5.0 Work Zones

5.1 Introduction

According to the Fatality Analysis Reporting System (FARS) data maintained by the National Highway Traffic Safety Administration (NHTSA), a total of 1,181 fatalities occurred in 1,029 fatal work zone crashes across the country during 2002. During that same year, nearly 35,000 injuries occurred in highway work zones, according to data from the General Estimates System (GES) (GES Analytical Users Manual, 2001). These numbers have grown significantly in recent years. For example, the FARS statistics represent a 70 and 73 percent increase relative to the number of fatalities and fatal crashes reported in work zones during 1997, respectively. Similarly, the 35,000 injuries estimated for highway work zones during 2002 are nearly 46 percent higher than the 24,000 injuries in work zones reported by GES in 1997.

More important than the absolute numbers of work zone crashes currently being reported, various before-after studies on this topic suggest that crash likelihood is increased by 20 percent or more (sometimes much more) at work zone locations. In a pro-litigious society as now exists in the U.S., the explicit creation of situations and conditions (albeit temporary) that actually increase crash risk has significant cost and liability implications to both the public and the private sector. Certainly, it would be desirable to emphasize designs and practices that minimize additional crash risk. Unfortunately, research to date has not been sufficient to fully define what work zone designs and practices are the safest, and perhaps more importantly, why they are the safest.

From a national research needs perspective, work zone safety has been correctly identified as a cross-cutting emphasis area (National Highway R&T Partnership, 2002). Indeed, work zone safety concerns overlay policy decisions, programming and planning activities, operations and mobility considerations. Furthermore, all roadways eventually require some type of maintenance and renovation to keep them capable of serving the travel needs for which they are intended. Insights gained and lessons learned relative to the design and conduct of work zones on all types of roadways has potential application to non-work zone locations as well.

At a broader level, it is difficult for either the FHWA or state agencies to determine whether program efforts to improve work zone safety have been successful at either the state or national level, or whether more drastic efforts are needed. Improved monitoring and analysis of work zone data, including safety data, is a critical component of the proposed rulemaking changes to 23 CFR 630 Subpart J. If the proposed rulemaking is adopted, the states will need significant guidance and assistance from FHWA to allow them to fully evaluate and monitor the effectiveness of programs and policies adopted to help improve work zone safety at the state and regional level.

In the following section, a series of research projects are outlined which provide a systematic process towards developing useful estimates of work zone exposure and work zone crash data from which work zone crash risk at a regional level can be computed. In addition, descriptions

of research that could help reduce work zone crash risk in the near term, given existing limited knowledge of work zone crash characteristics and trends, are also offered for consideration.

5.2 Specific Research Topics

Summary of Research Projects within Categories

Category	Project Title	Type of Research	Likelihood of success (1-5 scale)	Duration (months)	Cost (Millions)
Research Methodology – WZ Exposure Data	**WZ 1a:** Estimate WZ Exposure Characteristics from FMIS	Applied	High 4	30	$1M
	WZ 1b: Develop VMT Temporal Distributions to Estimate WZ Exposure	Applied	Very High 5	18	$0.5M
Research Methodology – WZ Crash Data	**WZ 2a:** Incorporate New WZ Data Elements into CDS Crash Investigations	Advanced	Moderately Low 2	60	$2M
	WZ 2b: Investigate Likelihood of Work Zone Crash Reporting	Applied	Very High 5	18	$0.5M
Determine WZ Crash Causation	**WZ 3a:** Feasibility and Validity of Region-wide WZ Crash Risk Estimation Techniques	Advanced	Moderate 3	30	$1M
	WZ 3b: Project-Level Crash Consequences of Work Zone Design Features	Applied	Moderate 3	60	$2.5M
Identify/Evaluate Countermeasures to Mitigate WZ Crash Risk	**WZ 4a:** Improving the Understanding and Measurement of Driver Behavior in High Driver Workload Environments	Advanced	Moderate 3	36	$1.5M
	WZ 4b: Evaluate Dynamic Queue End Warning Systems for WZ	Applied	Moderately 3	60	$1.5M
Develop/Apply/ Evaluate WZ Management Procedures	**WZ 5a:** Analyze State WZ Monitoring and Management Programs and Procedures	Applied	High 4	48	$1M

WZ = Work Zone
FMIS = Financial Management Information System
CDS = Crashworthiness Data System
GES = General Estimates System
VMT = Vehicle-Miles-Traveled

5.3 Knowledge Strongholds

A multitude of studies documented in the literature identify project-level comparisons of the effect of introducing a work zone into the roadway environment. Estimates suggest that doing so raises the likelihood of a crash on that roadway segment anywhere from 7 to 147 percent (Graham et al., 1977; Nemeth and Migletz, 1978; Wang and Abrams, 1981; Kemper et al., 1985; Kuo and Mounce, 1985; Pal and Sinha, 1996; Ullman and Krammes, 1991). The literature is also fairly clear that rear-end crashes, sideswipe crashes, and crashes involving large trucks in work zones tend to be overrepresented relative to non-work zone crashes (AASHTO, 1987; Richards and Faulkner, 1981; Flowers and Cook, 1981; Daniels et al., 2000; Garber and Zhao, 2002). It is also generally recognized that existing crash databases have significant limitations for use in evaluating work zone safety (Daniels et al., 2000; Wang et al., 1996). Several of these limitations are discussed in appropriate problems statements later in this section.

5.4 Knowledge Gaps

By far, there are more knowledge gaps than strongholds with regards to work zone safety. For instance, past studies have yielded contradictory findings as to whether work zone crashes are more severe or less severe than non-work zone crashes (Graham et al., 1977; Nemeth and Migletz, 1978; Kemper et al., 1985; Pal and Sinha, 1996; Ullman and Krammes, 1991; AASHTO, 1987; Richards and Faulkner, 1981; Flowers and Cook, 1981; Daniels et al., 2000; Garber and Zhao, 2002; Wang et al., 1996; Rouphail et al., 1988; Hall, 1989), whether work zone crash risk is more adversely affected during daylight or nighttime conditions (Graham et al., 1977; Ullman and Krammes, 1991; AASHTO, 1987; Daniels et al., 2000; Hall 1989), or even whether single-vehicle crashes (run-off-road, collisions with fixed objects or equipment) are more prevalent in work zones (Ullman and Krammes, 1991; AASHTO, 1987; Daniels et al., 2000; Garber and Zhao, 2002). Such inconsistency is not unexpected, since the term “work zone” represents a tremendously wide range of conditions and impacts to the roadway environment and to subsequent traffic operating conditions. The term “work zone” is presently too generic to be of significant use in crash causation analysis.

Presently, work zone locations and layouts are not captured as part of existing crash report forms or in the electronic databases. This is a significant knowledge gap that significantly restricts abilities to assess crash risk potential or to otherwise establish causal relationships regarding work zone designs under various roadway and traffic conditions. Given that work zones may change configuration from day to day (or night to night), much more detail regarding work zone conditions actually present at the time of a crash needs to be captured to support crash causation studies.

In addition to improving the understanding of how work zone decisions and practices influence safety, better data and understanding of factors influencing work zone crashes are believed to offer the potential to improve roadway safety in non-work zone locations as well. Work zones typically include use of design speeds, lane widths, lateral offsets, etc. that differ significantly

from “normal” conditions at that location and upstream of the work zone. In some cases, these values may even be exceptions to the minimums normally allowed for that type of facility or condition. This creates a unique opportunity to better understand the consequences of allowing such minimums or exceptions (and combinations thereof) upon crash risk and underlying driver behaviors. If highway designers are provided better data as to the safety consequences of selecting certain design element values (particularly if those values approach current minimum values), overall roadway safety may be improved while at the same time maximizing the efficiency with which public dollars spent on roadway repair and rehabilitation are utilized.

Another significant knowledge gap relative to the development and interpretation of work zone crash risk estimation pertains to work zone exposure computations during times when no actual work activity is occurring. Traffic control devices, barriers, and equipment are left adjacent to the roadside in some work zones but not in others. These devices and equipment are additional objects in the right-of-way that have a non-zero probability of being impacted by an errant vehicle. The devices are also potential sources of visual clutter and distraction that may contribute to crash causation in some instances. The amount and type of such equipment that may be present at a particular location varies significantly from project to project, making it extremely difficult to define how vehicular exposure past these inactive work zones should be defined. Depending on the assumptions utilized, dramatically different estimates of exposure will be developed (Ullman, 2003).

Current research is underway under the National Cooperative Highway Research Program (NCHRP Project 3-69, Design of Construction Work Zones on High-Speed Roadways) to look at develop improved design guidance under high-volume conditions. Similarly, work proposed under the FSHRP program for roadway renewal (TRB, 2003) includes studies to consider the safety ramifications of accelerated construction on highway workers (project 1-1.8) and to develop improved work zone traffic control and design guidance for high-volume roadways to emphasize consistency, visibility, and safety (Project 1-7.1). These projects further emphasize a perception, at least, that current work zone practices and standards can be improved, particularly in better accommodating the extremely high volumes of traffic that many regions now face.

Comment from R&T Partnership Steering Committee

General comments – One reviewer declined to review this paper due to the small relative size of the Work Zone (WZ) total crash and fatality problem. Also, another reviewer noted that WZ crashes that can realistically be affected by treatment might be only 20 percent of total crashes in WZ. Indeed, some research has shown that the risk in a work zone on at least Interstate roads is about 20% higher than on the same pieces of pavement when the zone was not there. Given that, unless we can make a work zone much safer than the target road we are building (e.g., slow all traffic down to 20 MPH and lead them through with a police car), it is wrong to imply that we can somehow reduce or eliminate all WZ crashes (unless it’s possible to make the WZ safer than the road being worked on). WZ “crash risk” can’t be defined with crash studies only – must have exposure and characteristics of WZ.

There's a real question on whether work zones deserve priority attention under the R&T Safety Partnership effort. Of course, we are not asking the authors to settle this issue, but the TRB oversight committee will address it in the future.

Response from White Paper authors

The reviewers correctly note that the relative magnitude of crashes identified as occurring in a work zone is small compared to the total number of crashes that occur on U.S. highways nationwide. Furthermore, many of these identified crashes may indeed have occurred even if the work zone had not been present. Consequently, it is reasonable to question the value of emphasizing work zone crashes as a priority area in the R&T Safety Partnership effort. However, the author believes that the need to research work zone safety lies not in the absolute numbers themselves, but in the strategic value in understanding the causes and consequences of those crashes that may be induced by work zones.

For example, the author believes that much can be learned by determining and understanding what work zone factors and combinations of factors contribute most significantly to the increased crash potential, and why those factors are so detrimental to safety. Armed with such knowledge, the consequences of future roadway design and operational decisions may more assessable than would otherwise be possible through traditional crash or epidemiological studies. At the present time, a roadway designer still must select a particular roadway design element (the actual radius of a horizontal curve to use at the end of a long tangent section, for example) to use without truly knowing what the likely consequences of that selection might be upon the expected crash risk of the roadway. Because of severe geographic or cost considerations, the designer may be interested in the implications of accepting a minimum, or even an exception to the minimum, value of a particular design element. The fact that work zones often represent such exceptions to standard practice offer a unique opportunity to better understand the consequences of such exceptions upon crash risk and underlying driver behaviors creates a de facto study environment in which to evaluate the ramifications of such decisions when made outside of work zone environments.

The author believes that the other key reason that work zones are a strategic area of research importance to the Safety R&T partnership is that work zones present severe and unique liability considerations to highway agencies and to the private sector, considerations that for the most part are not as prevalent when other types of crashes occur. Most roadwork today is carried out by private contractors, working for the particular roadway agency with authority for the roadway of interest. Such arrangements create dual defendant opportunities for plaintiffs looking to assign blame and to recoup damages for crashes. At the same time, decisions are routinely made (probably rightly so) to accept a lower quality of roadway service while such work occurs so that the necessary activities can be accomplished within a reasonable amount of time and a reasonable budget. These decisions increase agency exposure for litigation in comparison to other types of decisions, such as deferring the upgrade of an existing roadway section (due to funding limitations) to meet the most current safety standards. There are significant ramifications to the private contractor as well, evidenced by the recent multi-million dollar awards for negligence or other deficiencies that have led to motorist deaths or severe injuries at

work zone locations. These awards, in turn, drive up insurance costs which are then passed on to the general public through higher bid prices for future work activities. Ultimately, having better data on work zone crashes, the different work zone characteristics that contribute to crashes, and the amount by which crashes are influenced by these characteristics will all lead to better work zone designs and help highway agencies and contractors address future litigation demands.

Discussion of these key issues has been added to the introduction and the knowledge gaps sections of this topic area.

Research suggestions from R&T Partnership Steering Committee

Reviewers recommend a large well-funded study that measures crash-based effects of WZ characteristics (e.g., lane drop/narrowing methods, median crossovers). The cost will be in the collection of detailed WZ inventory data (which changes over time) and exposure data. Should there be inclusion of worker-safety in study? If so, this will require additional data on worker exposure.

Response from White Paper authors

The author agrees with the reviewers that this important facet of work zone safety deserves a significant level of research attention. It was omitted in the first draft of the white paper because of a long-anticipated publication of an FHWA study on work zone crashes, and an existing NCHRP project (3-69, Design Guidelines for Work Zones on High-Volume Roadways), of which the author is a member of the research team that was already underway to examine and consider these issues to some degree. In recent months, it has become clear that the NCHRP study will not be sufficient in scale or funds to effectively address all of the questions surrounding the crash-based consequences of many of the work zone characteristics. Furthermore, the FHWA publication has still not been released, and even once released, is not expected to provide data on all types of work zone characteristics that may influence crash risk. Therefore, a new project has been introduced (WZ 3b.) into this section to focus on these questions.

5.5 Specific Research Projects

WZ 1a. Exposure Data: Estimating Work Zone Exposure Characteristics from FMIS

Comment from R&T Partnership Steering Committee

There's agreement that "exposure" is critical to WZ studies, but "exposure" has different meanings. More clarity on specific "outcomes" from better national WZ exposure (e.g. program changes this could lead to?) is needed. FMIS data needs to be supplemented with data on non-FMIS WZs in at least a pilot study so that "expansion factors" can be developed. "Exposure" needs to include active/inactive work periods so that we can learn how to minimize the latter.

Response from White Paper authors

The author has included additional statements to address the possible outcomes of improved exposure data, the need to expand the study to allow extrapolation of FMIS data to non-FMIS work zones, and the need to incorporate exposure in terms of active and inactive work zones.

Narrative Description
The Financial Management Information System (FMIS) is the database used by FHWA to track information related to all highway projects financed with Federal-aid highway funds. FMIS data are used for planning and executing program activities, evaluating program performance, and depicting financial trends and requirements related to current and future funding. Projects are subdivided into a number of categories such as new construction, 4R construction, 4R maintenance, bridge new construction, bridge replacement, bridge rehabilitation, safety, and railroad/highway crossing. State and local agencies provide the data that populates FMIS, with FHWA personnel providing general review and oversight. Most of the information in FMIS is financial in nature, but project lengths, locations, days of activity, etc., are also requested from the states. These data are relevant for the purposes of estimating work zone exposure from a national, state, or regional perspective.

Problem Statement
The information included in FMIS has allowed FHWA to develop estimates of the amount of roadway that goes under contract each year (Highway Statistics Series, 2002). However, recent efforts to estimate annual work zone mileage on the NHS using field data sampling and extrapolation techniques did not correlate well with these FMIS estimates (Ullman, 2003). Rather, the FMIS estimates were much smaller than those obtained from field data, most likely because the FMIS estimate did not include several types of projects that also generate work zones (i.e., safety/traffic/traffic system management projects, environmental projects, special bridge projects, etc.). Furthermore, it was noted that FMIS does not capture much of the key data that is necessary to develop good estimates of work zone exposure. These data include the lengths of actual work activity; the times of the day or night when work is performed (i.e., capturing the difference between active and inactive work zones); the frequency, magnitude, and duration of capacity restrictions enacted at each work zone; and so on. The previous field data sampling and extrapolation effort indicates that these characteristics differ significantly depending upon project and roadway type, historical traffic volume levels, and other factors.

Despite these limitations, FMIS does offer the opportunity to more thoroughly estimate and track work zone exposure at a national level than is possible through field data collection efforts alone. Better estimates of true amounts of work zone exposure will allow FHWA and state DOTs to better relate existing meta-level work zone crash statistics to changes in amount of work activity that occurs yearly. In this way, the benefits of state and regional programs and other broad-based actions implemented to improve work zone safety can be monitored and evaluated for effectiveness. Typically, such programs and broad initiatives cannot be effectively evaluated at the individual project level.

Research is needed to more thoroughly understand the relationships between key characteristics that accurately capture and describe work zone exposure, and information now included in FMIS. With this understanding, appropriate unit values of these characteristics could be developed that, multiplied by the FMIS data, could yield reasonable estimates of work zone extent and exposure nationally as well as by state or region. Among other things, unit values will need to be generated to relate the amount of FMIS-documented work activity to the total amount (FMIS and non-FMIS) of work zone activity that occurs in a region or at the national level.

Method / Approach
The proposed research would require the research team to work with FHWA personnel who manage FMIS in order to develop a strong understanding of the various project categories and other data elements currently captured. Then, a number of regions will need to be identified (in a statistically-representative manner) where the research team could travel and gather key field data for all projects in those regions (including those not documented in FMIS). Based on these data, unit values of key work zone exposure characteristics would be developed and related to the population of FMIS projects in those regions. Statistical comparisons across regions, project types, and other factors would be performed to ascertain the robustness of the unit values for use in extrapolating beyond the boundaries of the sampling regions. As a final task, researchers would need to develop a plan for periodically updating these unit values in order to use them in following years.

Project Duration
The research team will require time to interact closely with FHWA personnel who manage FMIS in order to establish a clear understanding of its capabilities and limitations. Several geographic regions will need to be identified where field data can be obtained and correlated back to the population of FMIS project information for that region.

Payoff Potential
High – FMIS is currently the most comprehensive national database of work zone projects available. A mechanism for gathering project data from the states is already in place. Establishing the correlation between information already kept in FMIS and key characteristics that truly define work zone "exposure" in a region or state will allow FHWA to more accurately benchmark and track trends in work zone exposure, crash risk, and mobility impacts.

WZ 1b. Exposure Data: Develop VMT Temporal Distributions to Estimate WZ Exposure

Comment from R&T Partnership Steering Committee

There is agreement for the need, but questions on the method. It is noted that we do not even have good data on work zone vpd at this point, and that it is not clear what "different data sources available" means. Perhaps the need is for a project of automated collection of hourly/daily exposure in a cross-section of work zones – new, rather than existing data.

Response from White Paper authors

The author agrees that very little data on vehicular demands through work zones has been collected to date. The authors still believe there is value in evaluating existing traffic demand data sources such as HPMS, traffic surveillance counts obtained by ITS now installed in many urban areas nationwide to develop statistically-valid temporal distributions (probably stratified by region, roadway type, and other factors) for use in estimating traffic demands through work zones during times when work activity is occurring as well as when the work zone is inactive. However, there will indeed be value in gathering ground-truth data at actual work zone locations as well. Together, a multi-pronged approach could yield a much richer dataset. Additional sentences have been added to the methodology section to include such data collection and analysis in this proposed project.

Narrative Description
Estimates of total vehicle exposure to highway work zones will be needed if reasonable estimates of work zone crash risk are to be developed. In most cases, only historical daily traffic volume estimates are available on the roadway sections where work zone activity takes place. These estimates are generated from state DOT program and planning divisions, using a variety of traffic count samples and extrapolation techniques. The Highway Pavement Monitoring System (HPMS) is a database of roadway and traffic volumes collected on a representative sample of roadways nationwide. In some cases, installation of Intelligent Transportation System infrastructure in large urban centers can serve as another potential source of traffic volumes.

Problem Statement
Work zones are typically not active during all times of the day, especially when lane closures or other significant traffic disruptions are required. In fact, such work activities are typically performed during off-peak travel periods (albeit the actual hours of activity may change from day to day over the course of the project). Methods of adjusting daily traffic volumes to reflect vehicular exposure during work zone activity need to be established before work zone crash risk can effectively be estimated and compared across project and roadway types, traffic control conditions enacted, etc. Furthermore, these adjustments must also take into consideration temporal differences in exposure over the day by different vehicle types. Large trucks, for example, may tend to be more prevalent at night or during other off-peak periods in urban regions as commercial drivers schedule their trips to avoid peak period congestion.

Method / Approach
Researchers will need to examine the HPMS database and a sample of traffic volume data from ITS centers in urban areas nationwide to assess the hourly temporal distributions of traffic volumes as a function of daily traffic volumes, region, roadway type, vehicle type, and other factors. Statistical techniques would need to be employed to determine which stratifications are most significant.

Researchers will also need to develop a research plan to validate these distribution patterns developed through the existing HPMS and ITS databases by conducting a series of data collection efforts at work zones nationally to actually gather work zone traffic demand data. In addition, special attention will need to be given to work zones where traffic demands exceed the

capacity of the work zone during some portion of the day. Evidence suggests that traffic demand patterns change dramatically once demands exceed work zone capacity and congestion starts to develop (Ullman, 1996). Specifically, significant numbers of motorists will change routes (if available), reducing the amount of traffic actually approaching and passing through the work zone. The results of data collection sites are likely to yield diversion curves or other methods of adjusting historical traffic volumes to reflect actual work zone traffic demand when volumes exceed capacity. As a side note, diversion behavior does not appear to occur to any significant magnitude if traffic demands remain below the work zone capacity.

As with the previous project statement, researchers will also need to prepare recommendations for updating these distributions on a regular basis so that work zone vehicle exposure estimation using these distributions can be maintained over time.

Project Duration
The proposed research does not require significant field data collection. Significant cooperation and coordination from state or regional agencies is also not required. It is believed that this work could be accomplished in a relatively straightforward and timely manner within the proposed duration of the project.

Payoff Potential
High - It is unlikely that traffic surveillance infrastructure will be installed to sufficient levels nationally (particularly in rural areas on non-interstate highways) so as to allow reasonable real-time collection of vehicle exposure in work zones in an ongoing manner. Estimation tools will be required if any type of reasonable tracking of work zone vehicle exposure at a state, regional, or national level is to be realized.

WZ 2a. Crash Data: Incorporate New WZ Data Elements into CDS Crash Investigations

Comment from R&T Partnership Steering Committee

The white paper concentrates on CDS, as should be the case. GES should be deleted since it appears CDS is the target, and GES is extracted from existing police reports with no supplementing done. If CDS is the target, may require both changes in items and changes in sampling methodology (or a special study) since current sample of WZ crashes may be too small to be useful.

Response from White Paper authors

The author agrees with the reviewers. References to GES have been removed from the discussion. In addition, the potential need for a special pilot study to determine appropriate items and sampling methodology to use in assessing work zone crashes has been incorporated into the discussion.

Narrative Description

The Crashworthiness Data System (CDS), part of the National Accident Sampling System maintained by NHTSA, is designed to allow for consistent comparison and in-depth analysis of crash factors across jurisdictional boundaries. Currently, the information in the CDS does not capture information that would be deemed useful in the analysis of work zone crash causation. The Model Minimum Uniform Crash Criteria (MMUCC) prepared in 1998 identifies several additional data fields that are recommended for inclusion on state crash report forms (USDOT, 1998). However, the extent to which individual states will eventually modify their report forms to incorporate all or some of these variables is unknown at this time. Agencies continue to struggle with the balance between requiring as much detailed information about a crash as possible, and the amount of time required by an investigating officer to properly collect and code that information.

Problem Statement
Work zones are highly diverse, depending on the roadway alignment and cross section, traffic demands, and required work activities. Most often, the travel path required by motorists is temporary, such that existing roadway inventory files do not represent the actual driving configuration present on the roadway at the time and location of the crash. The lack of work zone layout and condition documentation hinders attempts at ascertaining actual causal links of work zone crashes. Research is needed to establish a mechanism for obtaining the necessary work zone configuration data at the time of a crash, and to use that data in crash causation studies to better understand the features and conditions that contribute to work zone crash risk on a national basis.

Method / Approach
For this project, researchers will need to first define a consistent set of work zone data elements that are likely to capture causal relationships of work zone crashes. For example, the prevalence of rear-end crashes in previous work zone crash studies suggests that information about the presence and length of a traffic queue (or about estimated work zone capacity values and traffic demands which could indicate congestion) at the time of the crash could be an important potential causal link to explore and quantify. Other elements might include the length and lateral offset of lane shifts, and/or the type and proximity of channelizing devices or barriers next to travel lanes.

Once the set of work zone data elements of interest is established, researchers will need to identify locations willing to pilot test the elements as part of their regular CDS data collection investigations. This pilot test may actually need to be a special study that explicitly focuses solely on the investigation of work zone crashes, so that a meaningful data sample to evaluate the protocol and quality of the information is collected in a reasonable period of time Following appropriate pilot testing and revisions, a more widespread implementation effort would be required. After sufficient time has elapsed to allow the use of the new data elements to be collected, follow-up analyses would be performed to validate expected causal relationships in work zone crashes and identify new ones as appropriate.

Proposed Duration
Because this project is based on establishing new data collection mechanisms to support improved work zone crash causation studies, a longer-term study period is needed. Researchers

will need to establish the proper data collection protocol, and work with several regions now included in the CDS sampling regions to pilot test the protocol. Then, the protocol will need to be implemented within as many regions as possible, and time allowed for enough data to be collected to allow proper statistical analysis. Obviously, the amount of time required for completion of the project will then depend on the number of regions that can be persuaded to adopt the new data collection criteria.

Payoff Potential

High – the collection of a new stream of data from which to assess work zone crash causation could prove highly useful in the identification of appropriate countermeasures and in the economic justification of such countermeasures on the basis of expected crash reductions.

WZ 2b. Crash Data: Investigate Likelihood of Work Zone Crash Reporting

Comment from R&T Partnership Steering Committee

This study looks feasible if the FMIS data has location information that is the same as on crash files (not always the case for other national databases).

Response from White Paper authors

The author agrees that the key will be to select regions and work zones within those regions whose project location data are consistent with police crash location reporting procedures. Although it would be advantageous to utilize the same regions and data sources as would be used for project statement WZ 1a. above, it is not an absolute necessity. The author has added a sentence to the methodology section to emphasize the criticality of being able to link work zone project location and crash location data together.

Narrative Description
In most states, the notation of the presence of a work zone is up to the discretion of the investigating officer. Two previous studies have concluded that the way that the presence of a work zone is noted on a state's crash report form affects the likelihood that a crash will be coded as being in a work zone by the reporting officer (Wang et al., 1996; Ullman, 2003). In another study, researchers found that only a fraction of crashes that occurred within the limits of a work zone project were actually coded as being in a work zone (Ullman and Krammes, 1991). These findings imply that the existing crash databases do not represent the full population of crashes that occur within highway work zones. Consequently, work zone crash risk estimates based solely on those crash records noted as occurring in a work zone will be lower than the risk that actually exists within work zones in the region.

Problem Statement
Although it is hypothesized that many crashes that occur in work zones are not coded as such, the implications of this underreporting in terms of effective use of available databases has not been determined. It is not known whether such underreporting is randomly distributed amongst

the population of crashes, or represents systemic trends in the data (i.e., more underreporting occurs at night, on long-term construction projects, on projects in larger urban areas, in northern climates, on non-injury crashes, etc.). Research is needed to investigate and document any such systemic trends, and to establish an estimate of the amount of underreporting that occurs nationwide.

Method/Approach
Researchers will need to identify a variety of work zone projects from several jurisdictions across the country. Specific information on dates and locations of work for each project will need to be identified, and all crashes on those dates and times at the identified locations extracted from the crash databases. Analyses of which crashes were and were not coded as being in a work zone will be identified, and appropriate statistical methods employed to determine what trends, if any, exist. The locations studied could be the same as those used to establish the FMIS estimates (see the first problem statement) to take advantage of previously-collected data. The use of the same locations will also allow for feasibility testing of region-wide crash risk estimation (discussed in a following problem statement). However, the most important criteria for the project to be successful is to select regions for which work zone location referencing and police crash reporting location referencing are the same (or at least can be easily translated between the referencing systems used).

Project Duration
It is expected that only limited field data may need to be obtained from each work zone project location. The remaining effort of this research would entail extraction and analysis of information from the electronic crash databases in those regions where the work zone projects of interest exist.

Payoff Potential
Moderate – This project is critical in bringing to light the magnitude and trends regarding work zone crash underreporting. The findings could prove useful to agencies in interpreting work zone crash statistics to more accurately reflect what is likely occurring from a regional or statewide perspective. However, the findings themselves are not expected to result in significant reduction in this phenomenon.

WZ 3a. Crash Causation: Feasibility and Validity of Region-wide WZ Crash Risk Estimation Techniques

Comment from R&T Partnership Steering Committee

The reviewers are unsure of merit of study. More justification is needed - more on what programs; practices might change if this study was completed? Unclear on actual model – crashes/vmt or something else? What does it tell us (particularly since majority of crashes would be present without WZ)? If issue is really “risk” as a function of WZ characteristics, need WZ inventory data (which changes over time within the same zone). Not sure if this is present in existing FMIS database.

Response from White Paper authors

The reviewers correctly note that any efforts to assess regional programs or countermeasure implementations will require detailed work zone inventory data over time, which is the goal of project WZ 1a above. Also stated in statement WZ 1a above is the ultimate goal of being able to assess regional program or countermeasure implementation effectiveness, something that is currently not possible through project-level analyses. Thus, the goal of this project is to examine whether it is possible to gather or estimate region-wide work zone characteristics (via FMIS unit value expansion factors or other means) and relate them to region-wide work zone crash data so as to evaluate regional effectiveness of a particular program or countermeasure. The author recognizes that the actual rates or model may not reflect "ground truth" data, due to such things as many crashes not really being related to the work zone, potential lack of consistent reporting of work zone crashes, etc. However, if this project is successful, it can serve as a mechanism for evaluating changes in conditions over time, and allow at least some degree of regional program effectiveness evaluation. As to the actual model that is anticipated, the author would expect something in terms of crashes per vmt to be the most feasible measure. However, sentences in the problem statement allow for the investigation of other model approaches that might be more appropriate for gauging changes in crashes over time at a region-wide level.

Narrative Description
At the national level, fatality risk is estimated as a function of vehicles miles of travel and roadway classification. Such an assessment requires both accurate crash data and realistic estimates of motorist exposure in terms of vehicle miles traveled on various types of roadways each year. For highway work zones, efforts to date have focused primarily on project-level estimates of crash rates and changes in those rates due to the introduction of a work zone into the roadway environment. Such project level investigations do not allow for assessments of broad regional, statewide, or national initiatives to improve work zone safety.

Problem Statement
This proposed research builds upon the expected results of the previous problem statements described in this white paper. Research is needed to explore alternative model structures for estimating region-wide work zone crash risk, to perform a sensitivity analysis of the various assumptions used in extrapolating both work zone vehicular exposure and work zone crash data, and to validate the model structure using data from regions not previously examined under this research effort.

Method/Approach
In this project, researchers will determine the appropriate model structure to incorporate both work zone exposure estimates (from FMIS) and vehicle exposure to each work zone (using VMT temporal distributions) into an appropriate region-wide work zone crash risk estimate. The model development would likely use the data already collected from various regions nationally in the previous research projects. Validation studies would then be performed to assess the reasonableness of the model structure deemed most appropriate. The validation would be based on data from a new set of regions not previously examined under this research initiative.

Project Duration
The initial model structure for risk estimation developed as the first part of this project would be performed on the data already obtained through the previous projects described earlier. However, the validation efforts of the new model structure will require additional data collection from FMIS, daily traffic volume estimates, and other regional roadway characteristics for use in the analysis. These additional data collection techniques will require sufficient time to coordinate efforts with appropriate agencies, collect and reduce the appropriate data, and perform the validation analysis.

Payoff Potential
High – this type of data has not been available to state or local agencies (nor FHWA) previously. The ability to establish region-wide crash risk estimates for work zones sets the stage for tracking work zone safety from a regional perspective, and systematic evaluations of changes in agency policies and procedures as they pertain to work zone safety. The results, if successful, will also allow agencies to assess whether or not work zone safety needs to be given additional priority relative to the other issues and initiatives also pressing for agency attention.

WZ 3b. Project-Level Crash Consequences of Work Zone Design Features

Narrative Description
Despite the studies that have been conducted to date pertaining to work zone safety, there is a general dearth of information as to what work zone design features and operating characteristics influence crash likelihood (positively or negatively). Other than comparisons of the relative difference between median crossover and single lane closure designs for interstate highways (e.g., Burns et al., 1989) or the influence of entrance ramp presence or design (Casteel and Ullman, 1992), very few studies have attempted to isolate the effects of particular work zone features or characteristics upon crash potential.

Problem Statement
Research is needed to better understand the crash consequences of the different design elements upon crash potential so that future work zones can be designed and implemented more safely. Furthermore, this understanding should extend beyond single-element analyses to the consequences of the more typical design element interactions that commonly exist of work zones, and should take into consideration the change in these elements relative to pre-work zone conditions and to conditions upstream of the work zone. Consequently, an adequate geographic distribution of sites will be necessary as well.

Method/Approach
A before-during study of crashes at a fairly large number of work zone locations, stratified by the design elements and conditions listed previously, would be the primary method of analysis. Control sites will be required for each project location included in the analysis to account for extraneous influences (primarily weather and traffic volume changes) that could also influence crash occurrence. Detailed daily project diaries or similar records will need to be accessed to isolate specific days of activity and dates of major traffic control changes to include in the analysis. The outcomes would be a set of crash adjustment factors associated with the design elements (and element combinations) evaluated. It may be necessary to rely on historical

projects more so than current projects, due to the delay that typically exists in obtaining police crash report data.

Project Duration
The sample size required to do this study properly will be substantial. Time will be necessary to identify appropriate design criteria, locate potential sites (work zones and control), and collect the detailed project information (including daily activity information, when necessary). The study will require researchers to become familiar with several crash record databases to extract the appropriate data from sites across the country.

Payoff Potential
High—The results of a well-conducted study on this topic has the potential to be immediately applied to work zone designs nationwide. As in the previous project description, the results will also allow agencies to assess whether or not work zone safety needs to be given additional priority relative to the other issues and initiatives also pressing for agency attention.

WZ 4a. Crash Risk: DeterImproving the Understanding and Measurement of Driver Behavior in High Driver Workload Environments

Comment from R&T Partnership Steering Committee

The reviewers are not clear on the underlying "knowns" or methodology. There are several questions. Does "human factors (HF) assessment" imply we know which HF measures affect driver behavior in WZs and by how much? If not, will "lab and field" measures of behavior be sufficient to validate treatments? If not, should we do a different research project – one than links HF measures with driver behavior in WZ (fundamental research)?

Response from White Paper authors

After consideration of the reviewer comments, the author agrees that a more fundamental research effort is needed in this area. The problem statement title and text have been modified accordingly.

Narrative Description
Current work zone traffic control (WZTC) standards are rooted in fundamental human factors principles of positive guidance, traffic control device visibility and legibility, and linear models of motorist information transmission approaching various work zone configurations (Post et al., 1981; McGee and Knapp, 19979; Hostetter et al., 1982). These models may be too simplistic for certain work zone situations, particularly on high-speed urban roadways. The presence of extraneous visual cues, vehicles, other traffic control devices, glare sources, etc. in some work zones may increase driver workload and decrease driving behavior. Unfortunately, reliable and calibrated measures of driver workload currently do not exist for work zones or non-work zone locations, nor has a linkage been established between any workload measures, driving behaviors, and ultimately crash outcomes. In a high-workload environment that is hypothesized to exist at many work zones, this type of linkage could prove useful in better understanding the underlying

causes of certain work zone crashes, and in developing work zone design evaluation methods and criteria in terms of their expected influence on driving behavior and crashes.

Problem Statement
Few studies have explicitly examined driver decision-making and behavior in a high driver workload environment such as can exist in a fairly complex work zone. A recent NCHRP report provides some guidance on driver information overload issues (Lerner et al., 2003), but more work is needed to further extend those concepts to address other driver workload issues, and to eventually provide assistance in work zone design and operations decisions. Specifically, research is needed to develop a more realistic model of driver cognition and behavior approaching and traveling through high work load situations such as exist at some work zones, to determine whether there are effective driver behavior performance measures that correspond to changes in driver workload, and to determine whether crash outcomes can be correlated to these driver behavior performance indicators of high workload conditions.

Method/Approach
The proposed research would consist of the development of a theoretical model of driver workload based on conditions and features present at work zone locations, identification of appropriate performance measures believed to be correlated with workload, laboratory studies to calibrate the performance measures to workload estimates, and validation studies to demonstrate a correlation between workload estimates (and corresponding driver behavior performance measures) and crash risk through before-during studies at work zones installed in the field.

Project Duration
A fairly lengthy duration is expected for this project. It may be possible to separate the model development and calibration activities (laboratory-based) from the crash risk validation portion of the study.

Payoff Potential
Moderate – Existing WZTC standards have functioned sufficiently for many years, and appear to be adequate for the majority of situations faced by practitioners nationwide. However, this project does have the potential to yield substantial benefits in more complex situations that often exist in work zones. The results of the study may be transferable to other complex driving situations as well, and so could extend the benefits realized to certain non-work zone locations.

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WZ 4b. Crash Risk: Effectiveness of Real-Time Queue End Warning Systems in WZ

Comment from R&T Partnership Steering Committee

This topic has some importance since many rear-end crashes happen near WZ but rear end accidents are less severe. There are a couple of issues with the proposed methodology. The reviewers are not sure that lab/simulation studies are sufficient unless we have the link between the lab measures and actual crashes. While before\after crash studies are possible, will require significant effort to identify a reference group, since computerized WZ inventory data is not available.

Response from White Paper authors

Whereas rear-end crashes in general tend to be less severe, they are not necessarily so at work zones where high-speed approaching traffic (i.e., 55 mph or higher) encounters a traffic queue at a work zone where vehicle speeds in the queue are often 10 mph or less. The problem may be particularly acute for the large-truck/automobile crashes at these queues. The author is aware of several fatal crashes at Texas work zones that have occurred when a large truck came up on an unexpected queue and did not stop before running completely over the automobile directly in front.

The lack of good causal relationships between rear-end crashes and the proposed countermeasure is indeed problematic. The author agrees that before-after crash studies would be the most relevant means of evaluation. However, this type of countermeasure can only be evaluated at a project level, as not all work zones in a region would benefit from such a warning system (those that do not generate unexpected traffic queues for example). The author has added a statement about the need to conduct before-after crash studies, with appropriate selection of reference sites to serve as the control, as the final level of evaluation. The author has also reduced the overall likelihood of success to further address the reviewer concerns, and has lengthened the duration of the study to allow for crash evaluations to be conducted. The author has kept the laboratory study evaluation as part of the study plan, however. Although the linkage between laboratory measures and crash reduction potential is not possible at the outset, laboratory studies do offer the potential to exclude a countermeasure from further evaluation if no changes in performance measures can be detected. If driver performance changes can be identified in the laboratory, only then would testing move to the field. An interesting benefit of this study could actually be the eventual calibration of such laboratory performance measures to the eventual level of crash reduction observed in the field.

Narrative Description
Several studies that have examined trends in work zone crashes have identified significant increases in the relative proportion of rear-end crashes (Graham et al., 1977; Daniels, 2000; Garber and Zhao, 2002). Most studies have then concluded that these increases are the result of non-recurrent congestion created on occasion at the work zone that violates driver expectancy and leads to crashes between motorists at the upstream end of the queue (where significant speed differentials between vehicles exists).

Problem Statement
Current WZTC guidance indicates that advance signing warning of the presence of a work zone and possible congestion should be placed far enough upstream so as to be beyond the limits of any congestion that develops. However, since congestion typically does not exist at all times at the work zone, these static signs are often misleading to motorists and become ignored over time. Recent advances in ITS technology now allows traffic conditions to be monitored at key points in a work zone, and dynamic warning messages to be displayed on portable changeable message signs when congestion is detected. To date, however, so systematic evaluations have been performed of the ability of this technology to reduce rear-end crash potential. Also missing are

effective guidelines to help practitioners determine the types of roadways and work zones for which this type of technology is most effective.

Method/Approach
A series of laboratory (possibly driving simulator) and possibly field studies would first be performed to evaluate whether real-time dynamic queue warning systems can alter driver performance measures (speed changes, erratic maneuvers, etc.) believed to be related to the likelihood of rear-end crashes at work zones. Assuming these studies suggest potential benefit, a series of controlled field deployments would be undertaken at appropriate work zones in several regions to conduct before-during crash comparisons. Similar work zones in each region would be monitored as well during this time to serve as the control group.

Project Duration
Testing of dynamic queue-end warning systems will involve significant cooperation and coordination with state and local agencies, and may also require special agreements to be established with private-sector vendors providing the technology (if the agency is not purchasing the equipment outright). Identification of locations where such technology is to be deployed may take some time as well.

Payoff Potential
Moderate – Rear-end crashes are believed to be a significant cause of crash risk in locations where unexpected slowdowns and congestion are created. However, many agencies have already established policies restricting hours and days when work activities can occur, in an attempt to minimize the frequency and extent of this congestion. As the likelihood of encountering unexpected congestion due to work zones decreases, though, so too does driver expectancy for such congestion. This may mean that dynamic warning systems could have an even greater impact at those locations where they are deployed, but may be required at only a limited number of work zones throughout a particular region.

WZ 5a. Management procedures: Analyze State WZ Monitoring and Management Programs and Procedures

Comment from R&T Partnership Steering Committee

As stated by the author of the white paper, the payoff for this proposed research is limited. There are two issues. If methodology is to compare current management practices to "Best Practices," have the latter been defined based on the effects of crashes? If study is to define which management practices are "best" or successful," then need to have data on jurisdictions with and without different management practices linked with some agreed-to "measure of WZ safety" as outcome variable.

Response from White Paper authors

A set of official "best practices" has not been identified through a crash analysis or similar assessment process. That lack of systematic evaluation to date is the primary impetus for recommending this type of study be done. The author agrees that additional emphasis on the

effects of these procedures on crashes is important. Modifications to the project statement have been made to emphasize these points further.

Narrative Description
The FHWA Work Zone Operations Best Practices Guidebook (FHWA, 2000) highlights a number of programs, policies, and procedures that state DOTs have enacted to help monitor and manage work zone safety and operations in their jurisdiction. Included in this category are such activities as statewide inspection programs, quality assurance reviews, and specific safety task forces. Other techniques may be in place in other states which were not included in the guidebook.

Problem Statement
To date, no efforts have been made to quantitatively assess the effectiveness of work zone monitoring and management activities from a statewide or regional perspective, as the data and methods for doing so have not previously been gathered or developed. This lack of assessment makes it difficult for agencies to determine which approaches are most appropriate for their particular situation. Research initiatives proposed earlier in this white paper are expected to offer an opportunity to evaluate region-wide programs and policies for work zones.

Method/Approach
A survey should be performed of the state DOTs to determine which regional or statewide monitoring and management programs or procedures are in place nationally, as well as when the programs or procedures were initiated. Information as to the specific activities undertaken, data obtained (if any), and decisions made based on such data should be collated. Crash analyses should be undertaken to compare crash experiences of those states that have established specific work zone programs and procedures with those states that have not.

Project Duration
Depending on the quality of historical crash data for work zones, some previously-implemented programs and procedures are potential candidates for immediate evaluation. For those programs and procedures that are implemented immediately prior or as part of the study, however, two to three years of data will need to be collected to allow adequate crash samples to be obtained for evaluation.

Payoff Potential
Moderate – An evaluation of work zone monitoring and management programs and procedures by state agencies upon crash experiences at the state or regional level could provide significant benefits to states by helping them identify actual benefits to be achieved and to justify any costs of implementing those programs and procedures found to be effective. The development of good evaluation data that help “sell” the effectiveness of such programs and practices is likely to further enhance the degree of agency buy-in and ultimate payoff to work zone safety improvement nationwide.

5.6 Summary

The projects described in this paper are all believed to have reasonable chance of success and payoff potential. However, those having the greatest chance to succeed relate to the development of better estimates of work zone exposure and crash data quality, and to evaluate state work zone safety management programs and procedures:

- Develop VMT Temporal Distributions to Estimate WZ Exposure
- Estimate WZ Exposure Characteristics from FMIS
- Investigate Likelihood of Work Zone Crash Reporting
- Analyze State WZ Management Programs and Procedures

Perhaps most needed is the establishment of better work zone crash data documentation via the existing GES and CDS data collection schemes. However, given the various administrative and contractual details likely to be required to move this particular research initiative forward, it appears to have only a marginal chance of being successful in the near term.