ROBERT E. PAASWELL
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Frequency of Work Zone Accidents on Construction Projects

Final Report
August, 2005

Yi Qi, Ph.D.
Assistant Professor
Department of Transportation Studies
Texas Southern University

Raghavan Srinivasan, Ph.D.
Senior Transportation Research engineer
Highway Safety Research Center
University of North Carolina

Hualiang Teng, Ph.D.
Assistant Professor
University of Nevada

Robert F. Baker
Transportation Research Engineer
University Transportation Research Center
City College of New York

In cooperation with

University Transportation Research Center, Region 2
City College of New York

New York State
Department of Transportation
and
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MARSHAK HALL J910
THE CITY COLLEGE OF NEW YORK, NEW YORK 10031 212-650-8050 FAX 212-650-8374
WWW.UTRC2.ORG

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Yi Qi, Ph.D. Texas Southern University Raghavan Srinivasan, Ph.D. University of North Carolina Hualiang Teng, Ph.D. University of Nevada Robert F. Baker. University Transportation Research Center, City College of New York	C-01-61

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16. Abstract

The overall objective of this research was to study work zone accidents in New York State, with particular attention to the occurrence and mitigation of rear-end vehicle accidents. The specific objectives were to:

- Recommend changes to the NYSDOT's accident database system for more efficient management and analysis.
- Conduct a detailed investigation of rear-end crashes in work zones and recommend measures that can reduce the frequency of these types of crashes.
- Report on traffic exposure data and accident patterns / parameters to be incorporated into future NYSDOT accident data analysis.

Task 1 focused on evaluating the current NYSDOT work zone accident reporting system, surveying practices used in other states, and providing recommendations for improvement. The results of this task revealed that the current NYSDOT work zone accident reporting system is the most comprehensive in the country. Further changes to improve the system were recommended based on a review of the literature and practices being implemented in other state agencies.

The first part of Task 2 was focused on analyzing rear-en accidents in work zones that occurred in New York State between 1994 and 2001. Since data were available only on work zones that had accidents, truncated count data models were estimated to study the relationship between crash frequency and work zone characteristics. Ordered probit models were developed to study crash severity.

The second part of Task 2 provides some corrective actions to reduce frequency of work zone accidents. These actions are primarily based on a review of the literature since information on changes made by NYSDOT at the project level was not available to the research team.

The first subtask of Task 3 provided some recommendations to incorporate more project information to the work zone database either through adding more variables or including project information in a separate database that can be linked through a project identification number. The second subtask of Task 3 focused on various venues and approaches for obtaining exposure to traffic for various types of work zones. The final subtask of Task 3 focused on identifying parameters correlated with work zones and the county level.

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ABSTRACT

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INTRODUCTION

Safety in work zones continues to remain a high-priority issue for highway agencies partly due to the limited understanding of the causes of the crashes. According to the National Work Zone Safety Information Clearinghouse[1], in one year, work zones in this country are associated with more than 700 fatalities, 24000 injury crashes, and 52,000 property damage-only crashes, and the estimated cost of these crashes exceed $4 billion per year. One could argue that the work zones are likely to increase in number due to the emphasis on repair and reconstruction. Hence, it can be expected that the number of accidents in work zone will increase correspondingly. Following is a brief discussion of results from previous studies on work zone safety.

Most studies seem to indicate that the introduction of work zones lead to an increase in accident rates[2], although this increase is highly dependent on traffic and geometric conditions, traffic control devices, and other aspects of the work zone environment. The increase in crash rate at work zones may be due to several reasons including “the general disruption of traffic due to closed lanes, improper lane merging maneuvers by drivers, and inappropriate use of traffic control devices” (Venugopal and Tarko 2000).

Khattak et al., (2002), based on their literature review indicate that injury crashes in work zones are less severe than injury crashes in non-work zones. However, Wang et al. (1996), in their review, indicate that some studies found crashes in work zones to be more severe while other studies came up with opposite findings. In addition, “fatal crashes in work zones seem to be more likely to involve another vehicle than non-work zone fatal crashes” (Daniel et al. 2000).

Work zones seem to be especially difficult for trucks. Benekohal and Shim (1999) surveyed 930 truck drivers and found that 90% of those surveyed considered traveling through work zones to be more hazardous than traveling through regular sections. Daniel et al. (2000) in their study of work zone crashes in Georgia found that “trucks are involved in a higher proportion of fatal crashes in work zones than in non-work zone locations”.

In work zones, apart from collisions between two or more vehicles or between vehicles and fixed objects, collisions between vehicles and workers can lead to serious injuries and fatalities. Bryden and Andrew (1999) conducted a study of work zone crashes in New York State and found that “traffic accident injuries involving pedestrian workers accounted for 15% of all serious injuries and more than 40% of the fatalities”.

Traffic control devices are intended to reduce the frequency of crashes. For example, Garber and Srinivasan (1998) found that changeable message signs with radar could reduce the possibility of speeding at work zones, and hence reduce the frequency / severity of crashes. In another study, orange rumble strips due to their high visibility were found to have a significant effect on vehicle speeds (Meyer, 2000). However, in some cases, these devices may themselves be a safety hazard to drivers, passengers, and the workers, and need to be studied carefully (e.g., see Bligh et al. 1998; Bryden et al. 1998).

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[1] See http://wzsafety.tamu.edu/files/brochure.stm [Accessed November 11, 2001]
[2] See Khattak et al. (2002) and Wang et al. (1996) for a review of the literature

Rear-end crashes have consistently been the most predominant type of crashes. This has been found to be true for work-zones as well. Between 30 and 40% of crashes at work zones are rear-end crashes (Wang et al. 1996). Very few published studies have analyzed the causes and the factors associated with rear-end crashes in work zones. One possible reason is the lack of detailed data. NYSDOT is one the few state agencies that has specific detailed information about its work zone accidents[3]. This database provides a unique opportunity to conduct a detailed investigation of these accidents, identify causal factors, and identify procedures to reduce these crashes.

OBJECTIVES

The overall objective of this research study is to study construction work zone accidents in New York State, with particular attention to the occurrence and mitigation of rear-end vehicle accidents. The specific objectives are to:

- Recommend changes to the NYSDOT's accident database system for more efficient management and analysis.

- Conduct a detailed investigation of rear-end crashes in work zones and recommend measures that can reduce the frequency of these types of crashes.

- Report on traffic exposure data and accident patterns / parameters to be incorporated into future NYSDOT accident data analysis.

TASKS

The objectives were achieved through the following three tasks:

Task 1. Review, evaluate, and recommend possible changes to NYSDOT work zone accident reporting system.

Task 2. Investigate rear-end crashes in work zones and recommend mitigation measures

Task 3. Report on traffic exposure data and accident patterns/parameters to be incorporated into the future NYSDOT accident data analysis

Further description of the individual tasks and the outcomes are discussed next. The conclusions from the study are provided in the end of the report.

[3] See NYSDOT RFP entitled: "Frequency of work zone accidents on construction projects"

TASK 1 REVIEW, EVALUATE, AND RECOMMEND POSSIBLE CHANGES TO THE NYSDOT WORK ZONE ACCIDENT REPORTING SYSTEM

Task 1 is divided into three subtasks: Task 1.1 reviews the current NYSDOT work zone crash reporting system, Task 1.2 reviews practices and policies used by other transportation agencies and industry practices, and Task 1.3 provides recommendations for improvement.

Task 1.1 Review of current NYSDOT related accident reporting system

Based on information provided by NYSDOT Construction division, the research team developed a good understanding of the NYSDOT work zone accident reporting process. Here are some of the salient features of the system:

<u>Definition of work zone</u>
The NYSDOT work zone accident reporting system categorizes crashes as simply ‘work zone related’ and ‘within project limits’. Work zone related means there are temporary traffic controls, workers, or equipment directly involved in the crash or that the traffic pattern/operations at the crash sites have been affected in some way by the work activity or temporary traffic control pattern. Within project limits indicates that the crash occurred within the limits of a highway section that is legally under contract.

<u>Responsibility for Reporting</u>
The Engineer-in-Charge (EIC) is a central figure in the accident reporting procedure, and will in most cases be responsible for initiating the process when an accident occurs. All inspection personnel – both Department and consultant employees – are responsible for notifying the EIC as soon as they become aware that an accident has occurred on the project. The Regional Construction Safety Coordinator (RCSC) is expected to assume responsibility for ensuring that the process is completed in a timely fashion, and that all reporting requirements are met. It is suggested that the EIC notify the RCSC by phone as soon as possible after learning of an accident. The RCSC will then assume responsibility for notifying regional staff and the Main Office, and for coordinating preparation of the required reports. The timeliness of the initial notification and the required level of reporting depend upon accident severity and the degree to which construction activities are involved.

<u>Maintenance of the work zone crash database</u>
The Construction division of NYSDOT in Albany maintains and updates the work zone crash database.

<u>Software used to maintain and update the database</u>
Until 2002, NYSDOT used Computer Associates Supercalc4 program for recording and maintaining the work zone crash program. Starting in 2003, NYSDOT has started using Microsoft ACCESS.

<u>The level of detail for each crash and causal factors</u>
This information is presented in Appendix A, which has the list of variables that are coded, and the definitions of selected variables.

Crashes in idle work zones
Since the primary responsibility is with the EIC, if the work zone is idle and the EIC is not around, the police typically notifies the NYSDOT Duty Officer, who in turn notifies the EIC and other staff.

Definition of the work zone crashes
Crashes are recorded if they are within project limits, but not if they are outside project limits and the work zone activity was not deemed to be causal factor.

Location of crashes involving workers
The variable "traffic accident type" has information to indicate whether a vehicle struck a worker in WZ or not.

Task 1.2 Research Other Transportation Agency and Industry Practices

This sub-task involved two activities. First, other States were surveyed to understand their reporting processes for work zones. Second, selected publications, documents, and databases were reviewed to study issues that specifically deal with the collection of crash data at work zones.

Survey of States

A survey of the work zone crash reporting systems and practices was sent to 23 States DOTs. Nine States responded to the survey. Appendix B gives a summary of the responses. Copies of the completed surveys and reports were sent to the NYSDOT as they were received during March and April.

All of the responses indicate that the primary responsibility for reporting work zone crashes rests with law enforcement. As discussed earlier, this is different from the policy in NYSDOT where the EIC has the primary responsibility. For traffic accidents, the report received from the EIC and RCSC is supplemented by the report from the police officer. This allows NYSDOT to maintain the quality of information that is recorded in the database.

All agency responses indicate that work zone crash data is coded on the Department of Motor Vehicle database or the central crash system database. Wyoming DOT maintains a separate database, in addition to the main database, for work zone crashes. The Wyoming work zone database collects information on the work zone total crashes, traffic control devices, flagging, detour or lane transition, contractor's equipment, severity, and motorcycle crashes. The Iowa DOT tracks work zone crashes though the Construction unit but did not note a separate database. No other respondent maintained a separate database for work zone crash analysis.

Three State DOT agencies define the work zone as the area between signs. The remaining agencies extend the area to before the first sign and past the termination area. All agencies use police judgment to determine if the crash was work zone related.

All agencies record work zone crash data along with other crash data. Three of the respondents use Oracle and one noted using a mainframe system. Although some did not specify the system, most agencies probably use the mainframe systems that are designed to handle large databases. Washington State uses a 3 tier Visual Basic application. Wyoming DOT uses Microsoft ACCESS database for work zone crashes, which is the system that New York State is moving to, starting in 2003.

The responses indicate that the NYSDOT's work zone crash database provides more detailed information about the work zone situation and type of accident, including construction accidents compared to the nine States that responded to the survey. However, some States (e.g., Washington, Iowas, and North Carolina) provide additional information regarding a few variables that NYSDOT may want to consider. For example, Iowa codes 3 variables for work zone related crashes:

> *Location*: before work zone warning sign, between advanced warning sign and work area, within transition area for lane shift, within or adjacent to work activity, between end of work zone and 'end work zone' sign, other work zone area (explain in narrative), or unknown
>
> *Type*: lane closure, lane shift/crossover (head-to-head traffic), intermittent or moving work, other type of work zone (explain in narrative), or unknown
>
> *Workers present?*: yes, no, or unknown

NYSDOT does include information about the type of work zone in the variable 'work zone situation', in more detail than the Iowa system. In addition, NYSDOT does not include information on specifically indicate whether workers are present. North Carolina, in their crash reporting form, indicate whether there is on going activity in the work zone, and information about the location of crash (before/after/in work area approach taper). Washington's crash report also includes information about the presence/absence of workers.

In addition to specific information for work zone crashes, many State agencies also record information on the following variables that are not currently included in the NYSDOT work zone crash database:

> Information about weather and lighting conditions. Currently, these are included in New York only if they are considered a contributing factor
>
> Damage location for the vehicle(s) involved in the crash
>
> Road characteristics, i.e., straight, curve, grade, etc.
>
> Safety equipment used by the occupants, i.e., seat belts and airbag
>
> Speed limit
>
> Pavement condition
>
> Vehicle action before the crash, i.e., going straight, turning left, etc.

Did the driver(s) have a valid driver's license?

In a correspondence with the FHWA[4], no other State agency is noted for having as "rich in detail and robust as the NYSDOT" work zone database. However, much of the data from the Work Zone Clearinghouse are not as comprehensive as NYSDOT.

Review of Relevant Literature

The literature review focused on a review of three types of studies:

1. Published studies that have utilized crash data to conduct statistical analysis. A review of these studies provided information about the databases that were utilized.
2. Studies that discuss data collection issues.
3. Existing crash databases at the federal level.

<u>Review of studies that utilized crash data</u>

The primary objective of these studies (e.g., Khattak et al., 2002; Graham and Migletz, 1983; Pal and Sinha, 1996a, 1996b; Venugopal and Tarko, 2000, Daniel et al., 2000; Garber and Zhao, 2002; Chambless et al., 2002) was to conduct statistical analysis of crash data from work zones to study the relationship between crash frequency, severity, and the characteristics of a work zone. A review of these studies indicated that the following variables are of interest in the study of work zone crashes and should be considered for inclusion in the NYSDOT work zone crash database:

ADT and directional mix of traffic volume. It is obvious that ADT is an important factor that influences the number of crashes that occur in a roadway segment. The presence of a work zone can influence traffic volume, although this information is rarely collected. ADT is currently being recorded in NYSDOT's work zone crash database, but may not be in the future.

Length and duration of work zone. This information has been used in many studies (e.g., Khattak et al., 2002; Pal and Sinha, 1996a, 1996b; Venugopal and Tarko, 2000). All other things being equal, a longer work zone that is in place for a longer time period will have more crashes. Currently, this information is not recorded in the NYSDOT's work zone crash database, but may be available from another source, such as a work zone inventory system.

Terrain (flat, rolling, mountainous). This variable was included in the analysis conducted by Khattak et al., 2002.

Project cost. Venugopal and Tarko (2000) included project cost divided by the product of the duration of a work zone and the length of the work zone as a measure of the

[4] Correspondence of March 12, 2003, Kenneth Opiela, Highway Research Engineer, TFHRC Safety R&D, Federal Highway Administration.

intensity of the work zone. This variable was found to be significant for crashes that occurred within a work zone but not for crashes that occurred in the approach to the work zone. NYSDOT's work zone database currently includes information about the total contract amount, but may not be included in the future.

Number of ramps and distance to work zone site. Venugopal and Tarko (2000) included this variable in their analysis.

Location of crash. Garber and Zhao (2002) conducted a detailed analysis of the types of crashes based on the locations of these crashes (i.e., advance warning, transition, longitudinal buffer, activity area, and termination).

<u>Studies that discuss data collection issues</u>

Wang et al. (1996), based on a critical review of the literature, discussed deficiencies of data reporting practices and issues of data needs pertaining to work zone safety. They also provided recommendations to improve data collection and fulfill information needs. They recommended that the following variables be included for work zone crashes:

1. Was there activity in the work zone at the time of the crash?
2. Was the work area marked with warning signs? If yes, where (before work area, approach taper, adjacent to actual work, etc.)
3. Type of work area (lane closure, lane shift/crossover, work on shoulder or median, intermittent/moving work zone)
4. Did the work area have an influence on or contribute to the crash?

The NYSDOT's work zone database does include information about items 3 and 4, i.e., the type of work area and whether the work area contributed to the crash. However, the database does not include information on whether there was activity in the work zone (item 1) and if there were warning signs (item 2), although the database does provide information on the presence/absence of flaggers.

Another study that has a detailed discussion on this issue is a document called the Model Minimum Uniform Crash Criteria (MMUCC, 1998). The MMUCC was developed in order to encourage uniformity between and within states in collection of crash data. It was sponsored by the National Highway Traffic Safety Administration (NHTSA), the Federal Highway Administration (FHWA), and the National Association of Governors' Highway Safety Representatives (NAGHSR). The latest version of MMUCC that is currently available was published in 2003. Numerous states, local agencies and organizations have contributed staff to its development, including staff from NYSDOT. The recommendations from MMUCC regarding the relevant variables for work zone crashes were at least partially based on the work by Wang et al. (1996). The MMUCC recommends the following information be included specifically for work zone crashes:

Location of the crash:

Before the first work zone warning sign

Advance warning area
Transition area
Activity area
Termination area

Type of work
Lane closure
Lane shift/crossover
Work on shoulder or median
Intermittent or moving work
Other

Workers present?
Yes
No
Unknown

More recently, Spainhour and Mtenga (2002) studied the work zone crash reporting system in Florida and recommended changes to the system. The researchers surveyed the practices followed in 17 states and noted that New York's crash reporting form for work zones was the most comprehensive. Based on their survey and a literature review, the researchers recommended a revised crash report form for recording information on work zone crashes (see Appendix C). The new form records information on three entities: (1) information about the project, (2) information about the crash site, and (3) information about the crash. Project information includes variables such as contract number, project financial number, federal project number, project type, district, and county that do not change for a given project. Site information includes information about the various divisions within the work zone (i.e., approach area, transition area, buffer space, work space, and termination zone), pavement markings, usage of traffic control devices and their spacing, use of advance warning signs, etc. Crash information includes crash report date, police crash report number, visibility, pavement conditions, speed restrictions, vehicle movement, and other crash related variables.

Spainhour and Mtenga (2002) acknowledged that there were limitations of the new recommended system. They felt that "the system is not well suited to more complex geometrics, including intersections, ramps, and changes in geometry". To be more useful, they indicate that the system has to be more complex to collect data for different types of roads and situations, e.g., the roadway is closed with off-site detour.

<u>Review of crash databases</u>

The most popular crash databases at the federal level are the Highway Safety Information System (HSIS), the Fatality Analysis Reporting System (FARS), and the General Estimates System (GES). The variables recorded in these databases were reviewed.

Highway Safety Information System. The Highway Safety Information System is a multistate database that contains crash, roadway inventory, and traffic volume data for a select group of

States. The HSIS uses data already being collected by States for the management of the highway system and for the study of highway safety. The HSIS is a roadway-based system that provides quality data on a large number of accident, roadway, and traffic variables. The data are acquired annually from a select group of States, processed into a common computer format, documented, and prepared for analysis. The HSIS is operated by the University of North Carolina Highway Safety Research Center (HSRC) and LENDIS Corporation, under contract with FHWA. The participating States were selected based on the quality of data available, and their ability to merge data from various files. Currently, nine States participate in the program: California, Illinois, Maine, Michigan, Minnesota, North Carolina, Ohio, Utah, and Washington. California records information about whether a crash occurred in a construction zone, but does not seem to provide additional detail. Maine and Utah also have variables that indicate whether a crash occurred at a construction zone, but very little additional information is provided. Michigan provides limited information on crashes that occur in construction and maintenance work zones. They indicate if the construction activity was on road or off road and whether the lane was closed. Ohio codes a variable called ‘special area’ that includes either road construction/maintenance area or school zone; however, very little additional information about the construction/maintenance area is provided, unless it is included in the narrative.

Fatality Analysis Reporting System. The Fatality Analysis Reporting System (FARS) is a collection of files documenting all qualifying fatal crashes since 1975 that occurred within the 50 States, the District of Columbia, and Puerto Rico. To be included in this census of crashes, a crash had to involve a motor vehicle traveling on a traffic way customarily open to the public, and must result in a death of a person (occupant of a vehicle or a nonmotorist) within 30 days of the crash. FARS does include a variable to indicate whether a crash occurred at a construction or maintenance zone, but very little further information about the work zone is provided.

General Estimates System. Data for GES come from a nationally representative sample of police reported motor vehicle crashes of all types, from minor to fatal. The system began operation in 1988, and was created to identify traffic safety problem areas. It provides a basis for regulatory and consumer initiatives, and forms the basis for cost and benefit analyses of traffic safety initiatives. The information is used to estimate how many motor vehicle crashes of different kinds take place, and what happens when they occur. GES also includes a variable to indicate whether a crash occurred at a construction zone, but like FARS, provides little information about the work zone.

Task 1.3 Recommendations for Changes to the NYSDOT Work Zone Crash Reporting System

As discussed earlier, NYSDOT's work zone crash reporting system is probably the most comprehensive in the country. However, for the database to be more useful and for better clarity, the following changes should be considered:

Modify the work zone situation variable so that the location of the crash/collision (e.g., before the advance warning sign, in the taper area, after the work zone, etc.) is clearly distinguished from the information provided from the variable on the type of work zone (flagger controlled, median crossover, lane shift, etc.)

Provide information on traffic control devices and the length of the approach, transition, buffer, work space, and the termination regions of the work zone

Provide information on the number and width of open lanes in the work zone

Provide information about the total length of the work zone and the duration of the work zone either in the crash report or through a link to another database. All other things being equal, a work zone that is longer and is in place for a longer duration will have more accidents. This information could also be provided in another source such as a work zone inventory system.

Total cost of the project. NYSDOT staff indicated that this was going to be removed; however, the cost information may provide some indication of the intensity of work that is going on.

Code other variables (examples given below) that are typically included in a crash report form but not in NYSDOT's work zone crash database:

Information about lighting and weather conditions. Currently, these are included only if they are considered a contributing factor.

Damage location(s) for the vehicle(s) involved in the crash

Road character, i.e., straight, curve, grade, etc.

Safety equipment used by the occupants, i.e., seat belts, airbag

Workers present/absent.

Speed limit in the work zone and immediately upstream of the work zone

Pavement condition

Vehicle action before the crash, i.e., going straight, turning left, etc.

Did the driver(s) have a valid driver’s license?

Regarding the software package for developing the crash database, NYSDOT has already started moving towards using Microsoft ACCESS, which is an appropriate environment to use. Wyoming uses ACCESS and based on their survey quite satisfied with its effectiveness.

TASK 2: INVESTIGATE REAR-END CRASHES IN WORK ZONES & RECOMMEND MITIGATION MEASURES

Task 2.1 Investigate Rear-End Crashes in Work Zones

The objective of this task is to identify the factors that are associated with the occurrence of rear-end accidents in a work zone. The first part of this section focuses on the frequency of rear-end accidents, and the second part focuses on the severity of rear-end accidents.

Frequency of rear-end accidents in work zones

The analysis was conducted by estimating a statistical model where the dependent variable was the number of rear-end accidents in a work zone. Accidents are considered 'count' data, i.e., they represent non-negative integers that are an outcome of rare events. In order to model accidents, traditional statistical procedures such as standard least squares regression are not applicable. Count data are properly modeled by using a number of methods, the most popular of which are Poisson and Negative binomial regression models. Because the data for this study were derived only from NYSDOT's work zone accident database, information for work zones where no accidents occurred was not available. Hence, all accident frequencies derived from the work zone incident database are non-zero, and traditional Poisson and Negative binomial models cannot be used. To address this problem, truncated count data models were used which allows model calibration based only on counts greater than zero.

Mathematical equations describing the truncated Poisson and Negative binomial models are discussed next. Following this, there is a discussion of the model calibration and the findings.

<u>Truncated Poisson Regression Model</u>

The Poisson regression model is based on the unconditional Poisson distribution:

$$\Pr\left(y_i \middle| X_i\right) = \frac{\exp\left(-\lambda_i\right)\lambda_i^{y_i}}{y_i\,!}, \tag{1}$$

for which the expectation of counts can be written as:

$$E\left(y_i \middle| X_i\right) = \lambda_i = e^{\beta' X_i}, \tag{2}$$

where, y_i is the dependent variable, which represents the number of rear-end accidents occurred in work zone i and X_i represents the independent variables that are associated with the occurrence of the accidents . When zero counts are not included in the accident frequency data, distribution of the accident frequency can be represented by a conditional distribution:

$$\Pr\left(y_i \middle| X_i, y_i > 0\right) = \frac{\exp\left(-\lambda_i\right)\lambda_i^{y_i}}{y_i\,!}\left[1 - \Pr\left(y_i = 0 \middle| X_i\right)\right]^{-1} = \frac{\lambda_i^{y_i}}{\left(\exp\left(\lambda_i\right) - 1\right) y_i\,!}. \tag{3}$$

The regression model based on this conditional distribution is called truncated Poisson regression with lower truncation point at 0, which was used in this study.

To estimate the parameters, maximum likelihood method can be used, for which the log-likelihood function is written as:

$$\ln L = \sum_{i=1}^{n} \left[-\ln\left(\exp\left(\lambda_i\right) - 1\right) + y_i \beta' X_i - \ln y_i ! \right], \tag{4}$$

where, n denotes the number of observations.

<u>Truncated Negative Binomial Regression</u>

A limitation of the Poisson model is its implicit assumption that the variance of y_{ij} is equal to its mean. Typically, with accident counts, its variance exceeds the mean. This is called overdispersion. If overdispersion exists, the parameter estimates will be biased and inefficient if a Poisson regression model is employed. In order to deal with overdispersion, Negative binomial regression models are commonly used. It generalizes the Poisson model by introducing an individual, unobserved effect into the conditional mean (Greene, 1997):

A Negative binomial distribution can be written as:

$$\Pr\left(y_i \middle| X_i\right) = \frac{\Gamma\left(1/a + y_i\right)}{\Gamma\left(y_i + 1\right)\Gamma\left(1/a\right)} r_i^{y_i} \left(1 - r_i\right)^{1/a}, \tag{5}$$

where $r_i = \lambda_i / \left(\lambda_i + \frac{1}{a}\right)$ and $\lambda_i = e^{\beta' X_i}$. When $a \to 0$, the negative binomial distribution reduces to a Poisson distribution. Considering only the counts greater than zero, a conditional Negative binomial distribution can be expressed as:

$$\Pr\left(y_i \middle| X_i, y_i > 0\right) = \frac{\Gamma\left(\frac{1}{a} + y_i\right)}{\Gamma\left(y_i + 1\right)\Gamma\left[\frac{1}{a}\right]} r_i^{y_i} \left(1 - r_i\right)^{\frac{1}{a}} \left[1 - \Pr\left(y_i = 0\right)\right]^{-1}. \tag{6}$$

The expectation of the count can be written as:

$$E\left(y_i \middle| X_i, y_i > 0\right) = \lambda_i \left[1 - \Pr\left(y_i = 0\right)\right]^{-1} = \frac{\lambda_i \left(1 + a\lambda_i\right)^{1/a}}{\left(1 + a\lambda_i\right)^{1/a} - 1} \tag{7}$$

In estimating the parameters using the maximum likelihood method, the following log-likelihood function can be used:

$$\ln L = \sum_{i=1}^{n} \ln\left(\Gamma\left(y_i + \frac{1}{a}\right)\right) - \ln\left(\Gamma\left(y_i + 1\right)\right) - \ln\left(\Gamma\left(\frac{1}{a}\right)\right)\lambda_i + y_i \ln\left(a\right) + y_i \beta' X_i - \left(y_i + \frac{1}{a}\right)\ln\left(1 + a\lambda_i\right)$$

$$-\ln\left(1-(1+a\lambda_i)^{1/a}\right) \tag{8}$$

Model Selection

Cameron and Trivedi (1990) and Greene (2000) have developed a test that can be used to choose between the Poisson regression model and the negative binomial model. Their test is based on the following hypotheses:

$$H_0 : Var(y_i) = E(y_i) \tag{9}$$
$$H_1 : Var(y_i) = E(y_i) + ag(E(y_i)) \tag{10}$$

The test is conducted by regressing

$$z_i = \frac{(y_i - \hat{\lambda}_i)^2 - y_i}{\lambda_i \sqrt{2}} \tag{11}$$

on λ_i and a constant term, which can be expressed as

$$z_i = c_i + \beta_{\lambda_i} \lambda_i \tag{12}$$

A simple t test for the coefficient λ_i is equivalent to a test of H_0 vs. H_1.

Second, as mentioned before, when the parameter a in Equation (5) close to 0, negative binomial becomes Poisson distribution. So, by testing the hypothesis of $H_0 :\ a = 0$ vs. $H_1 :\ a \neq 0$, the appropriate model can be the selected for the incident data used in this study. This test can be carried out by a t-test for the estimated a, a log likelihood ratio test, or a Lagrange Multiple(LM) test (Greene, 2000, p. 886).

Calibration of Truncated Models

Identification of Independent Variables

Based on the information provided in NYSDOT's work zone accident database, seven categories of variables were selected: work zone type, control device, layout, lane blockage, operation, location, facility type and traffic volume (see Table 1). There are six types of work zones: appurtenances, bridges, capacity, maintenance, pavement, and safety. Regarding traffic control devices, two could be identified from the information contained in the accident database: flaggers and arrow board. Two different layouts of work zones are considered in this study, alternating 1 way traffic and lane shift. Four different extents of lane blockages were found in the accident database, which are: full lane blockage, partial lane blockage, shoulder blockage and off shoulder blockage. In addition, a work zone can also be characterized as moving/short term or the others. Because the number of rear-end accidents can be different at intersections and other facilities, a variable "INTERSEC" was used to represent this particular facility. In the database, five facility types were available as shown in Table 2. Traffic volume was included as a factor that is associated with the occurrence of the rear-end accidents. By categorizing the AADT into five levels, five dummy variables were developed to indicate different levels of traffic volume in the work zone site.

Model Selection

The appropriate model was selected using the model selection methods discussed earlier. First, a poisson regression model was estimated (see Table 3). The results were used to calculate z_i given in Equation (11). Then, by regressing z_i on the $\lambda_i = e^{\beta' X_i}$, the t statistic for the coefficient λ_i was derived, which was found to be 6.0706. This result implied that the hypothesis $H_0 : Var(y_i) = E(y_i)$ can be rejected at the significant level 5%. Thus, a negative binomial regression model was selected. Furthermore, the hypothesis of $H_0 :\ a = 0$ versus $H_1 :$ $a \neq 0$ was tested.

The results of the three statistic tests were summarized as following:

- A t-test for the estimated a : the t statistic of the estimated a is 8.58877. Significant level was <<0.0001. H_0 was rejected.
- Likelihood ratio test: log likelihood for the Poisson model: -1639.26; log likelihood for the negative binomial model: -1515.52; the likelihood ratio: 2*(-1515.52 - (1639.26)) = 247.476, which follows chi-square distribution with 1 freedom. Therefore, the significant level of this statistic is <<0.0001. H_0 was rejected.
- LM test: LM statistic is 39, which follows chi-square distribution with 1 freedom. Therefore, the significant level of this statistic is very close to 0. H_0 was rejected.

Based on above statistic tests, the truncated negative binomial regression model was selected for this study.

Results

The estimated parameters in Table 4 were used to determine the association between the independent variables and the frequency of rear-end accidents. It is possible that at least some of the results may be due to the differences in exposure between the different work zone types and operational conditions. Since information on work zones with no accidents was not available for this study, we could not take into account such possible differences in exposure. Here is a discussion of the results:

- The ‘capacity’ and ‘pavement’ related work zones are associated with the highest frequency compared to other types of work zone type. The work zone types in the decreasing order of accident frequency are: capacity, pavement, safety, bridge, maintenance, and appurtenance.
- Regarding the two control methods that were investigated, work zones controlled by flaggers are associated with more rear-end accidents compared to those controlled by arrow boards.

- Work zones with alternating 1 way traffic tended to have more read-end accidents than the lane shift type. This might be due to the fact that there are more stop-and-go situations in the alternating 1 way traffic situation.
- Among the four lane blockage situations, full lane and partial lane blockages are associated with more rear-end accidents compared to ‘shoulder blocked’ and ‘off-shoulder or median work areas’.
- The results in Table 4 indicate that whether a work zone is ‘moving/short-term’ is a significant factor. When a work zone was ‘moving/short-term’, relatively fewer number of rear-end accidents occurred. This is may be because of the limited exposure associated with this operation.
- Work zones at intersections were not necessarily associated with more rear-end accidents compared to other locations. It is possible that motorists may have been more cautious when maneuvering at intersections than in mid-block. It is also possible that the number of work zones at intersections is much lower than the number of work zones at mid-block locations.
- Comparing the coefficients of the variables for facility type, it was found that work zones on urban and rural principle arterials tended to have more rear-end accidents compared to other roadway classes. This may be because traffic volumes in these two roadway classes are usually higher than in other roadway classes.
- As far as AADT was concerned, an increase in AADT (until 60,000) was associated with an increase the frequency of rear-end accidents. This was expected.

Table 1 Variables Considered in the Truncated Poisson and Negative Binomial Models

Variables		Description	Note
Category	**Name**		
Dependent variable	# of accidents per work zone	# of rear-end accidents per work zone	Identified based on Contract ID, Year, Month, and Work zone Situation #
Work Zone Type	APPURTEN	"Work Type" is appurtenances	
	BRIDGE	"Work Type" is bridges	
	CAPACITY	"Work Type" is capacity	This field includes other minor types and unknown type (baseline type)
	MAINTENA	"Work Type" is maintenance	
	PAVEMENT	"Work Type" is pavement	
	SAFETY	"Work Type" is safety	
Control Device	FLAGGERS	Flaggers are used	From the field "Work zone situation"
	ARROWBOA	Arrow board is used	
Layout	ALTERNAT	Alternating 1 way traffic	From the field "Work zone situation"
	LANESHIF	Lane Shift (on site diversion)	
Lane Blockage	FULLLANE	Full lane blocked	From the field "Work zone situation"
	PARTITIA	Partial lane blocked	
	SHOULDER	Shoulder blocked	This field also include unknown lane blockage
	OFFSOULD	Off shoulder or median work area	
Work Zone Duration	MOVING	Moving/short term work zone	From the field "Work zone situation"
Intersection Location	INTERSEC	Intersection	
Facility Type	URBANP	Urban principal arterial	From the field "Facility Type "
	URBANM	Urban other principal arterial	
	URBANCO	Urban collector and local	This field includes the unknown type (baseline type)
	RURALP	Rural principal arterial	
	RURALM	Rural minor arterial and major collector	
AADT	AADT1000	AADT<10000	From the field "AADT "
	AADT2000	10000<AADT<20000	
	AADT24	20000<AADT<40000	
	AADT46	40000<AADT<60000	
	AADTG6	60000<AADT	

Table 2 Facility Type

Facility Type	Description of Highway Type	Rural/Urban
01	Principal Arterial Interstate	Urban
	Principal Arterial Expressway Connecting Link	
	Principal Arterial Expressway Non-Connecting Link	
02	Principal Arterial Other Connecting Link	
	Principal Arterial Other Non-Connecting Link	
	Minor Arterial	
03	Collector	
	Local	
04	Principal Arterial Interstate	Rural
	Principal Arterial Other	
05	Minor Arterial	
	Major Collector	
06	Minor Collector	
	Local	

Table 3 Truncated Poisson Regression Model

Variables		Coeff.	t-Stat
Variable Category	Variable Name		
Constant	ONE	-1.04527	-9.91251
Work Zone Type	APPURTEN	-1.14362	-2.00197
	BRIDGE		
	CAPACITY	0.534107	4.25295
	MAINTENA	-0.51216	-3.72370
	PAVEMENT	0.555229	6.73999
	SAFETY		
Control Device	FLAGGERS	-0.2848	-1.94735
	ARROWBOA	-0.71432	-6.18950
Layout	ALTERNAT	0.503976	2.47877
	LANESHIF		
Lane Blockage	FULLLANE	0.340341	1.69182
	PARTITIA	0.549216	6.81405
	SHOULDER	-0.46606	-1.58983
	OFFSOULD	-0.54089	-1.10726
Work Zone Duration	MOVING	-9.53923	-0.26236
Intersection Location	INTERSEC		
Facility Type	URBANP	1.02779	10.44000
	URBANM		
	URBANCO	-5.0829	-0.13982
	RURALP	0.415878	2.68457
	RURALM		
AADT	AADT1000	-0.55722	-3.07617
	AADT2000	-0.42765	-2.81807
	AADT24		
	AADT46	0.341868	3.41701
	AADTG6	0.114017	1.13902
Log likelihood function		-1644.75	
Restricted log likelihood		-2567.58	
Chi-squared		1845.675	
Degrees of freedom		19	
Significance level		0	

Table 4 Truncated Negative Binomial Model

Variables		Coeff.	t-Stat
Variable Category	Variable Name		
Constant	ONE	-1.05413	-16.10580
Work Zone Type	APPURTEN	-1.1441	-1.86231
	BRIDGE		
	CAPACITY	0.530996	5.82066
	MAINTENA	-0.5033	-4.40834
	PAVEMENT	0.544666	10.69010
	SAFETY		
Control Device	FLAGGERS	-0.25169	-2.63600
	ARROWBOA	-0.72343	-6.96933
Layout	ALTERNAT	0.497029	2.73577
	LANESHIF		
Work Zone Location	FULLLANE	0.335615	2.68640
	PARTITIA	0.533206	10.56060
	SHOULDER	-0.42592	-2.13300
	OFFSOULD	-0.54139	-1.57578
Work Zone Duration	MOVING	-9.79628	-37.56540
Intersection Location	INTERSEC		
Facility Type	URBANP	1.00093	16.52840
	URBANM		
	URBANCO	-4.99509	-4.84210
	RURALP	0.418935	2.82561
	RURALM		
AADT	AADT1000	-0.54567	-3.05461
	AADT2000	-0.41585	-2.82351
	AADT24		
	AADT46	0.329965	6.17581
	AADTG6	0.102738	1.91587
Model Parameters	Alpha	0.100219	8.65557
Log Likelihood Function		-1520.4	
Log Likelihood Function of Poisson		-1644.75	
Restricted Log Likelihood		-2567.58	
Chi-Squared (1 df freedom)		248.696	
Significance Level		0	
Chi-Squared (1+19 df freedom)		2094.372	
Significance Level		0	

Severity of read-end accidents in work zones

In this study, severity of rear-end accidents was focused on the extent of injury represented as four categories: fatal, severe (life threatening), hospital (transported to) and minor. In the accident database available to this study, these categories are denoted as 1, 2, 3 and 4, respectively, which are ordered in nature. To investigate the relationship between the severity and site characteristics, an ordered probit model was estimated. Ordered probit models model the probability that a crash is fatal, severe, hospital, or minor, given that a crash has occurred.

Following is a description of the mathematical equations that illustrate the ordered probit model. This is followed by a discussion of the calibration of the model and the results.

Ordered Probit Model

The ordered probit model is built around a latent regression model:

$$y^* = \sum \beta_i X_i + \varepsilon \tag{13}$$

where X_i represents an explanatory variable which influences the severity of an rear-end accident. y^* is the dependent variable which is *unobservable* and represents the extent of severity. β_i represents the coefficient for X_i. ε denotes the error term. Let y represent the variable of the observed severity. Based on the ordered probit model, y can be determined by the unobserved variable y^* as follows:

$$\begin{aligned} y &= 1 \quad \text{if} \quad y^* \le 0, \\ &= 2 \quad \text{if} \quad 0 < y^* \le \mu_1, \\ &= 3 \quad \text{if} \quad \mu_1 < y^* \le \mu_2, \\ &= 4 \quad \text{if} \quad y^* \ge \mu_2, \end{aligned} \tag{14}$$

The μ's are unknown parameters that need to be estimated with β's. If ε is assumed to be normally distributed across observations and its mean and variance are normalized to 0 and 1, respectively, then we have the following probabilities:

$$Prob(y=1) = \Phi\left(-\sum \beta_i X_i\right) \tag{15.1}$$

$$Prob(y=2) = \Phi\left(\mu_1 - \sum \beta_i X_i\right) - \Phi\left(-\sum \beta_i X_i\right), \tag{15.2}$$

$$Prob(y=3) = \Phi\left(\mu_2 - \sum \beta_i X_i\right) - \Phi\left(\mu_1 - \sum \beta_i X_i\right) \tag{15.3}$$

$$Prob(y=4) = 1 - \Phi\left(\mu_2 - \sum \beta_i X_i\right) \tag{15.4}$$

The parameters of β's and μ's can be obtained based on maximum likelihood method. For these probabilities in Equation (14), the marginal effect of changes in a variable X_i can be expressed as:

$$\frac{\partial Prob(y=1)}{\partial X_i} = -\Phi\left(\sum \beta_\mathrm{i} X_i\right)\beta_i, \tag{16.1}$$

$$\frac{\partial Prob(y=2)}{\partial X_i} = \left[\Phi\left(-\sum \beta_i X_i\right) - \Phi\left(\mu_1 - \sum \beta_i X_i\right)\right]\beta_i \tag{16.2}$$

$$\frac{\partial Prob(y=3)}{\partial X_i} = \left[\Phi\left(\mu_1 \sum \beta_i X_i\right) - \Phi\left(\mu_2 - \sum \beta_i X_i\right)\right]\beta_i \tag{16.3}$$

$$\frac{\partial Prob(y=4)}{\partial X_i} = \Phi\left(\mu_2 - \sum \beta_i X_i\right)\beta_i \tag{16.4}$$

Since $\Phi(\cdot)$ >0, it can be found from Equation (15) that only the signs of the marginal effects on $Prob(y=1)$ and $Prob(y=4)$ can be determined by β_i, which represents the coefficients for X_i**.** For example, if β_i>0, the $Proby(y=1)$ will decrease with the X_i and the $Prob(y=4)$ increase with the increment of X_i**.** However, the changes to $Prob(y=2)$ and $Prob(y=3)$ are ambiguous because they are also determined by the values of X_i's**.** However, based on Equation (12), it can be argued that for positive values of the estimated coefficient β_i, the accident severity will increase with increase in X_i, and vice verse.

There are various ways to determine the goodness of fit of an ordered probit model. In this study, the quality of the calibrated ordered probit models were evaluated based on whether the coefficients are meaningful.

<u>Calibration of Ordered Probit Model</u>

Eleven categories of variables were used in the modeling: (1) contribution factors, (2) involved vehicle characteristics, (3) work zone type, (4) control device, (5) layout, (6) work zone duration, (7) intersection location, (8) work zone location, (9) incident location, and (10) facility type. Within the category of Contribution Factors, 22 variables are included:

1) Driver asleep, inattentive or distracted
2) Driver inexperience
3) Poor driver judgment (speeding, improper lane change, improper turn, failure to keep right, following too closely, etc.)
4) Careless backing
5) Alcohol/drugs/medication
6) Medical condition (heart attack, etc.)
7) Mechanical failure or vehicle not properly maintained
8) Slippery pavement
9) Night
10) Other poor visibility conditions (fog, rain, glare, etc.)
11) Oversize/overweight vehicle
12) Avoiding other vehicle
13) Avoiding animal/object/pedestrian/bicycle in roadway
14) Flagging signal misunderstood or inappropriate
15) Other inadequate, failed or missing traffic controls
16) Construction operation caused material to enter traffic lane
17) High winds, not driver fault
18) Pedestrian/bicyclist error
19) View obstructed by contractor's equipment/work
20) Debris from previous accident / incident

21) Defective pavement, such as pot holes etc.
22) Other, not fault of contractor or motorist

Two variables included in the categories of Involved Vehicle Characteristics are: (1) whether truck is involved and (2) the number of vehicles involved. The variables in the category of Accident Location are the indicators for three locations in a work zone: merge/transition, past transition area, and before taper. See Table 5 for details regarding the variables.

Summary of Findings

The results from calibration of the ordered probit model are presented in Table 6. Here is a summary of the findings:

- Rear-end accidents associated with alcohol, night, pedestrian, and roadway defects are more severe, while those associated with careless backing, stalled vehicles, slippery roadway, and misunderstanding flagging signals are less severe. Previous research has consistently shown that alcohol is associated with an increased frequency of severe crashes. In addition, it is well known that night driving is associated with lower visibility and higher speeds due to lower traffic volumes; pedestrian accidents tend to severe because of the vulnerability of pedestrians; and roadway defects can cause unexpected movements leading to severe crashes. Hence, it is not unreasonable that these four factors are associated with a higher level of severity for rear-end accidents.
- As far as the vehicles involved in a rear-end accident is concerned, the two variables considered in this investigation (whether there was a truck and the number of vehicles in an accident) are both associated with increased severity. It is not surprising that truck involving accidents are more severe compared to accidents without trucks.
- Among the six types of work zones, ‘bridge’, ‘capacity’, and ‘pavement’ are associated with more severe rear-end accidents than others. It is important to note that the results from the analysis of accident frequencies (discussed earlier) had shown that ‘capacity’ and ‘pavement’ work zones are associated with more rear-end accidents.
- Between the two control methods, rear-end accidents associated with work zones with flaggers are less severe.
- The variables for the layout, duration, intersection location, work zone location do not show any significant impacts on the severity of rear-end accidents.
- Among the three variables indicating the location of a rear-end accident, the results show that the accidents that occurred before the taper are significantly more severe compared to other locations in a work zone. Rear-end crashes that occur before the taper are probably associated with higher speeds compared to rear-end crashes that occur at other locations. This may explain the higher severity of accidents that occur before the taper.
- Regarding roadway class, the results indicate that rear-end accidents that occur on work zones in urban minor and rural minor roads are more severe compared to rear-end accidents on other roadways.

Table 5 Variables Used in Modeling Accident Severity

	Variable	Description	Note
Dependent Variable	Injury Category	The severity level of an incidents	From the Field "Injury Category"
Contribution Factors	1. Distraction	Driver asleep, inattentive or distracted	From the Field "Contribution Factors"
	2. Inexperience	Driver inexperience	
	3. Judgment	Poor driver judgment (speeding, improper lane change, improper turn, failure to keep right, following too closely, etc.)	
	4. Backing	Careless backing	
	5. Alcohol	Alcohol/drugs/medication	
	6. Medical	Medical condition (heart attack, etc.)	
	7. Broken	Mechanical failure or vehicle not properly maintained	
	8. Slippery	Slippery pavement	
	9. Night	Night	
	10. Visibility	Other poor visibility conditions (fog, rain, glare, etc.)	
	11. Oversize	Oversize/overweight vehicle	
	12. AvoidV	Avoiding other vehicle	
	13. AvoidA	Avoiding animal/object/pedestrian/bicycle in roadway	
	14. Misunderstood	Flagging signal misunderstood or inappropriate	
	15. MissingControl	Other inadequate, failed or missing traffic controls	
	16. Intrusive	Construction operation caused material to enter traffic lane	
	17. Wind	High winds, not driver fault	
	18. Pedestrian	Pedestrian/bicyclist error	
	19. Obstruct	View obstructed by contractor's equipment/work	
	20. Debris	Debris from previous accident / incident	
	21. Defective	Defective pavement, such as pot holes etc.	
	22. Other	Other, not fault of contractor or motorist	
Involved Vehicle Characteristics	HTRUCK	If the accident involved a heavy truck	From the Field "Heavy Truck Accident"
	NVEH	The number of vehicles involved in the accident	

Table 5 Variables Used in Modeling Accident Severity (continued)

	Variable	Description	Note
Dependent Variable	Injury Category	Severity level of incidents	From the Field "Injury Category"
Work Zone Type	APPURTEN	"Work Type" is appurtenances	
	BRIDGE	"Work Type" is bridges	
	CAPACITY	"Work Type" is capacity	This field includes other minor types and unknown type (baseline type)
	MAINTENA	"Work Type" is maintenance	
	PAVEMENT	"Work Type" is pavement	
	SAFETY	"Work Type" is safety	
Control Device	FLAGGER	Flaggers are used	From the Field "Work zone situation"
	ARROWBOA	Arrow boards are used	
Layout	ALTERNAT	Alternating 1 way traffic	From the Field "Work zone situation"
	LANESHI	Lane Shift (On Site Diversion)	
Work Zone Duration	MOVING	Moving/Short Term work zone	From the Field "Work zone situation"
Intersection Location	INTERSEC	At intersections	
Work Zone Location	FULLLANE	Full lane blocked	From the Field "Work zone situation"
	PARTITIA	Partial lane blocked	
	SHOULDER	Shoulder blocked	
	OFFSOULD	Off Shoulder or Median Work Area	
Accident Location	MERGET	If an accident occurred in a merge/transition area	From the Field "Work zone situation"
	PASTT	If an accident occurred in a past transition area	
	BTAPERWS	If an accident occurred before taper area but within countdown signing	
Facility Type	URBANP	Urban principal arterial	From the Field "Facility Type "
	URBANM	Urban other principal arterial	
	URBANCO	Urban collector and local	This field has the unknown type (baseline type)
	RURALP	Rural principal arterial	
	RURALM	Rural minor arterial and major collector	

Table 6 Calibrated Ordered Probit Model

	Variable	Estimated Coeff.	t-statistic
	Constant	-1.07909	-9.96623
Contribution Factors	1. Distraction		
	2. Inexperience		
	3. Judgment		
	4. Backing	-1.23933	-4.51054
	5. Alcohol	0.901044	5.24996
	6. Medical		
	7. Broken	-0.402745	-2.02415
	8. Slippery	-0.431569	-2.87199
	9. Night	0.379375	4.09202
	10.Visibility		
	11.Oversize		
	12.AvoidV		
	13.AvoidA		
	14.Misunderstood	-0.750168	-1.73397
	15.MissingControl		
	16.Intrusive		
	17.Wind		
	18.Pedestrian	1.35916	2.65443
	19.Obstruct		
	20.Debris		
	21.Defective	0.931658	2.43372
	22.Other		
Involved Vehicle Characteristics	HTRUCK	0.519399	7.05389
	NVEH	0.346501	9.65045

Table 6 Calibrated Ordered Probit Model (continued)

	Variable	Estimated Coeff.	t-statistic
Work Zone Type	APPURTEN		
	BRIDGE	0.157401	2.05339
	CAPACITY	0.318494	3.57679
	MAINTENA		
	PAVEMENT	0.0916238	1.46121
	SAFETY		
Control Device	FLAGGER	-0.142469	-2.02146
	ARROWBOA		
Layout	ALTERNAT		
	LANESHI		
Work Zone Duration	MOVING		
Intersection Location	INTERSEC		
Work Zone Location	FULLLANE		
	PARTITIA		
	SHOULDER		
	OFFSOULD		
Incident Location	MERGET	-0.221152	-3.08231
	PASTT	-0.275314	-4.60082
	BTAPERWS		
Facility Type	URBANP		
	URBANM	0.329229	3.95359
	URBANCO		
	RURALP		
	RURALM	0.369039	3.31258
Model Structure Parameters	μ_1	0.731711	26.8186
	μ_2	2.51107	23.19
	μ_3	2.76482	21.3563
Goodness of Fit	Log-L	-2402.493	
	Log-L(0)	-2547.222	
	Samples	2481	
	ρ^2	0.056818369	
	AOP	0.577186618	

Task 2.2 Evaluate remedial actions taken by the Department on projects experiencing rear-end accidents and assess the benefits of those actions

It is possible that New York State DOT's construction department made changes at two levels to reduce crashes in work zones:
1. at the system level by implementing improved policies and practices
2. at the project level by implementing remedial actions on specific projects experiencing a large number of rear-end accidents

Information on changes made at the project level were unavailable in a form that could be used by the research team. Hence the focus was on trying to understand changes that were made at the system level. One such change that was implemented in the late 1980's was the statewide work-zone inspection program. The research team reviewed the summary reports on the inspection program from 1994 to 2001 and a recent paper (Bryden and Andrew, 2001) that describes the program. It is important to note that in order to estimate the effectiveness of the inspection program on accidents, data are required not only from work zones that had accidents, but from work zones where accidents did not take place. As mentioned in Task 2, the research team was not able get access to information from work zones that did not have accidents.

Description of New York State Statewide Work Zone Safety Inspection Program

The New York State Statewide Work Zone Safety Inspection Program was initiated in the summer of 1987 to comply with the Federal Highway Administration Program Manual 6-4-2-12, now Federal Aid Policy Guide Part 630.1010 (e). The purpose of the Program is to gather information to evaluate the overall adequacy of work zone traffic control on Department projects and identify the areas where improvements are needed. Due to staffing limitations, the composition of inspection teams varied over the year depending on the type of work zones inspected. In general, three type three types of work zones have been inspected separately: capital projects, maintenance projects, and permit projects. Capital projects have been mostly extensively inspected starting from the beginning of the program. The inspections of the other two types of work zone have been continuously enhanced. During each inspection, the inspection team completes standard rating sheets where the rate scale ranges from 0 to 5 (the higher the rating the better the quality). In addition, a Regional Action Plan Checklist needs to be completed from which the Department can identify the recurrent deficiencies (copies of rating sheets are available from Bryden and Andrew, 2001). Based on average rating for the projects of these three types, the action checklist, and the identified recurrent deficiencies, project, regional and department follow-ups can be developed.

The Checklist of emphasis points used in 2001 is as follows:

1. All signs are expected to be in good condition. Faded and deteriorated panels and non-standard legends are not acceptable. All signs should look like they appear in the MUTCD.
2. Unneeded signs are to be fully covered, removed, or otherwise completely eliminated from the driver's view.

3. No low-mounted signs should be permitted, except for flexible panels meeting the current specification requirements.
4. Overlapping, conflicting, and unneeded countdown signs are not to be permitted.
5. Flagger signs are to be used only when a flagger is actually present and visible to the motorist. They must be covered or removed at all other times.
6. All signs should be placed at locations that provide good visibility. Signs hidden by foliage, roadway geometry, etc., result in a safety problem if an important message is missed.
7. A reasonable smooth, continuous, safety and convenient travel way appropriate for anticipated bicycle and pedestrian demand shall be maintained at all times.
8. Merge tapes lengths should meet minimum requirements in MUTCD Table 262-2. Location of tapers should provide optimal visibility to approaching motorists.
9. Flagging procedures are to follow the MUTCD and EI 93-022. Stop/slow paddles are to be used where appropriate, with flags used where paddles are not appropriate. Flag must be the appropriate size and color. Flaggers must be positioned to provide adequate visibility, and to enhance the safety of the flaggers. An adequate number of flaggers must be used to control all traffic streams.
10. Temporary concrete barriers must adhere to Department guidelines in Chapter 10 of the Highway Design Manual. Barrier ends must be flared at least 12 ft. always from the pavement on high-speed roads, or protected by crash cushions. Barrier flares in travel lanes and shoulders must be preceded by channelizing devices and adequate buffer space. All barrier runs must be designed to fully protect the hazard – short runs of one or two section are not effective. Barriers must be structurally sound with all joint connectors in place.
11. Pavement bumps – a reasonable smooth riding surface is to be maintained. Transverse pavement joints and paving rebates must be treated with temporary shims. “Bump” warning signs must be posted upstream and a channelizing device or object marker placed at the bump.
12. All temporary sign supports not protected by guiderail must meet the requirement of Section 619-3.02 of the standard specifications. Type A metal supports must meet Section 730-24 and materials details. Stub height must no exceed 100 mm (4 inches).

Bryden and Andrew (2001) in their paper indicate that the quality of temporary traffic control on construction projects as measured by the rating system has improved over the first few years after it has been put in place. For example, the statewide average of the annual inspection effectiveness score increased from 3.65 in 1991 to 4.35 in 1999. During this period, the percentage of construction zones with a rating of 3 or higher increased from 88.7% to 97.7%, and the percentage of construction zones with a rating of 4 or higher increased from 61.7% to 83.5%. Bryden and Andrew (2001) also indicate that using the results of the inspection program, NYSDOT implemented widespread improvements in work zone traffic control. Intuitively, one would expect that such changes should result in fewer work zone accidents and improved mobility. However, for reasons mentioned earlier, the research team did not have the information necessary to quantify the impacts of these changes on crash frequency and severity.

Task 2.3 Identification of Effective Countermeasures

The following discussion is based primarily on countermeasures that have been examined by other studies in order to reduce crashes in work zones.

Rumble strips: A vehicle passing over a rumble strip experiences a slight bump and alerts the driver to the hazards ahead. Recently, Bernhardt et al. (2001), installed orange rumble strips on approaches to work zones in an interstate work zone in Missouri. Overall, mean speeds decreased following the installation of the orange rumble strips. The specific rumble strips that were used in the study were not thick enough to produce a considerable amount of audible sound for trucks.

Speed Displays: Speed displays are radar activated signs that show the speed of approaching vehicles. The intent is that drives will slow down when they see their speed shown on the display. In addition, the radar unit in the display will activate radar detectors in advance of the work zone and influence drivers to slow down because of the perceived presence of a police officer. Fontaine and Carlson (2001) tested speed displays on two-lane rural high-speed low volume roads in Texas. The speed display was found to be quite effective in reducing speeds – speed reductions upto 10 mph were observed.

Measures to facilitate merge operations: Several state agencies have experimented with signs and displays that encourage motorists to vacate a closed travel lane farther upstream from the work zone – this is believed to offer a safety benefit. One such system is a flashing warning-light system that was tested in Texas (Finley et al., 2001). The system consisted of a series of interconnected synchronized flashing warning lights that produce the illusion of motion. This system was designed based on a University of Minnesota study (Vercuryssen et al., 1995) which found that lights positioned along the side of the roadway parallel moving toward the motorist caused motorists to reduce their speed. Finley et al. (2001) found that when the warning light system was installed on an urban freeway site (a relatively new lane closure), "there was a one-fourth reduction in the number of passenger vehicles and a two-thirds reduction in the number of trucks in the closed lane 1000 ft upstream of the lane closure". However, when the system was installed in a rural site that had lane closures for 6 months, it did not significantly affect the lane choice. Finley et al. (2001) concluded that the warning-light system may be more effective in short and medium duration maintenance or construction projects.

Flagger (stop/slow paddle) station: Flagger stations can also be used as a countermeasure for work zone intrusion. If flagger stations are installed far upstream of work zone, motorists can also be alerted and thus be prepared to slow down, which can reduce rear-end accidents.

Smart work zone technology: The Arkansas State Highway and Transportation Department deployed smart work zone technology systems on five projects starting in Spring 2000. One objective of these systems is to provide a queue-detection system to prevent or reduce rear-end accidents. Initial results seem to indicate that this system is effective in reducing fatal crashes in a rural site in Arkansas (Tudor et al. 2003).

Drone Radar: Drone radar has been recommended as a countermeasure by NYSDOT for work zone intrusion. Motorists can detect the existence of law enforcement in work zones and thus slow down correspondingly. According to the work zone crash report from 2000, one of the regions noted support for this countermeasure from workers who engaged in maintenance-type operations. “Although there was no way to measure driver response to drone radar, informal reports from workers indicated that at locations where it was used, slower speeds and smoother traffic flow were perceived.”

Implement improved practices for night time work zones. Bryden and Mace (2002) in their detailed study of this issue provide several guidelines for design and operation of nighttime traffic control.

TASK 3. REPORT ON TRAFFIC EXPOSURE DATA AND ACCIDENT PATTERNS/PARAMETERS TO BE INCORPORATED INTO FUTURE NYSDOT ACCIDENT DATA ANALYSIS

Task 3.1 Recommend Ways to Incorporate More Project Information into the Database

Based on a survey of other States that was conducted in Task 1, it is clear that New York State's work zone crash data base is unique in the amount of detail that is provided for each crash that occurs in a work zone. In fact, the analysis that was conducted as part of Task 2 revealed that the following variables were associated with either the frequency of crashes and/or severity of crashes.

1. Type of work zone (capacity, pavement, safety, bridge, maintenance, appurtenance, etc.),
2. Control method (flaggers, arrow boards, etc.),
3. Layout of work zone (alternating one way, etc.),
4. Geometric conditions in work zone (number of lanes blocked, which lane is blocked, etc.),
5. Scale of work zone (moving, phase by phase, etc.),
6. Location of work zone (intersection, mid-block, etc.),
7. Roadway classification where work zones are located (arterial, collector, etc.), and,
8. AADT.
9. Presence/absence of roadway defects

However, in addition to the detail of the work zone operations provided in the crash database, it is important that such information be available on all work zones including ones where there are no accidents. Such project information can either be included along with the work zone crash database or included in a separate database (e.g., a work zone inventory system) in such a way that, the two databases can be linked with each other through a project identification number.

In addition to the variables discussed above, the following project information can be extremely useful:

- The total length of the work zone and the duration of the work zone for different stages of a project. All other things being equal, a work zone that is longer and is in place for a longer duration will have more accidents. Typically, location information on construction projects is provided in the form of station numbers and this will have to be converted to milepoints/mileposts so that they can be linked to crash and traffic volume data.
- Number of lanes open and closed during different stages of the project. For projects where lane closures are long-term, this information could be recorded more easily compared to projects where lane closures are temporary.
- Information on type of work – e.g., grading, repaving, installing a guardrail.
- Information on the typical number of workers and equipment (e.g., number of dump trucks used in the operation) during different stages. Precise information on the number of workers and equipment is not critical. However, it will be useful to record the typical number of workers and equipment that is associated with a particular operation (e.g., such as paving).

- Information on signs and other traffic control devices that were used in a project. This information is typically available in project plans/drawings.
- Cost of the project. This information can be useful although the costs are highly dependent on the cost of living in a particular area – costs in Queens would be much higher compared to the costs in Rochester.
- Presence of enforcement personnel for a particular project. New York State allows for enforcement personnel to be present on specific projects. Presence of police can have an effect on motorist behavior and possibly the number of crashes.
- Roadway information. This includes information on the presence of vertical and horizontal curves and presence of intersections and interchanges ramps. However, such information is not typically available in construction project databases, but could be extracted from roadway inventory files if they are mileposted.

Task 3.2 Address Exposure of Traffic to Various Types of Work Zones

Exposure Data for Work Zones

In general, work zone exposure measures include traffic flow, length of a work zone, and hours of operations of a work zone. From these data, vehicle mile traveled (VMT) in work zones can be derived. The information on work zone length and hours of operation can be obtained from records that are maintained by agencies such as construction contractors and DOT maintenance agencies. The traffic flow information includes traffic volume, traffic composition, traveler composition, and pedestrians. Traffic volume is referred to the total flow of vehicle passing work zones. Typically, data on traffic flow are more easily available for major roads. Hence it is possible that traffic counts are not available for work zones in certain minor roadways. In some cases, AADT from a downstream or upstream location in the same route may be used as a substitute if available. Popular data sources for AADT are Highway Performance Monitoring System (HPMS) and other state and local traffic count systems. It is important to note that AADT represents the Annual Average Daily Traffic and does not provide information on the traffic volume passing through a work zone when work is being conducted and when an accident may have occurred. One could argue that the traffic flow going through work zones during different time periods is more directly related to crash frequency.

The second major data sources for traffic flow in work zones are data from Intelligent Transportation Systems that are implemented in many major highway systems in the country. These ITS systems include sensors buried in the pavement that provide information on real-time traffic conditions (e.g., INFORM in Long Island). In many cases, there is a higher probability of obtaining traffic counts through a work zone from an ITS system compared to from a traffic count station in a system such as HPMS.

Another major data source is through smart work zone systems. Smart work zones provide the motoring public with automated, real time, traffic information in work zones. They incorporate roadside speed and volume sensors to detect delay/congestion. This information is then transmitted to an on-site computer via radio, cellular, or satellite for processing. Delay information is then transmitted from the computer to portable Changeable Message Signs. As indicated in a recent report from the Federal Highway Administration (FHWA, 2002), most smart work zones have the capability of archiving data including traffic volume they collect. The real-time traffic volume data available from these smart work zones would be of immense help in studying safety issues related to work zones.

In addition to total traffic volume, it is also important to obtain information on vehicle type, since previous work has indicated that heavy-trucks and other heavy vehicles influence the occurrence and severity of accidents in work zones significantly. Information on vehicle type can be obtained from HPMS, ITS, and smart work zones. In addition, systems such as toll collection systems on highways, bridges, and tunnels also collect vehicle classification data. Commercial vehicle operations system is another data source for vehicle composition information (e.g., Commercial Vehicle Information System Network (CVISN) in NY).

The traveler behavior of individual drivers could also influence the occurrence and severity of accidents in work zone. For example, one could argue that individuals who are not familiar with a particular area and the work zones in that area may be less or more likely to make mistakes that lead to accidents. Although travel behavior is a useful piece of information, it is difficult to develop countermeasures to specifically address issues familiar or unfamiliar travelers separately. Data on travel behavior patterns can be obtained from the Censor Transportation Planning Package and other transportation planning databases (e.g., see Kweon and Kockelman 2002).

ITS in New York State

In the New York State, various ITS systems have been deployed. Examples of such ITS systems are described below.

Long Island INFORMS is an integrated freeway and arterial systems in Long Island. It is the first system in the U.S. where a ramp metering system was installed. Vehicle detection technologies such as inductive loop detector and RTMS have been deployed to collect vehicle information such as volume, speed, and occupancy. INFORM has provided archived traffic data for studies by FHWA and other agencies. Figure 1 provides a scope of INFORM.

New York City Traffic Management Center (see Figure 2) operates and maintains thousands of vehicle detection system and CCTV. Even though the traffic data from the detection system have not been archived, there are no known technical issues that would prevent the archiving of this data. Also, it is also possible to record the traffic on video, from which traffic related data can be extracted either manually or automatically.

EZ-pass in NY as shown in Figure 3 is a toll collection system on New York State Throughway. From this system, traffic volume and vehicle composition data can be obtained. Even though these data are not being archived, there are no known technical issues that would prevent the archiving of this data.

The highway system in Albany region as shown in Figure 4 is an ITS instrumented system. Traffic volume, speed, and occupancy data have been archived and provided to the Mobility Monitor Program at the Texas Transportation Institute.

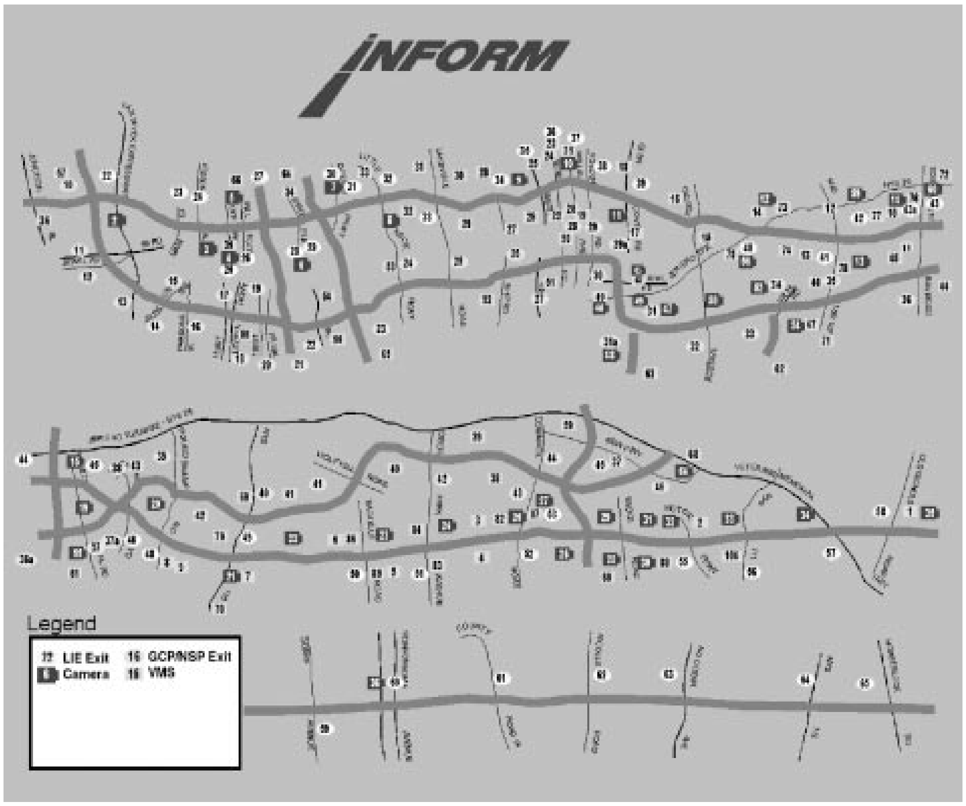

Figure 1 Long Island INFORM System

Source: Metropolitan Transportation Management Center, A Case Study, Long Island INFORM, FHWA-OP-99-006, October, 1999

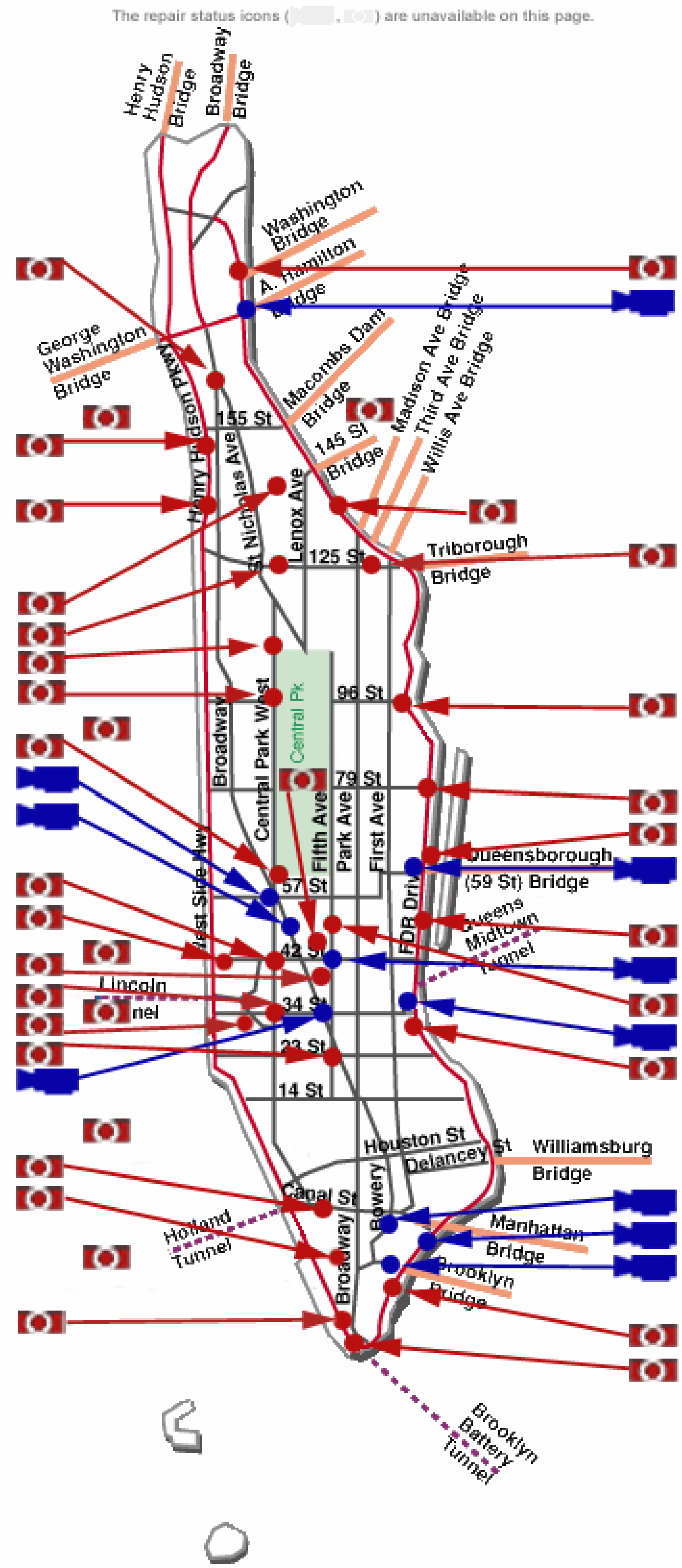

Figure 2 Cameras in Manhattan in NYC

Source: http://nyctmc.org/, accessed: 10/23/04

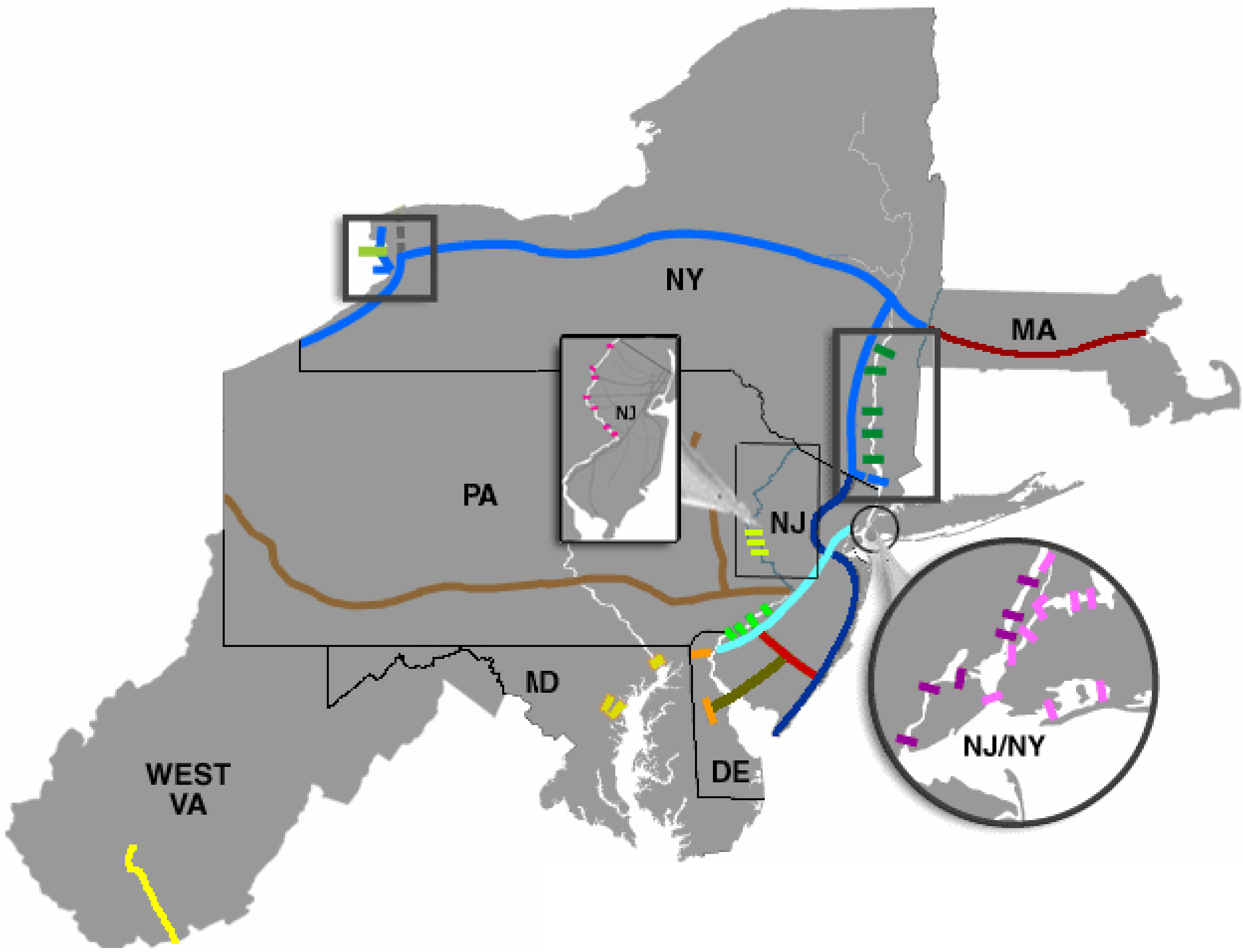

Figure 3 E-Zpass in the New York State

Source: http://www.ezpassny.com/static/info/index.html (accessed: 10/23/04)

Figure 4 Instrumented Freeway Routes in the Albany Region Source: http://mobility.tamu.edu/mmp/FHWA-HOP-04-011/ (accessed: 10/23/04)

Task 3.3 Identify Parameters to Provide Information about Accident Patterns

This task attempted to investigate the relationship between size of a county (in terms of area and population) and the frequency and severity of rear-end accidents. Locations in New York with a large number of rear-end accidents are highlighted in a map. In addition, zero-inflated frequency models were developed to study the relationship between number of accidents and county characteristics.

Number of rear-end work zone accidents in different parts of New York

Figure 5 shows the total number of rear-end accidents in each county. It can be seen that counties with more rear-end accidents do not include major cities such as NYC[5] and Buffalo. To take the population density into account, Figure 6 shows the ratio of total number of rear-end accidents to population. It can be seen that the counties having more rear-end accidents also have high population densities. Figure 7 displays the temporal pattern of the ratio. It can be found that most of counties demonstrate a pattern where the frequencies of rear-end accident are high in the beginning and middle years and decrease in recent years. It is important to note that this analysis is based only on work zones that had crashes – data from work zones that did not experience any crashes were not available to the researchers.

Modeling Rear-End Accident Frequency by County

To further study the relationship between the rear-end accident frequency and relevant regional variables, particularly population density, frequency models are developed.

Zero-inflated Frequency Model

In this study, zero-inflated frequency models were employed to investigate the relationship between the frequency of rear-end accidents and factors that characterize the county where the accidents occurred. The data in NYSDOT's work zone accident database indicate that there are a lot of cases where the values of the frequency are zero. Thus, zero-inflated frequency models are employed which have been shown in previous studies to be more appropriate in dealing with the data where a substantial number of "zeros" are observed.

The following is a description of the theoretical foundation for zero-inflated frequency models. These models assume that two different processes work together to generate the rear-end accident count data. One of these two processes only generates zeros. Two typical zero-inflated models, i.e., the zero-inflated Poisson (ZIP) and negative binomial (ZINB) models exist to handle the zero-inflated count data. Let y_{ij} denote the frequency of rear-end accidents in a county i and during a season j. It is assumed that it follows a probability distribution $f(y_{ij})$.

[5] It is important to note that these data are based on the reported accident statistics provided by NYSDOT. It is possible that some regions are more conscientious in reporting accidents compared to other regions. NYSDOT staffs have indicated that many work zone accidents in New York City are not reported to NYSDOT.

The two processes can be represented as $y_{ij} = 0$ with probability q_{ij} and $y_{ij} > 0$ with probability $1 - q_{ij}$. In a ZIP model, $f(y_{ij})$ takes a form as follows:

$$f(y_{ij}) = \frac{\exp(-\lambda_{ij})\lambda_{ij}^{y_{ij}}}{y_{ij}!}.$$

In the ZINB model, $f(y_{ij})$ takes a form as

$$f(y_{ij}) = \frac{\Gamma(1/a + y_{ij})}{\Gamma(y_{ij}+1)\Gamma(1/a)} r_{ij}^{y_{ij}} (1 - r_{ij})^{1/a} \tag{17}$$

where $r_{ij} = \lambda_{ij} / (\lambda_{ij} + 1/a)$. As in the Poisson and negative binomial regression models, we still assume $\lambda_{ij} = \exp(\beta' X_{ij})$ conditioned on the values of X_{ij}. Given these specifications, we have,

$$P(y_{ij} = 0) = q_{ij} + (1 - q_{ij}) f(0)$$
$$P(y_{ij} = k > 0) = (1 - q_{ij}) f(k)$$

where

$$q_{ij} = Logsitic(\tau\beta' X_{ij}), \tag{18}$$

which is a logistic cumulative distribution function. The maximum likelihood estimates can be used to estimate the parameters of the zero-inflated models, and confidence intervals can be constructed by likelihood ratio tests. The testing of whether a zero-inflated incident state is more appropriate than the non-zero-inflated incident state is complicated by the fact that the zero-inflated model is not nested within either the Poisson or the negative binomial models. That is, the restriction which produces the simpler model, i.e., $q_{ij} = 0$, is not a simple parametric restriction. Vuong (1989) has proposed a test statistic for distinguishing the non-nested model, which is described below:

$$v = \frac{\sqrt{n}\left[(1/n)\sum_{j=1}^{n} m_{ij}\right]}{\sqrt{(1/n)\sum_{j=1}^{n}(m_{ij} - \overline{m}_i)^2}} = \frac{\sqrt{n}(\overline{m}_i)}{S_{m_i}} \tag{19}$$

where:

m_{ij}	=	$\log \dfrac{f_1(y_{ij} \mid X_{ij})}{f_2(y_{ij} \mid X_{ij})}$,
$f_1(y_{ij} \mid X_{ij})$	=	the probability density function of the zero-inflated model,
$f_2(y_{ij} \mid X_{ij})$	=	the probability density function of either the Poisson or negative binomial distribution,
$\overline{m}_i$	=	the mean of m_{ij},
S_{m_i}	=	the standard deviation of m_{ij},
n	=	the sample size.

Asymptotically, the Vuong's statistic is distributed as standard normal. So its value can be compared to the critical value of the standard normal distribution, e.g., 1.96. The test is directional, i.e., values large than 1.96 favor zero-inflated model while values less than -1.96 favor Poisson or negative Binomial regression models.

Calibration of Zero-inflated Frequency Models

In this study, the area and population density are chosen to characterize a county from the perspective of rear-end accidents. Because the distribution of constructions activities in a year in Regions 8, 10 and 11 is different from that in Regions 1-7 and 9, separate zero-inflated frequency models were developed for these two groups of regions. In Regions 8, 10 and 11, construction typically continues for all the seasons in a year, while in Regions 1-7 and 9, there is a peak construction period, a non-peak period, and a period when there is no construction. To take these construction seasons into account, indicator variables PEAKC and OFFPEAKC were created in the model for Regions 1-7 and 9 (see Table 7). The no-construction period was used as the reference level in the modeling. In order to account for weather conditions that may influence the number of rear-end accidents, indicator variables were created: SSPR (representing Spring), SSUM (representing Summer), SFAL (representing Fall). Winter was taken as the reference level. The specific months included in the construction and weather seasons can be found in Table 7. In addition, two additional variables POPDENSIT (representing population per square mile) and AREA (square miles for a county) were included. It was postulated that the frequency of rear-end accidents would be more closely related to the population density, compared to the population itself. It is important to note that population and county-area are two variables for which the data can be retrieved from the Census Transportation Planning Package.

Table 8 lists the results of calibrating the model for Regions 1-7 and 9. The coefficients for variables representing peak construction and non-peak construction periods are positive as expected. This indicates that more rear-end accidents occurred in the construction period compared to the non-construction period. In addition, the coefficient for the variable representing the peak construction is higher than that of the non-peak construction period. This indicates that more rear-end accidents occurred in the peak construction period compared to the non-peak construction period. Again, this is consistent with our expectations. As far as the impact of weather condition on the frequency of rear-end accidents, coefficients of variables representing the spring, summer and fall seasons are positive, which shows that more rear-end accidents happened in these seasons compared to the winter season. The coefficients of the variables representing summer and fall are larger than that for the spring indicating that more rear-end accidents happened in summer and fall. The coefficient for POPDENST is positive implying that more rear-end accidents occurred in counties with high population densities. One could argue that population density is correlated with AADT, and the results of Task 2.1 have shown that AADT is a significant contributor to rear-end accidents. Hence, it is not surprising that counties with higher population densities have more rear-end work zone accidents. The coefficient for the last variable AREA is positive. This indicates that larger counties had more rear-end accidents.

Table 7 Description of Variables in the ZP Model

	Variable	Description
Dependent variable	INCIDENT	Number of incidents by county by season
Independent variables for Region 1-7 and 9	PEAKC	Peak Construction month (August-October)
	OFFPEAKC	Off Peak Construction month (April-July)
	SSPR	Spring Season month (March-May)
	SSUM	Summer Season month (June-August)
	SFAL	Fall Season month (September-November)
	POPUDENS	number of people per square miles
	AREA	square miles
Independent variables for Regions 8, 10 and 11	SSPR	Spring Season month (March-May)
	SSUM	Summer Season month (June-August)
	SFAL	Fall Season month (September-November)
	POPUDENS	number of people per square miles
	AREA	square miles

Table 8 Results of Zero-Inflated Negative Binomial Model for Regions 1-7, and 9

Variables		Coeff.	Std.Err.	t-ratio	P-value
Constant	ONE	-3.38323	0.366954	-9.21978	2.89E-15
	PEAKC	1.1687	0.171005	**6.83431**	8.24E-12
	OFFPEAKC	1.24798	0.20369	**6.12687**	8.96E-10
	SSPR	0.619905	0.262382	**2.3626**	0.018147
	SSUM	1.0515	0.254858	**4.12583**	3.69E-05
	SFAL	1.13529	0.234934	**4.83238**	1.35E-06
	POPUDENS	0.000637555	7.57428E-05	**8.41737**	2.89E-15
	AREA	0.00117883	0.000290028	**4.06456**	4.81E-05
Alpha (α)		1.77771	0.145594	12.21	2.89E-15
Tau (τ)		-0.34571	0.133938	-2.58111	0.009848
Log likelihood function		-2411.18728			
Restricted log likelihood		-3856.159			
Chi-squared		2889.94344			
Sample Size					
Degrees of freedom		7			
Significance level		0			
Good of fitness	Ro^2	0.374717879			

Table 9 shows the results of the calibration for Regions 8, 10, and 11. In general, these results again show that more rear-end accidents occurred during Fall and Summer compared to Spring and Winter. The coefficient for POPDENST is positive, but not significant, unlike the model that was developed for Regions 1-7, 9. This may be due to the fact that there is less variation in the population densities in these three regions compared to Regions 1-7 and 9. The coefficient for the last variable AREA is positive. This again indicates that larger counties had more rear-end accidents.

Table 9 Results of Zero-Inflated Negative Binomial Model for Regions 8, 10 and 11

Variables		Coeff.	Std.Err.	t-ratio	P-value
Constant	ONE	-0.0644797	0.0528615	-1.21979	0.222546
	SSPR	0.100818	0.0642298	**1.56965**	0.116497
	SSUM	0.295233	0.108145	**2.72997**	0.00633407
	SFAL	0.266974	0.106775	**2.50034**	0.0124073
	POPUDENS	1.5659E-06	1.75703E-06	0.89122	0.372812
	AREA	0.000196351	0.000102473	**1.91613**	0.0553491
Alpha (α)		1.19655	0.220098	5.43643	5.43598E-08
Tau (τ)		-6.78004	4.44586	-1.52502	0.127253
Log likelihood function		-1698.57472			
Restricted log likelihood		-2120.435			
Chi-squared		843.72056			
Sample Size		1344			
Degrees of freedom		5			
Significance level		0			
Good of fitness, ρ^2	Ro^2	0.198949876			

GIS Presentation of Severities of Rear-End Accidents

An ‘average severity level’ was calculated for each county by averaging over the severity levels of all work zone rear-end accidents in a county. A higher severity level indicates a more severe accident. It is important to note that different severity levels were given the same weight in this approach. In addition to average severity, the variation in severity for the rear-end accidents is presented using the numbers of injuries and fatalities in these accidents.

Figure 8 shows the average and variation of severity of all the rear-end accidents in each county that occurred from 1994 to 2001. It can be seen from the figure that the counties that had the most severe rear-end accidents are not necessarily the ones where more rear-end accidents occurred. Counties that contain the major cities in the New York State are also not necessarily the ones with the highest average severity. Figure 8 also presents the variation of the severity by showing the number of the rear-end accidents for two severity levels: fatality and injury. Counties with more fatal and injury accidents are not always the ones with higher average severity.

Figure 9 presents the relationship between population density and the average and variation of severity. There does not seem to be a strong correlation between these population density and severity levels.

In Figure 10, the temporal trend of average severities of the counties is displayed. From the figure, a clear trend of severity (declining or climbing) cannot be observed. The implication of this observation is that the average severity of rear-end accidents has not decreased even though the number of rear-end accidents has decreased during the same time period.

Summary

Based on the investigation to the frequency and severity of rear-end accidents, it can be concluded that population density and area are correlated with the frequency of rear-end accidents. In addition, construction season and weather are correlated with the frequency and severity of rear-end accidents.

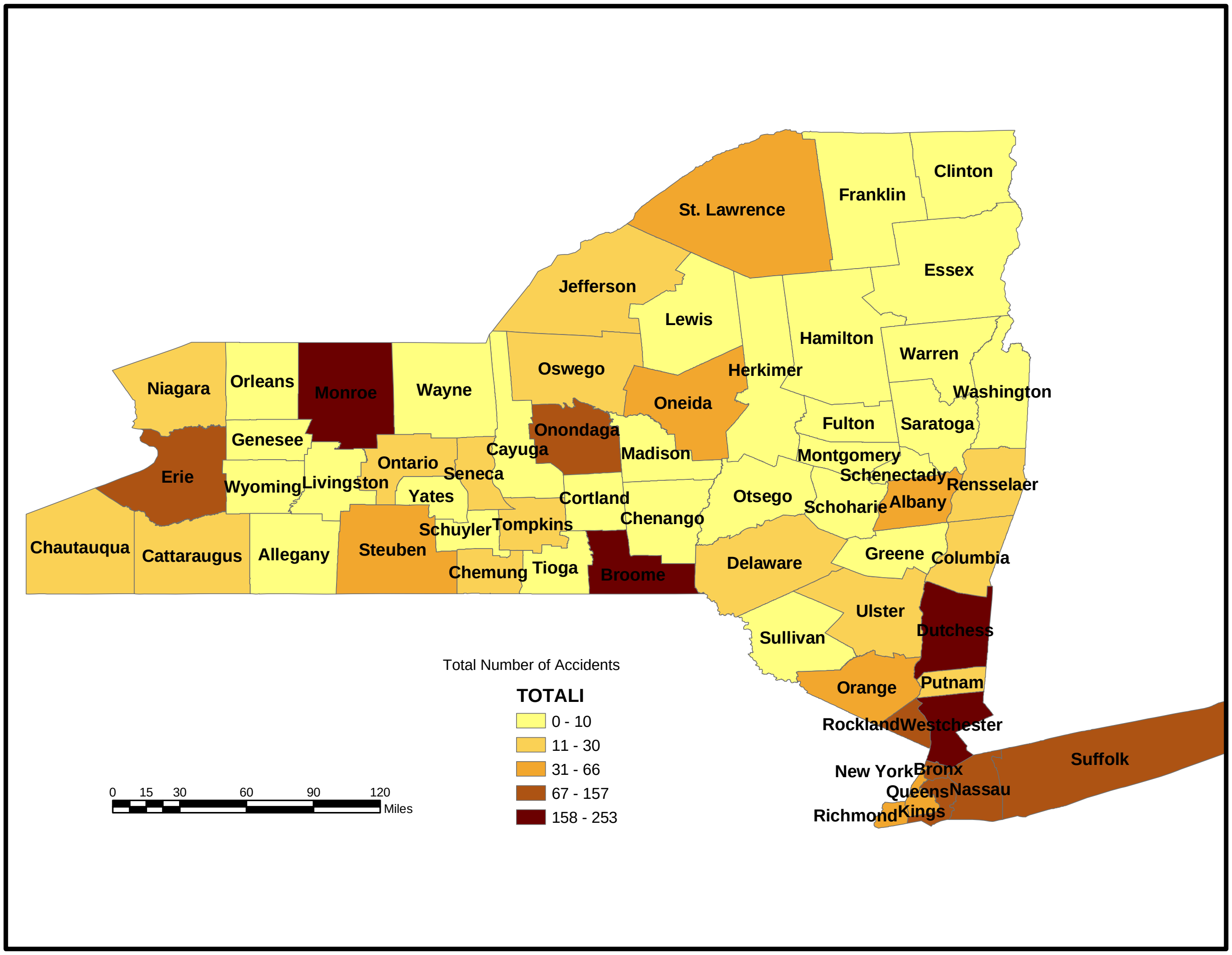

Figure 5 Total Number of Rear-End Accidents

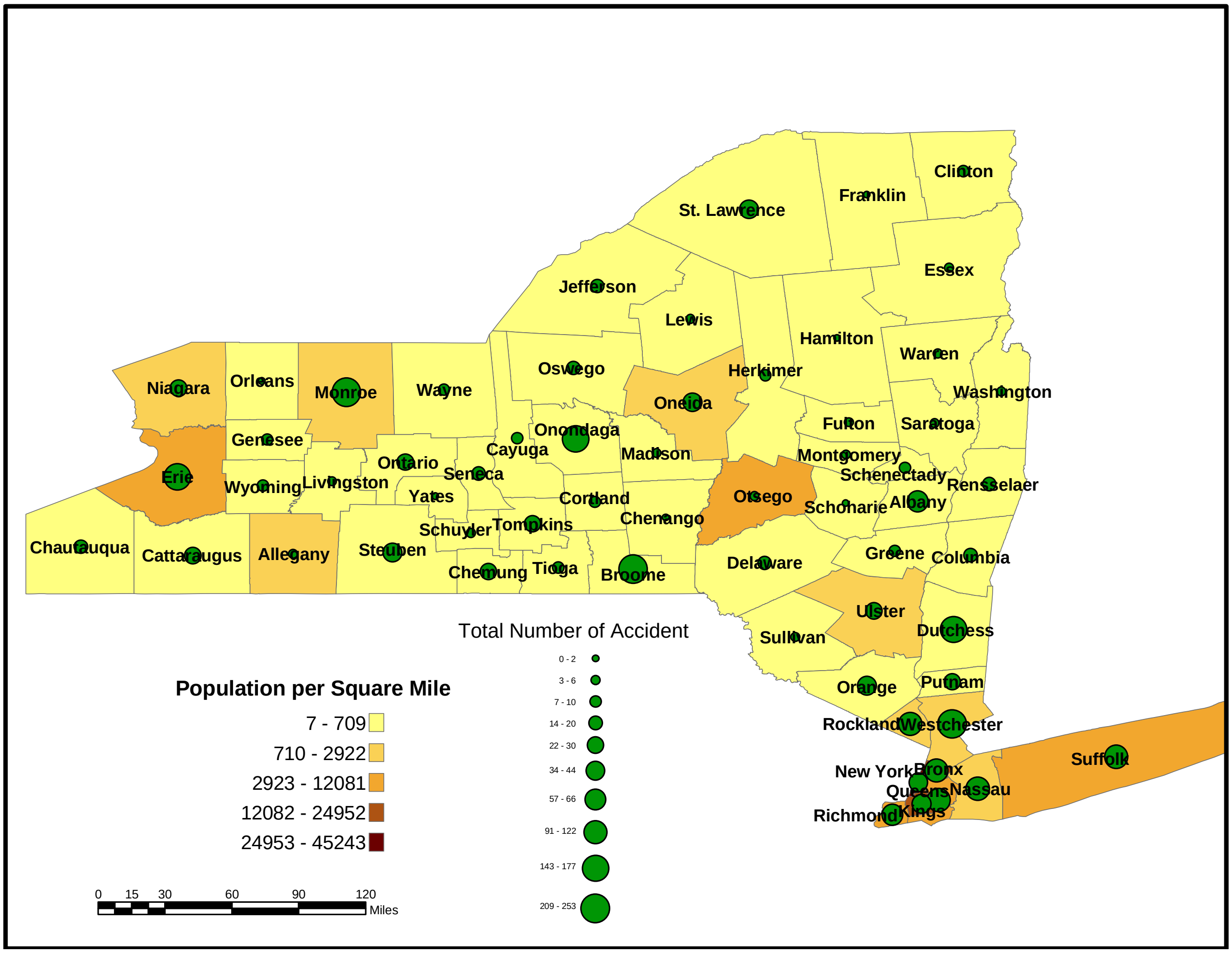

Figure 6 Total Number of Rear-End Accidents Versus Population Density

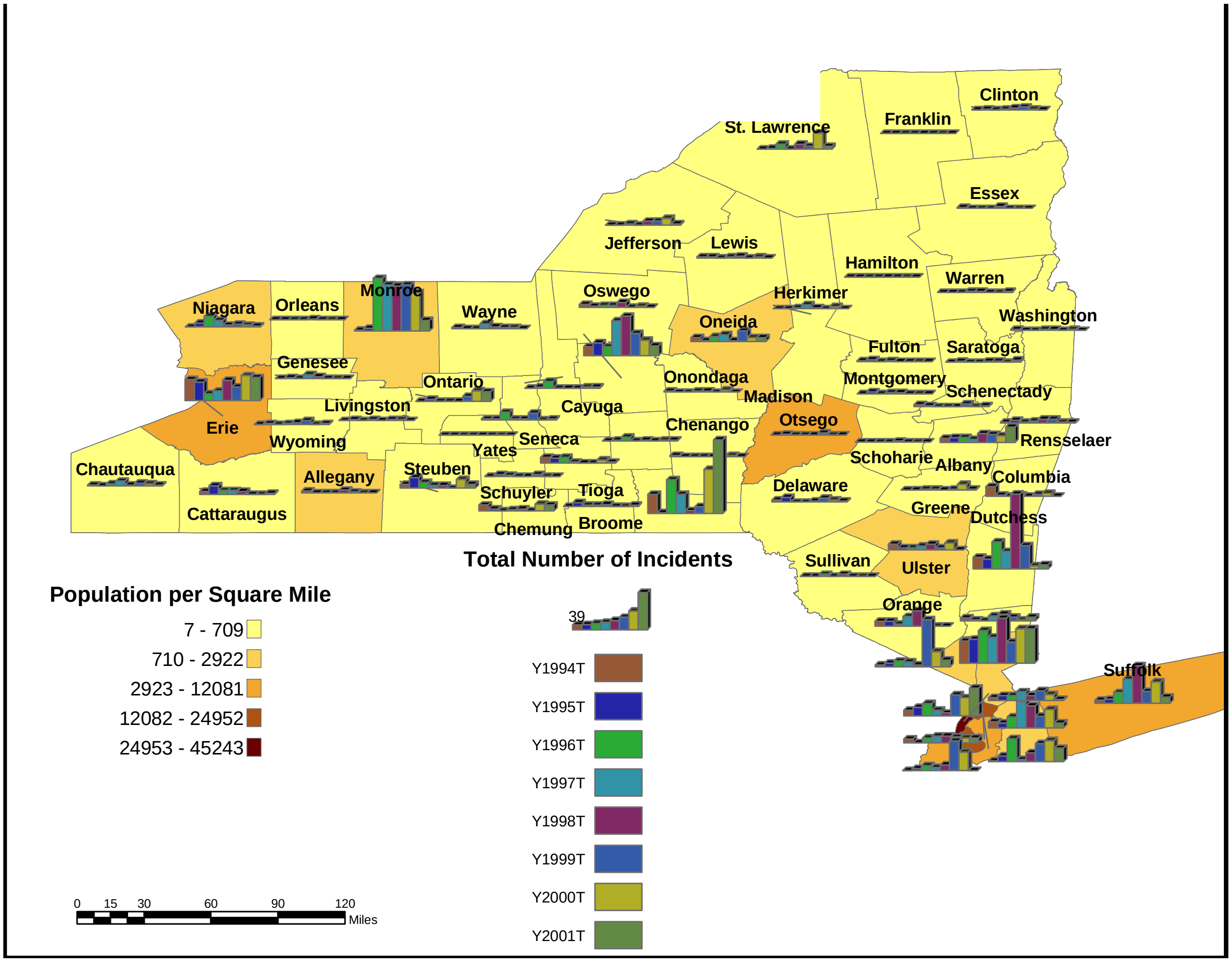

Figure 7 Total Number of Rear-End Accidents versus Population By Years

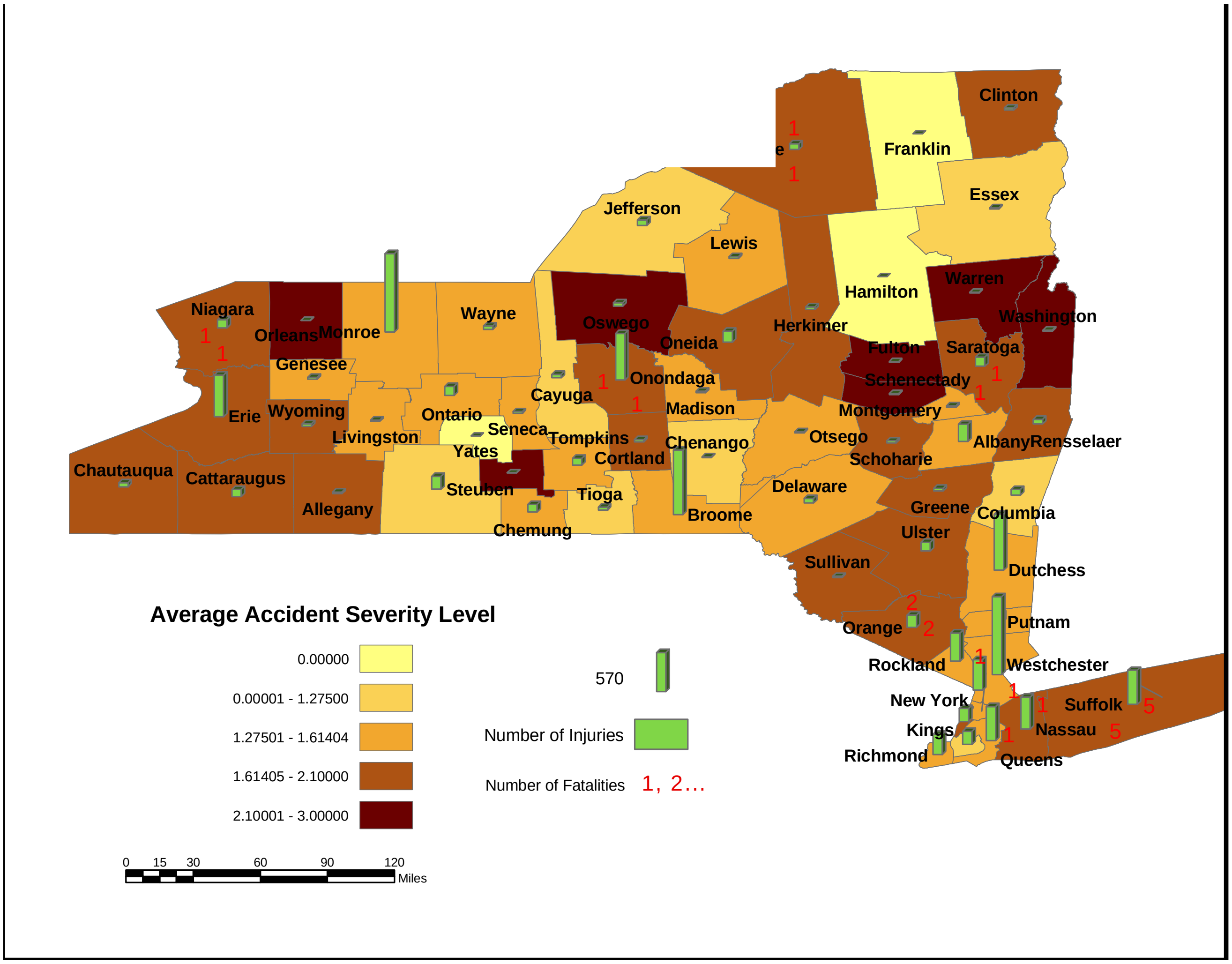

Figure 8 Accident Severity Variation of Severity of Rear-End Accidents

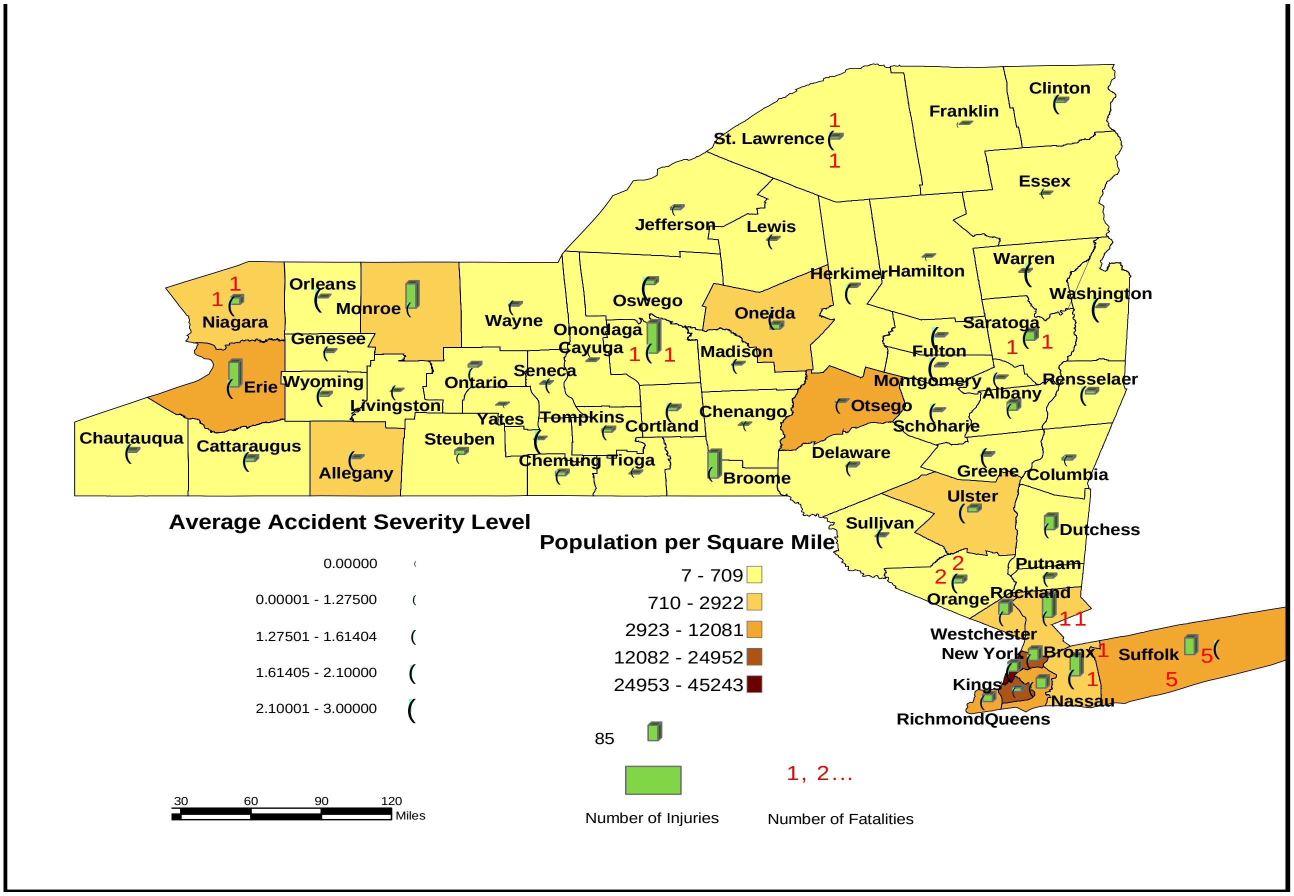

Figure 9 Accident Variation of Rear-End Accidents versus Population Density

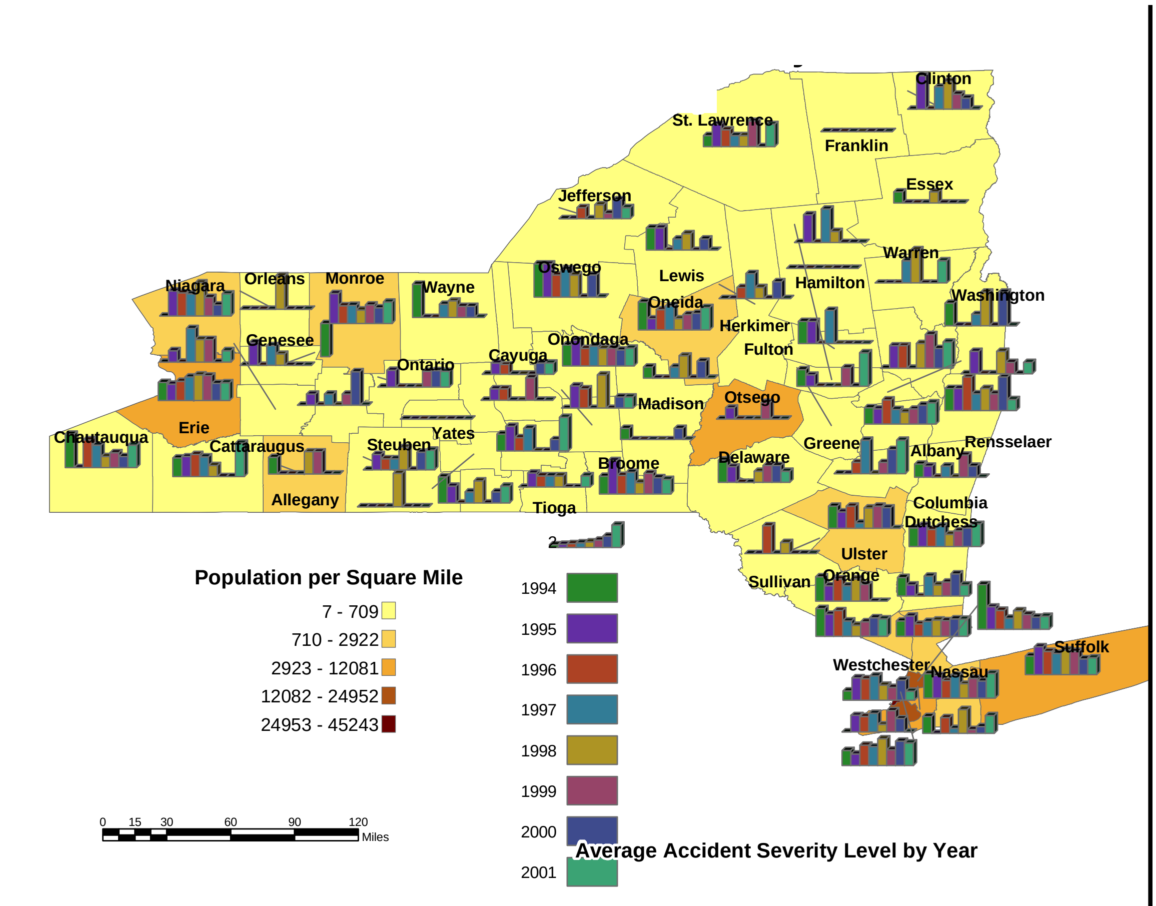

Figure 10 Accident Severity of Rear-End Accidents Over Years

SUMMARY AND FUTURE RESEARCH

The overall objective of this research was to study construction work zone accidents in New York State, with particular attention to the occurrence and mitigation of rear-end vehicle accidents. The specific objectives were to:

- Recommend changes to the NYSDOT's accident database system for more efficient management and analysis.
- Conduct a detailed investigation of rear-end crashes in work zones and recommend measures that can reduce the frequency of these types of crashes.
- Report on traffic exposure data and accident patterns / parameters to be incorporated into future NYSDOT accident data analysis.

The current NYSDOT work zone accident reporting system was evaluated. A survey was also conducted on practices used in other State agencies. The survey revealed that the current NYSDOT work zone accident reporting system is the most comprehensive in the country. Further changes to improve the system were recommended based on a review of the literature and practices being implemented in other state agencies. The research team recommended that the more variables need to be added to the database to provide information on the project (e.g., total length and duration of the work zone), traffic control devices, speed limit, and roadway inventory (e.g., number of lanes, lane width, presence of horizontal/vertical curves).

Data on work zone rear-end accidents that occurred in New York State between 1994 and 2001 were analyzed to study the relationship between crash frequency, crash severity, and work zone characteristics. Since data were available only on work zones that had accidents, truncated count data models to study crash frequency. Ordered models were developed to study crash severity.

The truncated count data models indicated that work zones with flaggers, alternating 1 way traffic, and higher AADT, had more rear-end accidents. Since, information on work zones without accidents were not available, some of these results may just reflect differences in exposure associated with these conditions. The ordered models indicated that rear-end accidents associated with alcohol, night conditions, and pedestrians are more severe. Truck involved rear-end accidents were more severe compared to non-truck rear-end accidents. In addition, rear-end accidents that occurred before the taper are significantly more severe compared to other locations in the work zone.

Based on a literature review, some corrective actions to reduce the frequency of work zone accidents were proposed. Examples include rumble strips, speed displays, measures to facilitate merge operations, smart work zone technology, drone radar, and improved night time traffic control practices.

Recommendations to incorporate more project information to the work zone database either through adding more variables or including project information in a separate database that can be linked through a project identification number, were provided. Various venues and approaches for obtaining exposure to traffic for various types of work zones including the Highway Performance Monitoring System (HPMS), Smart Work Zones, and Intelligent Transportation Systems, were discussed. Models were developed to identify parameters correlated with work zone crashes and the county level. As expected, area of a county, construction season, and population density were correlated with the frequency of rear end crashes in a county.

Future Research Directions

One of the limitations of this study was the lack of data from work zones that did not have a crash. It is important that future research in this area look at the characteristics of work zones that had crashes and those that did not.

The NYSDOT work zone crash database though quite comprehensive and unique does not have some critical variables on the exposure, e.g., the total length of the work zone and total duration of the work zone. Previous studies have found that these two variables are significantly associated with crash frequency, and future studies need to include these variables as well.

It is also important that data be collected on traffic volumes when work zones are in operation. Most studies have only used the AADT values which do indicate how much traffic may have diverted to alternate routes to avoid the congestion associated with work zones.

Several studies have already looked at the effect of different countermeasures to reduce accidents in work zones. These efforts need to continue.

Research is also required to study the implications of working at night versus working during the day. Night-time is associated with less traffic, but higher speeds and more impaired driving. The safety of the construction worker also needs to be considered in this context.

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APPENDIX A:

Variable descriptions: NYSDOT work zone crash database

Table A.1 **List of Variables with Descriptions**

Variable Name	Description
First field (Column A) before Report #	This field was used for indicator codes to help identify Near-miss and Off project accidents. I believe that O was not used very much in the later years. This field is not going to be used any more. Near-misses (construction incidents without injuries) will be considered accidents.
Report #	This variable is of the form XX-XX-XXXX XX. The first 2 characters represent year of crash, the next 2 represent region, and the next 4 represent regional sequence number. The last 2 represent initial forms received and in some cases separate events reported on the original sequence number: -A = A; -B = Form B; -C = Form C; -SAF(1,9) = Employee health and safety forms for accident & state vehicle accident.
REG	Region number 1 through 11, and occasionally MO for Main office
R/N Reportable/Not Rep' Able	R means reportable. Permit means a job in which work was permitted to the Department of Transportation by commercial business for work done in our right of way such as driveways and traffic light installation to benefit the businesses at their cost. Incident in which our work had no involvement. Examples are: heart attack sustained by worker, motorist, pedestrian, police chase or worker assaulted.
PR- Police Report	If Y (Yes), police accident report was eventually received often on subsequent reports. No, not yet received, in some cases never received or even made. LPR, local police report forms not standardized as DMV forms that used by our State Police and County Sheriffs. MR means motorist report. Normally, there would not be police reports for construction accidents. If a traffic accident is minor enough (no injuries or major property damage), a police report is not required.
Contractor	Name of the contractor
If WKR injured, sub contractor	If worker injured, name of sub-contractor
Contract #	Contract number
Pin #	PIN #
EIC	Name of the Engineer in Charge (EIC)
Work type	'Safety' is a work type of construction project in which improvements or new features such as traffic signals, turning lanes, vehicle presence detectors, pedestrian crosswalks, and signals are the major work. Other types would be bridges, appurtenances, pavement, etc.
Current contract amount	Contract amount in dollars. This will no longer be recorded.
Day	Day of the week (first 3 letters of the day are coded)
Acc. Date	Date of the accident coded as year/month/day (e.g., 2000/10/25)
Time of accident (military)	Time of accident (military)
A-C	Accident Category. Definitions of 3 categories are in the enclosed file.

Proj Inv	Project Involvement. Definitions are in the enclosed file.
Code	Accident Code (old system). Definitions are in the enclosed file.
Utility hits	Indicates if particular utilities were hit.
Work zone situation	Definitions are in the enclosed file.
TAT	Traffic accident type. Definitions are in the enclosed file.
TAT2	Traffic accident type 2. This will be coded only if it is necessary to include more than one accident type for the same accident. Definitions are in the enclosed file.
CAT	Construction accident type. Definitions are in the enclosed file.
Contributing factors – traffic accident (CF-TA)	Three contributing factors are possible. The first contributing factor is typically the most critical/important. Definitions are in the enclosed file.
Contributing factors - construction accident (CF-CA)	Three contributing factors are possible. The first contributing factor is typically the most critical/important. Definitions are in the enclosed file.
Acc Occu D-N	Indicates whether the accident occurred during day and night. Day (D) and Night (N) refer to light conditions of daylight (sun) or night-time (dark). It does change month to month during the year.
Project work operations day-night	Indicates when the project work is conducted – could be day (D), night (N), or day and night (D&N).
Inj-C (Injury Category)	This represents the most severe injury in the crash. F = Fatal; S = Severe (life threatening); H = Hospital (transported to); M = Minor, ER not admitted; N = None; U = Unknown, not reported.
Injury by Sector - DOT	Same as injury category above plus: Blank - indicates no involvement; N - indicates involved but no injury; PDO - indicates equipment or property damage; U - Unknown extent of injury
Injury by Sector - CONT	Same as injury category above plus: Blank - indicates no involvement; N - indicates involved but no injury; PDO - indicates equipment or property damage; U - Unknown extent of injury
Injury by Sector - SUB	Same as injury category above plus: Blank - indicates no involvement; N - indicates involved but no injury; PDO - indicates equipment or property damage; U - Unknown extent of injury
Injury by Sector - CONS	Same as injury category above plus: Blank - indicates no involvement; N - indicates involved but no injury; PDO - indicates equipment or property damage; U - Unknown extent of injury
Injury by Sector - PUB	Same as injury category above plus: Blank - indicates no involvement; N - indicates involved but no injury; PDO - indicates equipment or property damage; U - Unknown extent of injury
Obj/spec	Indicates the object that was struck by the motorist: cones, traffic drums, temporary concrete median barriers, guiderail types (G1 = light post cable GR, and similar types is found in AASHTO).

Heavy Truck Accident	Indicates if this accident involved a heavy truck.
Contractor equip	This is the equipment involved in the crash.
Contractor equipment involved, Brief description of the accident	Verbal description of Accident.
State emp Name #1	Name of state employee
Title#	Title of state employee
More State Employees	A code to indicate more state employees
Found in DWM files? DWMfiles	Coded as YES or ONLY. Accidents involving employees and State owned vehicles are reported the office Employee Health and Safety also. Files are annually checked to ensure that all such reports were received from needed regions.
Lost-time injury	Code to indicate lost time due to injury.
Time lost in days	Time lost in days
Prevent Accid?	This is used only for accidents involving DOT employees and their responsibility or contribution to the accident
Cont. emp name#1	This is contractor employee name #1
Title#1 CE	
More wkrs	This could yes or no.
Cont Emp name#2	Name of contractor employee #2
Title#2	Title of contractor employee #2
Total Fatal	Total of number of people killed in this accident
Male/Female	The gender of the individuals who were killed. M indicates Male. F indicates Female. If more than 1 person was killed, the gender codes are entered sequentially, e.g., if 2 males and 1 female were killed, it will be coded as MMF.
Total Tot I (injured?)	Total number of people injured in this accident
Male/Female	The gender of the individuals who were injured. M indicates Male. F indicates Female. If more than 1 person was injured, the gender codes are entered sequentially, e.g., if 1 male and 2 females were injured, it will be coded as MFF.
Vehicle responsible for accident	Number of the vehicle responsible for the accident. This typically seems to be coded as 1.
Veh#1	Codes to indicate the type of vehicle for vehicle #1. Definitions are in the enclosed file.

Sex#1	Sex of the pedestrian / driver.
Age#1	Age of the pedestrian / driver; P = Parked vehicle; U = Unknown
Loc#1	(Driver locality) - Code representing the distance between the driver and his/her residence. Definitions are in the enclosed file.
Veh#2	Codes to indicate the type of vehicle for vehicle #1. Definitions are in the enclosed file
Sex#2	Sex of the pedestrian / driver
Age#2	Age of the pedestrian / driver; P = Parked vehicle; U = Unknown
Loc#2	(Driver locality) - Code representing the distance between the driver and his/her residence. Definitions are in the enclosed file.
Veh#3	Codes to indicate the type of vehicle for vehicle #1. Definitions are in the enclosed file.
Sex#3	Sex of the pedestrian / driver
Age#3	Age of the pedestrian / driver; P = Parked vehicle; U = Unknown
Loc#3	(Driver locality) - Code representing the distance between the driver and his/her residence. Definitions are in the enclosed file.
Veh#4	Codes to indicate the type of vehicle for vehicle #1. Definitions are in the enclosed file.
Sex#4	Sex of the pedestrian / driver
Age#4	Age of the pedestrian / driver; P = Parked vehicle; U = Unknown
Loc#4	(Driver locality) - Code representing the distance between the driver and his/her residence. Definitions are in the enclosed file.
Contributory factors listed in report	Verbal description of the contributory factors listed in the report
Type of facility	'Facility type' in the old coding system. Definitions are in the enclosed file.
Suff Man FC	New 'new functional' classification. Definitions are in the enclosed file.
Highway type	Type of highway in verbal form
AADT	AADT of the roadway segment.
AADT year	Year corresponding to the AADT
Mile-marker	Mile marker
RT	Street name or route number
County	County where the incident occurred
Vehicle Model year V#1	Model year of the vehicle
Vehicle description V#1	Description of the first vehicle (e.g., Mercury 4DSD)
Traffic ticket V#1	Description of traffic ticket. Some of the records have a verbal description, others use codes
Vehicle model year V#2	Model year of the vehicle
Vehicle description V#2	Description of the vehicle (e.g., Mercury 4DSD)
Traffic ticket V#2	Description of traffic ticket. Some of the records have a verbal description, others use codes

Vehicle model year V#3	Model year of the vehicle
Vehicle description #3	Description of the vehicle (e.g., Mercury 4DSD)
Traffic ticket V#3	Description of traffic ticket. Some of the records have a verbal description, others use codes.
Vehicle model year V#4	Model year of the vehicle
Vehicle description # 4	Description of the vehicle (e.g., Mercury 4DSD)
Traffic tickets # 4	Description of traffic ticket. Some of the records have a verbal description, others use codes.

New York State Work Zone Crash database – Definitions of codes used in different variables

Accident Category

1 = Any fatal or serious injury to:

a) DOT Construction employee or if related to construction activity or maintenance and protection of traffic (M&PT)
b) consultant or contractor employee, or
c) traffic accident

2 = Injury requiring transport to hospital for:

a) DOT, consultant, or contractor employee directly related to construction activity
b) traffic accident directly related to construction activity or M&PT,
c) multi-vehicle (4+) traffic accident involving construction activity or

M&PT,regardless of injuries, or

d) any accident which had the potential to be fatal or result in serious injury.

3 =

a) Traffic accident within project limits resulting in a fatality or personal injury but not related to construction activity or within limits of active M&PT,

b) traffic accident involving M&PT or construction activity but not resulting in transport to hospital,
c) any construction related accident resulting in damage to private property, or
d) all other injuries to DOT employees.

<u>Project Involvement</u>

MPT = M&PT Involved
P = Project limits, traffic accident not related to construction
C = Construction
O = Off site
U = Unknown

Accident Code (OLD SYSTEM – Before 2002)

Non-Traffic Accident (Construction Accident)

1 = Fall (hole, trip, etc.)
2 = Sand blast
3 = Construction equipment - large
4 = Construction equipment - small
5 = Struck by falling/moving load
6 = Crane /lift device failure
7 = Utility - contact with electric cable/overhead lines or gas line
9 = Fall from elevated work area
51 = Snake/animal/insect bite/poison oak or ivy?
52 = Injured or struck by Tool/Material worked on
53 = Vandalism damage
54 = Dust/grit/etc in eye
55 = Injured while lifting/moving work
56 = Overcome by heat/other unknown non-injury event
57 = Employee drove vehicle into excavation, bridge underside etc.
58 = Fire
59 = Blasting debris
60 = Ladder slipped, etc., no fall
61 = Demolition accident
62 = Stepped on nail, puncture, cut, scratch injury
63 = Gun shot/pellet injury/thrown object/assault
64 = Trench accident

Traffic Accident (Not Construction Accident)

10 = Single vehicle run-off-road
11 = Multi-vehicle same direction
12 = Multi-vehicle angle
13 = Multi-vehicle head-on
14 = Flagger related – rear-end, sideswipe, angle, head-on, etc. at flagger controlled location
15 = emporary signal –rear-end, ROR, etc.- alternating 1-way
16 = Lane closure – rear-end, ROR, etc.
17 = Pedestrian/Bicycle - hit by vehicle - not employee
18 = Vehicle in work zone - intrusion – involves employees, construnction operation, equipment, etc.
19 = Vehicle damaged due to construction (pot hole, excavations)/objects in roadway
20 = Moving construction operation – construction equipment hit by vehicle
21 = TMA (?) struck
22 = Pedestrian fall, etc.
23 = Bridge/road closed - no construction people involved (in vicinity of closure)
24 = Vehicle in area not open to traffic - hits, FO, rollover, etc - not including employees
25 = Construction equipment hits motorist vehicle

26 = Vehicle struck by falling/moving load or object
27 = Accident in detour-single vehicle
28 = Flagger hit by motorist
29 = DOT employee hit by motorist
30 = Contractor employee hit by motorist
31 = Multi-vehicle multi-direction
32 = Accident in detour - multi-vehicle
33 = Over height vehicle - height restriction
34 = Animal involved in vehicle accident
35 = Contractor's equip/truck/vehicle hit by motorist not in WZ

U = Unknown

Work Zone Situation – 2002

First digit = # of flaggers. If flaggers are in place but the number is unknown, use X.

Flagger Control

X01 = Alternating 1-way traffic
X02 = Intersection
X03 = Permanent shoulder work area
X04 = Moving/short term shoulder work area
X05 = Stationary work area in travel lane (At merge/transition area)
X06 = Stationary work area in travel lane (past transition)
X07 = Moving work area in travel lane (at merge/transition area)
X08 = Moving work area in travel lane (past transition)
X09 = Full road or bridge closure
X10 = Letting vehicles/equipment/workers into or out of work zone

No-Flagger Control

021 = Alternating 1-way traffic with temporary signal
022 = Intersection - minor traffic controls/disruption
023 = Intersection - major work underway
024 = Permanent shoulder work area
025 = Moving/short term shoulder work area
026 = Stationary lane closure w/arrowboard (at merge/transition area)
027 = Stationary lane closure w/o arrowboard (at merge/transition area)
028 = Stationary lane closure (past transition)
029 = Stationary 2 lane closure w/arrowboards (at merge/transition area)
030 = Stationary 2 lane closure w/o arrowboards (at merge/transition area)
031 = Stationary 2 lane closure (past transition)
032 = Moving work area in travel lane (at merge/transition area), (painting lines)(sweeping)
033 = Moving work area in travel lane (past transition)(painting lines)(ww)
034 = Full road or bridge closure
035 = Vehicle/equipment/workers access point

036 = Off-shoulder or median work area
037 = On-site w/minor traffic controls in place but no work underway (temporary pavement markings, interim pavement courses, etc.)
038 = On-Site but no traffic controls in place and no work underway at location of accident
039 = Lane shift (on-site diversion)
040 = Median crossover (on crossover)
041 = Median crossover (on two-lane, two-way Section)
042 = Off-site detour
043 = Off-site accident involving job personnel or equipment
044 = Movable barrier relocation operation
045 = Pavement reconstruction area - subbase and gravel travel surface
046 = Setup/takedown of M&PT for lane closures, traffic stripe painting
047 = Accident before taper area (lane closure) but within countdown signing
048 = Off-site/off project accident (construction division staff)
049 = Closed area - contractor's yard, staging area
050 = Work being done overhead - on bridge, etc. no traffic controls below
051 = Traffic backed up due to adjacent project M&PT
052 = Tangent section - work active on one or both sides of traffic space

Traffic Accident Type – 2002

01 = Multi-vehicle rear-end collision
02 = Multi-vehicle head-on collision or sideswipe while traveling in opposite directions
03 = Multi-vehicle sideswipe while traveling in same direction
04 = Multi-vehicle left-turn accident
05 = Other multi-vehicle collision at an angle
06 = Multi-vehicle, multi-directional collision

11 = Construction equipment in WZ striking vehicle
12 = Construction equipment entering/exiting WZ striking vehicle
13 = Construction equipment outside WZ striking vehicle
14 = Vehicle struck by construction-related falling/moving load or object
15 = Vehicle striking construction equipment in WZ
16 = Vehicle striking construction equipment entering/exiting WZ
17 = Vehicle striking construction equipment outside WZ
18 = Vehicle striking truck-mounted attenuator
21 = Vehicle striking worker in WZ (other than flagger)
22 = Vehicle striking worker entering/exiting WZ (other than flagger)
23 = Vehicle striking worker outside WZ (other than flagger)
24 = Vehicle striking flagger
25 = Worker hit by object thrown from vehicle
26 = Vehicle striking fixed object - not ROR accident
31 = Single vehicle WZ intrusion other than above
32 = Single vehicle WZ intrusion (road/bridge closure) striking VAB or other barrier across roadway
41 = Single vehicle run-off-road striking temporary concrete barrier or other roadside TCD
42 = Single vehicle run-off-road striking permanent fixed object
43 = Single vehicle run-off-road and overturn
44 = Single vehicle run-off-road but no collision or overturn

51 = Vehicle driven into excavation/bump/construction-related object in open travel lane or shoulder
52 = Vehicle striking animal/non-construction-related object in open travel lane or shoulder

61 = Vehicle striking pedestrian or bicycle
62 = Construction equipment striking pedestrian or bicycle
63 = Pedestrian or bicycle struck by construction-related falling/moving load or object
64 = Pedestrian falling or tripping
65 = Motorcycle or bicycle wipeout

71 = Train striking vehicle/pedestrian/bicycle/construction equipment/worker
72 = Vehicle/pedestrian/bicycle struck by explosive blasting debris
73 = Vehicle/driver/pedestrian/bicycle struck by sandblasting debris
74 = Pedestrian criminal activity, B&E, etc.
75 = Vehicle dropping load/cargo

Construction Accident Type – 2002

01 = Trip or fall from non-elevated area
02 = Trip or fall from elevated area/ladder
03 = Struck by construction-related falling/moving load or object being lifted by crane
04 = Injured or struck by material/tool worked on
05 = Struck or pinned by small construction equipment (e.g. small tampers or rollers, buggys, joint sealing or sawcutting machines, etc.), or equipment overturn
06 = Struck or pinned by large construction equipment, or equipment overturn
07 = Crane/lift device failure or overturn
08 = Dirt/dust/grit/object in eye, arc welding eye burn
09 = Stepped on nail or other puncture/cut/scratch injury
10 = Injured during lifting/moving work - back injury
11 = Snake/animal/insect bite or poison oak/ivy
12 = Gunshot/pellet injury/thrown object/assault
13 = Hearing injury
14 = Heart attack, overcome by heat, or other non-injury event
15 = Sandblast-related accident
16 = Explosive-blasting related accident
17 = Other fire/explosion
18 = Utility - contact with electrical cable/overhead line or gas line
19 = Trench accident (cave-in)
20 = Vandalism damage
22 = Worker vehicle/construction equipment struck by other worker's vehicle/construction equipment
23 = Worker vehicle struck by construction-related falling/moving load or object
24 = Worker vehicle driven into excavation, bridge pier, etc.
25 = Worker struck by other worker's vehicle
26 = Worker fall from back of pick up or other truck type or equip
27 = Worker's hand/arm/leg pinched or caught in door, etc.
28 = Construction equipment hits fixed object
29 = Injured hand/leg/body, not fall or trip, only sprained or twisted - not back injury
30 = Struck by non-construction related falling/moving object
31 = Near miss electrical - no contact
32 = Existing feature collapse
33 = Occupational Safety and Health Administration citation for non-compliance

Contributing Factors - Traffic Accidents - 2002

01 = Driver asleep, inattentive or distracted
02 = Driver inexperience
03 = Poor driver judgment (speeding, improper lane change, improper turn, failure to keep right, following too closely, etc.)

04 = Careless backing
05 = Purposeful disregard of flagger or other traffic controls
06 = Alcohol/drugs/medication
07 = Medical condition (heart attack, etc.)
08 = Mechanical failure or vehicle not properly maintained
09 = Slippery pavement
10 = Night
11 = Other poor visibility conditions (fog, rain, glare, etc.)
12 = Oversize/overweight vehicle
13 = Avoiding other vehicle
14 = Avoiding animal/object/pedestrian/bicycle in roadway
15 = Flagging signal misunderstood or inappropriate
16 = Other inadequate, failed or missing traffic controls
24 = Construction operation caused material to enter traffic lane
26 = High winds - not driver fault
27 = Pedestrian/bicyclist error
28 = View obstructed by contractor's equipment/work
32 = Debris from previous accident / incident
33 = Defective pavement - pot holes etc.
34 = Other - not fault of contractor or motorist

Contributing Factors - Construction Accidents - 2002

17 = Worker inattentive or distracted
18 = Worker inexperience
19 = Careless backing
20 = Alcohol/drugs/medication
21 = Medical condition (heart attack, etc.)
22 = Mechanical failure or vehicle/equipment not properly maintained
23 = Not following recommended safety procedures
25 = Other cause beyond injured worker's control
29 = Not contractor's fault
30 = High winds
31 = Work area cluttered, debris not cleaned up

Vehicle Type (Code for the first four vehicles)

A = Pedestrian
B = Bus
C = Construction equipment
D = DOT
F = Flagger
M = Motorcycle

N = Bicycle
P = Passenger
S = Semi
SB = School bus
Sh = Ship
SP = State police vehicle
SV = State vehicle
T = Truck - single unit
U = Unknown
V = Van/pickup
W = Worker
&TR = And trailer
Plus MV-104A (police accident report) codes for trucks except pickup trucks and buses

Driver Locality

L = Local, less than 75 miles
I = Intermediate, 75 to 100 miles
D = Distant, more than 100 miles
U = Unknown, no information on driver's residence
P = Parked vehicle

Table A.2 Facility Type (OLD SYSTEM – Before 2002)

Facility Type Code	Rural/Urban	Verbal Description of Highway Type
01	Urban A	Principal Arterial Interstate
	Urban B	Principal Arterial Expressway Connecting Link
	Urban C	Principal Arterial Expressway Non-Connecting Link
02	Urban D	Principal Arterial Other Connecting Link
	Urban E	Principal Arterial Other Non-Connecting Link
	Urban F	Minor Arterial
03	Urban G	Collector
	Urban H	Local
04	Rural 1	Principal Arterial Interstate
	Rural 2	Principal Arterial Other
05	Rural 3	Minor Arterial
	Rural 4	Major Collector
06	Rural 5	Minor Collector
	Rural 6	Local

Table A.3 Functional Classification of Highways (NEW SYSTEM)

Code	Urban/Rural	Verbal Description of Highway Type
11	Urban	Principal Arterial Interstate
12	Urban	Principal Arterial Expressway
14	Urban	Principal Arterial Other
16	Urban	Minor Arterial
17	Urban	Collector
19	Urban	Local
01	Rural	Principal Arterial Interstate
02	Rural	Principal Arterial Other
06	Rural	Minor Arterial
07	Rural	Major Collector
08	Rural	Minor Collector
09	Rural	Local

APPENDIX B:

1. **Copy of the survey that was sent to 23 State agencies**
2. **A table summarizing the responses received from 9 State agencies**

New York State Department of Transportation
Frequency of Work Zone Accidents on Construction Projects

Survey

Conducted by:
Region 2, University Transportation Research Center, City College of New York
Highway Safety Research Center, University of North Carolina
Polytechnic University of New York

1. Do you record crashes that occur in work zones crashes? If yes, how are these crashes identified? Are these crashes compiled in a separate database?

____

2. How do you define a work zone for recording work zone crashes?

____

____

3. Who is responsible for reporting crashes on work zones? Are crashes reported by the police or are crashes reported by DOT personnel responsible for the work zone?

____

____

4. If you maintain a separate database for work zone crashes, which unit maintains and updates the database?

____

____

5. What software or data recording system is used to maintain and update the database? What experiences have you had with various types of such software? Have these systems been efficient?

____

____

6. What level or type of information and detail is recoded in the database for each work zone crash, e.g.,: type of traffic control device, type of crash, date & time, lighting conditions, severity, driver & passenger characteristics, type of vehicle(s) involved (car, truck, construction vehicle, etc.), vehicle maneuver, location (within work area, approach to the work area), etc. Can you send us the list of variables that are coded?

____

____

____

7. Does your recording system permit causal factors or engineering judge of crash factors based on the opinion of the reporting individual? What factors are recorded?

____

____

8. Are all crashes in a work zone recorded even if the work zone is idle, e.g. no workers present, or work zone is not a factor in causing the crash based on the opinion of the reporting individual?

____

____

9. In your reporting system, are crashes recorded as work zone related even if they occur outside the work zone but were caused by the presence of the work zone (e.g., rear-end crashes that occur outside the work zone but may be caused due to the queuing of vehicles)?

____

____

10. For crashes involving workers, does you system identify where the crash occurred, i.e., within the workspace (protection) or outside the workspace?

____

____

12. What project information (e.g., length and duration of work zone, total cost of the project, project type such as re-paving or adding lanes, etc.) is included for each work zone accident in your reporting?

____

____

13. What exposure data (e.g., number of vehicle miles, ADT, etc.) do you collect during the operation of a work zone?

____

____

14. What are the regional variables collected for each work zone accident in your reporting to identify accident patterns?

____

15. Have you conducted any recent research on work zone safety or work zone crash reporting? Do you use or have you researched any of SHRP Work Zone Safety products?

____

____

16. What countermeasures have you implemented to reduce crashes (especially rear-end crashes) in work zones (e.g., new traffic control devices, flagger control, more police enforcement, driver education activities)?

(a) If yes, how effective are these countermeasures? How much did it cost to implement the different measures? (Add separate sheet of paper, if necessary)

(b) Have you conducted any before-after or other studies to evaluate the effectiveness of these actions? If yes, please send us a copy of these reports.

Additional Comments: (Please add extra pages)

Survey Prepared by:____Date________________
Phone:
Email:

Please return
by March 28, 2003 to: **Robert Baker, University Transportation Research Center,**
City College of New York, Y-Building, Room 220
New York, NY 10031
FAX: 212-650-8374, Tel. 212-650-8074,
E-mail: rbaker@tid1s0.engr.ccny.cuny.edu

Survey Results
Frequency of Work Zone Accidents on Construction Projects

Responses: State Departments of Transportation

Table C.1 Survey Response

	Indiana DOT	Iowa DOT	Kansas DOT	Minnesota DOT
Questions				
1. Do you record crashes that occur in work zones crashes? Identification of crashes? Separate database for WZ?	WZ Crashes in full database.	Historical - Crash reporting system; Recent - WZ crash tracking system by Construction	Check box on accident form. WZ crashes in full database.	Yes. Single data entry
2. How do you define a work zone for recording work zone crashes?	Yes/No response by investigating officer	Per ANSI D.16 standards; WZ related if in or near construction.	Specific to KDOT construction zones: either construction or maintenance.	From advanced warning area to termination area.
3. Who is responsible for reporting crashes on work zones?	Investigating Police	Enforcement personnel report crashes; Construction tracks WZ crashes	Law enforcement (Accident form); Field personnel (Special WZ form)	By police
4. If you maintain a separate data base for work zone crashes, which unit maintains and updates the database?	N/A	Data provided by Traffic Safety: Construction maintains database	N/A	N/A
5. What software or data recording system is used to maintain and update the database?	Old - Mainframe New - Oracle database	Iowa DOT: DB2 database on mainframe; Law enforcement: Traffic & Criminal System	Accident records (Oracle database); MS Access tools for analysis??	Mainframe

6. What level or type of information and detail is recoded in the database for each work zone crash?	Data from crash report form	2001 Iowa Crash Reporting Form (location, type, and workers present?)	Typical accident form; very little information about WZ traffic control device	Typical Accident form
7. Does your recording system permit causal factors or engineering judgment of crash factors based on the opinion of the reporting individual?	No	Not on form: Judgment in data analysis.	Based on accident form. Comments are permitted.	Yes. Typical accident form.
8. Are all crashes in a work zone recorded even if the work zone is idle, e.g. no workers present, or work zone is not a factor in causing the crash based on the opinion of the reporting individual?	Based on judgment of Investigating officer	Yes: Judgment of the officer	Yes.	Yes
9. Are crashes recorded as work zone related even if they occur outside the work zone but were caused by the presence of the work zone?	Based on judgment of Investigating officer	Yes: Judgment of the officer	Subject to officers opinion	Yes.
10. For crashes involving workers, does you system identify where the crash occurred?	Within diagram or narrative	Yes	No. Only on diagram	Yes. Starting in 2003.
12. What project information is included for each work zone accident?	Probably None; INDOT does not closely monitor WZ crashes	None	None	None

13. What exposure data do you collect during the operation of a work zone?	Probably None	None	None	None
14. What are the regional variables collected for each work zone accident in your reporting to identify accident patterns?	Probably None	Question was not clear	Question was not clear	Through location of crash, we can link to regional variables
15. Have you conducted any recent research on work zone safety or work zone crash reporting? Do you use or have you researched any SHRP WZ safety products.	None.	None	None	Use SHRP products
16. What countermeasures have you implemented to reduce crashes (especially rear-end crashes) in work zones?	No standard: Project by Project implementation	Improved WZ signs, technician training, extra enforcement.	Increased enforcement and driver education	Researching "Smart Work Zone" technologies: direction indicator, autoflagger, extra enforcement, and flagger training
a. How effective are these countermeasures?	Not Available	No formal studies. Lump sum bidding for traffic control.	Don't Know	Studies being conducted.
b. Have you conducted any before-after or other studies to evaluate the effectiveness of these actions?	Not Available	No.	No	None

Survey Results
Frequency of Work Zone Accidents on Construction Projects

Responses: State Departments of Transportation

Table C.1 Survey Response (continued)

	Pennsylvania DOT	North Carolina DOT	Texas DOT	Washington DOT
Questions				
1. Do you record crashes that occur in work zones crashes? Identification of crashes? Separate database for WZ?	WZ crashes are indicated by a specific field on the accident form.	Yes. Coded by type of WZ, before and after WZ and location	Yes. Specific variable in Motor vehicle database	Yes. Do not compile in separate database.
2. How do you define a work zone for recording work zone crashes?	Prior to the first sign and through to the termination area	Starting at begin Work Zone sign to End of Work Zone sign. Police determine if WZ related crash	Police judgment	Based on instruction manual given to the police. "result of slowing or stoppage of traffic caused by work zone" and "evidence of work activity in the vicinity of the crash site"
3. Who is responsible for reporting crashes on work zones?	Police report to PennDOT's Crash Information System & Analysis Division.	Police report all crashes and report to DMV. If WZ reported to DOT to investigate.	Crashes reported by police. Crash data collected by Dept of Public Safety	Reported by law enforcement officer
4. If you maintain a separate data base for work zone crashes, which unit maintains and updates the database?	N/A	N/A. From 2000, Traffic Systems Management Unit created a database for fatal work zone crashes	N/A	N/A

5. What software or data recording system is used to maintain and update the database?	Forms are scanned into Filenet & Captiva, system does error checking; crash data can be input into a website.	Oracle and independent applications	N/A	3 tier Visual Basic Application (Collision Location & Analysis System) Very effective system
6. What level or type of information and detail is recoded in the database for each work zone crash?	Typical Crash form & "Type of WZ, WZ speed limit, workers present, etc".	All crash data on crash, person, vehicle, type of vehicle maneuver.	Same info for all crashes.	Crash report variables. Location information varies by Highway record, City Record or County record.
7. Does your recording system permit causal factors or engineering judgment of crash factors based on the opinion of the reporting individual?	Contributing factors determined by officer	Mainly for Fatal crashes	Causal factors coded base on reporting officer	Contributing circumstances reported by officer
8. Are all crashes in a work zone recorded even if the work zone is idle, e.g. no workers present, or work zone is not a factor in causing the crash based on the opinion of the reporting individual?	Yes. As long as it fits into PennDOT's definition of reportable WZ crashes.	Yes	Yes	Yes
9. Are crashes recorded as work zone related even if they occur outside the work zone but were caused by the presence of the work zone?	Crashes occurring prior to the first sign are coded as WZ if a queue results from the work zone	Recorded by pole as "Before work area, In work area approach taper, adjacent to actual work area."	Yes	Yes

10. For crashes involving workers, does you system identify where the crash occurred?	Data base can distinguish between protected or not protected WZ. Does not distinguish worker from non-worker	Yes	Yes	No
12. What project information is included for each work zone accident?	Database does not record details of the WZ but analysis can be project specific during construction.	No project information	None included in data base	Not included in report
13. What exposure data do you collect during the operation of a work zone?	No exposure data reported.	None is recorded	None	Not included in report
14. What are the regional variables collected for each work zone accident in your reporting to identify accident patterns?	County, Route segment and offset to analysis crash. Can be linked to regional data.	Probably not; Data can be entered into a narrative; but not standard practice.	Town population, County, City	None
15. Have you conducted any recent research on work zone safety or work zone crash reporting? Do you use or have you researched any SHRP WZ safety products.	SHRP Devices: direction indicator barricades, opposing lane dividers, flashing stop and paddles	UNC HSRC has conducted some research using HSIS data (NC is part of the system, but this study used California data)	Texas has ongoing research.	Research on local basis. Ongoing pilot program with Washington State Patrol. Used SHRP WZ safety products.

16. What countermeasures have you implemented to reduce crashes (especially rear-end crashes) in work zones?	State police in advance of queue, Wizard to broadcast to truckers	Increased law enforcement, smart work zone, speeding penalties	None	Driver education and training for WSDOT trainers
a. How effective are these countermeasures?	Police presence effective based on reduction in fatalities.	No in-depth study.		None
b. Have you conducted any before-after or other studies to evaluate the effectiveness of these actions?	None	No		None

Survey Results
Frequency of Work Zone Accidents on Construction Projects

Responses: State Departments of Transportation

Table C.1 Survey Response (continued)

	Wyoming DOT
Questions	
1. Do you record crashes that occur in work zones crashes? Identification of crashes? Separate database for WZ?	Yes. With an indicator box. Yes WY DOT maintains separate database
2. How do you define a work zone for recording work zone crashes?	Based on work zone signs
3. Who is responsible for reporting crashes on work zones?	Highway Patrol, sheriff, police
4. If you maintain a separate data base for work zone crashes, which unit maintains and updates the database?	Traffic Section
5. What software or data recording system is used to maintain and update the database?	Access database – good – yes efficient
6. What level or type of information and detail is recoded in the database for each work zone crash?	All crash related variables
7. Does your recording system permit causal factors or engineering judgment of crash factors based on the opinion of the reporting individual?	No
8. Are all crashes in a work zone recorded even if the work zone is idle, e.g. no workers present, or work zone is not a factor in causing the crash based on the opinion of the reporting individual?	No.
9. Are crashes recorded as work zone related even if they occur outside the work zone but were caused by the presence of the work zone?	No
10. For crashes involving workers, does you system identify where the crash occurred?	No
12. What project information is included for each work zone accident?	None.
13. What exposure data do you collect during the operation of a work zone?	None
14. What are the regional variables collected for each work zone accident in your reporting to identify accident patterns?	Weather & Road conditions

15. Have you conducted any recent research on work zone safety or work zone crash reporting? Do you use or have you researched any SHRP WZ safety products.	Yes
16. What countermeasures have you implemented to reduce crashes (especially rear-end crashes) in work zones?	Traffic Control devices, flagger control, more police enforcement
a. How effective are these countermeasures?	None
b. Have you conducted any before-after or other studies to evaluate the effectiveness of these actions?	None

APPENDIX C

Crash report forms recommended by Spainhour and Mtenga (2002) based on their work for the Florida Department of Transportation

Project Information

Report Date: ____________________Crash Date:_________________ State Road No:____________________

District:_______________ County __________________Traffic Crash Report No.______________________

FIN Project No:_____________________________ Federal Project No.____________________________

Contact No:_________________________________ WPI No:____

MOT Evaluation at Crash Site

Traffic Control Plan ☐
01 Original
02 Revised

Speed Limit
Posted Limit ☐
Construction Zone ☐

Radar Sign ☐
01 Yes
02 No

Construction Ongoing at time of Crash ☐
01 Yes
02 No

Type of Project ☐
01 Resurfacing
02 Widening
03 Reconstruction
04 New Construction Undivided Median
05 Intersection
06 Other____________

Visibility ☐
01 Clear
02 Limited

☐
01 Night (Darkness)
02 Night (Lighted)
03 Day

Pavement ☐
01 Wet
02 Dry

☐
01 Asphalt
02 Concrete
03 Other

Routing Where Crash Occurred ☐
01 Existing Pavement
02 Detour (Temporary)
03 Milled Pavement
04 New Pavement

Lane Closure ☐
01 Temporary Lane Closure at Start of Day
02 24-Hour Lane Closure
03 Temporary Lane Shift
04 24-Hour Lane Shift
05 Temporary Detour
06 24-Hour Detour
07 Shoulder Closure
08 No Lane Closure

Vehicle Movement

Vehicle 1 ☐ Vehicle 2 ☐ Vehicle 3 ☐

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/Runaway Vehicle
13 All Other

Geographical Location ☐
01 Urban
02 Rural

Roadway Under Construction ☐
01 2-Lane
02 2-Lane with Center Turn Lane
03 4-Lane Divided Median
04 4-Lane Undivided
05 4-Lane with Center Turn Lane
06 6-Lane Divided Median
07 6-Lane Undivided
08 6-Lane with Center Turn Lane
09 Intersection 2-Lane
10 Intersection 4-Lane
11 Intersection 6-Lane
12 Exit Ramp
13 Entrance Ramp
14 Other

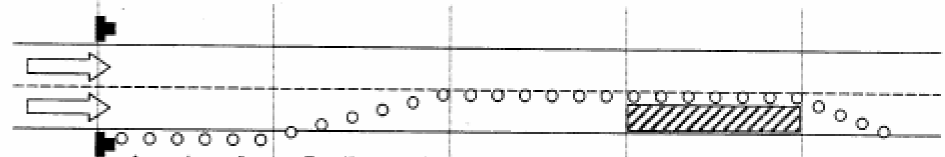
Harmful Event/Traffic Crash

HE 1 ☐ HE 2 ☐ HE 3 ☐

01 Collision Rear-end
02 Collision Head-on
03 Collision Angle
04 Collision Sideswipe
05 Collision Construction Worker
06 Collision Other Pedestrian
07 Collision Fixed Barrier
08 Collision Moveable Barrier
09 Collision Guardrail
10 Collision Crash Attenuator
11 Collision Other Fixed Object—Permanent
12 Collision Other Fixed Object—Construction Related
13 MV Ran into Ditch/Culvert
14 MV Overturned
15 Tractor/Trailer Jackknife
16 Other Collision
17 Construction Vehicle
18 Law Enforcement Vehicle

Report Completed by:____Date:____________________

Report Reviewed by:____Date:____________________



	Approach____ft	Transition____ft	Buffer____ft	Work Space____ft	Termination____ft
MOT Devices	01 Cones 02 Drums 03 Barricades 04 Barrier 05 None	01 Cones 02 Drums 03 Barricades 04 Barrier 05None	01 Cones 02 Drums 03 Barricades 04 Barrier 05 None	01 Cones 02 Drums 03 Barricades 04 Barrier 05 None	01 Cones 02 Drums 03 Barricades 04 Barrier 05 None
Pavement Markings	01 Paint 02 RPM 03 Tape 04 Other 05 None	01 Paint 02 RPM 03 Tape 04 Other 05 None	01 Paint 02 RPM 03 Tape 04 Other 05 None	01 Paint 02 RPM 03 Tape 04 Other 05 None	01 Paint 02 RPM 03 Tape 04 Other 05 None
Electronic Board in Use	01 Message 02 Arrow 03 Radar Speed Limit 04 None	01 Message 02 Arrow 03 Radar Speed Limit 04 None	01 Message 02 Radar Speed Limit	01 Message 02 Arrow 03 Radar Speed Limit 04 None	01 Message 02 Arrow 03 Radar Speed Limit 04 None
Location of Other Traffic Control Activities	01Police Vehicle 02 Flagger	01 Police Vehicle 02 Flagger	01Police Vehicle 02 Flagger	01Police Vehicle 02 Flagger	01Police Vehicle 02 Flagger
Other MOT Issues	Number of Advanced Warning Signs (post mounted) Total Num. of Signs Approx. Sign Spacing	Approximate Spacing of MOT Devices Location of Electronic Board 01 Beginning of Closure 02 Behind Closure	Clear of Obstructions 01 Yes 02 No	Number of Open Lanes Width of Open Lanes	

NOTE: Complete form UP TO and including the division where the crash occurred. DO NOT complete the divisions after the one in which the crash occurred.