Yes	No
1	How effective is infrared intrusion alarms to work zone safety?									
2	How effective is microwave intrusion alarms to work zone safety?									
3	How effective is pneumatic tube alarms to work zone safety?									
4	How effective is SonoBlaster to work zone safety?									
5	How effective is radar drones to work zone safety?									
6	How effective is speed display trailer to work zone safety?									
7	How effective is radio transmitter to work zone safety?									
8	How effective is panic button type safety clothing to work zone safety?									
9	How effective is flashing STOP/SLOW paddle to work zone safety?									
10	How effective is portable traffic signals to work zone safety?									
11	How effective is portable rumble strip to work zone safety?									
12	How effective is well designed MOT to work zone safety?									
Others/ Comments										

Form 8	Measures (Protective Devices) (Please Check or Type "x" in the Boxes on the Right Side)	Unknown	Not Effective			Most Effective			Applied in Your State	
			0	1	2	3	4	5	Yes	No
1	How effective is truck mounted attenuator to work zone safety?									
2	How effective is remotely driven vehicle to work zone safety?									
3	How effective is water-filled barrier to work zone safety?									
4	How effective is balsi beam to work zone safety?									
5	How effective is portable crash cushion trailer to work zone safety?									
6	How effective is quad guard system to work zone safety?									
7	How effective is alternative worker vest to work zone safety?									
8	How effective is cone shooter to work zone safety?									
9	How effective is **robotic highway safety marker** to work zone safety?									
10	How effective is pavement sealer to work zone safety?									
11	How effective is vehicle visibility Improvement to work zone safety?									
12	How effective is temporary stop bar to work zone safety?									
Others/ Comments										

Form 9	Measures (Guiding Devices) (Please Check or Type "x" in the Boxes on the Right Side)	Unknown	Not Effective Most Effective						Applied in Your State	
			0	1	2	3	4	5	Yes	No
1	How effective is larger/fluorescent sign to work zone safety?									
2	How effective is fluorescent orange roll-up sign to work zone safety?									
3	How effective is arrow panel to work zone safety?									
4	How effective is opposing traffic lane divider to work zone safety?									
5	How effective is directional indicator barricade to work zone safety?									
6	How effective is portable changeable message sign to work zone safety?									
7	How effective is queue length detector to work zone safety?									
8	How effective is all terrain sign and stand to work zone safety?									
9	How effective is pavement marking and reflector to work zone safety?									
Others/ Comments										

APPENDIX D VARIABLES AND CODES OF WORK ZONE FATAL CRASH

Table D-1 Variable of Work Zone Fatal Crash

Variable	Description	Type
YEAR	The year of work zone fatal crash	Nominal
TIME	The time of work zone fatal crash	Nominal
AGE	The age of driver at fault	Ordinal
VEHMOVEMENT	The movement of vehicle at fault before accident	Nominal
CRASHTYPE	The type of crash	Nominal
VEHICLETYPE	Heavy vehicle involved?	Nominal
FUNCLASS	The function of roads	Nominal
TRWAYCHR	Road Characteristics (level / curve?)	Nominal
MAXSPEED	The speed limit	Continue
SECTADT	The AADT of the section of work zones	Continue
TYPESUR	The type of road surface	Nominal
SITELOCA	Site Location	Nominal
LIGHTCONDITION	Light condition	Nominal
WEATHERCONDITION	Weather condition	Nominal
ROADSURFACE	Road surface condition	Nominal
VISION	Vision Obstructed	Nominal
RDACCESS	Access control type	Nominal
SURWIDTH	The width of roads	Continue
CONTRIBUTINGFACTORS	The contributing factors	Nominal
TRAFCONT	Traffic Control	Nominal

Table D-2 Codes for TIME

Codes	Description
1	6:00-10:00
2	10:00-16:00
3	16:00-20:00
4	20:00-6:00

Table D-3 Codes for AGE

Codes	Description
1	<19
2	20-24
3	25-34
4	35-44
5	45-54
6	55-64
7	>65

Table D-4 Codes for VEHMOVEMENT

Codes	Description
01	STRAIGHT AHEAD
02	SLOWING/STOPPED/STALLED
03	MAKING LEFT TURN
04	BACKING
05	MAKING RIGHT TURN
06	CHANGING LANES
07	ENTERING/LEAVING PARKING SPACE
08	PROPERLY PARKED
09	IMPROPERLY PARKED
10	MAKING U-TURN
11	PASSING
12	DRIVERLESS OR RUNAWAY VEH.
77	ALL OTHERS
88	UNKNOWN

Table D-5 Codes for CRASHTYPE

Codes	Description
01	COLL. W/MV IN TRANS. REAR-END
02	COLL. W/MV IN TRANS. HEAD-ON
03	COLL. W/MV IN TRANS. ANGLE
04	COLL. W/MV IN TRANS. LFT-TURN
05	COLL. W/MV IN TRANS. RGT-TURN
06	COLL. W/MV IN TRANS. SIDESWIP
07	COLL. W/MV IN TRANS. BAKD INTO
08	COLL. W/PARKED CAR
09	COLLISION WITH MV ON ROADWAY
10	COLL. W/ PEDESTRIAN
11	COLL. W/ BICYCLE
12	COLL. W/ BICYCLE (BIKE LANE)
13	COLL. W/ MOPED
14	COLL. W/ TRAIN
15	COLL. W/ ANIMAL
16	MV HIT SIGN/SIGN POST
17	MV HIT UTILITY POLE/LIGHT POLE
18	MV HIT GUARDRAIL
19	MV HIT FENCE
20	MV HIT CONCRETE BARRIER WALL
21	MV HIT BRDGE/PIER/ABUTMNT/RAIL
22	MV HIT TREE/SHRUBBERY
23	COLL. W/CONSTRCTN BARRICDE/SGN
24	COLL. W/TRAFFIC GATE
25	COLL. W/CRASH ATTENUATORS
26	COLL. W/FIXED OBJCT ABOVE ROAD
27	MV HIT OTHER FIXED OBJECT
28	COLL. W/MOVEABLE OBJCT ON ROAD
29	MV RAN INTO DITCH/CULVERT
30	RAN OFF ROAD INTO WATER
31	OVERTURNED
32	OCCUPANT FELL FROM VEHICLE
33	TRACTOR/TRAILER JACKNIFED
34	FIRE
35	EXPLOSION
36	DOWNHILL RUNAWAY
37	CARGO LOSS OR SHIFT
38	SEPARATION OF UNITS
39	MEDIAN CROSSOVER
77	ALL OTHER (EXPLAIN)

Table D-6 Codes for VEHICLETYPE

Codes	Description
00	UNKNOWN/NOT CODED
01	AUTOMOBILE
02	PASSENGER VAN
03	PICKUP/LIGHT TRUCK (2 REAR TIR)
04	MEDIUM TRUCK (4 REAR TIRES)
05	HEAVY TRUCK (2 OR MORE REAR AX)
06	TRUCK TRACTOR (CAB)
07	MOTOR HOME (RV)
08	BUS (DRIVER + 9 - 15 PASS)
09	BUS (DRIVER + > 15 PASS)
10	BICYCLE
11	MOTORCYCLE
12	MOPED
13	ALL TERRAIN VEHICLE
14	TRAIN
15	LOW SPEED VEHICLE
77	OTHER
88	PEDESTRIAN NO VEHICLE

Table D-7 Codes for TRWAYCHR

Codes	Description
1	STRAIGHT-LEVEL
2	STRAIGHT-UPGRADE/DOWNGRADE
3	CURVE-LEVEL
4	CURVE-UPGRADE/DOWNGRADE

Table D-8 Codes for TYPESUR

Codes	Description
01	SLAG/GRAVEL/STONE
02	BLACKTOP
03	BRICK/BLOCK
04	CONCRETE
05	DIRT
77	ALL OTHER

Table D-9 Codes for SITELOCA

Codes	Description
01	NOT AT INTERSECTION/RRX/BRIDGE
02	AT INTERSECTION
03	INFLUENCED BY INTERSECTION
04	DRIVEWAY ACCESS
05	RAILROAD CROSSING
06	BRIDGE
07	ENTRANCE RAMP
08	EXIT RAMP
09	PARKING LOT/TRAFFIC WAY
10	PARKING LOT AISLE OR STALL
11	PRIVATE PROPERTY
12	TOLL BOOTH
13	PUBLIC BUS STOP ZONE
77	ALL OTHER

Table D-10 Codes for LIGHTCONDITION

Codes	Description
01	DAYLIGHT
02	DUSK
03	DAWN
04	DARK (STREET LIGHT)
05	DARK (NO STREET LIGHT)
88	UNKNOWN

Table D-11 Codes for WEATHERCONDITION

Codes	Description
01	CLEAR
02	CLOUDY
03	RAIN
04	FOG
77	ALL OTHER
88	UNKNOWN

Table D-12 Codes for ROADSURFACE

Codes	Description
01	DRY
02	WET
03	SLIPPERY
04	ICY
77	ALL OTHER
88	UNKNOWN

Table D-13 Codes for VISION

Codes	Description
01	VISION NOT OBSCURED
02	INCLEMENT WEATHER
03	PARKED/STOPPED VEHICLE
04	TREES/CROPS/BUSHES
05	LOAD ON VEHICLE
06	BUILDING/FIXED OBJECT
07	SIGNS/BILLBOARDS
08	FOG
09	SMOKE
10	GLARE
77	ALL OTHER (EXPLAIN)

Table D-14 Codes for RDACCESS

Codes	Description
1	FULL
2	PARTIAL
3	NONE

Table D-15 Codes for CONTRIBUTINGFACTORS

Codes	Description
01	NO IMPROPER DRIVING/ACTION
02	CARELESS DRIVING
03	FAILED TO YEILD RIGHT OF WAY
04	IMPROPER BACKING
05	IMPROPER LANE CHANGE
06	IMPROPER TURN
07	ALCOHOL-UNDER INFLUENCE
08	DRUGS-UNDER INFLUENCE
09	ALCOHOL DRUGS-UNDER INFLUENCE
10	FOLLOWED TOO CLOSELY
11	DISREGARDED TRAFFIC SIGNAL
12	EXCEEDED SAFE SPEED LIMIT
13	DISREGARDED STOP SIGN
14	FAILED TO MAINTAIN EQUIP/VEHIC
15	IMPROPER PASSING
16	DROVE LEFT OF CENTER
17	EXCEEDED STATED SPEED LIMIT
18	OBSTRUCTING TRAFFIC
19	IMPROPER LOAD
20	DISREGARDED OTHER TRAFFIC CONT
21	DRIVING WRONG SIDE/WAY
22	FLEEING POLICE
23	VEHICLE MODIFIED
24	DRIVER DISTRACTION
77	ALL OTHER (EXPLAIN)

Table D-16 Codes for TRAFCONT

Codes	Description
01	NO CONTROL
02	SPECIAL SPEED ZONE
03	SPEED CONTROL SIGN
04	SCHOOL ZONE
05	TRAFFIC SIGNAL
06	STOP SIGN
07	YIELD SIGN
08	FLASHING LIGHT
09	RAILROAD SIGNAL
10	OFFICER/GUARD/FLAGMAN
11	POSTED NO U-TURN
12	NO PASSING ZONE
77	ALL OTHER

APPENDIX E DATA FIELDS OF THE DATA TABLES

Table E-1 Data Fields of SUMMARY Table

Index	Field Name	Type	Size	Description
1	CRASHNUM	CHAR	10	CRASH ID
2	CRASHDTE	CHAR	10	CRASH DATE
3	TIMEOFAC	CHAR	5	CRASH TIME
4	SRNUM	CHAR	10	STATE ROAD ID
5	CONTYDOT	CHAR	5	DEPT. OF TRANS. COUNTY
6	DOTFORM	YES/NO		DOT FORM
7	IMPACTSOFWZ	CHAR	2	IMPACTS OF WORK ZONE
8	LANECLOSED	CHAR	2	LANE CLOSURE METHOD
9	HARMEVN1_AT_FAULT	CHAR	2	HARMFUL EVENT
10	CONTCAU_AT_FAULT	CHAR	2	CONTRIBUTING CAUSE
11	UTILITYWORK	YES/NO		UTILITY WORK
12	RECONCILIATION	CHAR	2	RECONCILIATION FIELDS BETWEEN NATIONAL DATABASE (FARS) AND DOT DATABASE (CAR)
13	RECONEXPLANATION	CHAR	255	EXPLANATION
14	DESCRIPTION	MEMO		DESCRIPTION
15	CRASH_INFO	YES/NO		

Table E-2 Data Fields of CRASH Table

Index	Field NAME	Type	Size	Description
1	CARNUM	CHAR	9	CRASH NUMBER
2	CRASHDTE	DATE	10	DATE OF CRASH
3	TIMEOFAC	CHAR	4	TIME OF ACCIDENT (MILITARY)
4	DAYOWEEK	CHAR	1	DHSMV DAY OF WEEK
5	MANDIST	CHAR	2	MANAGING DISTRICT
6	CONTYDOT	CHAR	2	DEPT. OF TRANS. COUNTY
7	SECTNMBR	CHAR	3	SECTION OF ROAD WITHIN COUNTY
8	SUBSECT	CHAR	3	SUB-SECTION OF ROAD WITHIN CO.
9	LOCMP	DEC	7	CRSH LOC FINAL MP ON ROADWAY
10	LOCNODE	CHAR	5	FINAL REF NODE# CRASH LOC
11	LOCDIST	DEC	8	CRSH LOC FINAL DIST REL NODE#
12	LOCMEACD	CHAR	2	FINAL MEAS CDE - CRSH LOC
13	LOCDIRCD	CHAR	1	CRASH LOCATION - FINAL DIR
14	ROUTEID	CHAR	8	ROUTE/ROAD FULL ID NUMBER
15	USRTNO	CHAR	8	US ROUTE NUMBER
16	ACCISEV	CHAR	1	ACCIDENT SEVERITY CODE
17	SITELOCA	CHAR	2	SITE LOCATION
18	ACCSIDRD	CHAR	1	ACCIDENT SIDE OF ROAD
19	ACCLANE	CHAR	1	LANE OF ACCIDENT CODE
20	TYP_DR_ACDNT_CD	CHAR	1	TYPE DRIVER ACCIDENT CODE
21	RDSURFCD	CHAR	2	ROAD SURFACE CONDITION
22	LGHTCOND	CHAR	2	LIGHTING CONDITION
23	WEATCOND	CHAR	2	WEATHER CONDITION
24	TRWAYCHR	CHAR	2	TRAFFICWAY CHARACTER
25	LANDUSE	CHAR	1	PREVAILING TYPE OF LAND USE
26	TYPESUR	CHAR	2	SURFACE TYPE
27	TRAFCONT	CHAR	2	TRAFFIC CONTROL
28	TRAFCON2	CHAR	2	TRAFFIC CONTROL CODE-2ND OCC.
29	UNKNOWN			
30	ROADCOND1	CHAR	2	ROAD CONDITIONS TIME OF CRSH 1ST
31	ROADCOND2	CHAR	2	ROAD CONDITIONS TIME OF CRSH 2ND
32	VISION_OBS1	CHAR	2	VISION OBSTRUCTED 1ST
33	VISION_OBS2	CHAR	2	VISION OBSTRUCTED 2ND
34	FAHWYSYS	CHAR	1	FEDERAL HIGHWAY SYSTEM

				CODE
35	FUNCLASS	CHAR	2	HWY. FUNCTIONAL CLASS CODE
36	CRRATECD	CHAR	2	CRASH RATES CALC CATEGORY CDE
37	RDACCESS	CHAR	1	ACCESS CONTROL TYPE
38	PLACECD	CHAR	4	CENSUS PLACE CODE
39	SURWIDTH	CHAR	3	THRU PAVEMENT SURFACE WIDTH
40	SHLDTYPE	CHAR	1	HIGHWAY SHOULDER TYPE
41	SHLDTYP2	CHAR	1	HIGHWAY SHOULDER TYPE TWO
42	SHLDTYP3	CHAR	1	HIGHWAY SHOULDER TYPE
43	SLDWIDTH	DEC	4	HIGHWAY SHOULDER WIDTH
44	SHLDWTH2	DEC	4	HIGHWAY SHOULDER WIDTH
45	SHLDWTH3	DEC	4	HIGHWAY SHOULDER WIDTH
46	MEDWIDTH	CHAR	3	HIGHWAY MEDIAN WIDTH
47	HRZDGCRV	CHAR	6	HORIZONTAL DEGREE OF CURVE
48	MAXSPEED	CHAR	3	MAXIMUM POSTED SPEED LIMIT
49	TYPEPARK	CHAR	1	TYPE OF ROADWAY PARKING
50	SECTADT	CHAR	6	SECTION AVG.ANNUAL DAILY TRAFF
51	AVGTFACT	DEC	5	RDWY.SECTION AVG. "T" FACTOR
52	SKTRESNM	NUM	5	SKID TEST RESULT NUMBER
53	ALCINVCD	CHAR	1	ALCOHOL INVOLVED IN ACCIDENT CODE
54	HARMEVN1_AT_FAULT	CHAR	2	FIRST HARMFUL EVENT AT FAULT DRIVER
55	HARMEVN2_AT_FAULT	CHAR	2	2ND HARMFUL EVENT AT FAULT DRIVER
56	ACFMSECT_AT_FAULT	CHAR	2	FORM SECTION NUMBER AT FAULT
57	VEHFLTCD_AT_FAULT	CHAR	1	VEHICLE FAULT CODE AT FAULT DRIVER
58	VEHTYPE_AT_FAULT	CHAR	2	TYPE OF VEHICLE AT FAULT DRIVER
59	VEHUSE_AT_FAULT	CHAR	2	VEHICLE USE AT FAULT DRIVER
60	POINTIM_AT_FAULT	CHAR	2	POINT OF IMPACT AT FAULT DRIVER
61	VEHMOVE_AT_FAULT	CHAR	2	VEHICLE MOVEMENT AT FAULT DRIVER
62	TRAVDIR_AT_FAULT	CHAR	1	DIRECTION OF TRAVEL AT FAULT DRIVER
63	CONTCAU_AT_FAULT	CHAR	2	CONTRIBUTING CAUSE AT FAULT DRIVER

64	AGE3_AT_FAULT	CHAR	3	AGE - 3 POSITIONS AT FAULT DRIVER
65	ALDGUSE_AT_FAULT	CHAR	1	DHSMV ALCOHOL/DRUG CODE AT FLT DRVR
66	ACFMSECT_NEXT_VHCL	CHAR	2	NEXT FORM SECTION NUMBER
67	VEHFLTCD_NEXT_VHCL	CHAR	1	VEHICLE FAULT CODE NEXT DRIVER
68	VEHTYPE_NEXT_VHCL	CHAR	2	TYPE OF VEHICLE NEXT DRIVER
69	VEHUSE_NEXT_VHCL	CHAR	2	VEHICLE USE NEXT DRIVER
70	POINTIM_NEXT_VHCL	CHAR	2	POINT OF IMPACT NEXT DRIVER
71	VEHMOVE_NEXT_VHCL	CHAR	2	VEHICLE MOVEMENT NEXT DRIVER
72	TRAVDIR_NEXT_VHCL	CHAR	1	DIRECTION OF TRAVEL NEXT DRIVER
73	CONTCAU_NEXT_VHCL	CHAR	2	CONTRIBUTING CAUSE NEXT DRIVER
74	AGE3_NEXT_VHCL	CHAR	3	AGE - 3 POSITIONS NEXT DRIVER
75	ALDGUSE_NEXT_VHCL	CHAR	1	DHSMV ALCOHOL/DRUG CODE NEXT DRIVER
76	TOT_CRSH_DMG_AMT	NUM	12	TOTAL CRASH DAMAGE AMOUNT
77	TOT_VHCL_DMG_AMT	NUM	12	TOTAL VEHICLE DAMAGE AMOUNT
78	TOT_PROP_DMG_AMT	NUM	12	TOTAL PROPERTY DAMAGE AMOUNT
79	TOT_OF_PERS_NUM	NUM	5	TOTAL NUMBER OF PERSONS
80	TOT_OF_DR_NUM	NUM	5	TOTAL OF DRIVER NUMBER
81	TOT_OF_VHCL_NUM	NUM	5	TOTAL NUMBER OF VEHICLES
82	TOT_OF_FATL_NUM	NUM	5	TOTAL NUMBER OF FATALITY
83	TOTNONTRAFFATL_NUM	NUM	5	TOTAL NONTRAFFIC FATALITY NUMBER
84	TOT_OF_INJR_NUM	NUM	5	TOTAL NUMBER OF INJURIES
85	TOT_OF_PEDST_NUM	NUM	5	TOTAL NUMBER OF PEDESTRIANS
86	TOTOF_PEDLCYCL_NUM	NUM	5	TOTAL OF PEDAL CYCLIST NUMBER

Table E-3 Data Fields of MOT Table

Index	Field Name	Type	Size	Description
1	MOT_ID	AUTONUM		MOT DATA ID
2	CRASHNUM	CHAR	10	CRASH ID
3	CRASHDTE	CHAR	10	CRASH DATE
4	TIMEOFAC	CHAR	5	CRASH TIME
5	SRNUM	CHAR	8	STATE ROAD ID
6	MANDIST	CHAR	2	DISTRICT NUMBER
7	CONTYDOT	CHAR	5	DEPT. OF TRANS. COUNTY
8	SECTNMBR	CHAR	3	ROAD SECTION NUMBER
9	LOCMP	CHAR	7	MILESPOST
10	FINNUM	CHAR	20	FIN PROJECT NUMBER
11	FATAL	YES/NO		FATALITY
12	WZLOCATION	CHAR	3	WORK ZONE LOCATION
13	OTHERCRASH	YES/NO		HAVE THERE BEEN OTHER CRASHES IN THE VICINITY OF THE WORK ZONE?
14	OTHERCRASHDATE_1	CHAR	10	OTHER CRASH DATE 1
15	OTHERCRASHDATE_2	CHAR	10	OTHER CRASH DATE 2
16	OTHERCRASHDATE_3	CHAR	10	OTHER CRASH DATE 3
17	OTHERCRASHDATE_4	CHAR	10	OTHER CRASH DATE 4
18	RECOMMENHANCE	MEMO		RECOMMENDED ENHANCEMENTS

APPENDIX F FLORIDA WORK ZONE CRASH DATABASE USER MANUAL

F.1 LOGIN/LOGOUT

Florida work zone crash database (WZCD) runs as a web application on the FDOT intranet system. To access this service, users need to get authorization from system administrators via the assignment of a user name and a password. Different user names may have different access privileges. Figure F-1 shows the login page which prompts users for a user name and a password.

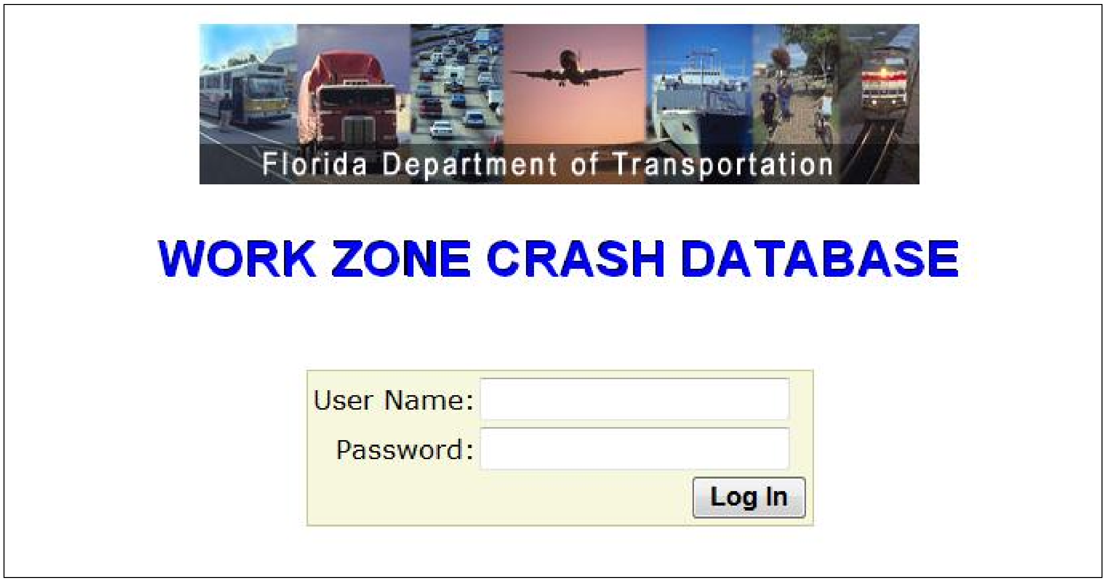


Figure F-1 Login Page

After entering username and password, the main page will display to users. This page provides the starting point to access four major functions: query, analysis, update, and manage (Figure F-2).

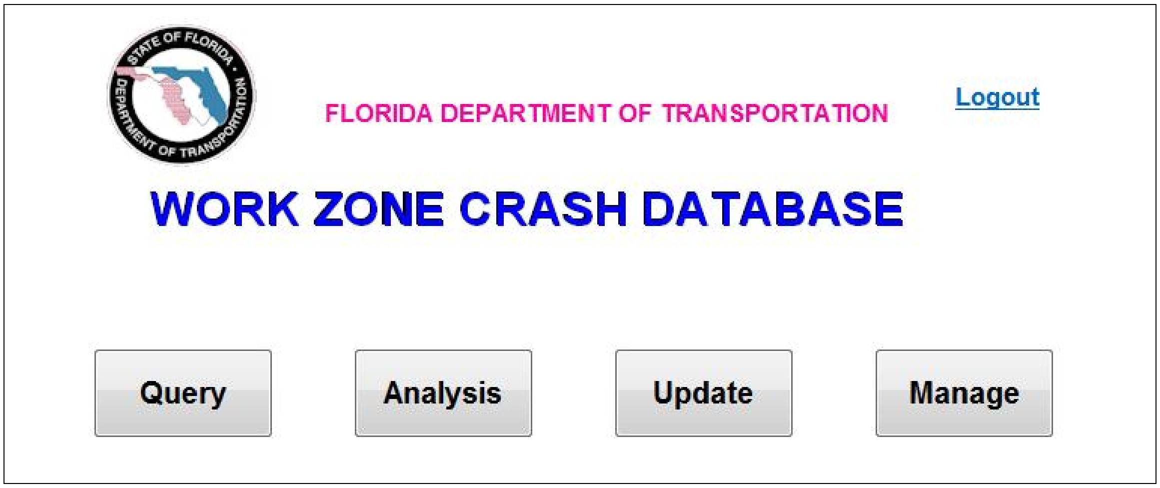


Figure F-2 Main Page

To quite the service, users can click the “Logout” hyperlink on the right upper corner of each page. In addition, when the system is idled for more than half hour, users will be prompted to re-login for resuming the session.

F.2 QUERY FUNCTION

By clicking the "Query" button on the main page, users can access the query page on which two query functions are provided: conditional query and code query (Figure F-3).

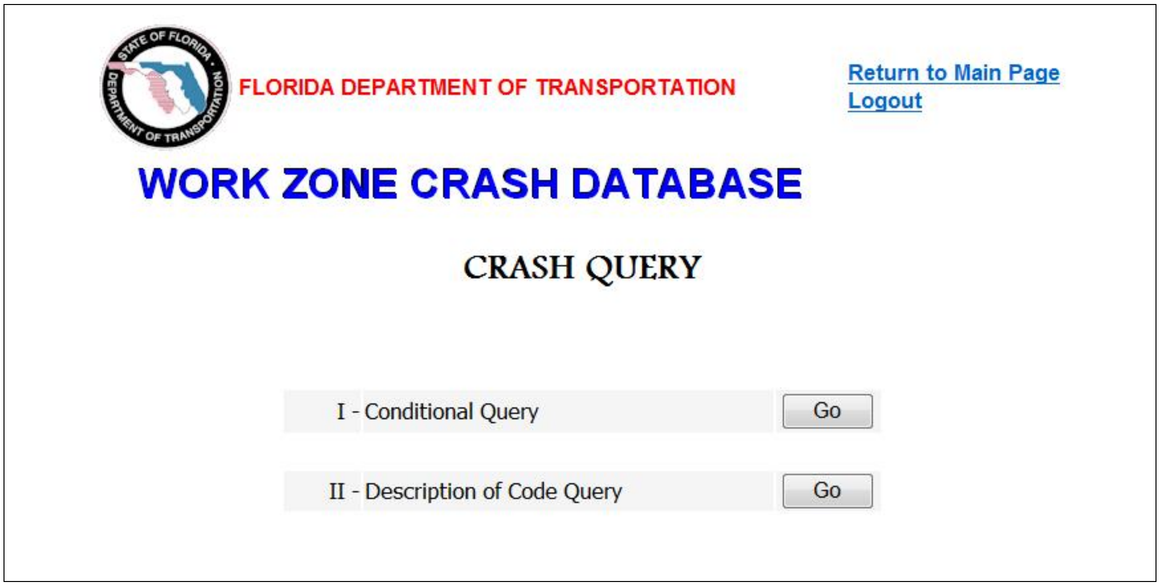


Figure F-3 Query Page

F.2.1 Conditional Query

To perform a conditional query, users should click the "Go" button corresponding to conditional query on the query page. This will bring up the conditional query page as shown in Figure F-4. On the page, users can specify query conditions and review the query results. The steps for specifying query conditions are given as follows:

- Specify Time range, Road ID, and Milepost range in the general condition category. The last two items are optional fields which could have blank values.

- Specify values of Variable 1 and Variable2. To perform this activity, users should select a variable from the variable list after indicating a variable level at first; after then specify values of the selected variable.

- *Note: If no value of a variable or all values of it are selected, the variable will have no influence on the data query.*
- Indicate the logic relationship between the two variables. The default value is "OR".
- After specifying query conditions, the query request is sent to server by clicking the "Submit" button on the conditional query page. The result will display on the conditional query result page (Figure F-5) for reviewing. In addition, users can click the "Download" button on the result page to download the query result to client computer as a tab-separated text file which can be opened with MS Excel.

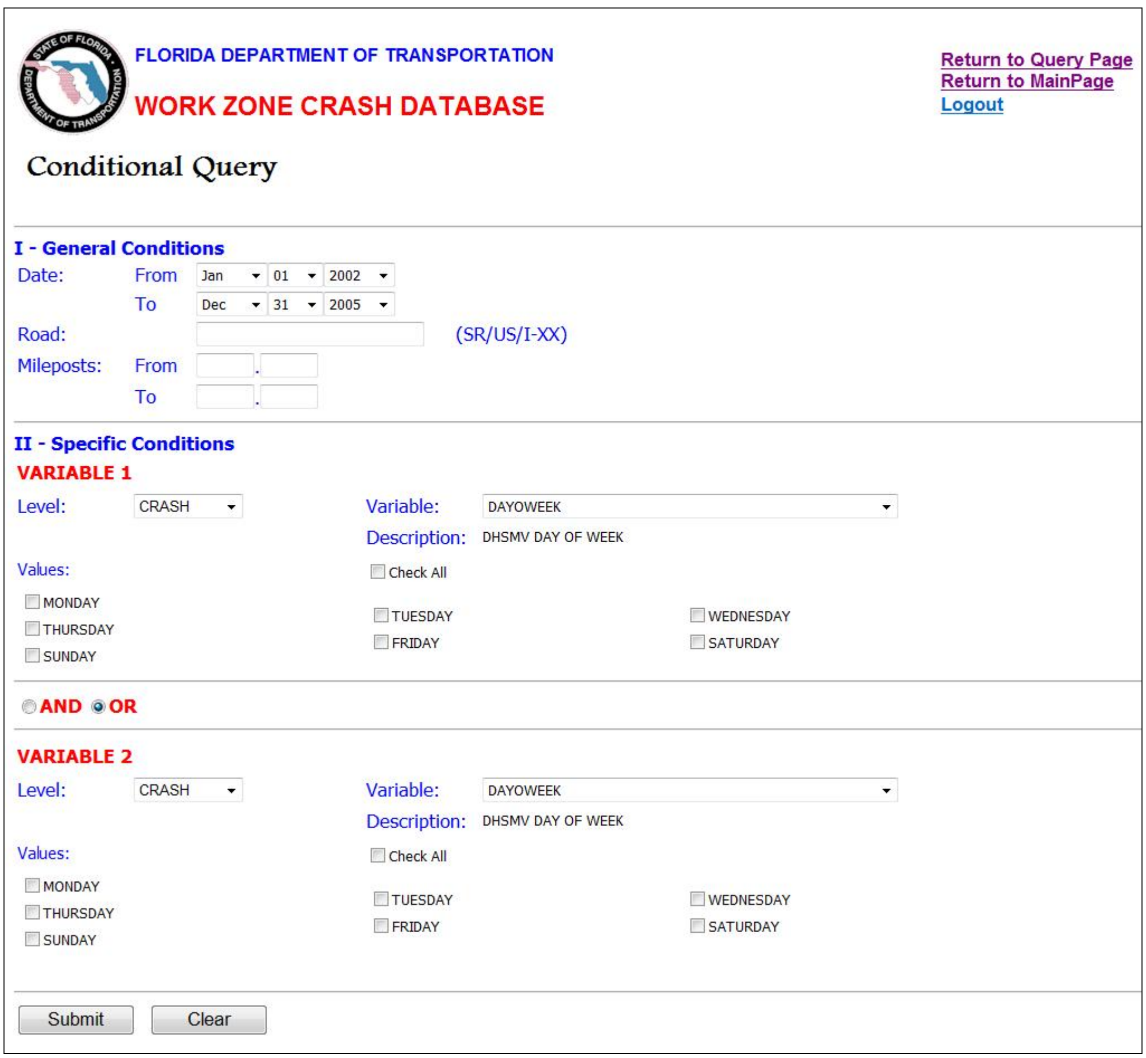


Figure F-4 Conditional Query Page

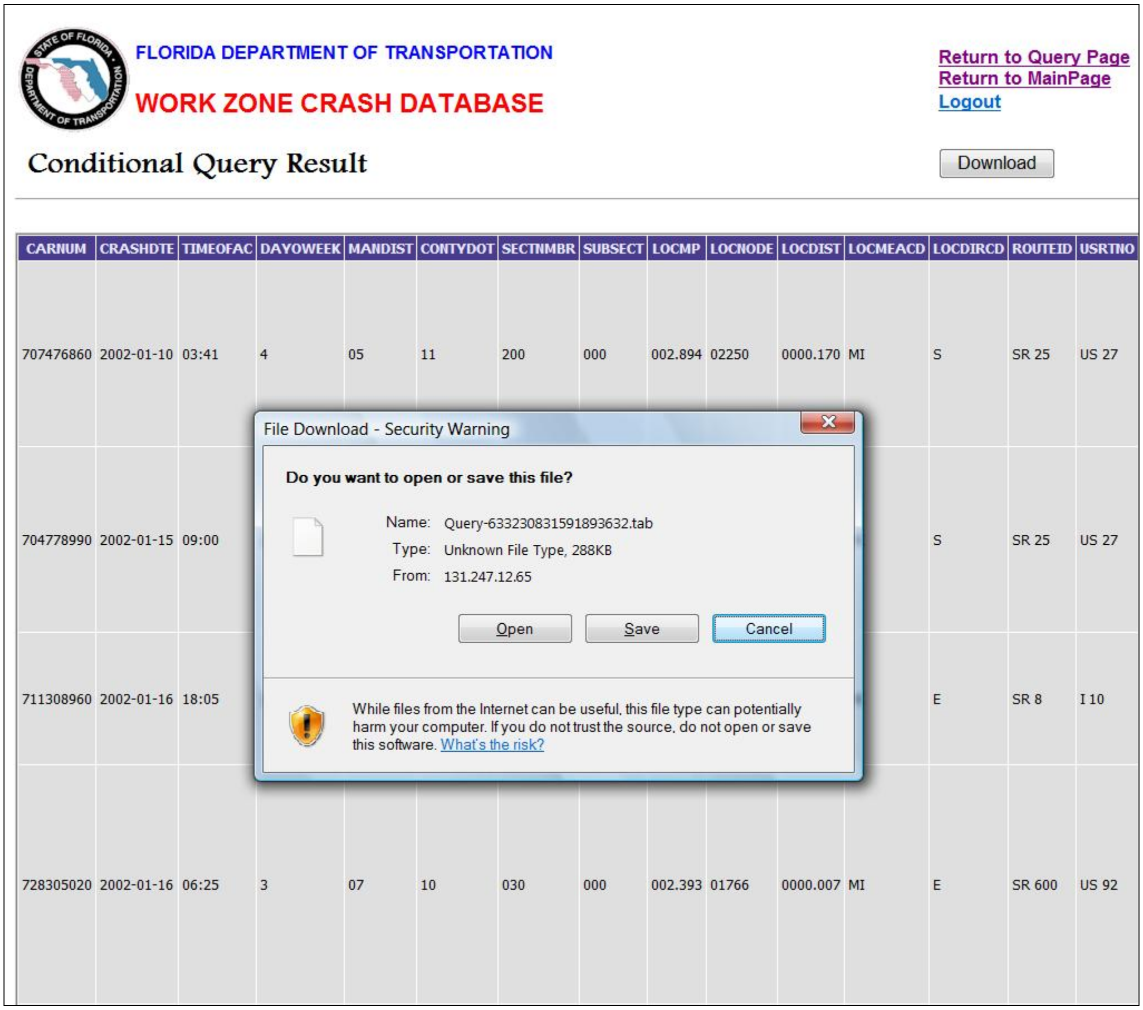


Figure F-5 Condition Query Result Page

F.2.2 Code Query

For helping users to read the query result, the system provides two kinds of code query functions to list all codes and their corresponding descriptions of a certain variable. The fist function shown in Figure F-6. Users select a variable after indicating a variable level, and then the list of code descriptions of the selected variable will display on the page. If the variable name is unknown, users can search the codes based on keywords. As shown in Figure F-7, users input some keywords into the "Keyword" textbox followed by clicking the "Submit" button. After then all possible variables are given in the variable list. Users can select the proper variable from the list, and review the corresponding code descriptions.

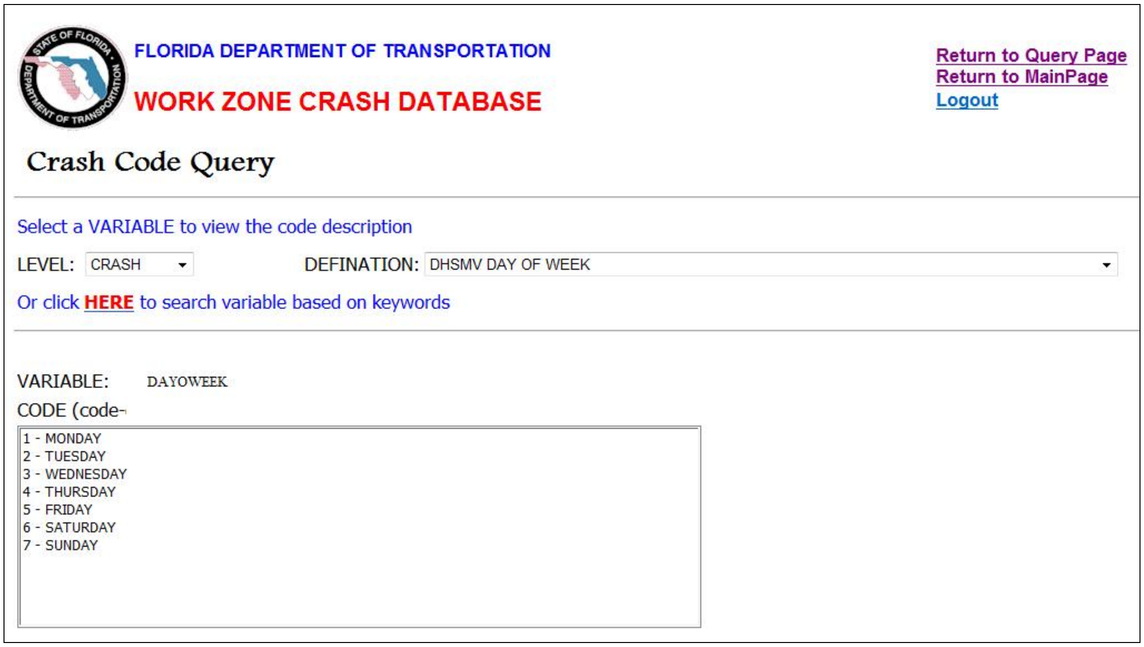


Figure F-6 Code Query Page (Selecting Variable)

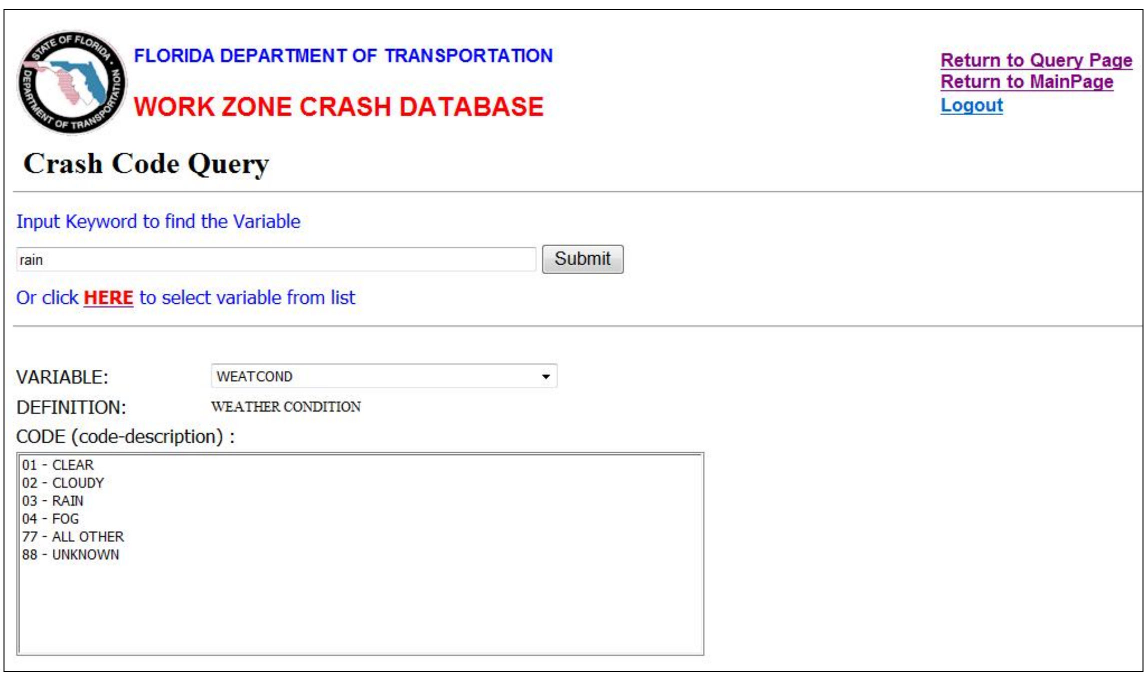


Figure F-7 Code Query Page (Keywords)

F.3 ANALYSIS

By clicking the "Analysis" button on the main page, users can access the analysis page (Figure F-8). Three analysis functions are provided: Fatal Crash Trend, Comparison of Work Zone Crash with Non-Work Zone Crash, and Contributing Causes Analysis.

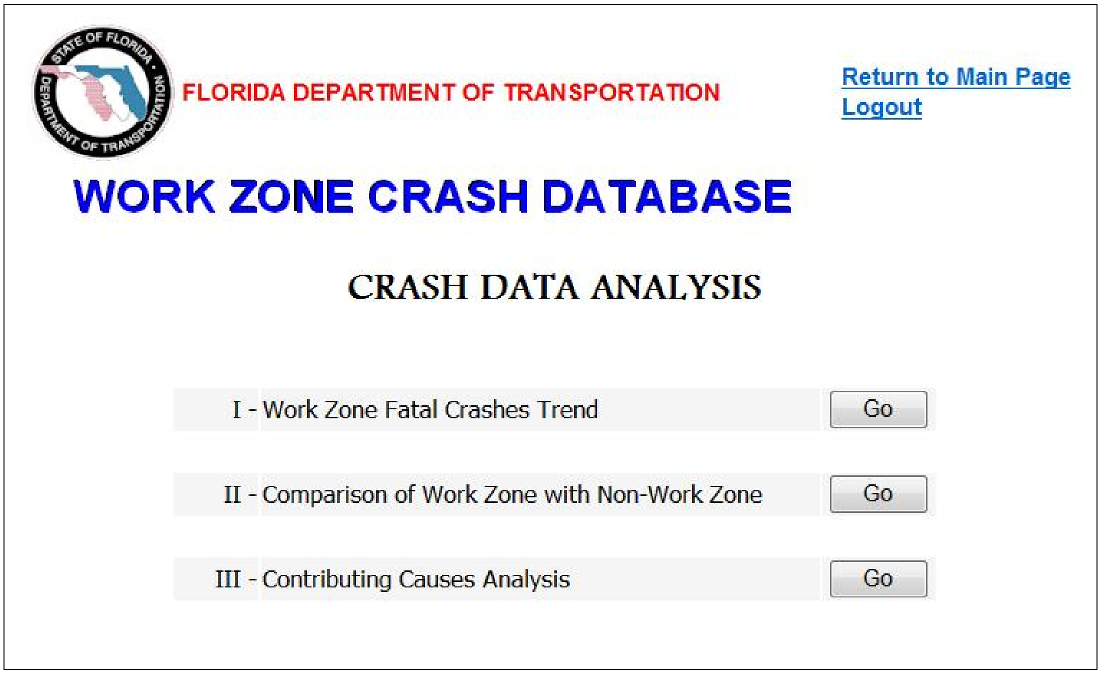


Figure F-8 Analysis Page

F.3.1 Fatal Crash Trend

This function is used to describe the temporal trend of work zone fatal crashes over certain variable values by years. The steps for performing this function are shown in Figure F-9 as follows:

- Select a variable level, and then all variables belonging to this level are given in the variable list.
- Select a variable from the variable list.
- Specify the year range.
- Specify values of the selected variable in step 2.

- Click the "Submit" button to perform the analysis, and then the result will be generated as a PDF file. Users can review it on screen if a PDF reader has been installed in the client computer. Furthermore, users can save it to local hard disk and print it.

Figure F-9 Fatal Crash Trend Page

F.3.2 Comparison of Work Zone Crash with Non-Work Zone Crash

This function compares work zone crashes with non-work zone crashes by a certain variable to investigate the characteristics of work zone fatal crashes. In addition, the comparison of contributing factors for the principal values of the variable between work zone and non-work zone is also provided to address the major causes for the difference in the characteristics between two kinds of crashes.

To perform the function, as shown in Figure F-10, users follow the steps on the comparison analysis page:

- Indicate a variables level;
- Select a variable from the variable list;
- Specify the time range;
- Specify the display range (for variables and contributing factors);
- Give the display order of contributing factors.
- Click the "Submit" button to perform the analysis, and the result will be generated as a PDF file. Users can review it on screen if a PDF reader has been installed. Furthermore, users can save it to client computer and print it.

Note: If the proportion difference of a factor of the selected variable between work zone and non-work zone is over a critical value which is indicated in step 4 (display range for variables), this factor will display in results. Similarly, if the proportion of a contributing factor for a certain displayed factor of the variable is over a critical value (display range for contributing factors), this contributing factor will display in results. The display order of contributing is indicated in step 5.

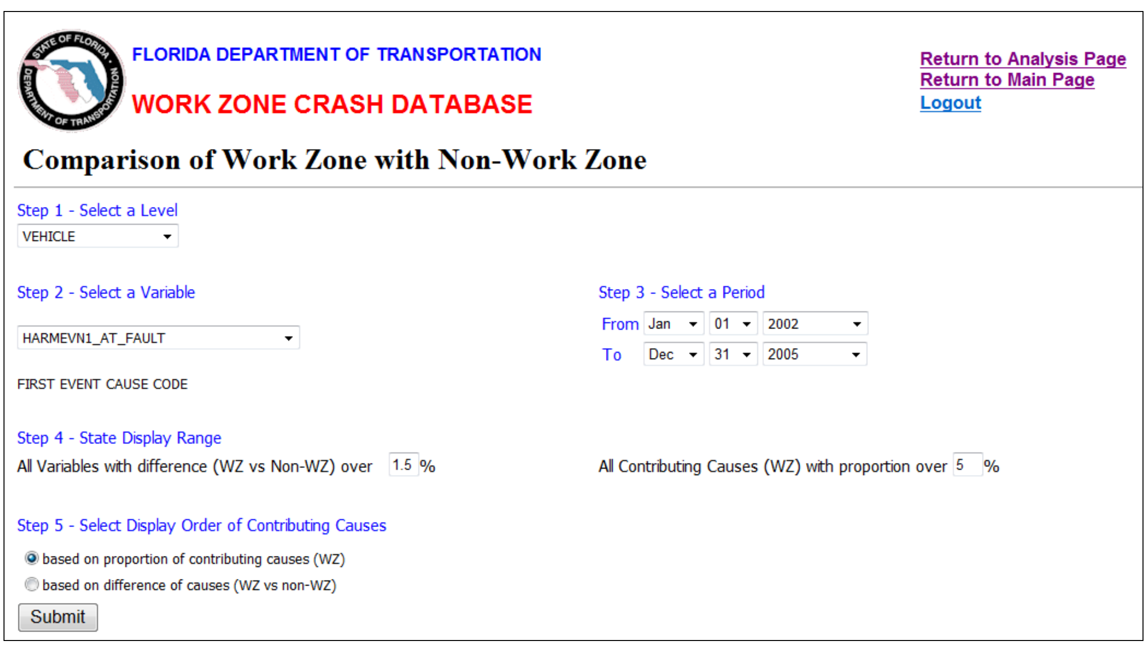


Figure F-10 Comparison Analysis Page

F.3.3 Contributing Causes Analysis

This function addresses the principal factors of a certain variable in an ascending order, and then the predominant contributing causes (factors) for the principal factors are investigated. To perform this function, as shown in Figure F-11, users follow the steps on the contributing causes page:

- Indicate a variables level.
- Select a variable from the variable list.
- Specify the time range.
- Specify the display range for the variable.
- Specify the display range for the contributing factors.
- Click the "Submit" button to perform the analysis, and the result will be generated as a PDF file. Users can review it on screen if a PDF reader has been installed. Furthermore, users can save it to client computer and print it.

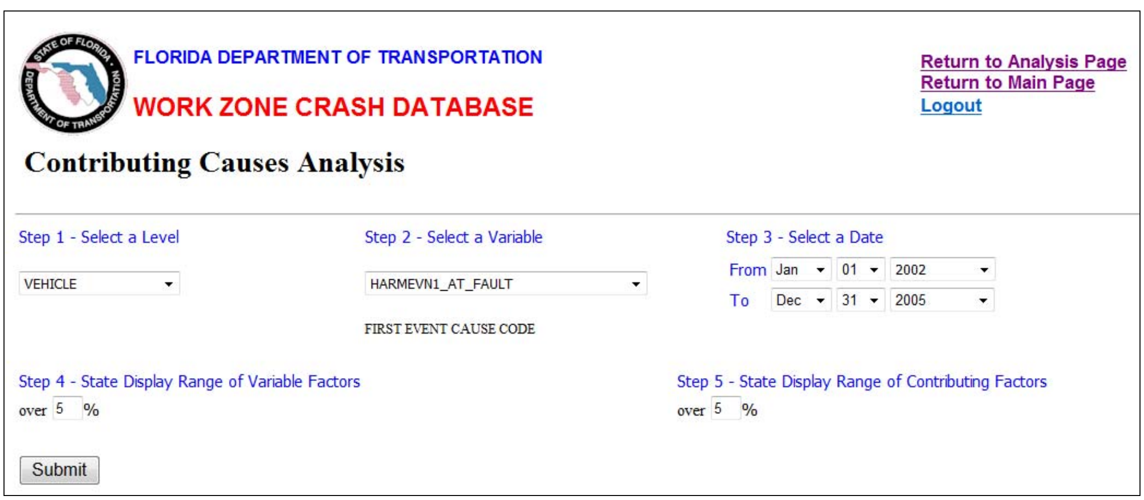


Figure F-11 WZCD Contributing Causes Analysis Page

F.4 MANAGE

F.4.1 User Groups

For protecting the security of the Florida Work Zone Crash Database, the system divides users into 4 groups with difference access privileges. The description of the user groups and their corresponding access privileges is shown in Table D-1.

Table D-1 the User Groups

User Group	Description	Access Permission
General	The common user who uses the query and analysis functions.	Query pages Analysis pages
Updater	The user who updates the Summary data.	Query pages Analysis pages Update pages
MOT	The user who updates the MOT data.	Query pages Analysis pages MOT pages
Manage	The system administrator	All pages

F.4.2 Manage Page

All management functions are realized on the manage page. To access this page, login as a manage user (Administrator) is required. By clicking the “Manage” button on the main page, the manage page will display as shown in Figure F-12. If a user login without a manage privilege, he/she only accesses the personal configure page to change his/her password or email address (Figure F-13).

On the manage page, manage users can add or delete a user; even change the access privilege of an existing user.

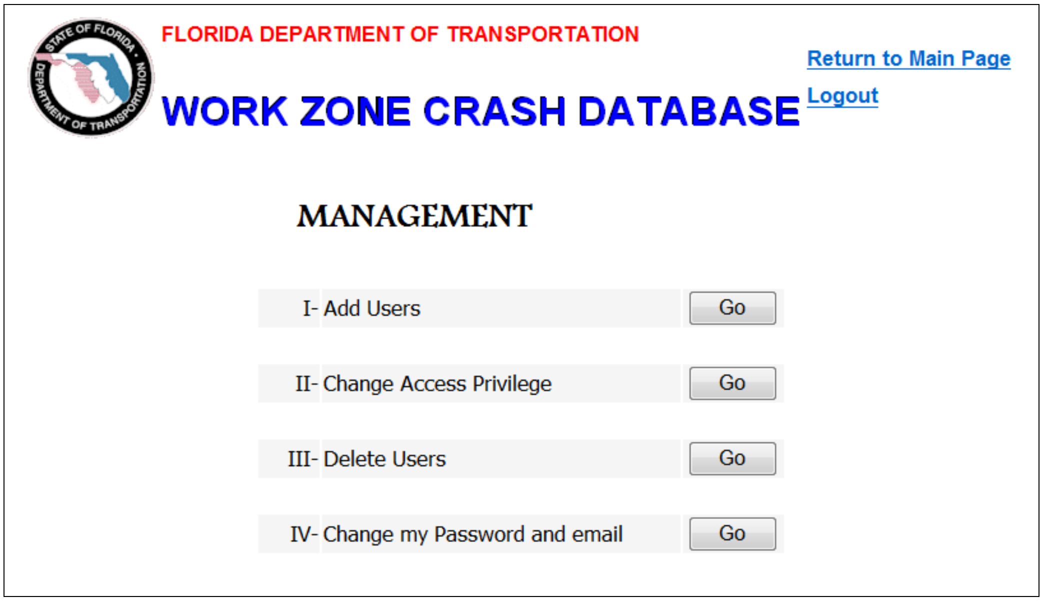


Figure F-12 Manage Page

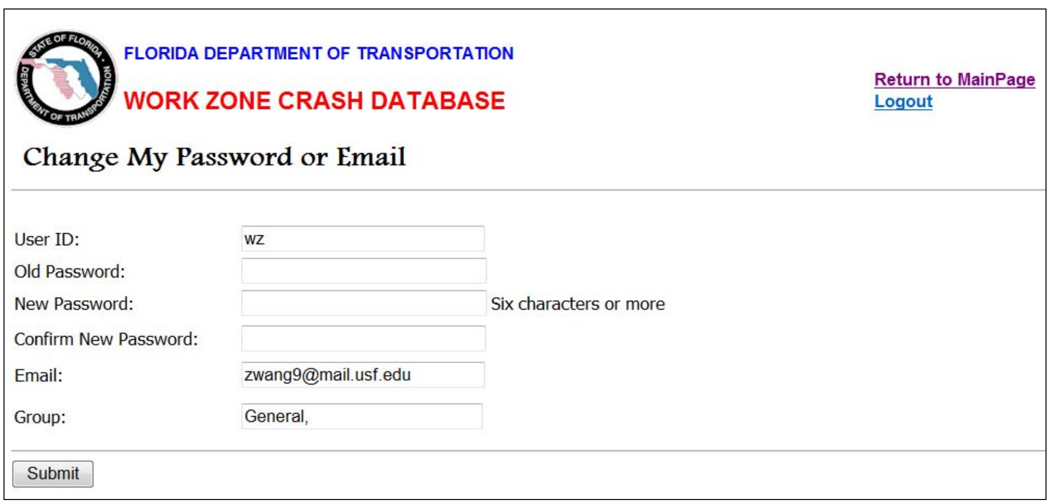


Figure F-13 Personal Configure Page

F.4.2.1 Add a User

Figure F-14 shows the add user page. To add a new user, administrator should assign a user name (ID) for the new user, and specify the password, email address, and user group. After submitting the request to the server, a new user will be added to database successfully.

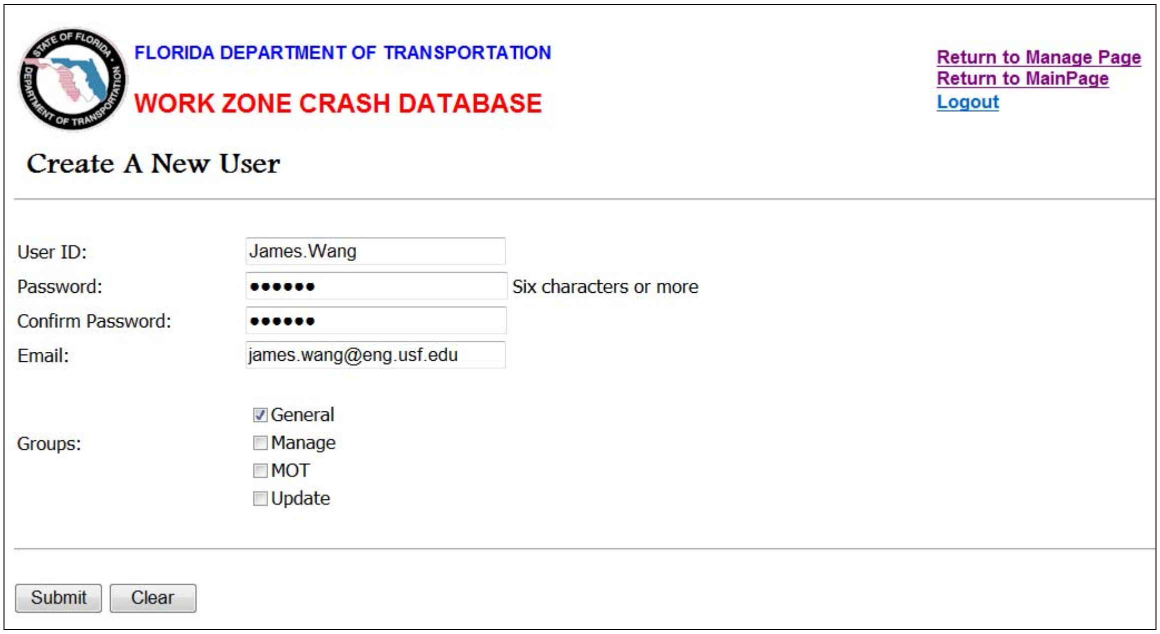


Figure F-14 Add User Page

F.4.2.2 Delete a User

To delete an existing user from database, administrator should access the delete user page (Figure F-15) to select a user from the user list. By clicking the "Delete" button to submit the request to server, the selected user will be deleted.

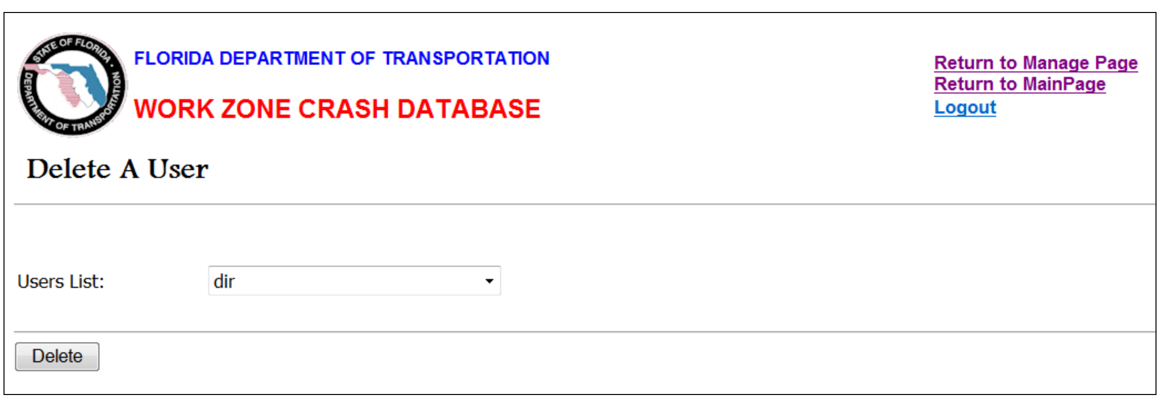


Figure F-15 Delete User Page

F.4.2.3 Change Privilege of an Existing User

Figure F-16 shows the change privilege page on which administrator can change the access privilege of an existing user. To perform this function, administrator should select an existing user from the user list, after then change the user groups of the selected user. After submitting this request to server, the privilege of the existing user will be changed successfully.

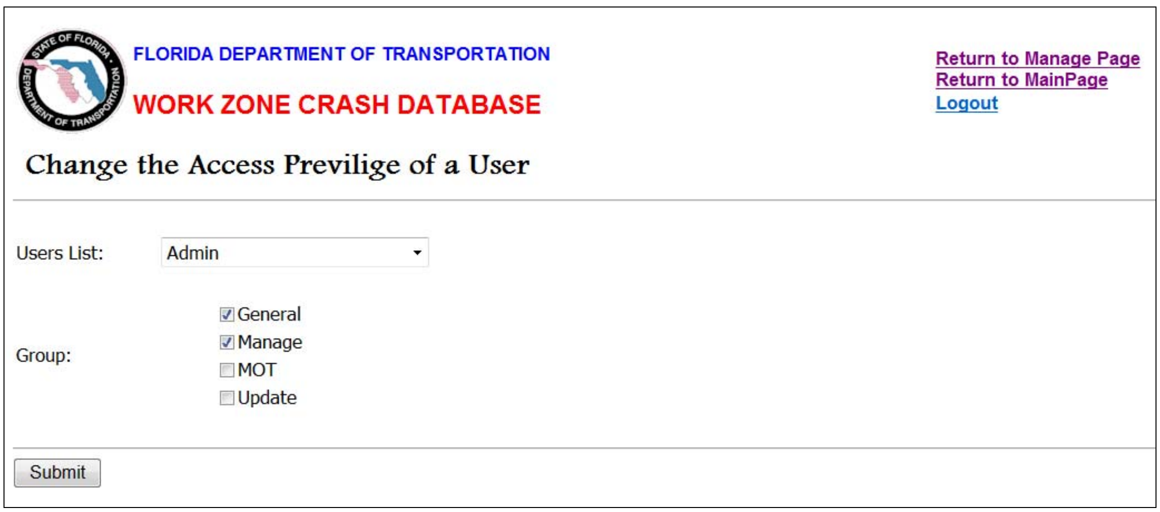


Figure F-16 Change Privilege Page

F.5 DATA UPDATE

The WZCD needs to be updated annually from three data sources: Summary Report, CAR system, and MOT Forms. This system provides a set of functions to realize the data update. To access these functions, users who have update or manage access privileges click the "Update" button on the main page to open the update page as shown in Figure F-17.

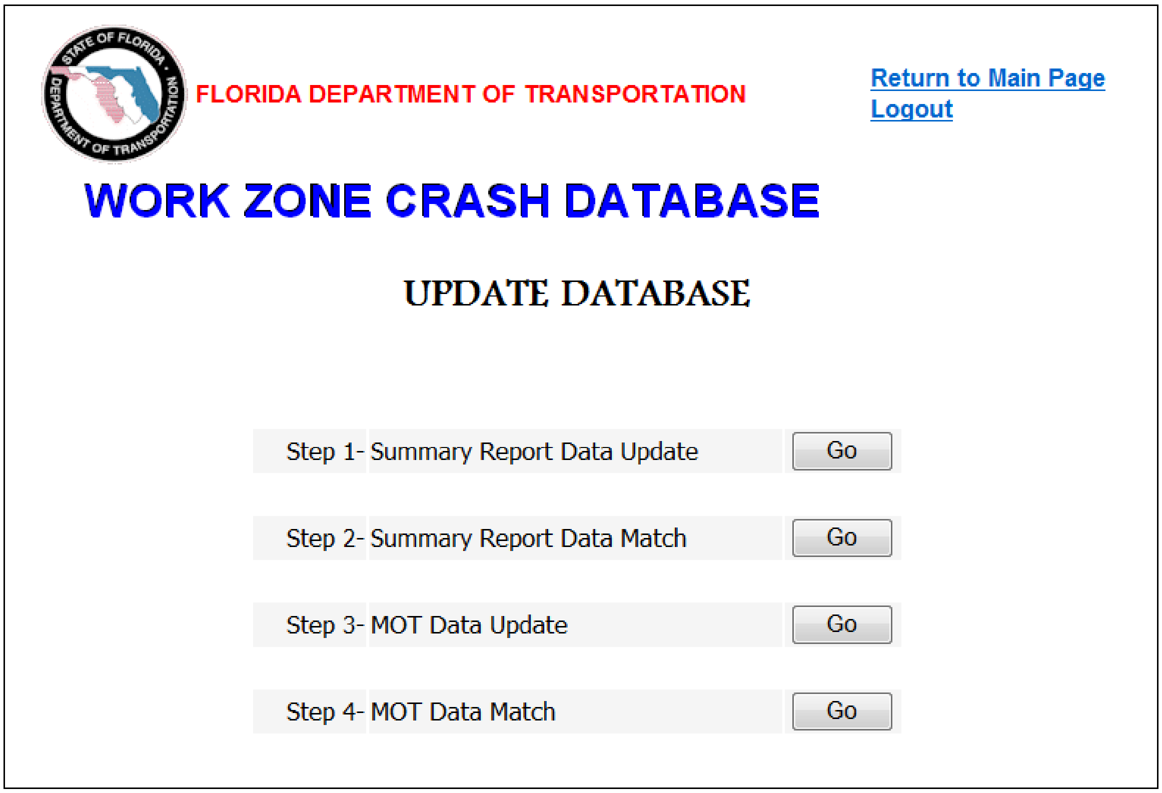


Figure F-17 Update Page

F.5.1 Upload Crash Data

Before updating summary data and MOT data, the crash data abstracted from FDOT CAR system should be uploaded to the server. The procedure of uploading the crash data is shown as following:

- Download crash data from CAR system by years. The data files are comma delimited text file which could be opened with MS Access.

- *Note: To download crash data from CAR system, users should login to the FDOT mainframe. In main menu, users select "2-CRASH DATA REPORTS, ALL ROADS OR NON-STATE ROADS", after then select "4-EXTRACT FOR PC" in the report selection screen. A detailed description for the downloading process is offered in the USER MANUAL FOR THE CRASH ANALYSIS REPORTING SYSTEM (CAR).*
- Go to the template page to download the CAR data template file.

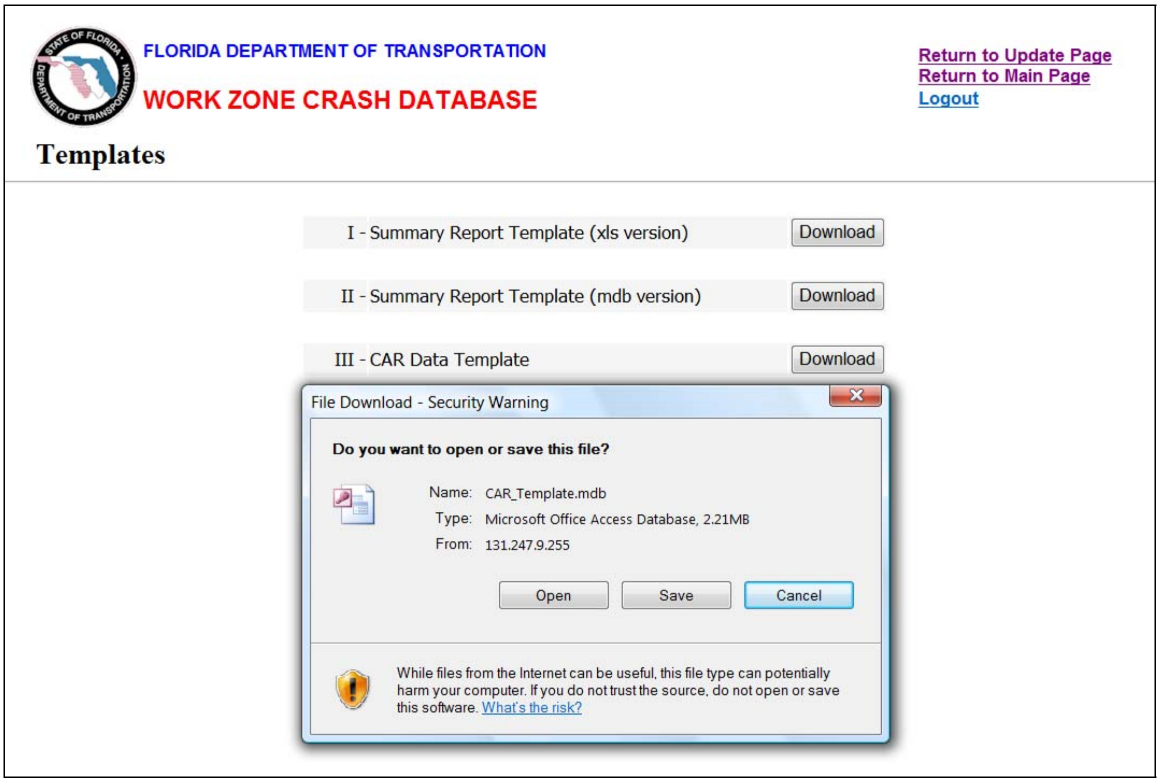


Figure F-18 Download CAR Data Template

- Open the template file with MS Access, and import the comma delimited files downloaded from CAR system using the import function of MS Access. Figure F-19a to Figure F-19e illustrates the procedure of importing external data in MS Access.

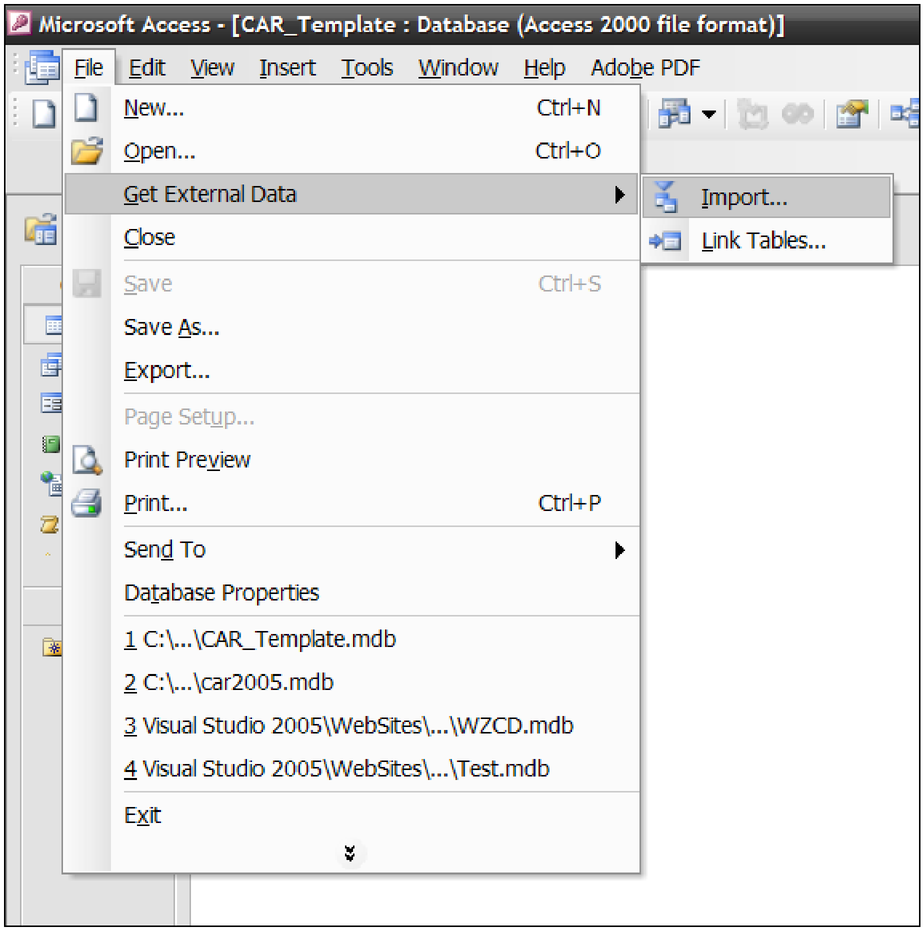


Figure F-19a Using Import Function of MS Access

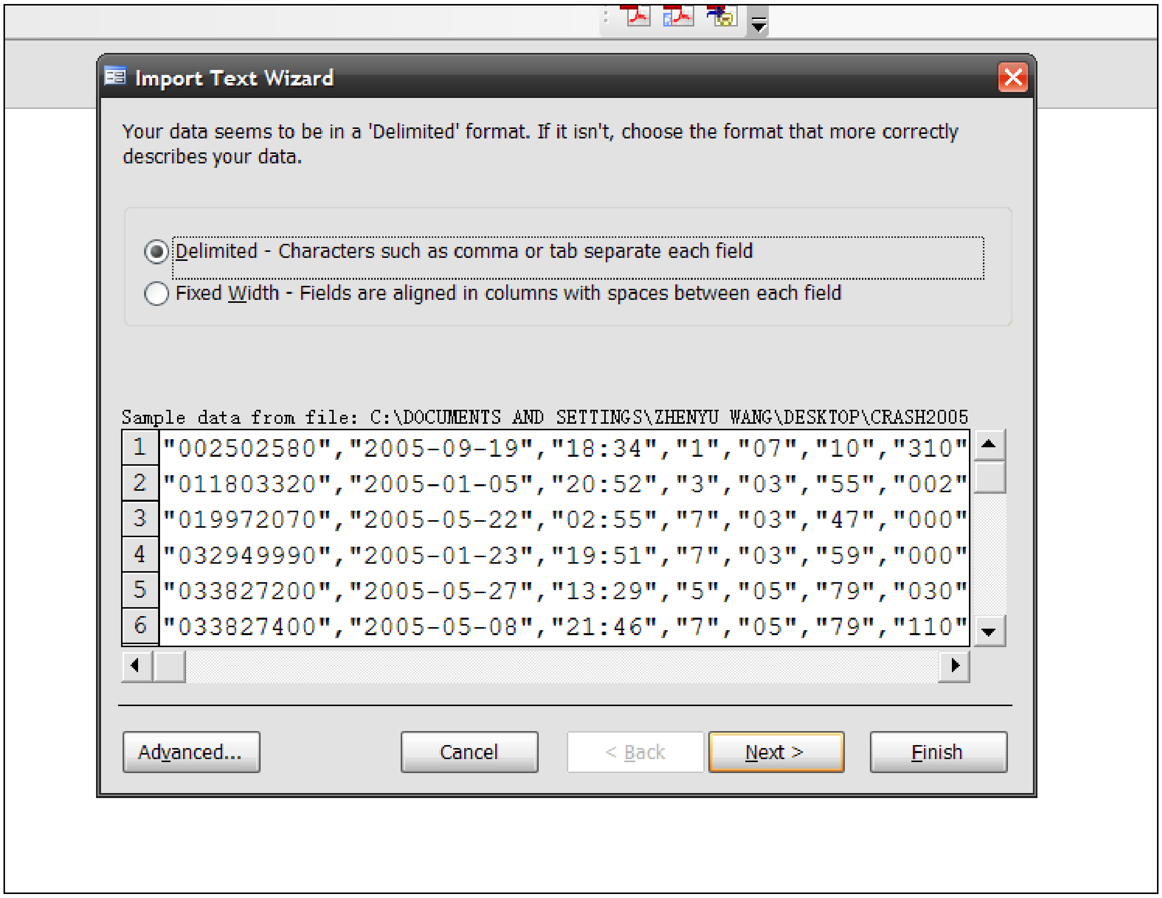


Figure F-19b Import Text Wizard

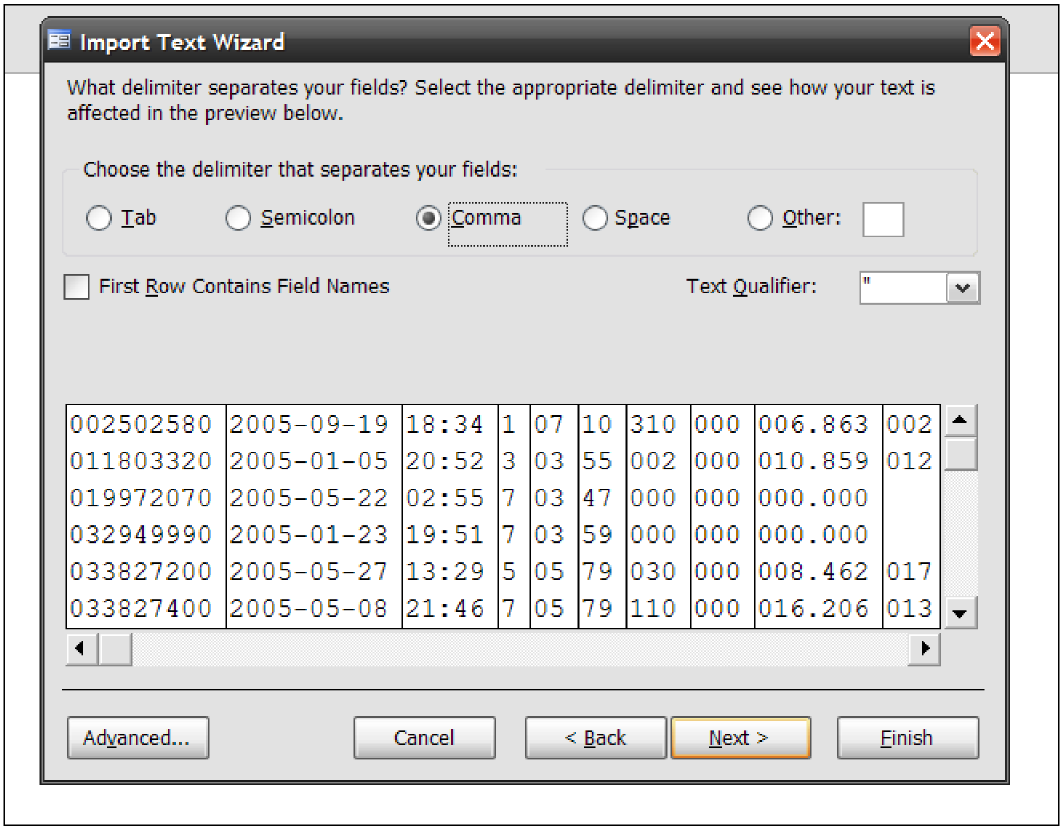


Figure F-19c Choose Comma Delimiter

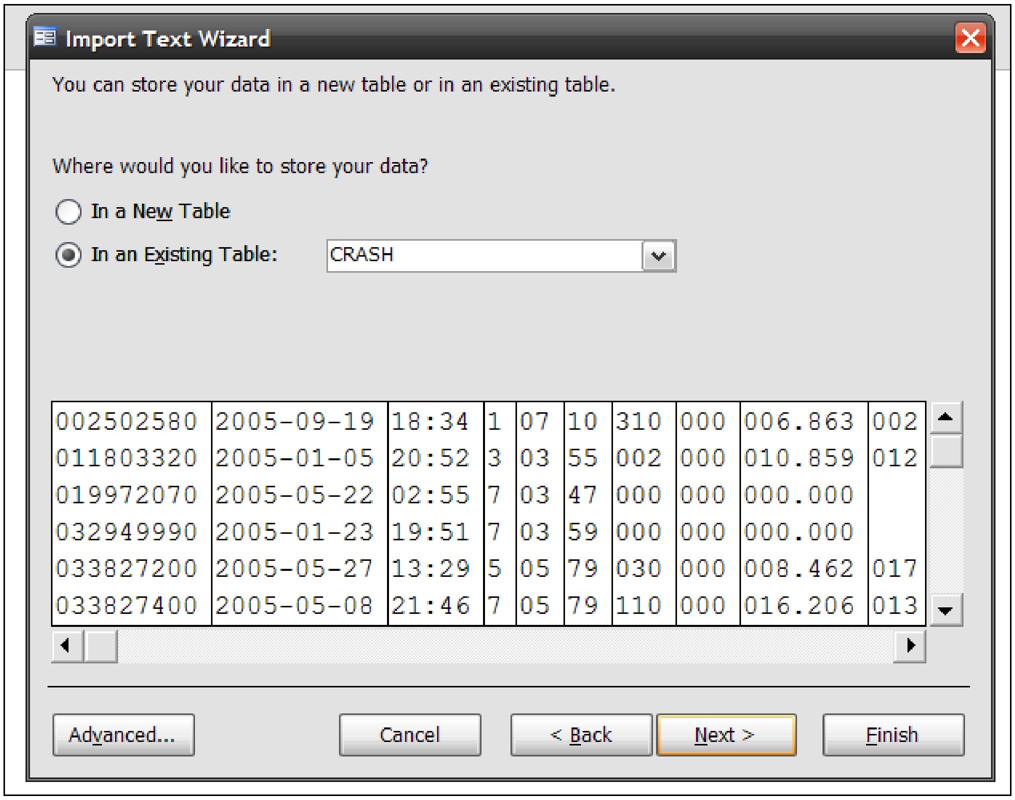
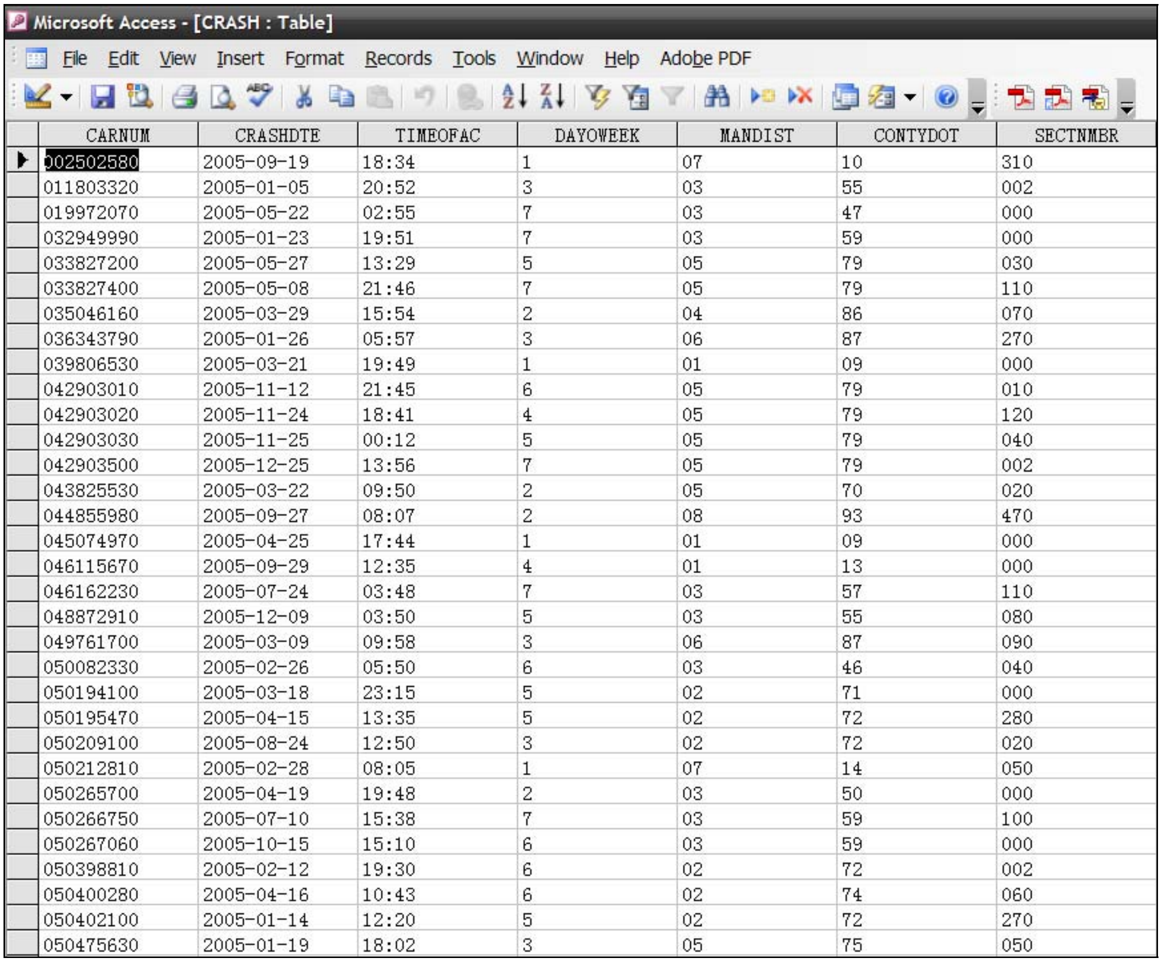


Figure F-19d Add Data to the CRASH Table



CARNUM	CRASHDTE	TIMEOFAC	DAYOWEEK	MANDIST	CONTYDOT	SECTNMBR
002502580	2005-09-19	18:34	1	07	10	310
011803320	2005-01-05	20:52	3	03	55	002
019972070	2005-05-22	02:55	7	03	47	000
032949990	2005-01-23	19:51	7	03	59	000
033827200	2005-05-27	13:29	5	05	79	030
033827400	2005-05-08	21:46	7	05	79	110
035046160	2005-03-29	15:54	2	04	86	070
036343790	2005-01-26	05:57	3	06	87	270
039806530	2005-03-21	19:49	1	01	09	000
042903010	2005-11-12	21:45	6	05	79	010
042903020	2005-11-24	18:41	4	05	79	120
042903030	2005-11-25	00:12	5	05	79	040
042903500	2005-12-25	13:56	7	05	79	002
043825530	2005-03-22	09:50	2	05	70	020
044855980	2005-09-27	08:07	2	08	93	470
045074970	2005-04-25	17:44	1	01	09	000
046115670	2005-09-29	12:35	4	01	13	000
046162230	2005-07-24	03:48	7	03	57	110
048872910	2005-12-09	03:50	5	03	55	080
049761700	2005-03-09	09:58	3	06	87	090
050082330	2005-02-26	05:50	6	03	46	040
050194100	2005-03-18	23:15	5	02	71	000
050195470	2005-04-15	13:35	5	02	72	280
050209100	2005-08-24	12:50	3	02	72	020
050212810	2005-02-28	08:05	1	07	14	050
050265700	2005-04-19	19:48	2	03	50	000
050266750	2005-07-10	15:38	7	03	59	100
050267060	2005-10-15	15:10	6	03	59	000
050398810	2005-02-12	19:30	6	02	72	002
050400280	2005-04-16	10:43	6	02	74	060
050402100	2005-01-14	12:20	5	02	72	270
050475630	2005-01-19	18:02	3	05	75	050

Figure F-19e Import Data

- Save the imported data file. The file name usually contains year information, for example, "CRASH2005.MDB", which indicates this file store the crash data of 2005.

- Copy this file to the crash data file directory on the server: "~\uploads\crash_upload". The "~" represents the root directory of web service on the server. The uploaded crash data files will be used to match summary data and MOT data.

Note: Because the crash data files is too large to upload via web page, the best way is to copy the files to the server by administrator.

F.5.2 Update Summary Data

After uploading crash data, users can update summary data by following the steps on the update page.

F.5.2.1 Update Summary Data

By clicking the "Go" button corresponding to step 1 on the update page, the summary data upload page will display as shown in Figure F-21.

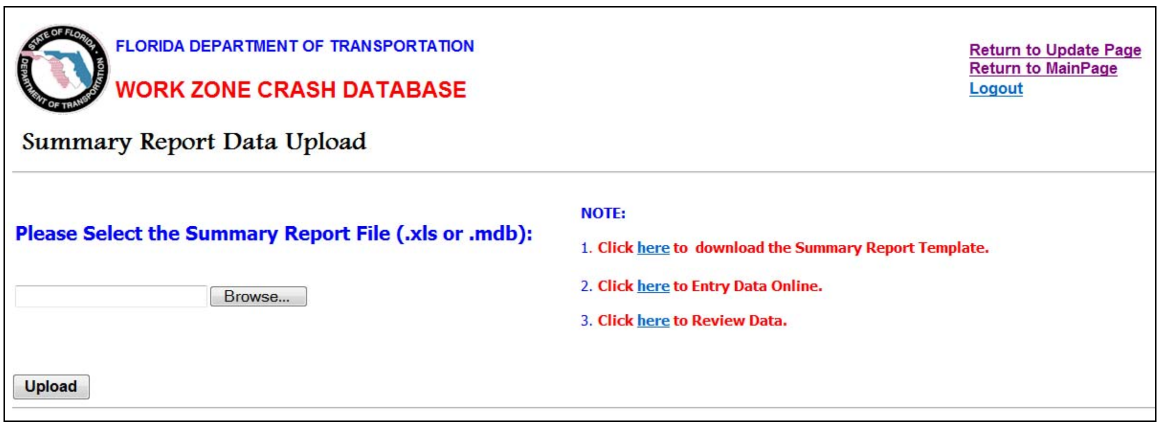


Figure F-21 Summary Data Upload Page

Users have two choices to update summary data: upload summary data file or entry summary data online.

Upload Summary Data

- Click the hyperlink 1 on the upload page to open the template page (Figure F-22);

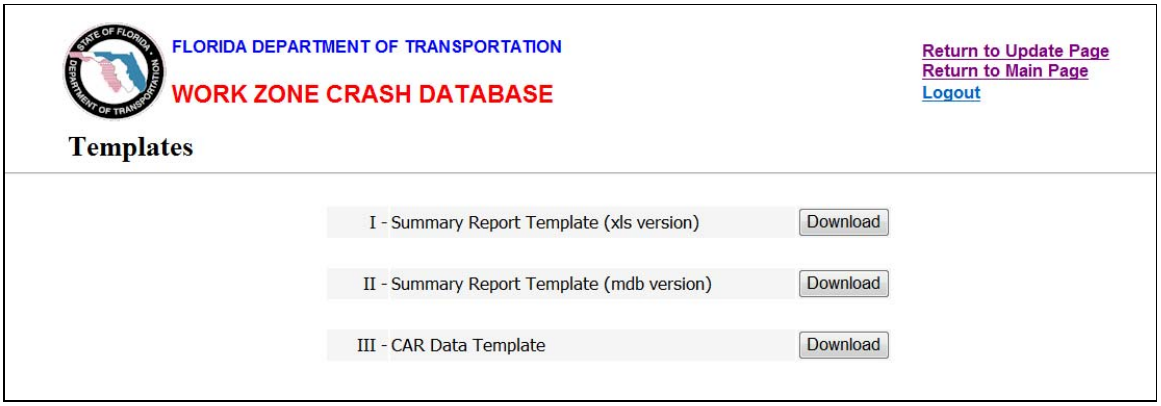


Figure F-22 WZCD Template Page

- Download the template file at XLS format (option 1) which can be opened with MS Excel.

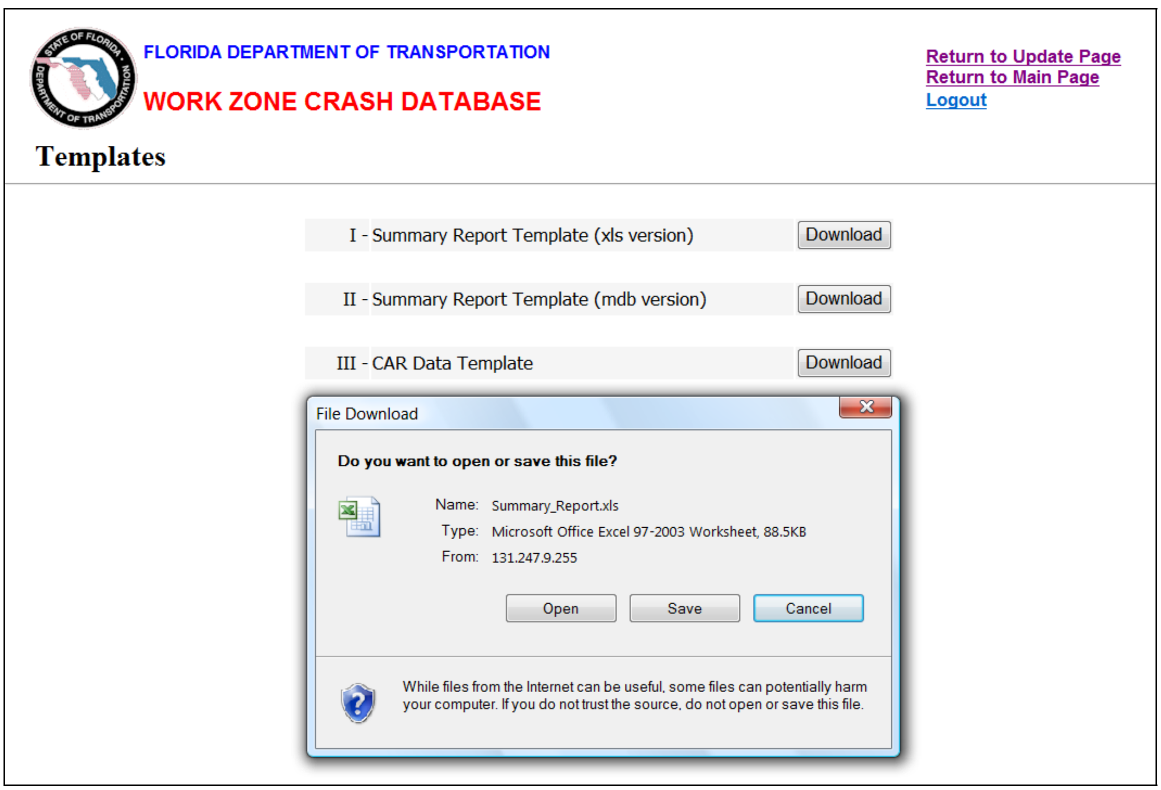


Figure F-23 Download Summary Data Template File

- Fill the Template File with summary data from the summary report;

	Crash #	Date	Time	AM or PM	SR#	County #	DOT Form	Description	WZ Not Mentioned	WZ Mentioned	WZ Unlikely Factor	Closed Lane - by TTC Devices	Closed Lane by Flagger	Closed Lane by Rolling Roadblock
2	75263957	1/2/2005	7:44	PM		16		**1. ** 1/2/2005 (7:44 PM, dark, no street light), CR 655, Polk Co. (75263957) –** The driver of a light truck was speeding (45+/45) when he drifted off the roadway for an unknown reason. The driver overcorrected, overturned several times before colliding with a utility pole and tree stump. After the collision with the tree stump, the driver (male, age 21, not wearing seat belt) was ejected from the truck and died at the scene. Toxicology results indicated marijuana use, as well as BAC test results of .195 for the deceased. (Officer coded Road Conditions 01, Work Area 03, but no work zone was noted in the narrative or diagram.)		1				
3	05398765	1/9/2005	7:00	PM	9	79		**2. 1/9/2005 (7:00 PM, dark, no street light), I-95 (SR 9), Volusia Co. (05398765) –** A pedestrian (female, age 39) was crossing I-95 when she walked into the path of an automobile, was struck and died at the scene. Walking on an Interstate highway was noted as a contributing factor. BAC test results were negative. (Officer coded Road Conditions 04, Work Area 03, and identified evidence of a work zone on the diagram.)	1					
4	72367727	1/12/2005	4:40	PM	8A	48		**3. 1/12/2005 (4:40 PM, daylight), I-110 (SR 8A), Escambia Co. (72367727) –** An automobile driver was traveling on the I-110 northbound on ramp, merged onto I-110, but did not notice the two vehicles behind her. In attempts to avoid collisions the 2 vehicles swerved and one struck the guardrail and the 3rd vehicle struck the left side of the 2nd vehicle, at which time the driver of the 2nd vehicle (male, age 60, wearing a seat belt) died. BAC test results were negative. (Officer coded Road Conditions 01, Work Area 03, but no work zone was noted in the narrative or diagram.)		1				
5	74040804	1/13/2005	9:24	PM	35	4		**4. 1/13/2005 (9:24 PM, dark, no street light), SR 35, Desoto Co. (74040804) –** An automobile driver (male, age 47, not wearing a seat belt) traveling on SR 35, crossed the centerline in an attempt to pass another vehicle. After crossing the centerline, the automobile collided with a tractor trailer and then the vehicle it was attempting to pass. The driver was ejected and died at the scene. BAC test results were .194 for the deceased. Improper passing was noted as a contributing cause. (Officer coded Road Conditions 01, Work Area 03, but no work zone was noted in the narrative or diagram.)		1				
6	73746310	1/15/2005	4:17	PM	25	16		**5. 1/15/2005 (4:17 PM, daylight), US 27 (SR 25), Polk Co. (73746310) –** An automobile driver traveling on US 27 lost control of the vehicle, and in an attempt to return to the roadway, overcorrected and slid sideways across the median into opposing traffic where it collided with the front of an oncoming vehicle. Two passengers (males, ages 35 and 2 months, both wearing seat belts) in the vehicle that lost control as well as one passenger in the other vehicle (female, age 74, wearing a seat belt) were killed. Careless driving was noted as a contributing cause. (Officer coded Road Conditions 04, Work Area 03, and identified evidence of a work zone on the diagram.)	1					
	70435684	1/21/2005	12:46	AM	9	93		**6. 1/21/2005 (12:46 AM, dark, no street light), I-95 (SR 9), Palm Beach Co. (70435684) –** Two vehicles were traveling on I-95. One vehicle stopped due to road construction, but the second car was unable to stop and rearended the first. After the collision, the second vehicle rotated counterclockwise into the outside lane and struck an arrow board. A passenger (male, age 7 months, using a child restraint) in the stopped vehicle was killed in the crash. BAC test results were .095 for the driver of the second car. Careless driving was noted as a contributing cause. (Officer coded Road Conditions 04, Work Area 03, and	1			1		

Figure F-24 Fill Summary Data Template File

- On the summary data upload page, click the "Browse" button to select the filled summary data file; The full name of the file will display in the file textbox (Figure F-25);

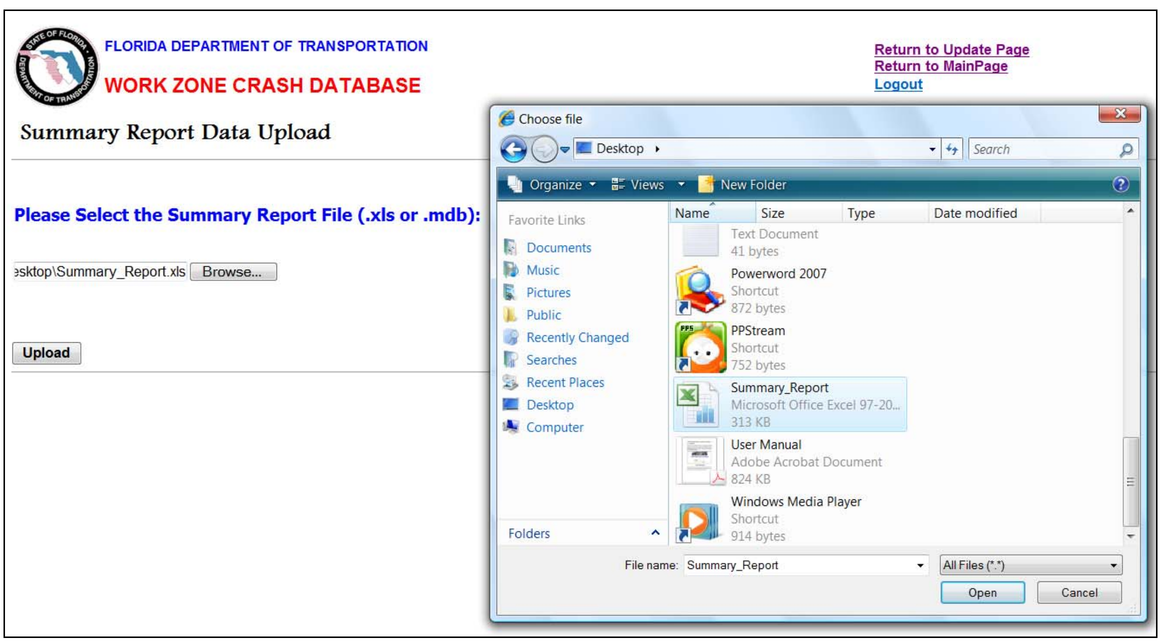


Figure F-25 Select Filled Summary Data Template File

- Click the “Upload” button to upload the summary data file; the result displays in the notice box.

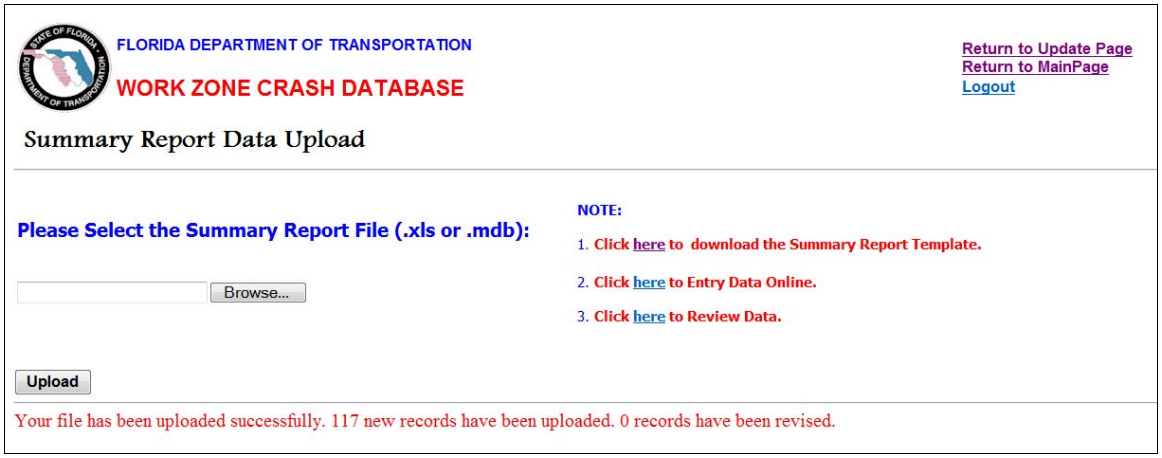


Figure F-26 Result of Uploading Summary Data File

Entry Summary Data Online

- Click the hyperlink to entry data online on the summary upload page, and then the summary data input page displays as shown in Figure F-27;

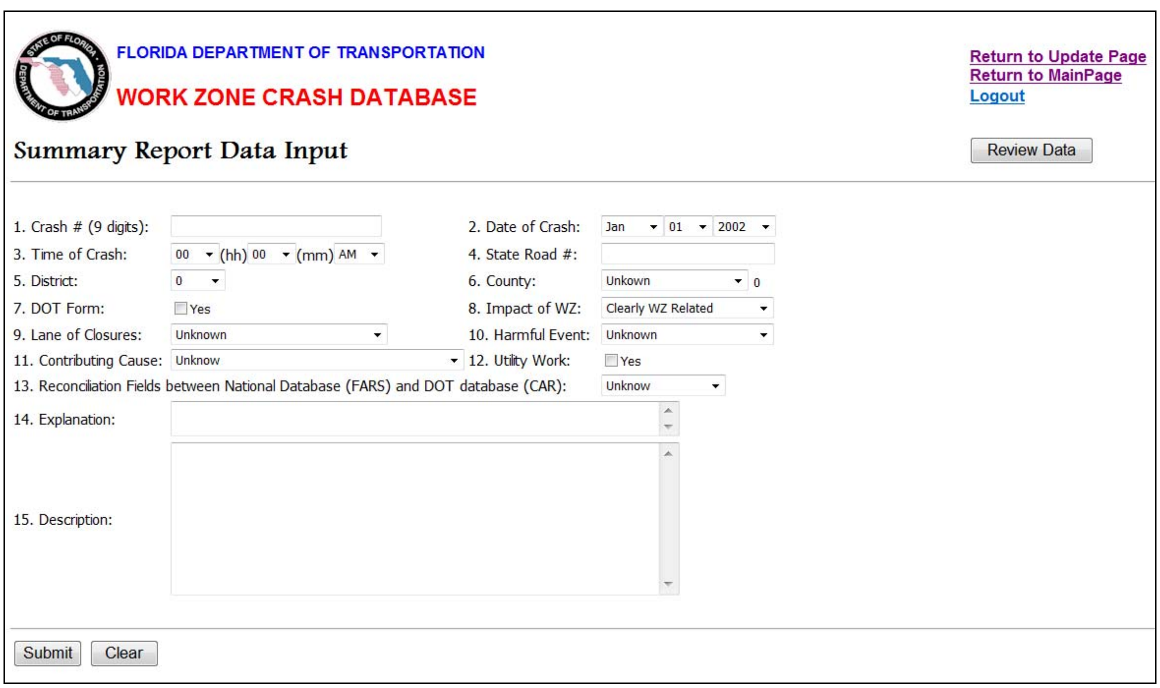


Figure F-27 Summary Data Input Page

- Fill each field online;
- Click the “Submit” button on the page to send the data to the database.

Review Summary Data

- To review the existing summary data in database, click the “Review Data” button on the summary data upload page or the data input data. After then, the summary data review page displays as shown in Figure F-28;

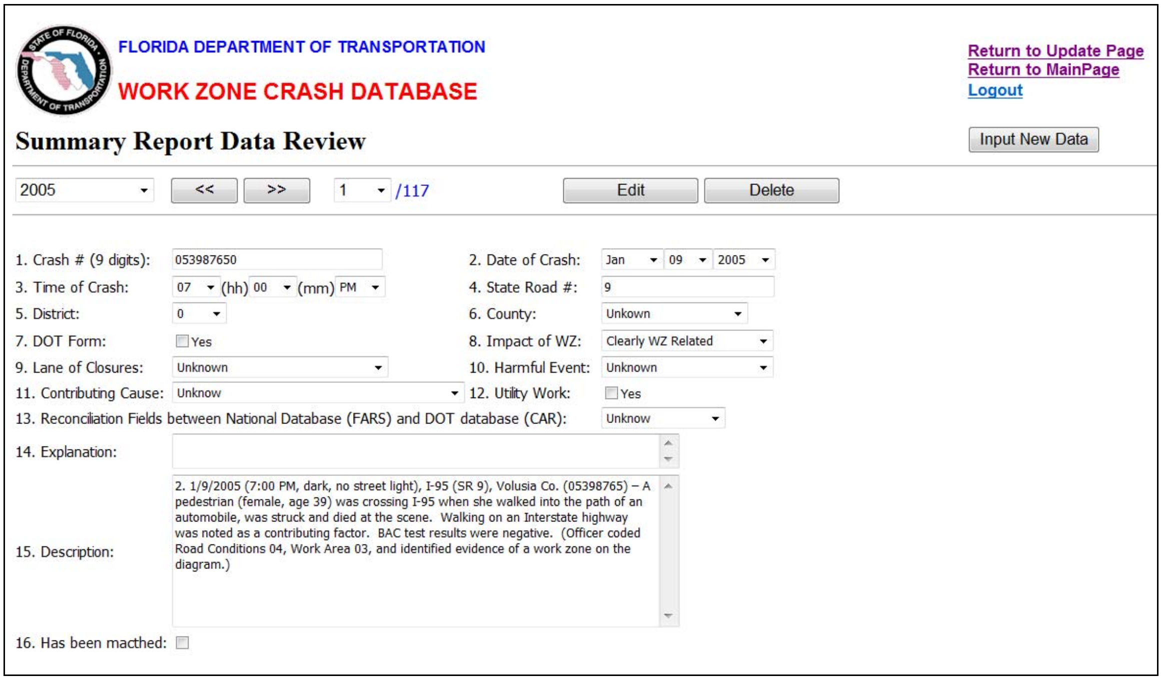


Figure F-28 Summary Data Review Page

- Users can browse all existing data by clicking the “Last” (<<) or “Next” (>>) button;
- To delete an existing record, users can click the “Delete” button on the top of the page; and a “Confirm” button displays on the bottom of the page. Click it; the current record will be deleted from the database.

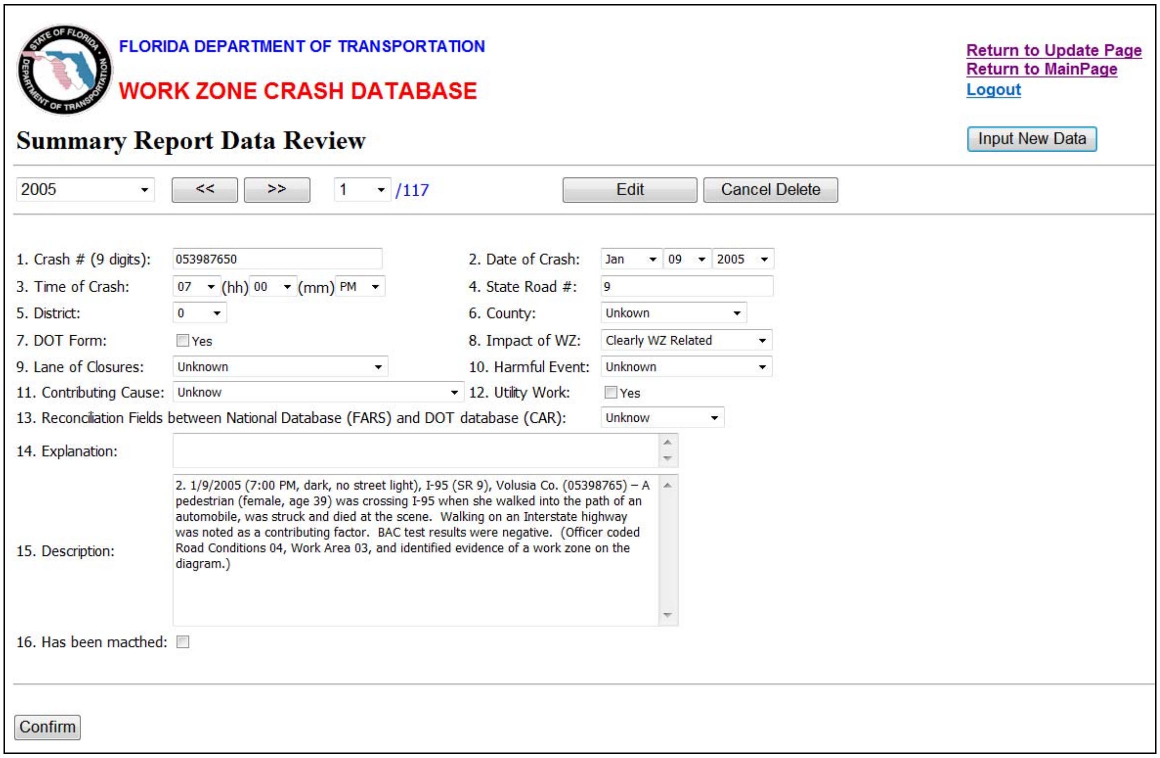


Figure F-29 Delete Existing Summary Data

- To revise an existing summary record, click the “Edit” button on the top of the review page. After revising data fields, click the “Submit” button to send the revised record to database.

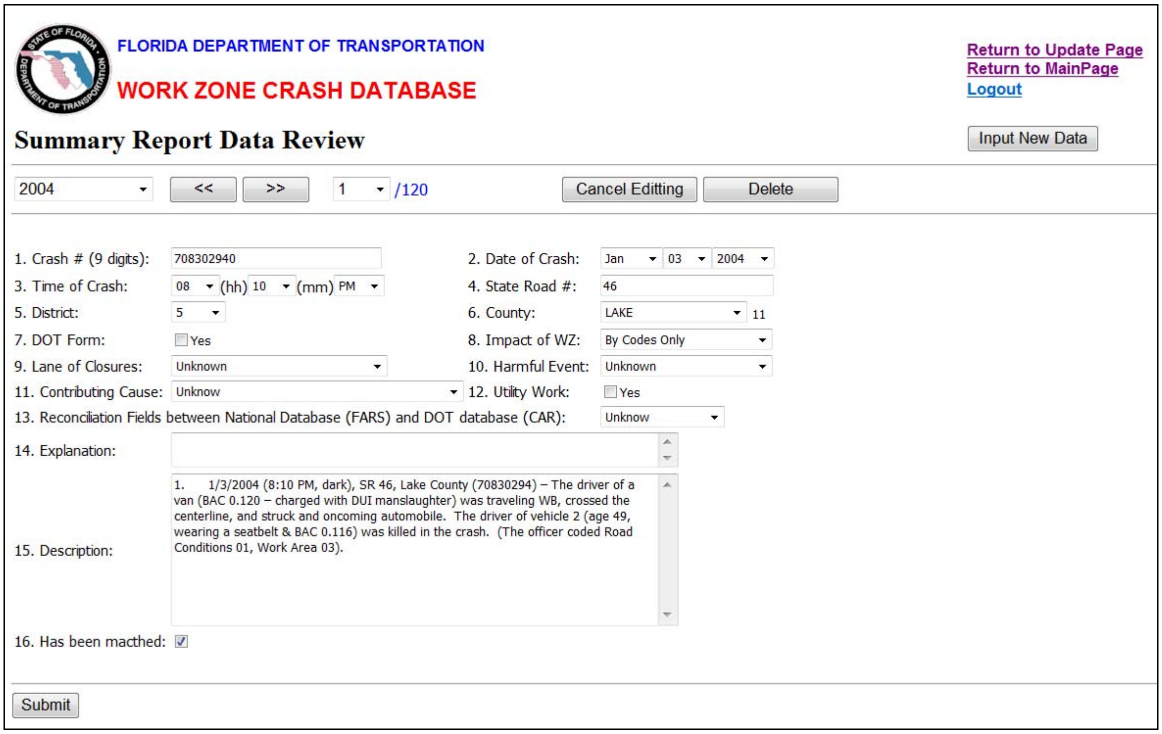


Figure F-30 Revise Existing Summary Data

F.5.2.2 Match Summary Data

After updating the summary data, we need to find their corresponding records in the crash files. This procedure is called as "data match". As the result of a successful match, the corresponding crash data are stored in Crash Table, and the match tag fields (Crash_Info), which indicates if the record has been matched in Summary Table, is checked as "TRUE".

- Click the "Go" button corresponding to step 2 on the update page to open the summary data match page;

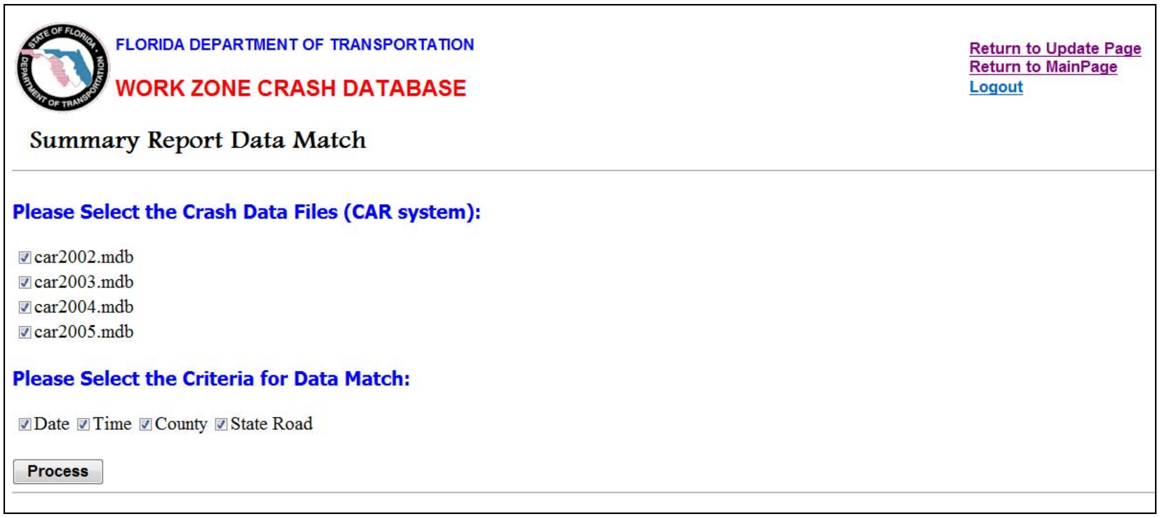
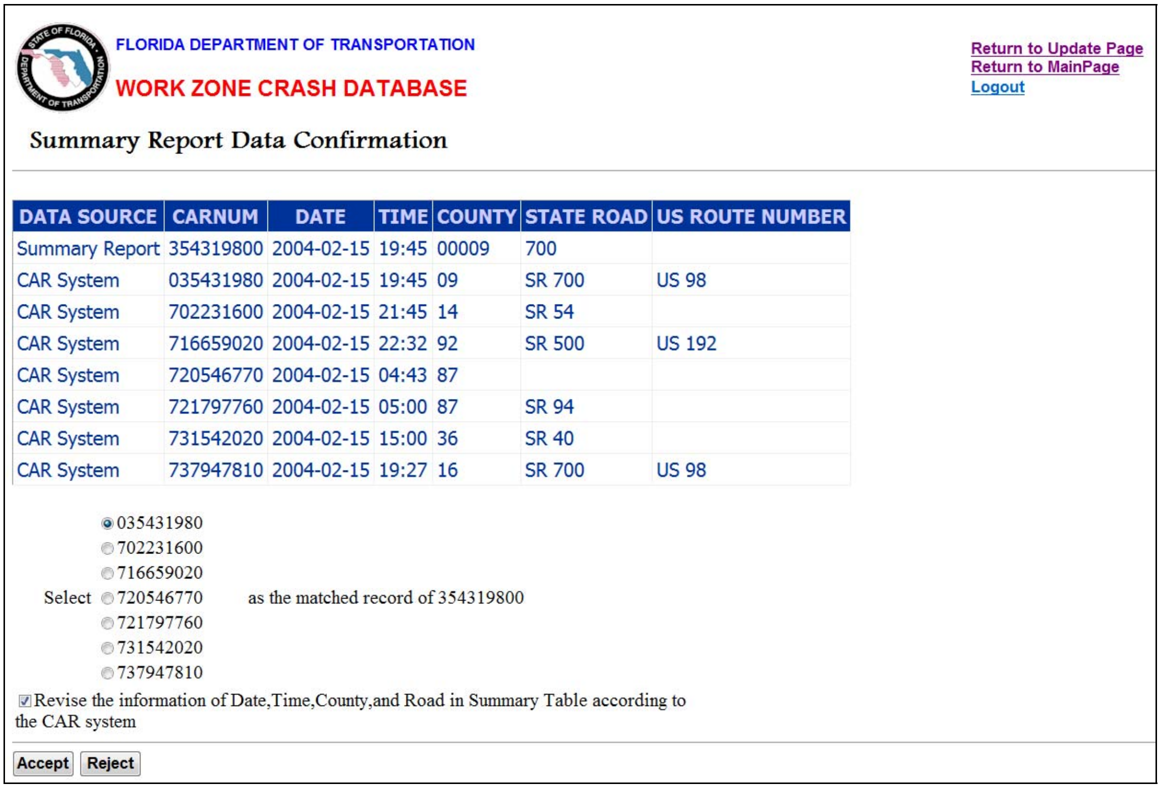


Figure F-31 Summary Data Match Page

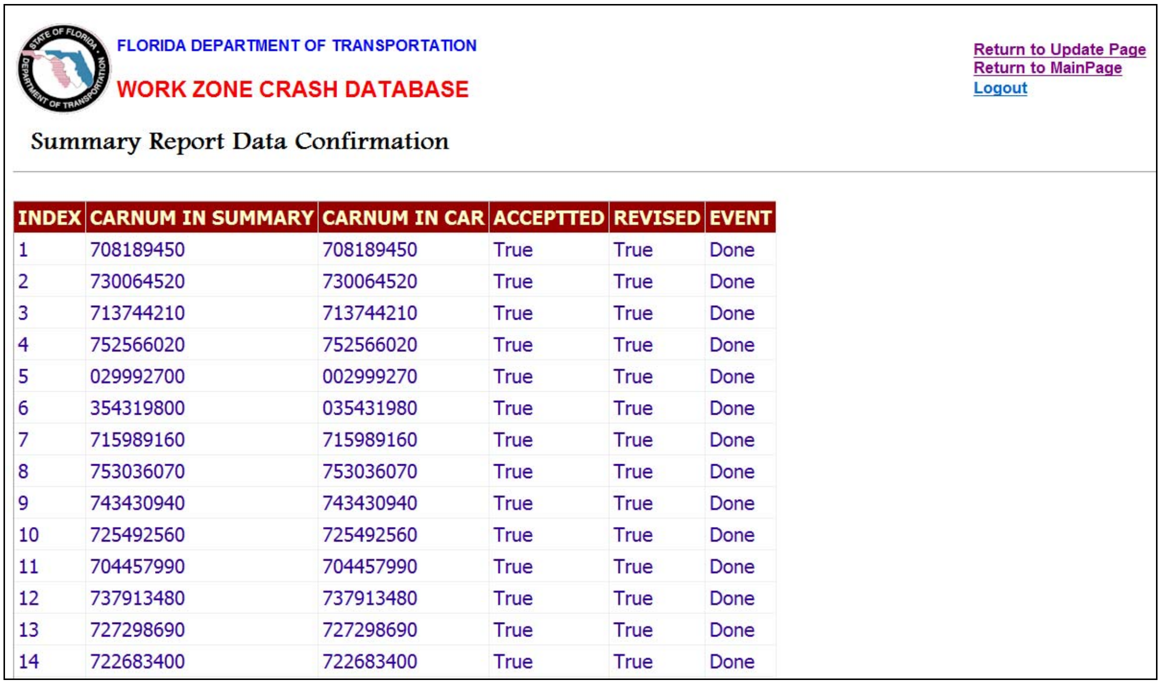
- Select the crash data files which are abstracted from FDOT CAR system.
- Specify the criterion for data match. When a new summary record cannot match to a crash data based on Crash ID, the system will use the match algorithm developed in Chapter 6 to find its matched record in crash data files. More criterions being selected means that the data match is more restrictive.
- Click the “Process” button to execute the data match.
- If all data are matched successfully, the system will display “All data have been matched”. Otherwise, the data match confirmation page will display. On the page, users can accept a matched data from a candidate list, or reject the data match.



DATA SOURCE	CARNUM	DATE	TIME	COUNTY	STATE ROAD	US ROUTE NUMBER
Summary Report	354319800	2004-02-15	19:45	00009	700	
CAR System	035431980	2004-02-15	19:45	09	SR 700	US 98
CAR System	702231600	2004-02-15	21:45	14	SR 54	
CAR System	716659020	2004-02-15	22:32	92	SR 500	US 192
CAR System	720546770	2004-02-15	04:43	87		
CAR System	721797760	2004-02-15	05:00	87	SR 94	
CAR System	731542020	2004-02-15	15:00	36	SR 40	
CAR System	737947810	2004-02-15	19:27	16	SR 700	US 98

Figure F-32 Summary Data Match Confirmation Page

- After all matched data are confirmed, a list of matched data is given on the match result page as shown in Figure F-33.



INDEX	CARNUM IN SUMMARY	CARNUM IN CAR	ACCEPTTED	REVISED	EVENT
1	708189450	708189450	True	True	Done
2	730064520	730064520	True	True	Done
3	713744210	713744210	True	True	Done
4	752566020	752566020	True	True	Done
5	029992700	002999270	True	True	Done
6	354319800	035431980	True	True	Done
7	715989160	715989160	True	True	Done
8	753036070	753036070	True	True	Done
9	743430940	743430940	True	True	Done
10	725492560	725492560	True	True	Done
11	704457990	704457990	True	True	Done
12	737913480	737913480	True	True	Done
13	727298690	727298690	True	True	Done
14	722683400	722683400	True	True	Done

Figure F-33 Result of Summary Data Match Confirmation

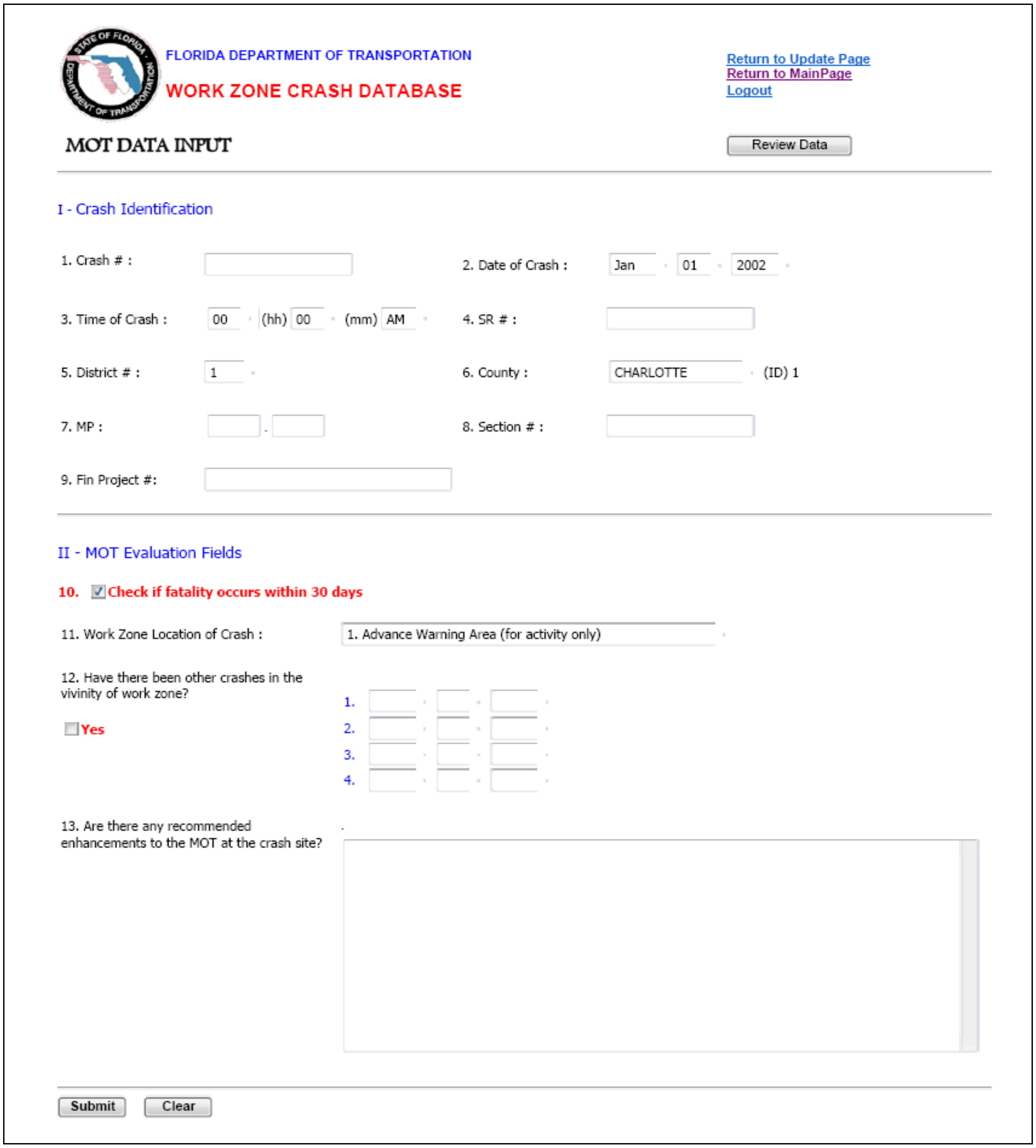
- If there are some summary data cannot find the matched records, return to the summary data match page, and remove some match criterions. And then repeat step 4 until all data are matched.

Note: Do not select too many crash data files in step 2 at same time. A large scale data may induce a very slow process in data match, even a running failure.

F.5.3 Update MOT Data

F.5.3.1 Entry MOT Data

- Click the "Go" button corresponding to "Step 3" on the update page, and then the MOT data input page display as shown in Figure F-34.



FLORIDA DEPARTMENT OF TRANSPORTATION

WORK ZONE CRASH DATABASE

Return to Update Page
Return to MainPage
Logout

MOT DATA INPUT

Review Data

I - Crash Identification

1. Crash # :

2. Date of Crash : Jan 01 2002

3. Time of Crash : 00 (hh) 00 (mm) AM

4. SR # :

5. District # : 1

6. County : CHARLOTTE (ID) 1

7. MP : .

8. Section # :

9. Fin Project #:

II - MOT Evaluation Fields

10. Check if fatality occurs within 30 days

11. Work Zone Location of Crash : 1. Advance Warning Area (for activity only)

12. Have there been other crashes in the vivinity of work zone?

Yes

1.
2.
3.
4.

13. Are there any recommended enhancements to the MOT at the crash site?

Submit Clear

Figure F-34 MOT Data Input Page

- Fill each field online.
- Click the "Submit" button on the page to send the data to the database.

- To review the existing MOT data in database, click the "Review Data" button on the summary data upload page or the data input data. After then, the MOT data review page will display as shown in Figure F-35.

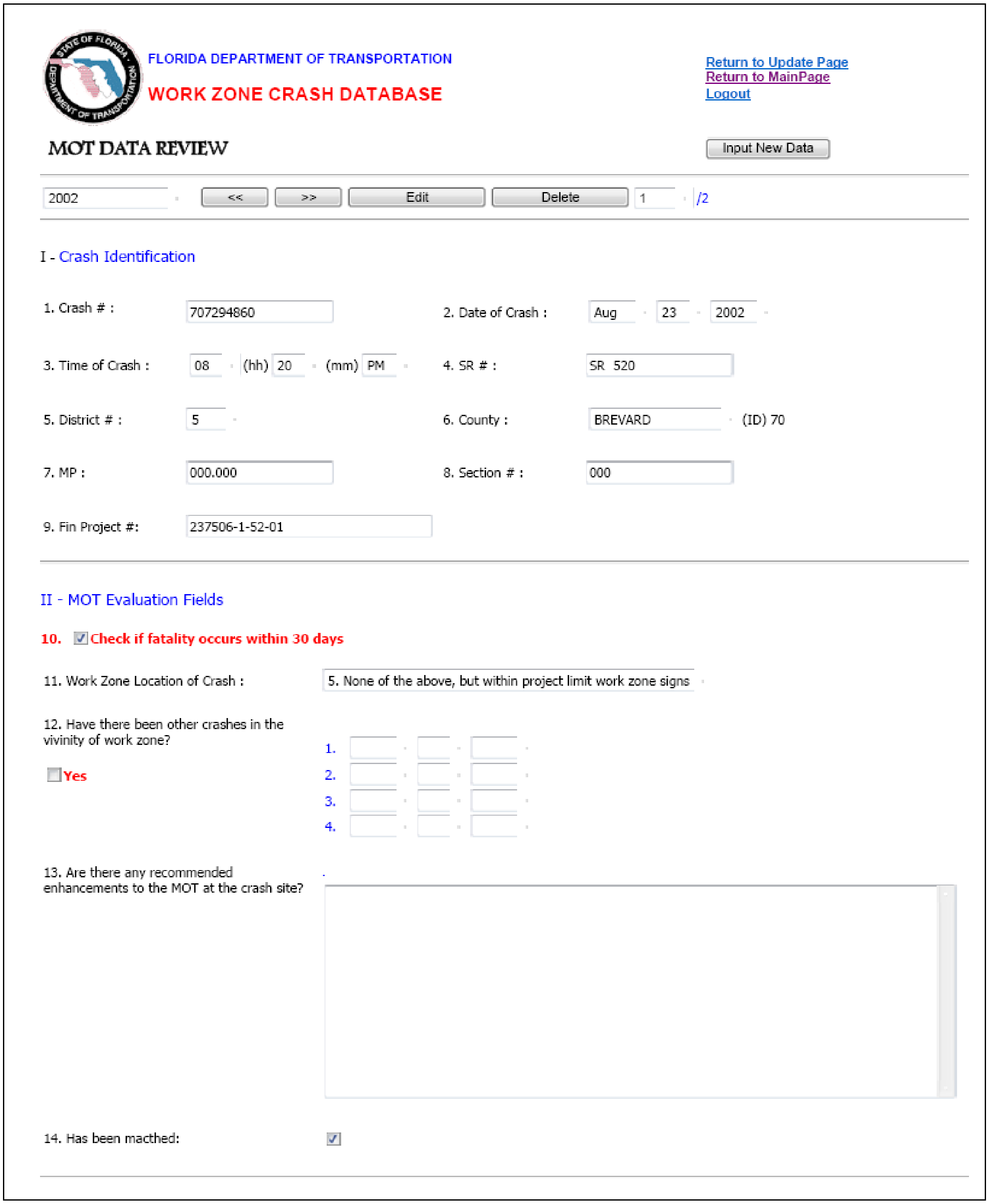


Figure F-35 MOT Data Review Page

- Users can browse all existing data by clicking the "Last" (<<) or "Next" (>>) button;

- To delete an existing data, users can click the "Delete" button on top of the page, a "Confirm" button will display on the bottom of the page. Click it; the current record will be deleted from the database.

- To revise an existing summary data, click the "Edit" button on the top of the review page. After revising the data fields, click the "Submit" button to send the revised data to database.

F.5.3.2 Match MOT Data

Being similar to updating summary data, we need to find the corresponding records of MOT data in the crash database if the Crash IDs of MOT data are not available or incorrect. As the result of a successful data match, the Crash IDs of MOT data will be revised according to the corresponding records in the crash data files, and the match tag fields (Crash_Info) in MOT Table are checked as "TRUE".

- Click the "Go" button corresponding to "Step 4" on the update page to open the MOT data match page;

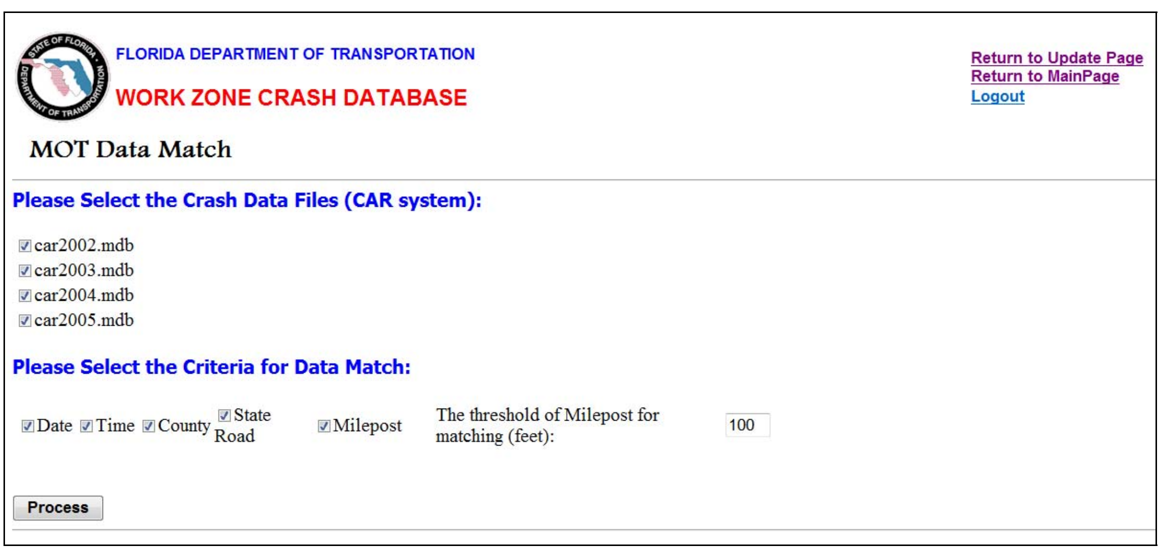


Figure F-36 MOT Data Match Page

- Select the crash data files which are abstracted from FDOT CAR system.
- Specify the criterion for data match. When a MOT data cannot match to a crash data based on Crash ID, the system will use the match algorithm developed in Chapter 6 to find its matched record in crash data files. That more criterions are selected mean that the match procedure is more restrictive.
- Click the "Process" button to execute the data match.
- If all data are matched, the system will display "All data have been matched". Otherwise, the data match confirmation page will display. Users accept a matched data from a candidate list on the page, or reject the data match.
- After all matched data are confirmed, a list of matched data is given on the match result page.
- If there are some summary data cannot find the matched records, return to the MOT data match page, and remove some match criterions. And then repeat step 4 until all data are matched.